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Low-Frequency Oscillation

Technology Networks-on-Chip

Highlights

Robustness Evaluation Study

Extansive Review of Emerging

Discovering Thoughts, Inventing Future

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Effects of Generator's Under-Excited Operation on Power System Low-Frequency Oscillation

By Qian Xu, Zhifei Chen & Hailong Zhang
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Abstract- In this paper, the wavelet method is applied to identify the time-varying frequency and damping ratio based on the PMU recorded data during Pingwei generator's under-excited operation. The relation of oscillation frequency and damping ratio with the variation of reactive power is then attained. Furtherly, the damping torque is used to analyze the reason for easily oscillation during generator's leading phase operation with an OMIB system. The effects of tie-line's reactive power on inter-area oscillation damping have also been studied and results of the 4-machine 2-area system are used to verify the conclusions.

Keywords: the degree of generator's under-excited operation; low-frequency oscillation; wavelet transform; frequency; damping ratio.

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Keywords: the degree of generator's under-excited operation; low-frequency oscillation; wavelet transform; frequency; damping ratio.

I. Introduction

With the continuous expansion of the scale of power grids and the establishment of UHV along with long-distance power transmission network，the problem of higher voltage of power system in valley period becomes important increasingly. Research shows that generator's under-excited operation has been applied gradually as a means for adjusting voltage because of its special excellences, including simple executive, security, economy, adjust continuously, etc.

Generator's under-excited operation belongs to the normal low-excitation synchronous operation state. Generator's capability of absorbing the capacitive reactive power, namely the degree of generator's under-excited operation is restricted by many factors such as stator end fever, the decrease of bus voltage of auxiliary power system, steady-state stability limit, transient stability limit, etc. Therefore, generator's capability of the leading phase operation should be determined scientifically during generator's leading phase operation. Only in this way can power system be ensured to operate safety under the leading phase mode. Reference [2-4] analyses on leading phase operation capacity of huge hydro generator and turbo generator; Reference [5] analyses the influence of generator's und Manuscript received "Date here here" Excitation On Stability Of Zhejiang Power System; Reference [6] Analyses The Effects Of Generator's Under-Excitation Operation On Voltage And Reactive Power; Reference [7] Analyses The Effects Of Generator's Under-Excitation Operation On Power System Transient Stability; Reference [8] Offers A Set Of Effective On-Line Monitoring System Of The Leading Phase Of Generator. Reference [9] Analyses Effects Of Different Generator Excitation Modes On Generator's Under-Excitation Operator Stability, And Proposes The Improvement On Phase Lead Stability Of Generators For A Nonlinear Excitation Control System.

Study on effects of generator's under-excited operation on static stability of the electric power system was calculating the static stability reserve coefficient at some degree of generator's under-excited operation which couldn't present the effects of time-varying reactive power on oscillation frequency and damping ratio. The wavelet method is applied in this paper to identify the time-varying oscillation frequency and damping ratio based on the PMU recorded data during Pingwei generator's under-excited operation, and the relation of oscillation frequency and damping ratio with the variation of reactive power has been attained; Furthermore, the damping torque is used to analyze the effect on low-frequency oscillation damping during generator's leading phase operation with an OMIB system. The effects of tie-line's reactive power on inter-area oscillation damping have also been studied.

II. Pingwei Generator's Low-Frequency Oscillation Accidents

a) *Pingwei Generator's Low-frequency Oscillation Accidents*

With two 720MVA transformers, Generator1, 2 of Pingwei generator are upgraded to 500 kV. They are connected to the main grid of Shandong province through the 500kV transmission line. The connection between Pingwei generators and the system is shown in Fig.1.

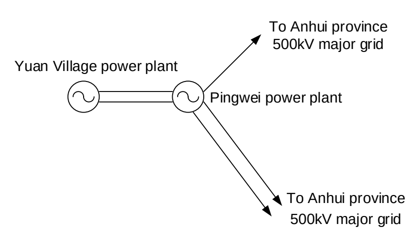

Figure 1: The diagram of Pingwei generators

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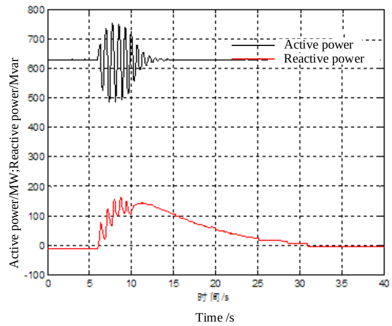
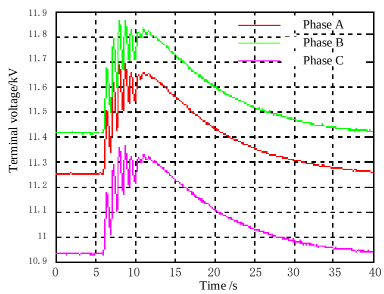
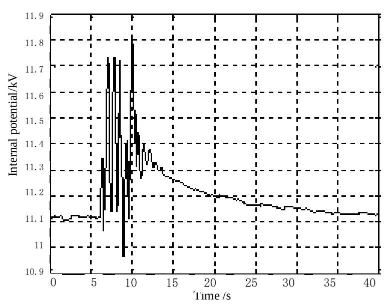
PMU recorded data such as active power, reactive power; terminal voltage magnitude, the internal voltage and power angle of generators are shown in Fig.2.



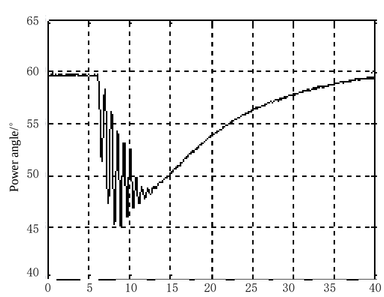
(a) active power and reactive power of generator



(b) terminal voltage magnitude of generator



(c) internal voltage of generator

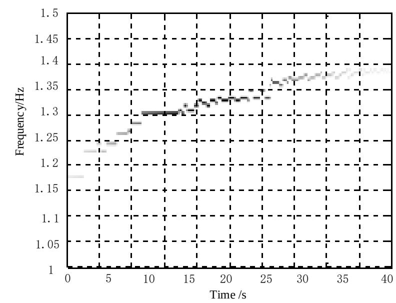


(d) power angle of generators

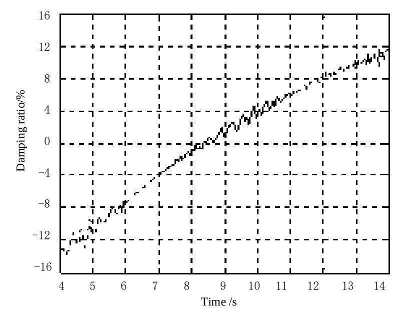
Figure 2: PMU data of oscillation accidents

Fig.2 (a) shows that during Pingwei generator's leading phase operation, the increasing amplitude oscillation accident of generators happens at 6s. With the increase of reactive power of generators, the vibration of the system decays to steady-state operation.

Fig.2 (b-d) shows that during the period when generator's under-excited operation varies into lagging phase operation again after 10s, the internal and terminal voltage of generators decrease continuously, while the power angle increases continuously. After that, there comes another low-frequency oscillation accident. Based on the active power oscillation trajectory of generator during 4-14s in Fig.2 (a), the continuous wavelet transform method is applied to identify the time-varying oscillation frequency and damping ratio. The results are shown in Fig.3.



(a) Identified frequency



(b) Identified damping ratio

Figure 3: Identified frequency and damping ratio based on wavelet method

Because of the ending effect, wavelet method has little influence on identified frequency error and has much influence on identified damping error. According to the method of area elimination of ending effect in reference [12], the effective damping ratio area can be seen in the solid line of Fig.3 (b).

From Fig.3, during generator's under-excited operation varies into lagging phase operation, with the increase of reactive power, the frequency of the low frequency oscillation increases and the oscillation damping increases from a negative to a positive accordingly. Therefore the system has turn to a system of small signal stability.

b) Damping Torque During Oscillation

To make it simple, the impact of generator's under-excited operation on oscillation damping torque is studied on an OMIB system.From Reference [13], electromagnetic torques variation ΔT_e consists of two parts： ΔT_{e1} and ΔT_{e2} . ΔT_{e1} is synchronizing torque

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equals with $k_1\Delta\delta$; ΔT_{e2} includes two parts namely synchronizing torque $\Delta T_s\Delta\delta$ and damping torque $\Delta T_D\left(jh\Delta\delta\right)$. Where, ΔT_s and ΔT_D are additional synchronizing torque and damping torque coefficients respectively. $\Delta\delta$ represents the increment of generators' power angle. p represents differential operator, $p=jh$.

$$\Delta T_e=\Delta T_{e1}+\Delta T_{e2}=k_1\Delta\delta+\Delta T_s\Delta\delta+\Delta T_D\left(jh\Delta\delta\right) \quad (1)$$

Suppose that the excitation system $G_e\left(s\right)=\dfrac{k_A}{1+T_A s}$ is in one-order inertia. Where, k_A and T_A are the gain and inertial time constant of the excitation system respectively. According to reference [13], ΔT_s and ΔT_D are shown as follows:

$$\Delta T_s=\frac{-k_2k_5k_A}{1/k_3+k_6k_A-T'_{d0}T_Ah^2} \quad (2)$$

$$\Delta T_D=\frac{k_2k_5k_A\left(T_A/k_3+T'_{d0}\right)}{\left(1/k_3+k_6k_A-T'_{d0}T_Ah^2\right)^2} \quad (3)$$

Where,

$$k_1=\frac{E'_qU}{x'_{d\Sigma}}\cos\delta+U^2\frac{x'_d-x_q}{x'_{d\Sigma}x_{q\Sigma}}\cos\left(2\delta\right) \quad (4)$$

$$k_2=U\sin\delta/x'_{d\Sigma} \quad (5)$$

$$k_3=x'_{d\Sigma}/x_{d\Sigma} \quad (6)$$

$$k_5=\frac{U_{td0}}{U_{t0}}U\left(\frac{x_q}{x_{q\Sigma}}\cos\delta-\frac{x'_d}{x'_{d\Sigma}}\sin\delta\right) \quad (7)$$

$$k_6=\frac{U_{tq0}}{U_{t0}}\frac{x_e}{x'_{d\Sigma}} \quad (8)$$

$$x'_{d\Sigma}=x'_d+x_e \quad (9)$$

$$x_{q\Sigma}=x_q+x_e \quad (10)$$

Where $E'_q,\delta,x'_d,x_q,x'_{d\Sigma},x_{q\Sigma},T'_{d0}$ are sub-transient voltage, power angle, direct-axis sub-transient reactance, quadrature-axis reactance, direct-axis sub-transient time constant of generators respectively; U_{t0},U_{tq0},U_{td0} are terminal voltage of generators, quadrature-axis and direct-axis component of terminal voltage of generators respectively, the suffix 0 means initial values; U is terminal voltage of infinite bus; x_e is Transformer and total line reactance between generators and infinite bus.

During the period of generator's under-excited operation varies into lagging phase operation, the internal and terminal voltages of generators decrease continuously, while power angle increases continuously. With power angle increasing gradually, k_5 decreases by degrees. When $k_5<0$, the damping torque $\Delta T_D<0$, then increasing amplitude oscillation accident of generators occurs. That's the reason for easily oscillated during generator's leading phase operation.

III. Pingwei Generator's Low-Frequency Oscillation Accidents the Effects of Tie-Line's Reactive Power on Inter-area Oscillation Damping

Take the 4-machine 2-area system shown in Fig.4 as an example. Its network and generators possess the same parameters as those in reference [14]. In the case of two-axis generator model with power system stabilizer and constant impedance load model, the total active power load and total reactive power are 2734MW and 200MVar respectively.

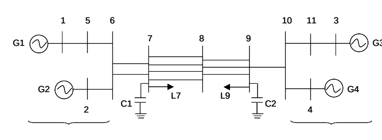

Figure 4: A two-area system

According to the results of power flow, the total power of tie-line 8-9 is $\tilde{S}_{8-9}$, where $\tilde{S}_{8-9}=390.3-j15.9$ MVA, namely the active power from bus 8 to bus 9 is 390.3MW and the reactive power from bus 8 to bus 9 is -15.9Mvar. By the use of the small signal analysis tool (SSAT), inter-area oscillation mode of the system is the oscillation between generating units G1, G2 and generating units G3, G4. The oscillation frequency of the mode is 0.7032Hz and damping ratio is 1.55%.

While active power from bus 8 to bus 9 is a constant, the reactive load of bus 7 and 9 varies. The change of inter-area oscillation damping with variation of the tie-line's reactive power is simulated and studied.

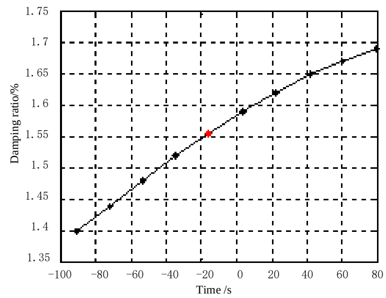

Figure 5: The change of inter-area oscillation damping with variation of the tie-line's reactive power

Fig.5 shows that oscillation damping is higher with the tie-line's positive reactive power's increase, and vice versa. When tie-line's reactive power is negative, which is in the reverse direction of active power, will give rise to inter-area oscillation negative damping/poor damping.

As generating units of area 1 and area 2 are coherent, therefore generating units of area 1 and area 2 can be aggregated into an equivalent, and bus 7 and 9 can be regarded as near zones of the equivalent. The original system is equivalent to a 2-machine system. So when tie-line's reactive power is in the reverse direction of active power, it can bear a resemblance to generator's under-excited operation. The increase of negative reactive power is not conducive to the damping of the system.

IV. Conclusion

The wavelet method is applied in this paper to identify the time-varying frequency and damping based on the PMU recorded data during Pingwei generator's under-excited operation, and the relation of oscillation frequency and damping ratio with the variation of reactive power has been attained; Furthermore, the damping torque is used to analyze the reason for easily oscillated during generator's leading phase operation.

When the active power is constant, the effects of tie-line's reactive power on inter-area oscillation damping have also been studied in this paper. When tie-line's reactive power is in the reverse direction of active power, it can give rise to negative damping/poor damping, which causes inter-area oscillation of power system.

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Monitoring of the Synchronous Machines Parameters and their AEC using Synchronized Vector Measurements

By T.G. Klimova, A.I. Kovalenko & O.O. Nikolaeva
National Research University

Abstract- Currently, devices of synchronized vector measurements (Wide-Area Monitoring Systems–WAMS) are becoming more widespread in power systems. With a high accuracy, they measure complex current and voltage values and also frequency in places of their installation. Obtained data allow to create an objective picture of power system state. This paper shows the possibility of using WAMS measurements for parameters estimation of synchronous machines (SM) and their automatic excitation controllers (AEC).

At present for a variety of tasks widely used simulation modeling of synchronous machines (SM) in software and hardware-software packages. In this case there are often difficulties in forming accurate models of real SM due to the lack of raw data. In view with the foregoing, the urgent task is to create a tool for clarifying and determining the SM model parameters. This tool can be formed based on various optimization algorithms (including genetic algorithm).

Keywords: *synchronous machine, automatic excitation controller, phasor measurement units, optimization algorithms, synchronous machines parameters, automatic excitation controller parameters.*

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T.G. Klimova [α], A.I. Kovalenko [σ] & O.O. Nikolaeva [ρ]

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For definition of SM parameters sharing WAMS devices and optimization algorithms is perspective and actual research direction. To solve this issue, can be used well-known differential equations system of Park-Gorev. All phases currents and stator voltage, voltage and current of excitation, network frequency are easily detected through WAMS and are known values. The availability of data on SM electric values combined with using differential equations system of Park-Gorev allows to determine of SM parameters with prescribed periodicity.

As a result of further development of the proposed technique of determining SM parameters it can be the basis for SM parameters monitoring system according to the data obtained from WAMS in real time.

Another relevant application of the developed technique is the solution of the issue of power system equivalenting or its part according to the data obtained from WAMS.

Working of synchronous machines is impossible without automatic excitation control. This paper shows the possibility of using WAMS measurements for estimate AEC parameters of synchronous generator for different AEC types from various manufacturers in ideal and real conditions. By using the simulation in the hardware and software system RTDS (Real-Time Digital Simulator), WAMS measurements have been obtained for different modes of AEC operation. The developed technique is based on the processing of obtained measurements by different optimization algorithm. As a result of the comparative analysis, the most suitable type of optimization has been chosen. The paper shows the possibility of determining AEC parameters in different modes of its operation with different model various noise power arising in the scheme of the power system, and connecting the scheme to the network real power system.

The developed technique determines AEC parameters in different modes of operation with sufficient accuracy by using WAMS measurements. Thus, the technique allows to extend the field of WAMS application, and with further development, will allow to monitor the AEC and calculate its parameters in real time.

Keywords: synchronous machine, automatic excitation controller, phasor measurement units, optimization algorithms, synchronous machines parameters, automatic excitation controller parameters.

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I. Introduction

Currently, phasor measurement units (PMU) are becoming more widespread in power systems. With a high accuracy, they measure complex current and voltage values in the installation sites of PMU. Obtained data allow creating an objective picture of power system state.

At this time, in carrying out various researches, simulation of synchronous generators (SG) is widely used. The possibilities and, consequently, the list of parameters that need to be set in the SG block model, in a variety of Program Complexes (PCs) and Program Apparatus Complexes (PACs) are different. At that, a situation when there are no values of various parameters required for setting in the SG models often happens. This factor has a negative influence in forming the model and its further use.

To determine the SG model parameters both classical methods described in [1] and different from them can be used. For example, different optimization algorithms can be successfully used for this, that will increase the accuracy of simulation SG.

Optimization algorithms can also be used to verify the SG models used at carrying out the researches, what is an important factor in confirming the authenticity of the results.

II. Determination of xd, x'd, x"d, T'd, T"d

Forming SG model and testing of optimization algorithms were held on a PC based Matlab Simulink. As an object of simulation can be a real SG or SG model, made in another PC, PAC. Necessary data to determine the parameters of the real SG can be obtained by PMU usage.

To determine the Xd parameter by the traditional method in accordance with [1, 3] is required to construct open-circuit characteristic (OCC) and three-phase short-circuit characteristic (SCC). These characteristics must be built on the same plane, and then for a certain value of the excitation current (is taken equal to 1,0) Xd parameter as the ratio is a voltage (for OCC) to a current (in SCC). The resulting parameters value will be saturated. You must perform to obtain an unsaturated Xd value the same steps using straightening unsaturated OCC. OCC and SCC, built for the SG model, constructed in PC Matlab, shown in Fig 1.

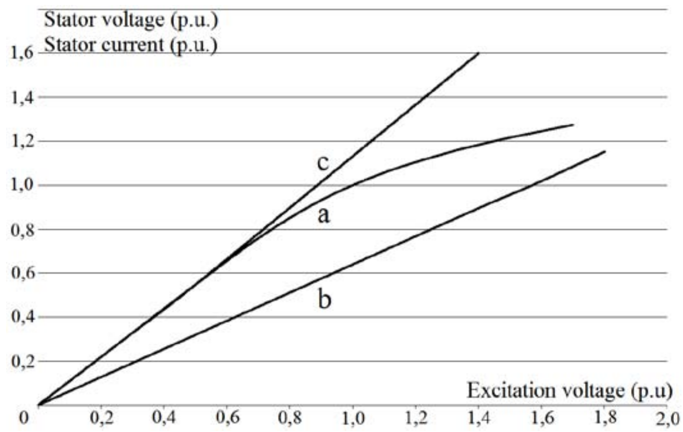

Figure 1: Saturated open-circuit characteristic (a), unsaturated, (c), the characteristic of the three-phase short-circuit (b) built for the SG model

Xd definition by using the optimization algorithm implies the comparison and the minimization of the difference between the OCC, belonging to the object of simulation, and OCC obtained in formed model, by automatically selecting the Xd parameter value. At that time, the OCC, belonging to the synchronous generator model, is benchmark characterstic, and OCC, belonging to the newly formed SG model, are automatically reset for each new set Xd value, as long as it does not match the benchmark OCC with a given accuracy.

To determine the X'd, X"d, T'd, T"d parameters by the traditional method in accordance with [1] is required to hold the experience sudden three-phase short circuit (TSC). Fixed open circuit voltage immediately prior the short circuit (SC) and the phase currents of the stator SG. X'd is defined as the ratio of the open circuit voltage to the initial value of the periodic component of the short-circuit current net subtransient component.

X"d is defined as the ratio of the open circuit voltage to the initial value of the periodic component of the short-circuit current.

T'd is defined as the time during which the transient component of the stator current decreases to its initial value of 0.368.

T"d is defined as the time during which the subtransient stator current decreases to its initial value of 0.368.

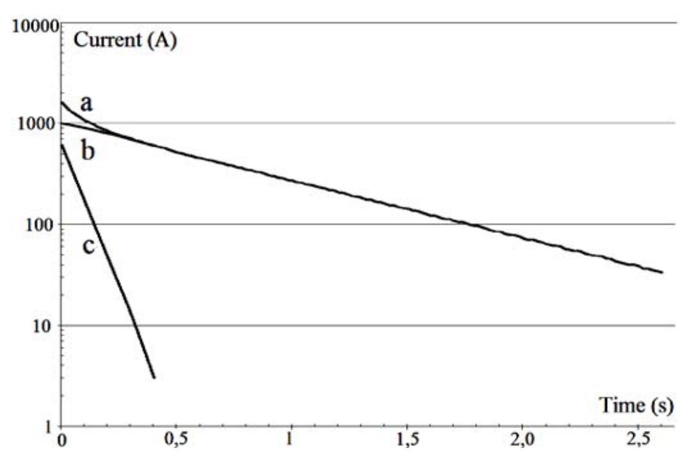

Figure 2: The amount of the Subtransient and transition phase current components (a), a transition component (b), subtransient component (c) of the short-circuit current

To determine the X'd, X"d, T'd, T"d parameters by using optimization algorithms an optimization function, whose arguments are all required to parameters, is formed. On the SG model the experience sudden TSC is held and an oscillogram of phase stator current is fixed. From fixed oscillograms stands out periodic component of the current is defined as the half-algebraic ordinates of the upper and lower envelopes amplitude (shown in Fig. 2). After that the difference between the resulting curve and standart is minimized.

III. Determination of Rs, Ta, X_2

The Rs and Ta parameters should be determined from the experience of a sudden three-phase short circuit on the attenuation of the periodic component of the current in the excitation circuit, by the traditional method in accordance with [1]. For this the oscillogram of the excitation current is fixed at the shorted SG phase stator winding, which works in an idling.

From the fixed oscillogram, the periodic current component stands out and is plotted in semi-logarithmic coordinates.

Value of the time constant of the aperiodic stator current component Ta is defined as the time during which a periodic component of the current drive circuit decreased to its initial value of 0.368.

To determine the stator winding resistance, the equation can be used [2]:

$$Rs = 0.8 \cdot X_2 / (\omega_c \cdot T_a) \qquad (1)$$

Where X_2 is an unsaturated parameter and can be determined by the equation [2]:

$$X_2 = 1.1 \cdot X''d \qquad (2)$$

The approach to the determination of the Rs and Ta parameters by using optimization algorithms is similar to the one, which was used to determine the X'd, T'd parameters. Optimization function, whose argument is the desired parameter Rs, is formed. On the SG model the experience sudden TSC is held. From a fixed excitation current oscillogram the periodic component stands out. After that the difference between the resulting curve and benchmark is minimized.

The subsequent determination of the Ta time constant is produced by the equation (1).

At the same time X_2 is defined by (2), wherein the subtransient inductive reactance X"d has already been defined by the optimization method. It should be noted, that all data about necessary electrical quantities can be obtained by PMU usage.

IV. Determination of T'd0

For the determination of the transient time constant along a longitudinal d-axis at the open stator winding by the traditional method in accordance with [1], a voltage recovery method can be used.

The difference between the steady-state value voltage and recovery voltage U (∞) -U, defined by their amplitudes, is plotted in semi-logarithmic coordinates. Determination of the T'd0 parameter by the voltage recovery method consists in determining time during which a transient voltage component ΔU' decreases to its initial value of 0.368.

The procedure for determining T'd0 parameter by the optimization algorithms similar to the procedure, which was performed in determining Xd parameter. At the same time is held the voltage recovery experience on the SG model and the stator voltage recovering oscillogram is also fixed, then from fixed oscillogram stands out the envelope and the difference between the benchmark curve and the obtained on the SG model is minimized.

V. Determination of SG Stator Winding Leakage Inductive Reactance XL

XL parameter according to the [1] can be determined graphically by OCC, SCC and the point of load characteristics, which corresponds to the nominal values of voltage and current in the stator overexcitation mode (shown in Fig. 3).

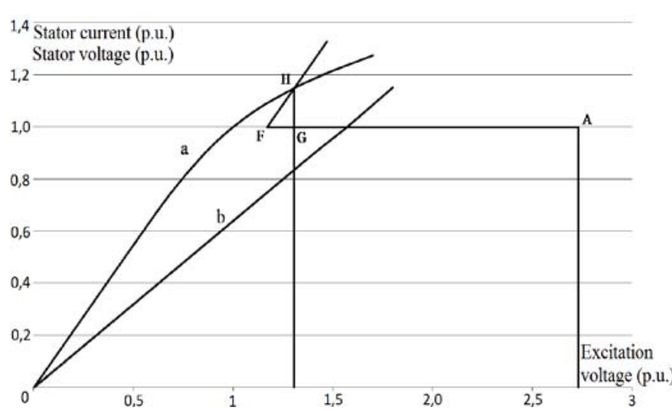

Figure 3: Graphical determination of the SG stator winding leakage inductive reactance Xl

To the left of the point A parallel to axis of abscissas AF segment is laid, equal to the value of the excitation current to be determined at the nominal stator current on the steady TSC characteristic. From point F the line parallel to the initial part of the OCC to intersect the latter at a point H is laid. Perpendicular from the point H on the line AF there is a voltage drop across the leakage inductive reactance Xl at the nominal stator current.

Calculated inductive reactance Xl is determined by the equation:

$$Xl = U_{HG} \tag{6}$$

Plotted on the Fig.3 characteristics can be obtained using PMU data (about changes of electrical quantities).

Determinations of the Xl parameter by the optimization method is performed similarly to the synchronous inductive reactance along a longitudinal d-axis Xd. The only difference is that the argument of the optimization function is the stator winding leakage inductive reactance resistance Xl.

VI. Determination of Tj, H

The nominal time of the machine acceleration Tj and the storage-energy constant H can be determined by the run-out idling method, by the traditional method according to [1].

Rate speed test machine is set above the nominal, then the power source is disconnected. At the same time the SG rate speed change is fixed, then the time Δt, during which the machine changes rate speed in the range of Δn, is determined.

The nominal time of the machine acceleration Tj is determined by the equation [1]:

$$T_j = n_n \cdot \frac{\Delta t}{\Delta n} \cdot \frac{P_{mech} + P_{steel}}{P_n} \tag{3}$$

n_n - nominal speed;
P_n - nominal active power;
S_n - nominal apparent power;
P_{mech} - mechanical losses at the nominal speed;
P_{steel} - iron losses at a voltage of experience and the nominal speed.
Storage-energy constant H can be determined by the equation [1]:

$$H = \frac{n_n}{2} \cdot \frac{\Delta t}{\Delta n} \cdot \frac{P_{mech} + P_{steel}}{S_n} \tag{4}$$

To determine the H, Tj parameters by the optimization method the SG rate speed changes oscillogram, which is fixed during the run-out idling experiment, should be used. The optimization function, whose argument is a storage-energy constant H, is formed. On the model of SG the run-out idling experiment is held, and then the difference between the resulting curve and standard is minimized.

Tj parameters can be determined by the equation, wherein the storage-energy constant H has already been defined by the optimization method:

$$T_j = 2 \cdot H \cdot \frac{S_n}{P_n} \tag{5}$$

VII. Comparative Analysis of the SG Parameters Determining Methods

To determine the SG parameters different optimization functions from Matlab library can be used [4, 5, 6]: fmincon, fminbnd, fminsearch, fminunc.

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Table 1: The Values of Errors of the Sg Parameters Determination

SG parameter	The value set in the SG model (data sheet), p.u.	The value obtained by the method of GOST (traditional method), p.u.	The value obtained by the optimization method, p.u.	Error of the method according to GOST, %	Error of the optimization method, %
Xd	1,71	1,692	1,7098	1,05	0,012
X'd	0,172	0,157	0,17199	8,72	0,006
X''d	0,119	0,109	0,11899	8,4	0,008
T'd	0,77	0,764	0,76998	0,78	0,003
T''d	0,0962	0,108	0,96104	12,27	0,1
Xl	0,18	0,15	0,179981	16,67	0,011
T'd0	1	0,999	0,993437	0,1	0,66
Rs	0,0028	0,001897	0,002801	32,31	0,08
Ta	0,132	0,161	0,119	21,97	9,85
X_2	0,145	0,1199	0,1309	17,3	9,72
H	2,136	2,0259	2,136035	5,16	0,0016
Tj	5,3406	5,06475	5,340875	5,16	0,0052

At the same time fminunc function provides such methods of smooth unconstrained optimization:

- Steepest Descent method;
- BFGS-method;
- DFP-method (Davidon–Fletcher–Powell).

Most simple to use is a function of multivariate unconstrained optimization - fminsearch. In this paper, this optimization function is used. The rest of these the optimization algorithms require a more detailed analysis of their work, setting limits and the initial data.

The values of errors of the SG parameters determination by the methods, provided [1] and the optimization method, are shown in Table 1.

VIII. SG and AEC Parameters Monitoring by the Optimization Algorithms Usage

One of the important directions of the optimization algorithms usage is the synchronous machine parameters determination in real-time environment or at specified sampling rate.

Differential equation system of the Park-Gorev can be used to solve this problem. All the phase stator currents and voltages and rotor current and voltage are recorded by means of phasor measurement units (PMU) and are known quantities.

On excitation winding the test signals are served and, at the same time, the stator phase currents and voltages are fixed. Knowing the input signal and the output signal using the optimization algorithms the SG parameters can be determined.

The development of the theme of the SG parameters determination by using the measurements obtained from the PMU can serve as the basis for forming the system of monitoring the synchronous machine parameters condition.

It is possible to form the function, where the AEC parameters act as unknown, by using methods of spectrum analysis for PMU measurements processing and analyzing frequency methods of the automatic control theory [16].

Optimization algorithms allow processing this function and finding unknown coefficients.

This article deals with the technique of determination of the AEC parameters by using synchronized pharos measurements.

IX. Brief Description Of The Investigational AEC

Development of the technique is based on controller operation analysis of AEC with two stabilization systems (ARV-2SS) of the Russian production.

Fig. 4 shows mathematical model of microprocessor controller ARV-2S algorithm, all the model elements are described by the transfer functions of the continuous operator s.

As input parameters of stabilization channels in ARV-2SS can be used frequency deviation of voltage of synchronous generator stator and its first derivative, first derivative voltage of generator stator and first derivative of the rotor current [17].

Main coefficients of AEC channels are listed below. These coefficients are used in this technique as unknown.

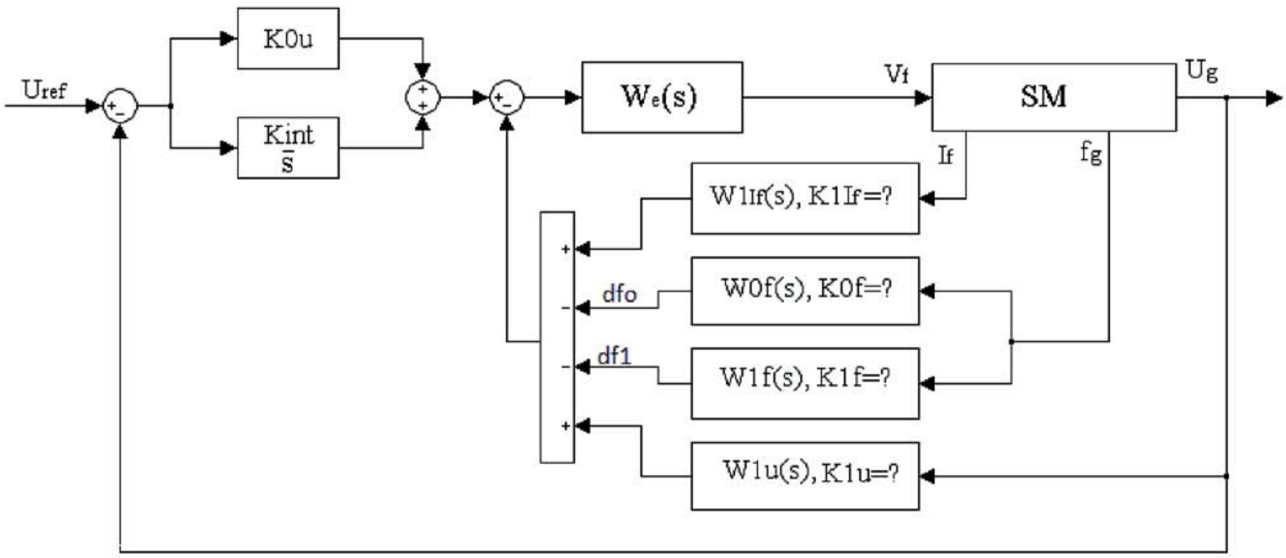

Figure 4: Mathematical model AEC with two stabilization systems AFV-2SS

The parameters of the automatic voltage regulator (AVR) channel:

- K0u, pu — proportion gain on voltage deviation of generator stator;
- Kint, sec — integral gain in circuit regulating the stator voltage.
- The parameters of the external stabilization:
- K0f, pu/Hz — gain on frequency deviation;
- K1f, pu/Hz/sec — gain on the first derivative frequency.
- The parameters of the internal stabilization:K1u, pu/sec — gain on derivative of the stator voltage;
- K1if, pu/sec — gain on the first derivative of the rotor current.

X. Description of the Developed Technique

The technique is based on determination of main AEC parameters by optimization algorithms using PMU measurements.

By using the simulation in the hardware and software system RTDS (Real-Time Digital Simulator) [18], PMU measurements have been obtained for different modes of AEC operation. The PMU measurements have been formed in data sets, which have been further processed in MATLAB using optimization algorithms.

These algorithms find minimum of the objective function, which represents the difference between transfer function obtained from PMU measurements and transfer function calculated with the unknown coefficients of the AEC channels.

During technique development, several optimization algorithms have been considered, they are described below. All algorithms use the same objective function.

a) Fminunc algorithm

The function Fminunc(fun, x0, options) from Optimization Toolbox MATLAB implements unconstrained nonlinear optimization methods [19]. Each experiment is calculated with ten starting points (x0), chosen at random within the possible coefficients range.

Fig. 5 shows the process of calculating coefficients K0u and Kint. Different initial values (starting points) are marked with colours. The convergence is observed for all initial values after about 150 iterations.

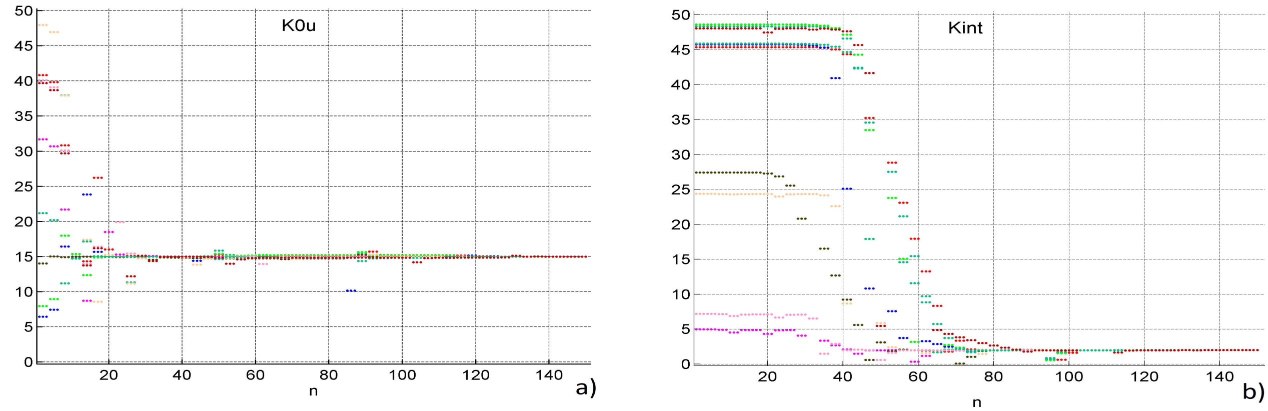

Figure 5: Calculation of coefficients K0u (a) and Kint (b) by Fminunc algorithm

b) Fmincon algorithm

The function Fmincon from Optimization Toolbox MATLAB attempts to find a constrained minimum of a scalar function of several variables so this function implements constrained nonlinear optimization or nonlinear programming [20]. The algorithm allows to restrict the range of variation of the unknown coefficients. The results obtained by using this algorithm fully match with the results of calculation by Fminunc algorithm. However, it must be noted that in some cases this algorithm calculates faster.

c) Genetic algorithm

The possibility of using genetic algorithm (GA) to calculate the AEC parameters have been considered. The genetic algorithm is a method for solving optimization problems based on biological principles of natural selection and evolution. In this paper, we have applied a standard GA without modification, which is presented in MATLAB.

Fig. 6 shows process of calculating coefficients of AVR channel. The horizontal axis denotes the number of individuals, i.e. the number of possible solutions of algorithm.

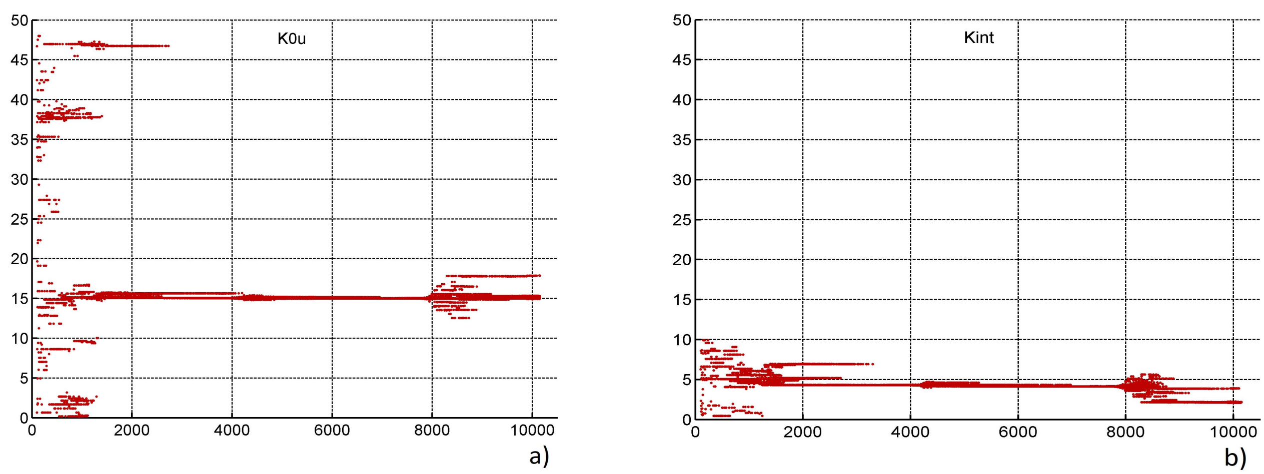

Figure 6: Calculation of coefficients K0u (a) and Kint (b) by genetic algorithm

Since the GA uses the principles of calculation different from that of the Fminunc algorithm there are differences in the presentation of the results (mismatch of scale on the horizontal axis in Fig. 5 and Fig. 6). However, the calculation results of both algorithms coincide.

The calculation time for any presented algorithms is considerably increased when increasing the number of unknown parameters in the objective function.

d) Comparison of optimization algorithms

During the comparative analysis of considered algorithms, the calculation time and maximum errors of calculation have been estimated. As a result, despite the good performance and sufficient accuracy, all things being equal, the GA requires much more time to calculate than the other algorithms, especially when increasing the number of unknown parameters.

Therefore, further calculations have been performed using Fminunc algorithm.

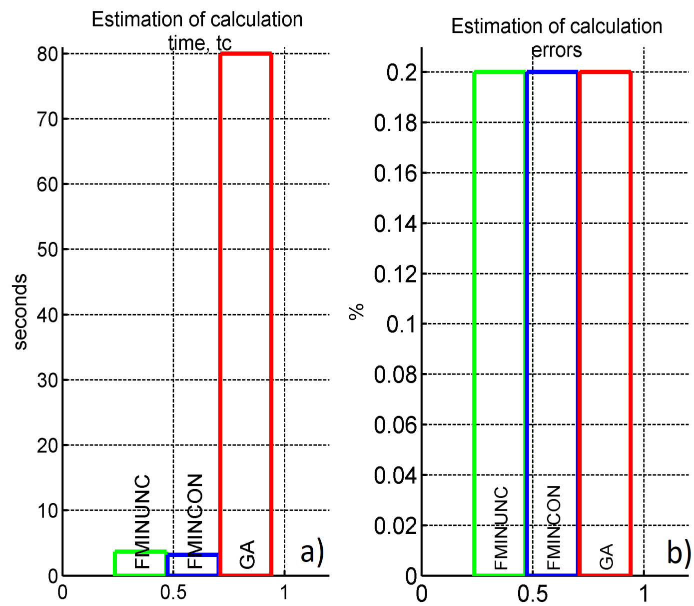

Figure 7: Column diagram of calculation time (a) and maximum errors of calculations (b) for considered algorithms when all stabilization channels are turned off

XI. The Results of Using the Technique

The presented technique have been checked by analyzing operation of AEC with two stabilization systems. The modes of AEC operation, listed in Table II, have been researched. For each mode of operation, it uses the same objective function, containing six unknown – main coefficients of AEC channels.

Table 2: The Researched Modes of Ace Operation

Mode number	Mode description
1	Only ARV channels work, and the channels of system stabilizer are turned off
2	ARV and external stabilization channels work
3	ARV and internal stabilization channels work
4	ARV channels work, and all the channels of system stabilizer are turned on

Fig. 8 shows amplitude spectrums of oscillations of the rotor voltage (Vf) for each modes of AEC operation. The number under the picture corresponds to the number of operating mode (Table II) for which it has been plotted. The amplitude spectrums of oscillations of the rotor voltage, based on PMU measurements, are plotted in figure by the solid green curve. The amplitude spectrums of oscillations of the rotor voltage, obtained through calculated coefficients, are plotted in figure by the dotted red curve. In all cases, the curves coincide with sufficient accuracy.

The presented technique uses two methods to form the objective function for determining of the AEC parameters by using obtained measurements. The first method uses transformation from spectrum of oscillation of the rotor voltage Vf to spectrum of oscillation relevant input signals of stabilization channels (Ug, fg, If) in the closed automatic control system (ACS), while it is necessary to know a transfer functions of synchronous generator SM through relevant variables. When these data on a synchronous generator absence, the objective function forms by transformation from the spectrum of oscillation input signals of stabilization channels (Ug, fg, If) to spectrum of oscillation of the rotor voltage Vf in opened ACS. This is the second method to form the objective function.

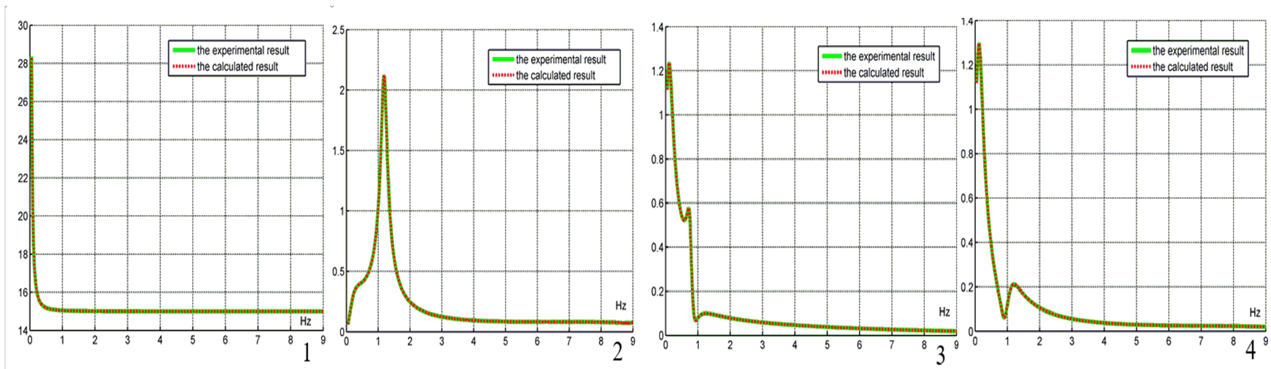

Figure 8: Amplitude spectrums of oscillations of the rotor voltage for different modes of AEC operation

The results of calculation of the AVR channels parameters in modes, listed in Table 2, are shown in Fig. 9. The results of calculation of the coefficients of internal and external stabilization channels (Fig. 10) are shows only for modes in which these coefficients are non-zero. Each figure shows the calculation results for both methods.

The errors of the coefficients calculation are mostly less than 1%. In some cases, the error can reach 3%.

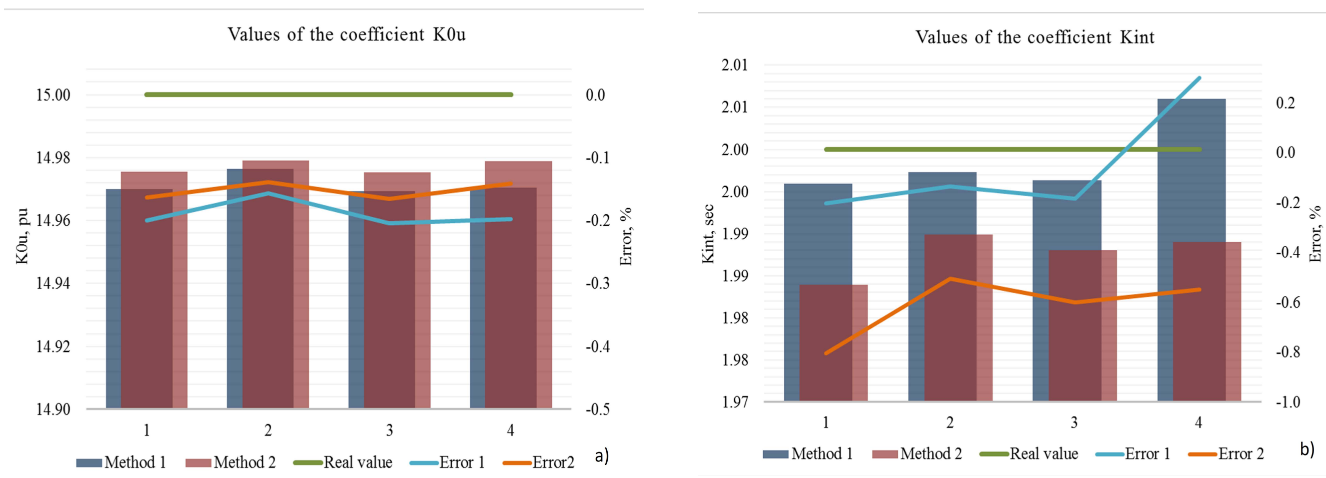

Figure 9: Combined graphs of the values of the coefficient K0u(a) Kint(b) and its error calculation for different modes of AEC operation

The second method allows to perform calculations quickly. However, when calculating the coefficients Kint, K1if, K1u and K0f, there is an increase of the error unlike first method.

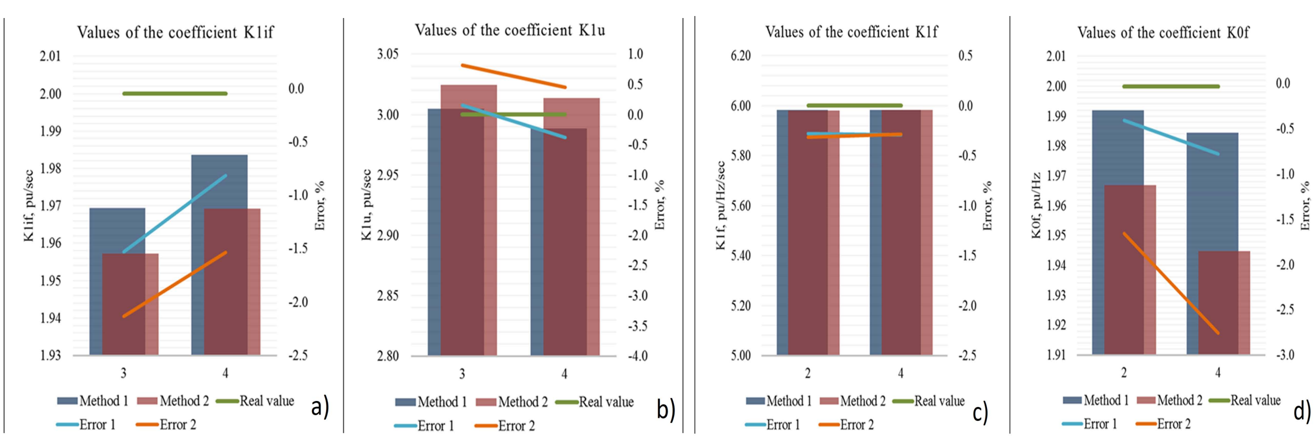

Figure 10: Combined graphs of the values of the coefficients of internal stabilization channels K1if (a), K1u (b), K1f (c) and K0f (d) and its errors calculation for different modes of AEC operation

Also the presented technique has been checked, when in the circuit there is a noise of different power level. For these experiments, we have used ower system model in RTDS.

As previously, the calculations have been carried out in two methods using the Fminunc algorithm with six unknown parameters in objective function. The technique is fully confirmed.

XII. Conclusion

In this paper several synchronous generator parameters were determined; the other SG parameters can also be determined by using the optimization algorithms.

These results confirm the effectiveness of the proposed alternative methodology for the SM model parameters determining. The error in the parameters determining of this method is much lower than with classical methods and almost absent. The error in determining Ta and X2 parameters involves the usage of the approximate calculation equations. On further research this error can be reduced. Method using the optimization algorithms can also be used in combination with traditional methods.

The developed method can also be used to verify the existing SM model, taking into account the fact that the needed oscillograms and characteristics of simulated machine exist.

The proposed method is universal and can be used in the different PCs and PACs. Since the parameters are selected by iterations directly in the simulation environment, the method automatically takes into account the peculiarities of simulation SG in any given PCs or PACs.

Developing the direction of application of optimization algorithms to determine the SM parameters can achieve even more accurate forming the SM model, which will increase the quality of carried by them researches and also have a positive impact on the reliability of the results.

Another actual direction of the optimization algorithms usage is the synchronous generator parameters monitoring in real-time environment using the PMU.

The proposed technique allows to use PMU measurements to determine the AEC parameters by optimization algorithms. The technique has been checked on AEC with two stabilization systems in different modes of AEC operation.

Also in the study the comparative analysis of applying different optimization algorithms has been performed. As a result, despite the good performance and sufficient accuracy the GA requires much more time to calculate than the other algorithms, especially when increasing the number of unknown parameters.

The developed technique determines AEC parameters with sufficient accuracy by using PMU measurements, including when in the circuit there is a noise of different power level.

Thus, the technique allows to extend the field of PMU application, and with further development, will allow to monitor AEC and calculate its parameters in real time.

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An Extensive Review of Emerging Technology Networks-on-Chip Proposals

By Ahmed Ben Achballah, Slim Ben Othman & Slim Ben Saoud
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Abstract- Many synthesis works discussed emerging technology networks–on–chip (NoC) from different aspects. These works were and still are a solid foundation of the state of the art for emerging technology NoC research and practices. However, with respect to their quality and conciseness, the available literature is outdated or don't give an extensivere view of the available contributions in this area. In this paper, we iterate and discuss our findings in terms of research and practices for emerging technology NoC for the last ten years. The analyzed proposals are exposed chronologically. This will help to answer to the questions of when and how the concept was introduced, what is its present state and what the future directions are.

Keywords: noc, on-chip interconnect, emerging technology noc, 3d noc, onoc, photonic noc, winoc, rf–interconnect.

GJRE-F Classification: FOR Code: 290903

ANEXTANSIVEREVIEWOFEMERGINGTECHNOLOGYNETWORKSONCHIPPROPOSALS

Strictly as per the compliance and regulations of:

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Ahmed Ben Achballah [α], Slim Ben Othman [σ] & Slim Ben Saoud [ρ]

Abstract- Many synthesis works discussed emerging technology networks–on–chip (NoC) from different aspects. These works were and still are a solid foundation of the state of the art for emerging technology NoC research and practices. However, with respect to their quality and conciseness, the available literature is outdated or don't give an extensivere view of the available contributions in this area. In this paper, we iterate and discuss our findings in terms of research and practices for emerging technology NoC for the last ten years. The analyzed proposals are exposed chronologically. This will help to answer to the questions of when and how the concept was introduced, what is its present state and what the future directions are.

Keywords: noc, on-chip interconnect, emerging technology noc, 3d noc, onoc, photonic noc, winoc, rf–interconnect.

I. Introduction

Networks-on-chip are a widely used technology within recent systems-on-chip (SoC) and chip-multi-processors (CMP)[1]. However, several emerging technology NoC are proposed as a potential replacement for classical NoC [2, 3]. To this aim, several research works have focused on the design of emerging technology NoC. The research in this particular field is further developed because the fabrication processes of integrated circuits are also evolving. Unfortunately, the literature for emerging technology NoC is scattered and is not extensively reported[4, 5].

In this paper, the lack of a global review of the emerging technology NoC research is addressed. An extensive review of the available literature regarding emerging technology NoC is executed, resulting on the analysis of more than 200 papers. Additionally, the available surveys and textbooks in the NoC domain are reported. The analyzed research papers are exposed chronologically. This will help to answer to the questions of when and how the concept was introduced, what is its present state and what the future directions are. To organize the survey, we categorize the available research and contributions for emerging technology NoC as it is shown in Figure 1. Our approach is a technology–based approach.

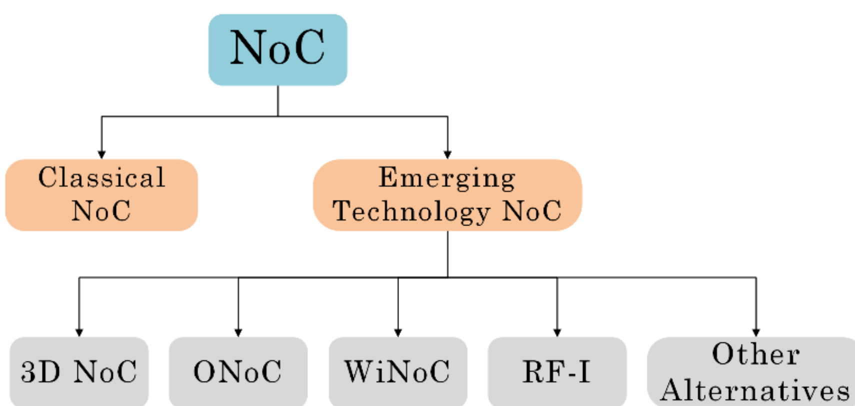

Figure 1: Technology–based classification of NoC

Before we move forward in this review, we briefly introduce in the following the two NoC's alternatives that are classical or emerging technology NoC.

- *Classical NoC* constitute an established baseline technology in the field and the unique commercialized technology. Most of the available efforts in the literature were built around such technology. The research community has explored this lead very well. However, the most significant result, is in the industrialization of the NoC concept, for both sides, providers of NoC solutions [6-8] and SoCs/CMPs vendors[9-12].
- *Emerging technology NoC* are a direct result from exploiting any valuable advances from silicon industry. Usually, the research efforts regarding emerging technology NoC are divided in four major categories, which are 3D NoC, Optical NoC (ONoC

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also reported PNoC for Photonic NoC), Wireless NoC (WiNoC also reported WNoC), and finally Radio-Frequency Interconnect (RF-I also reported RFNoC). However, there are other original attempts. They targeted some of the advanced and under development technologies such as graphene substrate.

The remaining of the manuscript is organized as the following: we briefly recall and classify the available surveys and textbook in the second paragraph. In the third paragraph, we review the emerging technology NoC literature subdivided in terms of principal research axis while in the fourth paragraph we conclude the manuscript.

II. Related Surveys And Textbooks

For the last fifteen years, many surveying works had enriched the NoC literature. Such synthesis papers constitute a solid backbone for present and future research as well as for this work. Through this paragraph, we tried to collect and expose these works as the literature lacks such collection. This is also an interesting aid for new NoC researchers as it could shorten their state-of-the-art investigation exercise. Table I lists the available surveying works that we found in the literature. In addition, we give a list of the published textbooks in the same area.

Table I: NoC–Related State of the Art

NoC– related surveys and synthesis efforts		NoC– related textbooks	
Authors [Date]	Reference	Authors [Date]	Reference
Seitz [1990]	[13]	Dally and Towles [2003]	[14]
Dally and Towles [2001]	[15]	Duato et al. [2003]	[16]
Benini and De Micheli [2002]	[17]	Jantsch and Tenhunen [2003]	[18]
Ogras et al. [2005]	[19]	Ogras and Marculescu [2006] from Chen (Editor) [2006]	[20]–[21]
Pande et al. [2005]	[22]	De Micheli and Benini [2006]	[23]
Bjerregaard and Mahadevan [2006]	[24]	Kogel et al. [2006]	[25]
Owens et al. [2007]	[26]	Yoo, Lee and Kim [2008]	[27]
Salminen et al. [2007] – [2008]	[28]–[29]	Pasricha and dutt [2008]	[30]
Atienza et al. [2008]	[31]	Jerger and Peh [2009]	[32]
Dafali et al. [2008]	[33]	Chrysostomos et al. [2009]	[34]
Zydek et al. [2008]	[35]	Gebali et al. [2009]	[36]
Feero and Pande [2009]	[37]	Murali [2010]	[38]
Marculescu et al. [2009]	[39]–[40]	Flich and Bertozzi [2011]	[41]
De Micheli et al. [2010]	[42]	Silvano et al. [2011]	[43]
Deb et al. [2010]	[44]–[45]	Cong-Vinh [2012]	[46]
Rahmani et al. [2010]	[47]	Cota et al. [2012]	[48]
Chen et al. [2011]	[49]	Fu and Ampadu [2012]	[50]

Gu [2011]	[51]	Ogras and Marculescu [2013]	[52]
Fernandez−Alonso et al. [2012]	[53]	Palesi and Daneshtalab [2013]	[54]
Kim et al. [2012]	[55]	Bergman et al. [2014]	[56]
Postman and Chiang [2012]	[57]	Tatas et al. [2014]	[58]
Ben Achballah and Ben Saoud [2012]	[59]		
Buckler et al. [2012]	[60]		
Choudhary and Samota [2012]	[61]		
Radetzki et al. [2013]	[62]		
Abbas et al. [2014]	[63]		
Bertozzi et al. [2014]	[1]		
Wang and Jin [2014]	[5]		

III. Emerging Technology NoC Proposals

a) 3D NoC

A natural evolution in the NoC paradigm is the transition from 2D to 3D NoC. As the integration technology is evolving, many 3D techniques are developed allowing the stacking of multiple dies with numerous processing elements and memories. The connection between these dies is physically assured by interconnect techniques such as wire-bounding, micro-bumps, TSVs and lately wireless capacitive- and inductive-coupling [64]. These interconnects fabrics are shifting from simple point to point connections to more developed networks that link at the same time between the die elements and the dies from different layers, called 3D NoC. Several comparative studies between 2D and 3D NoC are available [58, 64-66]. The research in this area is very mature compared to the other emerging technology NoC. In fact, we can find in the literature many established works where the efforts have evolved from simple architectural dimensioning to high-level abstraction, routing algorithms, fault tolerance and resolving physical related problems like the TSVs failures or the thermal overheads. In the following, a distillation of the recent works is provided.

i. *Fault tolerant and reliable 3D NoC*

3D NoC offer a better area-performance ratio compared to 2D NoC thanks to the third dimension. However, this has triggered additional issues. Among them, we can find the containing of the TSVs number and the design of more low-power architectures. Hence, the reliability of 3D NoC is more challenging and by consequence is heavily investigated in academia. Recently, Jiang and Xu surveyed the works as regards fault−tolerant 3D NoC architectures[4]. The authors provided an extensive classification of defects and fault models. A listing of the existing fault-aware routing algorithms as well as a comparative study are also provided. In this section, some of the studied proposal in [4]are considered. In addition, the more recent proposals that are not studied by Jiang and Xuare also discussed.

Researchers targeted the deadlock freedom of 3D NoC. For example, Ben Ahmed and Ben Abdallah proposed an efficient fault−tolerant and deadlock free algorithm for 3D NoC called Hybrid-Look-Ahead-Fault-Tolerant (HLAFT)[67]. The presented algorithm showed better results than XYZ algorithm and its predecessor called LAFT [68].

Dubois et al. [69]and Somas undaram et al. [70] respectively developed two other similar works. The first one is an algorithm called Elevator-First. It is a distributed algorithm with deadlock-and live lock-freedom capabilities. It is also applicable to both 2D and 3D partially connected architectures. The second one is a deadlock-free algorithm and when combined to a 3D NoC topology developed by the same team, outperforms the proposition of the first work [69].

Lee et al. in their turn [71], attempted to enhance the Elevator-First approach from [69]. The authors maintained the performances of the Elevator-First algorithm with the elimination of virtual channels, which is a very area-saving maneuver. More recently and also based on the Elevator-First algorithm, Lee et al. developed a new energy-efficient and deadlock-free algorithm for 3D NoC called Redelf [72]. The evaluation results showed that the proposed algorithm acted better than the basic Elevator-first in terms of energy consumption and latency.

Ebrahimi et al. established a similar approach[73]. The authors developed a fault-tolerant routing algorithm for 2D and 3D NoC using the advantages of the Hamiltonian path. NaghibiJouybari and Mohammadi, in their turn, developed another fault tolerant algorithm for 3D mesh NoC[74]. The authors proposed FT-DyXYZ, a fault tolerant adaptive routing algorithm that was able to avoid permanent faulty links. The same team proposed a newer fault-tolerant and energy-efficient algorithm for TSV-based 3D NoC called FT-Z-OE[75]. Finally yet importantly, some of the other efforts focused on developing innovative 3D NoC architectures. As an example, Ben Ahmed et al. presented in [67]a 3D NoC router architecture called 3D-Fault-Tolerant-OASIS while Marcon et al. developed a lightweight and fault–tolerant 3D NoC architecture called Tiny NoC[76].

ii. *Novel 3D NoC architectures*

To bypass the limitations caused by TSVs, other research efforts explored wireless capacitive-and inductive-coupling between the stacked dies [77]. The difference between the two technologies is that for capacitive-coupling only two dies or chips can be connected in a face-to-face fashion. However, with inductive-coupling, many dies can be stacked together. Take et al. [78]and Miura et al. [79]respectively proposed two 3D NoC architectures called Cube-0 and Cube-1. The communication between the different layered chips was assured by inductive-coupling links that are organized in a ring topology. These architectures are also reported as 3D wireless NoC (3D WiNoC) in the literature [77].

Later, several extended studies related to 3D NoC architectures with wireless vertical links were conducted. Matsutani et al. executed in [80]a routing and topology design space exploration. The authors used spanning tree optimizations to reduce the hop count of the network. Zhang et al. developed in [81]an optimized power management scheme. The authors managed to dynamically activate and deactivate the supply power for a portion of the vertical links. The two studies demonstrated that a good balance between the proposed power management technique and the spanning tree optimizations achieved good performances at a reasonable power cost.

Recently, Matsutani et al. investigated the use of an extra NoC layer with a random or mesh topology to enhance the performances of 3D ICs[82]. Two approaches were developed. The first one targeted NoC-less 3D ICs while the second one targeted NoC-based 3D ICs. The authors experimented several configurations scenarios. Several combinations between four vertically-layered ICs with all-mesh, all-random or mixed topologies NoC were benchmarked. The simulation results showed that such configurations could reduce the latency of the transferred packets especially when random topologies were considered. It was also demonstrated that one or two NoC layers with a random topology are sufficient to reduce the packets latency [82].

The latter works have shown a very interesting economic potential with the 3D wireless NoC architectures. Rather than integrating components in a single chip like for SoCs, the required IPs can be vertically stacked on multiple chips equipped with inductive coupled links in a System-in-Package (SiP). As a direct consequence, many chip combinations can be established with legacy designs at moderate design costs.

Finally, other esoteric studies were also developed. For example, Elmiligi et al. used a genetic algorithm to build 3D mesh NoC with reduced power consumption from a given application[83]. The algorithm was tested and validated in an architecture of 32 microprocessors. Daneshtalab et al. presented a novel methodology to reorder request packets without the need of the two conventional solutions: the dimension–order routing by limiting the packet to use the same path that is performance degrading, or the packets reordering inside the network interfaces that is area expensive[84].

iii. *Design space exploration for 3D NoC*

To tackle the several challenges of 3D NoC, a design space exploration of the 3D NoC-based designs is important. This goes through the developing of analytical models for 3D NoC components as well as for common defects and faults. Khayambashi et al. studied the impact of the TSVs' failures on the reliability of 3D NoC[85]. This allows a more accurate estimation of the area overheads versus the performance gains from the use of TSVs in the design. Jiang et al. proposed the resolution of the latter compromise at higher levels of abstractions[86]. The authors developed an adaptive algorithm that can provide low latency and low power without increasing the TSVs number. This solution maintained a reduced TSVs number for larger 3D NoC-based designs. Ying et al. [87], in their turn, developed a task allocation method for 3D NoC with limited number of TSVs. The proposed method was contrasted with prior methods such as the genetic algorithm and the simulated annealing.

Ebrahimi et al. explored several partitioning methods of multicast communications in 3D mesh NoC in addition of developing analytical models for each method[88]. They came with a conclusion that among the applied methods, the recursive method was the productive one. A similar approach was proposed by Meena et al. called 3D-RPM for 3D recursive partitioning multicast routing algorithm[89].

Lastly, Dahir et al. discussed the reduction of the 3D NoC temperature[90]. The authors alleviated this challenge from the application layer. The authors used a runtime thermal management technique called DPN to moderate the traffic flow in the network, hence assuring a moderate silicon temperature.

b) Optical-Photonic NoC

Optical-photonic NoC are a very serious candidate to succeed to classical NoC. In fact, Optics were and still are a viable and widespread solution used in macroscopic networks from the simple single–server installation to the complicated data centers. The reason is such technology offered a very interesting performance by power consumption ratio among other important benefits. Optical interconnects have been imagined for ICs in very earlier studies such as in these works [91, 92]. At the same time, many efforts showed that in the transistor scale, the integration of basic optical components in CMOS technology, such as laser sources [93, 94], modulators [95], on–chip waveguides [96], and finally detectors [97], was feasible. Moreover, basic functionalities such as buffers [98]and optical-based logic functions [99]were experimented. These discoveries have not only triggered the research and the exploration of optical interconnects, but also proved their positive potential for an eventual commercialization [100].

Earlier established studies by Haurylauet al. in [101], Chen et al. in [102], and Petracca et al. in [103], discussed the performances that might emanate from CMOS compatible optical components. Depending on the available or the projected technology, the authors also contrasted the optical interconnect performances with their electrical counterparts to demonstrate the electrical interconnect limitations in the future.

i. *All-optical NoC*

To the best of our knowledge, Kirman et al. presented the first attempt to develop an on-chip optical network[104]. The authors designed a ring-based topology optical NoC where the network consisted of an optical ring or loop on which four switches are connected. Each switch managed a set of IPs such as memory controllers or L2 caches. The results showed performance enhancements in terms of latency for the proposed architecture, a four-node opto-electrical buses, compared to its pure electrical counterparts especially when two or more distinct wavelengths were used.

ATAC was also another alternative to build optically interconnected many-core processors chips [105]. The proposed architecture utilized an on-chip optical network to connect 64 clusters for 1024 cores. Compared to a similar electrically-interconnected 1024 cores architecture, ATAC succeeded on 39 % of speed-up [106, 107].

Shacham and Bergman executed another attempt in the field[108]. The authors presented an optical interconnect called SPINet. The experimental architecture of SPINet is a 2x2 switching node that exploited wavelength division multiplexing (WDM) for a total bandwidth up to 160 Gb/s (16 wavelengths x 10 Gb/s link). As an experimental setup, the authors tested a four nodes architecture to demonstrate the SPINet capabilities. Later, a second demonstration with six SPINet nodes was described [109].

Vantrease et al. proposed a 3D optical network called Corona[110]. The optical interconnect was used to link up to 64 clusters composed essentially by four cores with a shared L2 cache and where on top of them were placed optically connected memories (OCMs). The optical interconnect was a global broadcast optical bus where all the clusters were connected. Corona showed high performances of 10 Tb/s for OCMs and 20 Tb/s for the clusters' cores. However, the separation between the optical interconnect, the clusters and the OCMs omitted the scalability problems. This is one of the most important challenges for ONoC. Vantrease et al. developed a related work to Corona consisting of an optical arbitration mechanism to maximize the channels utilization of optical interconnects[111].Moreover, Hendry et al. tackled in [112]the posed problems by a circuit–switching ONoC such as in [108]. The authors started from the results of an earlier established analysis[113]. After, they proposed a TDM arbitration scheme to replace the electrical parts, which were responsible of the network resources allocation.

Similarly, Biberman et al. developed an electro-optical switch architecture with up to 40 Gb/s data transfer rate[114]. Furthermore, a multi layered version, based on the previous switch architecture, was presented by the same team [115]. In addition of the CMOS compatibility and the high scalability of the architecture, the authors demonstrated the usefulness of such switch fabric in the case of data-centers. The switch architecture consisted of 256x256 non-blocking ports for a 51.2 Tb/s bisection bandwidth capable of linking up to 2560 server racks.

As conventional processors were scaling to many-core systems with higher bandwidth networked memories (usually DRAMs) [116], many solutions have emerged not only to alleviate such demands but also with energy efficiency considerations. In [117] and [118], and later extended in[119], the authors presented a monolithic processor-memory network architecture based on photonic technology. The architecture used dense wavelength-division multiplexing (DWDM) in local meshes to global switches (LMGS) ring matrix topology. Up to 256 cores could be connected to 16 DRAM modules for an improved throughput of 8 to 10 times compared to an aggressive purely electrical network.

Joshi et al. developed another related LMGS architecture that was organized on an U-like shape[120]. This architecture showed a less power consumption for thermal tuning circuits but suffered from higher power losses in the waveguides and the end-to-end through.

Beamer et al. [121]proposed a novel photonically interconnected DRAM (PIDRAM) architecture based on a previous design that has been described earlier in [117]. Major enhancements were high per–pin bandwidth with on-and off-chip energy savings, compared to equivalent, even future, pure electrical counterparts. More details for the design of on-chip core-to-core and core-to-memory photonic networks are provided in[122]and in [123].

Joshi et al. also presented a similar architecture based on Clos networks[124]. Simulation results demonstrated that Clos networks had a smaller power and area impacts compared to a baseline NoC or to a photonic NoC with global crossbars (centralized and distributed). In addition, the Clos photonic network maintained a uniform latency and throughput thanks to its extensive path diversity. The Clos network was also used to design a buffer less photonic Clos-based NoC called BLOCON [125]. A contention-free algorithm called Sustained and Informed Dual Round-Robin Matching (SIDRRM) along with a path allocation scheme named Distributed and Informed Path Allocation (DIPA) were used as routing mechanisms for the proposed architecture. Similarly, Koohi and Hessabi developed a contention-free all−optical routing method called CoNoC[126]. An extended version of the developed efforts with CoNoC is available here [127].

The research on the field of pure photonic point−to−point interconnects for on-chip communications had continually evolved. The proposals that we have already discussed like the Cornell ring architecture [104], the MIT ATAC [105], the Columbia SPINet [108] and Corona [110] constitute a foundation to the following works.

Pan et al. proposed a nanophotonic architecture called Firefly[128]. The authors combined electrically connected nodes (organized by clusters of four nodes) with a global photonic wave-guide for intra-clusters communications. For a more energy efficiency, a reservation-assisted single-write-multi-read (SWMR) design was implemented. Initially, all the network receivers are disabled. To send a packet, the router broadcasts a packet with the destination and the control information. Hence, only the receiving router is activated. Overall, the Firefly architecture resulted on performances better than the state-of-the-art all-optical or all-electrical architectures.

Later, the same authors tackled a very common challenge in optical NoC that is the reduction of the static power consumption[129]. They presented Flexi Share: a crossbar architecture with minimum but globally shared channels for all the nodes. Although such architecture seemed to add more energy constraints due to the design complexity, the energy gain was perceptible due to the reduction of the channels' number with their static power overhead.

Morris and Kodi investigated on their turn the feasibility of a 64 cores ONoC called PROPEL and its extended version E-PROPEL for up to 256 cores architecture[130]. The two versions were confronted to Batten et al. [117] and Vantrease et al. [110]proposals, at an equal number of wavelengths. The comparison was discussed in terms of hardware complexity with metrics such as the number of waveguides, microring resonators and photodetectors. The power loss and the optical/electrical areas were also considered. The comparative study also compared the proposed ONoC architecture with a conventional mesh NoC in terms of the obtained throughput and power consumption.

Xue et al.[131]studied another optimistic approach. The authors presented a 3D optical interconnect using free-space optics. This type of propagation medium offered a speed of light propagation with a small energy loss. However, this technique relied on the technological advancements of optical components like micro-lenses and micro-mirrors. In addition, to demonstrate the feasibility of their design, the authors conducted a study related to newly-developed or emerging devices, circuits, and optical dedicated technologies. A prototype in relation with this study was also fabricated[132].

In the last 3 years, many ONoC architectures have emerged. Among them, we can find the Olympic ONoC[133]. A full-optical ring topology NoC where local and global rings were used to mitigate the low latency versus the high-energy consumption problem.

Luminoc was another all-optical mesh topology NoC that took advantages from MWSR (multiple write single read) arbitration method and from point-to-point connection for data transmission[134]. Simulation results showed that Luminoc acted better than electrical mesh NoC and the Clos architecture from[124]. However, such topology still depends on technology integration of dense optical channels on a silicon chip. Recently, Kakoulli et al. considered the integration of optical components in silica to develop a comparable approach to Luminoc in terms of performances[135]. Unlike Luminoc, the P-sync proposal was a shared-bus based architecture that used Photonic Synchronous Coalesced Access Network (PSCAN) [136]. The full architecture targeted long range interconnect applications that require non-local data accesses such as the distributed Fast-Fourier Transform (FFT).

Zulfiqar et al. studied in [137]the impact of the point-to-point and shared channels for optical interconnects for a fixed laser power budget. The authors pointed the static power consumption of ONoC in particular the laser sources that were the major consumers. As a solution, they estimated an ideal sharing degree in function of the optimal sharing gain and proposed wavelength stealing. The proposed solution used the same topology as for point-to-point networks with N2 channels. Each channel had at least two nodes, the owner and one or more stealers. Evaluation results demonstrated that such architecture provided between 20 and 23 % energy-delay product (EDP) improvement compared to point-to-point topology.

Similarly, PROBE was another alternative to diminish the static power consumption of ONoC [138]. The authors proposed the use of tunable splitters instead of the passive power-inefficient ones. The authors used the tunable splitters to scale the available bandwidth dynamically. For an accurate scaling of the bandwidth, a prediction evaluation was computed from the link and the buffer utilizations of every output port.

At a higher level of abstraction, Chao et al. tried to alleviate the challenges of the laser power consumption[139]. Their proposition was to split the energy budget among the network buses based on a weighted time–division–multiplexing scheme. The TDM mechanism was based on the instantaneous bandwidth requirements of the running applications. Later by 2014, the same authors proposed a methodology for the placement and the sharing of on-chip laser sources for an optimal and high energy-efficient use [140]. Additionally, the last study included a relevant state-of-the-art synthesis for ONoC research axis. In the same way, Heck and Bowers conducted a study to demonstrate that on-chip laser sources can increase the source efficiency and the energy consumption compared to off-chip laser sources due to the modularity they offer and because of the absence of coupling losses.[141]. Pintus et al. unveiled in [142]a novel all-optical and ring–based ONoC architecture. Recently, Gambini et al. detailed the prototyping of the same ONoC in silicon[143]. The ONoC was centralized on a principal ring coupled to multiple local micro-rings. The authors provided simulation scenarios for both performances and fabrication tolerances with a silicon-on-isolator (SOI) technology platform.

Network interfaces (NIs) were at the heart of the study presented by Ortín-Obón et al. [144]. The authors discussed the lack of the research in the NI level in ONoC in spite of its important participation for the data transfer of an optical on-chip network. The authors proposed the design of a complete NI architecture for wavelength routed ONoC. They also demonstrated that to maintain an acceptable bandwidth with realistic power budget, 3- to 4-bits parallelism should be applied. Less than 3-bits parallelism results on a very low bandwidth while more than 4-bits parallelism results on poor power behavior in particular with the static power consumption.

Two other all-optical wavelength-routed NoC proposals were developed by Koohi and Hessabi in [145] and [146], respectively. The first one, called 2D-HERT used a novel topology based on a passive routing with wavelength-routed optical switches (WaROS). The obtained results showed a reduced energy consumption and a lower data-transmission average delay compared to a baseline ONoC as well as to a classical NoC with torus topology. The second all-optical architecture was called Power-efficient Scalable Wavelength-routed Network-On-Chip (PeSWaN). The proposed ONoC had the ability of a controlled scaling. In fact, the implemented control mechanism of PeSWaN used N/4 control units for a total number of N nodes along with contention-free switching data circulation.

Hamedani et al. developed a similar architecture[147], namely QuT. The QuT proposal was based on a ring topology constructed with microring resonators in addition of strategically placed shortcuts. Compared to a baseline ONoC such as Corona[110], QuT had smaller insertion losses but more microring resonators. Compared to CoNoC[127], QuT had a smaller number of microring resonators but more insertion losses. Overall, QuT offered a balanced power and energy consumption for a better scalability than Corona and CoNoC.

Similar to QuT, Werner et al. proposed an ONoC based on a mesh-like topology called Amon[148]. The proposed architecture outperforms QuT and several other ONoC. With a limited overhead in the waveguides area, Amon offered a better power consumption as well as a lower area consumption for the microrings area while maintaining similar performances.

Wu et al. [2014] presented SUOR[149]. The authors designed a cluster organized ONoC for up to 256 cores. Dedicated clusters called cluster agent (CA) assured the flow control and the data channels set–up. Simulation results showed a more reduced EDP compared to Corona [110] and Flexi Share [129].

Last but not least, Xiaolu proposed a ring–based packet-switched ONoC called RPNoC[150]. The proposed architecture showed a better energy/bit consumption compared to an optical NoC with a mesh topology, and an electrical NoC with mesh or ring topologies. RPNoC also had a higher packet throughput and a lower latency compared to the aforementioned NoC.

ii. *Hybrid-optical NoC*

A common practice for hybrid emerging technology NoC was the combination of a local electric baseline NoC or some of its components with a global optical one. The Phastlane architecture was an example of such heterogeneity [151]. The authors tackled the contention that might occur in optical NoC with electrical buffers in a manner that the received packets could be electrically-buffered or dropped then retransmitted.

Ye et al. proposed a hybrid electric-optical router to build a torus topology based ONoC[152]. The proposition called THOE was composed of clusters (4 cores per cluster with electrical interconnections) connected with an optical network with, full-optical, circuit-switching capabilities. THOE showed not only better power consumption compared with a classical NoC with the same topology but also better resource usage compared to baseline ONoC such as the torus network [153] and Corona [110].

Meteor was another hybrid optical-electrical NoC [154]. The architecture coupled an optical ring-shaped waveguide with 2D mesh electrical NoC. This architecture offered a more simplified optical network with its power efficiency and reduced latency combined to a full-distributed 2D electrical mesh. METEOR offered an interesting modularity with its Photonic Region of Influence (PRI) in a way that the optical waveguide could connect a set of cores' islands from 2 to up 36 cores. When compared to the state-of-the-art ONoC such as Corona [110]., Firefly[128], the optical mesh from [153]and a 2D mesh equivalent NoC, METEOR had a reduced power consumption and EDP with a simpler photonic architecture.

Close to the Meteor proposal, Grani and Bartolini established another effort[155]. An optical ring NoC in combination or not with a conventional NoC was studied in terms of power consumption and latency. Many simulation scenarios were provided including diverse arbitration strategies along with the possibility of the variation of the optical ring numbers.

Fu et al. developed a similar electrical-optical NoC architecture, namely, HEON[156]. The authors tackled long electrical wires with a global optical one in a serpentine shape to link the distant cores. They also used a dynamic power strategy capable of dynamically managing the network components. Simulation results showed that HEON had more than 43 % EDP gain compared to a baseline NoC and ONoC, respectively.

In [157], Tan et al. described a hybrid locally-electrical and globally-optical connected architecture (HONoC). The architecture was organized in a BFT-based topology. HONoC relayed on hybrid routers to link between locally-electrical cores and globally-optical connected clusters. The latter were in their turn connected via a generic wavelength-routed optical router (GWOR) developed earlier by Xianfang et al. [158].Moreover, Büter et al. developed a controller called DCM for distributed channel management that was capable of switching between two different parallel NoC such as an ONoC and an electrical one[159]. The DCM was also able to reconfigure the same electrical NoC if reconfigurability was implemented. For a hybrid configuration, the authors used the two baseline ONoC architectures from [153] and [130] to validate their approach.

Finally yet importantly in the optical-electrical hybrid NoC direction, Balboni et al. [160] studied the internal interconnect fabric of general-purpose processor accelerators (GPPA). The authors addressed the global electrical NoC that serve to link processing elements on-and off-the chip with an optical one. The proposed hybrid network architecture was simulated for 1- to 4- bits parallelism. After that, it was compared to its pure electrical counterparts. Results showed an important overhead on static power, however in the dynamic energy domain the proposed hybrid ONoC was more efficient.

As another direction for hybrid emerging technology NoC, 3D optical NoC were developed. Ye et al. utilized two superposed layers, an optical layer and an electrical one[161]. The optical upper layer was used to transfer data packets while the bottom electrical layer handled the control packets as well as controlling signals to the optical switches. The communication between the two layers was assured with vertical TSVs. Similarly, Le Beux et al. proposed the exploitation of the low power and latency advantages of an additional optical ring NoC (ORNoC) layer to connect multiple conventional NoC-based layers in a 3D fashion[162]. The proposition also provided guidelines for an optimal placement of the NoC layers and the TSVs as the distance separating the upper ORNoC layer from the lowest NoC ones could be considerable. Moreover, Qing et[163] presented a comparative study between 3D ONoC and 2D ONoC. After developing the 3D ONoC router model, they demonstrated that 3D ONoC alleviated 2D ONoC related problems such as long interconnects. They also provided better results in terms of the delay and the packets losses.

iii. *Design space exploration for Optical-Photonic NoC*

No efforts related to ONoC we cited above would be achievable if the research community did not execute a rigorous design space exploration [1]. In the following we cite our findings in terms of design space exploration, analysis and tools related to optical interconnects.

Hendry et al. initiated the analysis of photonic networks through a developed model for omnet++ tool[113]. Many simulation scenarios with diverse loads and topologies were executed. Later, Chan et al. [164] investigated several tools and design methodologies. The authors developed an extensive study as regards ONoC [165]using a dedicated ONoC tool called Phoenix Sim [166]. The same team explored the physical layer of ONoC. A variety of the basic components for ONoC was modeled [167]. More recently, Abadal et al. studied ONoC in terms of area and energy scalability[2].

The industry was also involved on the design space exploration of optical NoC[168] while Koka et al. presented an earlier proposition[169]. The authors conducted an extensive comparative study between many baseline ONoC architectures. The studied architectures were token ring, point-to-point, limited point-to-point, circuit switched and two-phase with two ramifications. The simulation results of the considered 8x8 microchip developed by Krishnamoorthy et al. demonstrated that the point-to-point optical network showed an interesting EDP[170].

From a topology perspective, Faralli et al. investigated the performances of bus- and ring- based ONoC[171]. The authors contrasted the performances of the ring-based ONoC developed in [143]with a bus-based one. The comparative study was proceeded at the physical layer with real prototypes. The obtained results showed that the performances of ring- and bus-based ONoC are comparable in worst-case scenarios. However, if interferences could be avoided, the ring-based ONoC outperforms the bus-based one.

As optical component are thermally sensitive and by consequence can degrade the system performances, thermal management of ONoC is a research direction of a huge interest. To remedy to the deviation of on-chip optical components, Zhang et al. proposed to localize the hotspots on the targeted platform with an accurate simulation[172]. Based on the latter results, a new task allocation scheme was deployed to contain the temperature of the network modulators and filters while maintaining the bandwidth full-availability.

Since PhoenixSim, many other DSE tools have emerged such as VANDAL [173], DSENT [174] and PROTON [175]. More recently, other tools were developed such as CLAP [176], OTemp [177], PROTON+ [178] and the ONoC dedicated reliability-aware design flow in [179]. Additional information for ONoC dedicated tools are also available in this textbook [56] (Refer to the fourth chapter).

Even with the recent advancements on the technology integration of on-chip optical components [180], some recent studies putted the accent on the exploration of the physical layer. Mainly because the physical layer is a major bottleneck for an ONoC-based design. In this way, Ramini et al. studied the power behavior of wavelength routed ONoC (WRONoC) with multiple topology configurations[181]. The authors also demonstrated how a design could diverge from its high-level initial expectations due to the place & route constraints. In addition, they pointed the lack of CAD dedicated tools for ONoC at the physical layer. A potential solution to this challenge were presented by Boos et al.[175], Ramini et al.[182] and recently[178]. Moreover, Ramini et al. questioned with respect, the viability of ONoC solutions and demonstrated how an aggressive conventional NoC outperformed its optical counterpart[183]. A key assumption on the last attempt was the consideration of an accurate modeling framework (AMF) instead of the common one (CMF). This led to a meticulous consideration of every design power parameter.

iv. *Final remarks*

To conclude this paragraph, we cite some recent and very promising results obtained at the physical layer for optical on-chip components and networks. Qian et al. succeeded on integrating a quantum-dot light emitting diodes on a multilayer structures[180]. Qiang et al. designed and profiled a compact silicon optical switch based on the thermo-optic effect instead of the usage of traditional microring resonators or Mach-Zehnder interferometers[184]. Lately, Wang et al. presented a complete ONoC integrated in Si-CMOS platform[185]. Similarly, Yang et al. presented a reconfigurable and non-blocking four port optical router[186]. The fabrication process as well as the measured performances results were reported.

The Hubeo+ project is also another promising work that was presented by Thonnart and Zid in [187]. In fact, a demonstrator of an optical networks-on-chip is planned for 2016 for up to 36 cores with a bandwidth up to 2 THz and a 20 W power consumption. The authors also claimed that by 2020 the expected performances will reach 4 THz for more than 72 cores with the same power consumption of 20 W. The targeted cores of the demonstrator were supposed to be microprocessors and memories. Finally, readers can find an updated and extensive listing of the available literature for inter- and intra-chip optical-networks in this online bibliography[188].

c) *Wireless NoC*

Wireless NoC can circumvent many of the persistent issues related to classical NoC. For example, WiNoC can tackle the correlated increase of the power consumption and the computation capacity or the on−chip long-range wires vulnerability[189]. As the integration technology matures, the research for WiNoC is evolving. In addition of the various feasibility studies that are elaborated by Ding et al. [190], Karim et al. [191]and Xinmin et al. [192], there are now various hardware prototypes which are developed[193, 194]. According to many simulation scenarios[195], WiNoC have the best bandwidth by packet energy ratio among other emerging technology NoC. Moreover, WiNoC showed a very interesting scalability for 512 cores system size and more. This important scalability is offered with a limited area overhead due to the absence of wires [44]. Only RF-Interconnect or Optical NoC can compete with such capabilities, in some aspects. Ganguly et al. investigated the design methodologies, the technology specifications and the performance evaluation for WiNoC architectures[196] but recently Abadal et al. established a new design space exploration related to WiNoC[3].

The wireless NoC architectures can be classified in two major categories. The first one is composed of many wired NoC clusters that connect a set of cores. Usually, they are organized in a mesh topology fashion. Each one of the sets communicates with the other ones through wireless shortcuts. The second one, called small-world wireless NoC, aims on developing a NoC with a balance between short local links and long range wireless links[45]. Hence, this approach alleviates the topology-inflexibility problems of the mesh-based WiNoC. The idea was inspired from natural networks such as the brain neurons networks or from macroscopic networks like the Internet and some social networks.

i. *Mesh-topology based wireless NoC*

The first attempts have targeted the first type of WiNoC architectures. The proposed work by Zhao and Wang figured among these efforts[197]. The authors developed a WiNoC architecture based on CMOS ultra wide band (UWB) technology. Later, the same authors relied on the flexibility of the wireless nodes to rebuild as needed the network topology to meet the application constraints[198]. An unfeasible operation with wired nodes without considerable area overheads. Moreover, a limited set of wired links are used to control the

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wireless nodes and so leaving 100 % of the wireless link bandwidth to data transportation. When the topology is fixed, a location-based routing (LBR) is used to circulate the data among the nodes.

An additional impact of topology rebuilding was the possibility of multi-channeling in a way that a node can broadcast the same data to many other nodes, hence increasing the network throughput. Moreover, deadlock avoidance capability was implemented to maximize the determinism and the reliability of the proposed architecture. The enhanced WiNoC architecture was called multi-channel wireless NoC (McWiNoC).

Zhao and Ruizhe[199]presented an overlaid mesh topology where “big” wireless nodes with long-range multi-channel links were placed among “small” nodes with simple short-range links to the bigger ones. They also developed a network capacity model that was used to search the optimal topology configuration for the network. The followed methodology relied on a zone-aided routing algorithm to assure deadlock freedom for the data transfer without sacrificing the network efficiency[200]. The multi-channeling and arbitration methodology we cited above was later enhanced with DuSCA that stood for dual selection channel arbitration scheme. DuSCA was developed to arbitrate receiving and sending conflicts at the receiver and the transmitter sides with a static channel assignment scheme [201].Lately, Ruizhe and Zhao proposed a more developed arbitration scheme[202]. The authors targeted conflicts that might occur from static channel assignments when many senders solicited the same receiver simultaneously. The authors presented a load adaptive multi-channel arbitration mechanism to alleviate DuSCA limitations and eliminated the contention problems.

Lee et al. in their turn, proposed a centralized single transmitting antenna to multiple receiving antennas WiNoC architecture, namely WCube[203]. The architecture can achieve 20% to 40% latency gain with less or comparable 2D mesh network for 1024 cores. Hanhua et al. developed in this work [204]an algorithm called APW that resolved some limitations of the WCube architecture [203]. The addressed limitations were the poor scalability of WCube and its dependency to its recursive topology that is necessary to avoid deadlock issues. The proposed APW algorithm and its ramification DAPW were deadlock–free and guaranteed the reachability of partial network structures. The scalability problem was resolved by an incremental interconnection structure called IWCube that allowed the construction of the network without maintaining the complete topology of WCube.

Chifeng et al. developed a similar architecture called WNoC[205]. The network was based on a 2D mesh wired NoC called Network-based Processor Array (NePA) divided on equal islands. Each one of the island had a wireless router to assure wireless communication with the rest of the islands.

DiTomaso et al. developed an architecture called iWise[206]. The network was organized under 16 clusters to where four cores are attached. Clusters can communicate using high bandwidth wireless link for a one-hop 64 cores’ system and expandable to 256 cores for a total of three-hop count. The same team presented later another WiNoC architecture called A-WiNoC that can increase the bandwidth in hotspots, locally and globally, using local and global controllers[207].

Recently, Dai et al. proposed a hybrid WiNoC architecture[208]. The considered 8x8 mesh-topology is composed of several subnets of four IPs with a star topology. Each one of the subnets had its proper wireless router and all the wireless routers are fully-connected. The authors adopted a multicast scheme for the data transmission. However, an energy-efficient technique was proposed. The authors used the power gating technique to deactivate the wireless routers that are not involved on the multicast transmission. Although this architecture introduced several new techniques, the considered topology is inflexible and is not suitable for recent dense and heterogeneous designs.

More recently, Zhao et al. proposed an irregular and reconfigurable WiNoC architecture to alleviate the density and the heterogeneity problems of the recent designs[209]. The authors proposed an application-aware placement of the wireless routers. Hence, an application-specific topology will be obtained. For a more efficient exploitation of this custom topology, the authors developed a new routing scheme called region-aided routing (RAR). The combination of the latter features led to better performances when compared to regular topologies WiNoC with table-driven or location-based routing algorithms.

ii. *Small-world wireless NoC*

Small-world wireless NoC, which are the second type of WiNoC architectures, were explored and studied by Chang et al. [210] and Deb et al. [211], respectively. They proposed a WiNoC design called mm-wave small–world wireless NoC (mSWNoC). The mSWNoC outperforms largely its classical NoC counterparts. Recently, Pande and Heo[194] extended and presented the former studies from[210] and [211]. The mSWNoC transmitting circuit fabrication results that consisted of an on–off Keying (OOK) modulator chip were explained [212]. Lately, Xinmin et al. have also unveiled the details of the receiving part that consisted of an OOK demodulator[213].

Extra studies in relation with mSWNoC were also conducted. In one hand, Wettin et al. investigated the performances and the thermal profile of mSWNoC[214]. In the other hand, Murray et al. conducted a study regarding dynamic voltage and frequency scaling (DVFS) using MROOTS and ALASH routing algorithms[215]. In relation with the DVFS, Wonje et al. proposed to prune as possible the underutilized voltages thus reducing the design of the mSWNoC[216].

To obtain the desired performances from WiNoC, flow control algorithms and fault resilient techniques have to be investigated. Ganguly et al. exploited the fault tolerance behavior of natural networks such as microbes' colonies and the internet to develop a fault tolerant architecture of a small-world WiNoC[217]. The authors demonstrated that even at high fault rates, the developed architecture showed an interesting resilience compared to wired mesh NoC [196]and WiNoC. Moreover, the authors presented an error control coding mechanism that can maintain the network reliability thus achieving similar high performances of its wired NoC counterparts[218].

iii. *Design space exploration for wireless NoC*

Design space exploration studies are necessary to build power-efficient and reliable WiNoC. To this aim, Mineo et al. [219]studied an adaptive technique to control the transmitting power at runtime for WiNoC. The authors integrated a specific block called VGA (voltage gain amplifier) which is responsible of controlling the transmitting power via the power amplifier. This technique was integrated into two WiNoC architectures that are iWISE [206] and McWiNoC[198]. The evaluation of the iWISE and the McWiNoC architectures was carried within Noxim simulator [220]. The authors provided results that showed a significant gain in power consumption compared to a baseline power-management scheme. Lately, a more detailed study of this technique was developed[221]. The authors applied their technique to an additional WiNOC architecture namely HmWNoC[211].

Similarly, Laha et al. conducted an extensive study followed by a general exploration of the design landscape for WiNoC transceivers at the physical layer[222]. In their work, the authors discussed several alternatives for the design of transceivers in term of the fabrication technology, not only for on-chip wireless interconnect but also for off-chip wireless networking.

In the same way, Abadal et al. explored the enhancement of broadcast-enabled multicore designs with WiNoC[223]. The authors proposed to use a hybrid NoC architecture that was composed of a WiNoC and a classical one. The WiNoC will be used as a global shared medium for data broadcasting while the classical one assured the remaining of the data flow. Additionally, an insightful discussion of the WiNoC state-of-the-art and related challenges was developed.

The design of fault tolerant and reliable WiNoC is more and more explored. Hence, congestion-aware and conflicts-free techniques for WiNoC are necessary. For example, Murray et al. investigated the impact of a congestion-aware routing in the network thermal performances[215]. Additionally, the authors combined this routing scheme with dynamic voltage and frequency scaling to build power-efficient WiNoC.

It is also important to develop design methodologies that are capable to consider QoS factors for WiNoC. Recently, Mansoor et al. [224] presented a design methodology to build fault-resilient WiNoC. The authors considered in their study transient and permanent faults. The proposed methodology combined an optimization of the network topology, a medium access mechanism and an error correction code to build a robust WiNoC. Dehghani and Jamshidi studied a similar approach[225]. First, the authors developed a strategy for an optimal placement of the WiNoC router. Second, they used several fault−tolerant communication protocols to test the efficiency of their WiNoC architecture.

d) *RF-Interconnect*

Another known direction to explore for emerging technology NoC is RF-Interconnects (also reported RF NoC). The established works by Socher and Chang [226] and later by Tam et al. [227] could be a good starting point to this section. The authors answered very carefully to the question on how RF-Interconnect can enhance future chips. In fact, the benefits are diverse and can be summarized in the following:

- In the first place, RF-Interconnect are completely scalable and compatible with current and future CMOS fabrication processes.
- Secondly, they are totally immunized against noise thanks to their higher modulation frequency starting from 10 GHz.
- Thirdly, they are a valuable solution to chips with multiple clocked IPs since frequency-division multiple-access algorithms (FDMA) can be used to assure a multi-carrier link. This is useful to modulate heterogeneous clock domains data and transmit them simultaneously but spectrally separated.
- Finally yet importantly, multicast simultaneous communication can be implemented on a single physical waveguide for many receivers.

In addition of the explanations exposed above, the authors provided realistic implementation results of some prototypes to facilitate the design exploration of RF-Interconnect based architectures.

Conceptually, this technique is similar to the macroscopic RF networks. It is based on transceivers and waveguides as propagation medium but rely essentially on integration technology when applied to on−chip or to chip-to-chip networks. Chang et al. [228] discussed this potential solution since 2001. Havemann and Hutch by, in their turn, discussed the other potential emerging solutions[229]. However, first proposals emanated later for off-chip connections from the works of Shin et al. [230, 231] and Chang et al. [232, 233]. Furthermore, there are other works that discussed on-chip interconnects such as in [234] and [227].

i. *RF-Interconnect proposals*

Chang et al. conducted to the best of our knowledge, the first design exploration for RF NoC[234]. The study compared a baseline NoC of 10x10-mesh topology with the same sized architecture but enhanced with a Z-like shaped global waveguide. Shortcuts to the global transmission line were strategically placed to minimize the hop count among the distant routers. The proposal, called MORFIC, showed that for an extra area of 0.13 %, the latency was reduced by 22%, compared to the cited baseline NoC above. Moreover, Tam et al. developed a tri−band RF NoC fabric for a simultaneous, up to 10 Gb/s transmission rate[235].

Liping and Hanson studied the addition of an extra layer on the top or at the bottom of the silicon substrate called guiding layer[236]. Although the study focused on the physical characterization of the guiding layer, it demonstrated, first the feasibility and second the potential of such propagation medium for on-chip interconnects.

Last but not least, we can cite some recent efforts involving the use of Orthogonal Frequency Division Multiple Access (OFDMA) modulation to build an RF NoC. Such approaches were described successively in[237], [238]and[239]. In the first effort[237], a feasibility study of an architecture composed of 32 clusters that were connected with OFDMA RF-based NoC, was developed. Each of the clusters had 16 tiles with 4−cores each one, for a total of 2048 cores CMP. In addition, the authors developed an arbitration scheme that reduced the average latency by 3.5x. Drillet et al. exploited the OFDM RF NoC fabric to build a 4096 cores CMP sharing up to 20 GHz of bandwidth [238]. Hamieh et al. in their turn[239], conducted a design space analysis at the physical layer of the same OFDM RF NoC transmission line. A power study was established for an efficient communication with two different shapes for the transmission line (U- and X-like shapes). Recently, Brière et al. presented a similar architecture[240]. The OFDMA technique was used to maximize the use of the available bandwidth. Hence, lower network resources will be needed.

ii. *Design space exploration for RF−Interconnect*

As it was the case for the other emerging technology NoC, many design space exploration exercises for RF-Interconnects were also proceeded. Among the first studies, we can cite the established proposal for intra-chip RF-Interconnect that we had already explained earlier in [234], and also for inter-chip communication like in[241]. Despite the fact that the study in[241]was intended for chip-to-chip communications, the components which were modeled and analyzed in the study, such as waveguides and UWB transceivers, could be used similarly for intra-chip communication purposes. Schinkel et al. proposed a more representative example of the design space exploration at the physical layer[242]. The authors designed a transceiver that can be exploited on a RF NoC capable of up to 5 Gb/s data rate where differential twisted links were used. RF on-chip components that could be utilized for on-or off-chip communications such as transceivers were also studied in [243]and [244], respectively.

Recently, Pourshirazi and Jahanian presented a more developed study[245]. The authors proposed an algorithm for an optimal placement of RF resources in addition of a maximum utilization of the available RF bands. The results showed that routing congestion and critical delay were significantly reduced at power and area costs of 2.33 % and 11.89 %, respectively. Later, ValadBeigi et al. presented another NoC architecture based on a novel framework to reduce the delay and the power consumption[246]. The proposed architecture was a hybrid architecture composed of a conventional NoC along with supplementary RF nodes that might use dedicated shortcut paths for a fast data traversal between distant nodes. The mechanism was assured by a router architecture that had the five classic input/output ports (East, West, North, South and local) in addition of the RF Tx/Rx ports for radio-frequency based communication. Xiao et al. presented a similar exercise[247]. The author discussed key problems related to the design of hybrid RF NoC combined with 2D mesh NoC.

Finally, a very promising attempt was developed by Yu et al. in [248]. The authors proposed the expansion of RF-interconnect capabilities to vertical layers through partially hollow TSVs (air-gap-based coaxial TSVs). Compared to its dielectric counterpart, the modeled air-gap TSV had a smaller power and area consumptions thanks to its reduced hardware footprint.

e) *Other alternatives for the NoC design*

In this section, we review some of the original proposals or outstanding still in-progress works. Most of these works are based on substrate materials such as graphene or carbon nano-tubes (CNTs)

Previously in Table IV, we mentioned that WiNoC bandwidth might be increased to THz domain with CNTs. CNTs were investigated for on-chip interconnect for many years [249]. Recently, Kaushik and Majumder reviewed the evolution of interconnects from a technological perspective[250]. In addition, the authors provided an extensive study on the performances of CNT-based interconnect.

Brun et al. developed a study in relation with CNT-based antennas[251]. The authors verified their study with a practical methodology of a CNT growth process[252]. Thus, they proposed CNTs as an RF-interconnect propagation medium. In addition, CMOS compatibility experiences of the proposed CNTs were described to demonstrate that they could be adopted on conventional CMOS processes.

The organic substrate feasibility and further its productivity were also widely investigated. In this

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direction, grapheme-based electronics was not only stated for grapheme-based transistors[253], but also in the particular cases of THz enabled nano-antennas [254, 255] and for wireless NoC[256]. In the last work, the authors studied the feasibility of grapheme-based WiNoC. Moreover, a design space exploration was initiated to study a grapheme-based WiNoC and ONoC hybrid architecture [257] and by consequence these advancements have attracted the industry [258]. More details of this attempt are provided in [259].

As it was the case in Anthony's work[100], the industry contributed on enriching the intra-chip connection paradigm, as well as the inter-chip one. In this context, Mitchell et al. proposed a proximity communication (PxC) scheme[260]. The concept was based on capacitive coupled channels of up to 4 Gb/s for each one, with less than 2.5 mW/Gb/s (the same concept was also used in a 3D NoC proposal [78] (refer to Section 3.2). The authors claimed that such inter-chip interconnect fabrics could be a viable solution to stack heterogeneous chips such as DRAMs and processors chips. However, they concluded on the fact that augmenting the number of connected chips degrades the overall system latency due to the on-chip metal wiring and they proposed optical interconnects as a potential solution.

f) Summary

In this section, we have reviewed the available literature for emerging technology NoC. We have covered the principal directions in this area namely 3D, Optical-Photonic, Wireless, and Radio-Frequency NoC, in addition of some original alternatives. For a more convenient reading, Table II provides a classification of the studied works in the previous paragraphs.

Table II: Summary of Emerging Technologynoc Proposals

		Relatedworks	Design space exploration efforts
3D NoC		[4][67][68][69][70][69][71][72][73][74][75][76][77][78][79][80][81][82, 83][84]	[85][86][87][88][89][90]
Optical	All-Optical	[104][105][106, 107][108][109][110][111][112][113][114][115][116][117][118][119][120][121][122][123][124][125][126][127][128][129, 130][131][133, 134][135][136, 137][138, 139][140][141][142][143][145][146][147][148][149][150]	[1][113][164][165][166][167][2][168][169][170][171][143][172][173][174][175][176][177][178][179][180][181][175][182][178][183][180][184][185][186][187]
	Hybrid	[151][152][153][154][153][155][156][157][158][159][153][160][161][162][163]	
Wireless NoC		[189][190][191][192-194] [195][44][196][3][45][197][198][199][200][201][202][203][204][203][205][206][207][208][209][210][211][194][210][211][212][213][214][215][216][217][218]	[219][206][198][220][221][211][222][223] [215][224][225]
RF –I		[234][235][237][238][239][238][239][240]	[241][242][243][244][245][246][247, 248]
Other Alter natives		[249][250][251][252][253][254-256][258][259][100][260][78]	

IV. Conclusion

In this work, we reviewed emerging technology NoC proposals for the last ten years. This includes 3D NoC, Optical NoC and Wireless NoC. We also discussed several other alternatives for the NoC design such as graphene based NoC.

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Robustness Evaluation Study of Power RF LDMOS Devices after Thermal Life Tests

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Abstract- This paper presents a synthesis of robustness evaluation on power RF LDMOS devices and its relation with electrical and physical behaviours after RF life-tests. It is important to understand the physical degradation mechanism effects and the liaison on drifts of critical electrical parameters after life ageing tests, in I-V such as threshold voltage (Vth), the feedback capacitance (Crss) in C-V and the S-parameter (S21) in RF. It shows with tracking of set parameters that Hot Carrier Injection (HCI) phenomenon appears. It is the main cause for device degradation leading to the interface state generation (traps), which results in a build up of negative charge at Si/SiO2 interface. More interface states are created due to a located maximum impact ionization rate at the gate edge. Such simulations correctly take into account interactions coupled between electrical, thermal and RF behaviours in device inside using the FEM method. A numerical model (Silvaco-Atlas) was used to confirm degradation phenomena. The problem of hot-electron should be taken into consideration in the design of the power RF MOS devices and can be a useful tool to investigate reliability in MOSFET.

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ROBUSTNESSEVALUATIONSTUDYOFPOWERRFLDMOSDEVICESAFTERTHERMALLIFETESTS

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Robustness Evaluation Study of Power RF LDMOS Devices after Thermal Life Tests

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Abstract- This paper presents a synthesis of robustness evaluation on power RF LDMOS devices and its relation with electrical and physical behaviours after RF life-tests. It is important to understand the physical degradation mechanism effects and the liaison on drifts of critical electrical parameters after life ageing tests, in I-V such as threshold voltage (V_{th}), the feedback capacitance (C_{rss}) in C-V and the S-parameter (S_{21}) in RF. It shows with tracking of set parameters that Hot Carrier Injection (HCI) phenomenon appears. It is the main cause for device degradation leading to the interface state generation (traps), which results in a build up of negative charge at Si/SiO_2 interface. More interface states are created due to a located maximum impact ionization rate at the gate edge. Such simulations correctly take into account interactions coupled between electrical, thermal and RF behaviours in device inside using the FEM method. A numerical model (Silvaco-Atlas) was used to confirm degradation phenomena. The problem of hot-electron should be taken into consideration in the design of the power RF MOS devices and can be a useful tool to investigate reliability in MOSFET.

I. Introduction

Lateral diffused metal-oxide-semiconductor (LDMOS) have been widely used in many smart power applications. Also on base stations, TV broadcast or in radar applications with high capabilities particularly in terms of RF, output power and Power Added Efficiency (PAE). These applications can cause damage and limiting factors to device reliability, especially to the gate oxide of MOS devices [1,2,3]. Quite often accelerated life tests of MOS capacitors are performed by applying a high constant voltage at the gate contact (constant voltage stress: CVS) or by injecting a constant current across the oxide (constant current stress: CCS) over a period of time. They produce electrical instabilities which have been the subject of numerous experimental studies in MOS devices [4,5]. Current is a more effective parameter than voltage for defect detection in MOSFET devices and CMOS ICs, although both are necessary for complete testing.

Problems related to oxide degradation are of increasing concern for the development of MOS technology. The leakage current represents one of the most important issues of oxide reliability, especially for MOS applications [6]. The leakage current with temperature can contribute to the thermal runaway of device [7]. Many papers have been devoted to the study of leakage current and its relation with device lifetime [6,8]. Leakage current in a MOSFET can be a significant contributor to power dissipation [9]. A small amount of leakage current is always present, even in healthy devices. The maximum allowable leakage current in a MOSFET is the manufacturer specified zero-gate-voltage drain current (I_{DSS}) and gate body leakage current (I_{GSS}). I_{DSS} is the current flowing between the drain and the source when the gate and source are at the same potential. I_{GSS} is the current flowing between the gate and the source when the source and drain are at the same potential.

An electrical stress can produce an increase of the low field leakage current across thin gate oxides, further reducing the lifetime of devices [8]. Failures that are precipitated by excessive leakage currents include junction and dielectric failures [9]. Which consist of leakage through the oxide layer leading to destruction of the dielectric film. Therefore, the leakage current can reach the semiconductor surface and may lead to degradation of the electrical properties of the transistor [9]. It is required to study the hot electron induced performance degradation of MOS transistors. In order to qualify new power RF LDMOS reliability for radar applications, a 3000 h pulsed RF life test has been conducted on a dedicated RF S-band test bench in operating modes [11].

This work presents a degradation study to the properties and various mechanisms of thin gate oxides, based on the electric characterization of leakage current increase on power MOSFET transistor behaviour after new experimental accelerated ageing tests under various conditions. The content of this paper is presented as follows: the section 2 describes the life test bench and the general power RF LDMOS transistor performances. The discussion of simulation and experimental results are shown in Section 3. The conclusion and prospects are given in Section 4.

II. Experimental Setup of Ageing Test Bench and Simulation Process

Recently, the characterization, optimization, and reliability of power RF LDMOS devices have drawn much attention [12,13]. For this purpose, we designed

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and implemented an innovative reliability bench able to keep track of all RF powers, voltages and device base-plate temperatures whose values correspond to stress operating conditions [14].

This bench is able to keep track many parameters like voltages, currents, base-plate temperature, and peak power. Eight devices is the bench capacity to be tested simultaneously in order to keep it easy to manage. The Fig. 1 and Fig.2 represent the component under test placed on its test fixture, supplied by DC power and connected to RF connector (type N). The conditions of pulsed RF life test are much closed of radars applications with operating 24h/24h.

The bench consists of three interdependent subsets:

* a microwave part,
* a control/command part piloted by PC,
* thermal module for each devices.

The microwave part essentially allows the power injection and measurement in every branch for each device. Each branch contains a tuner to set precise output VSWR stress on any of the devices. The command/control system ensures the achievement of the following functions:

* biasing voltage supply and current measurement tracking,
* separate control and measurement of each device temperature,
* power switching between the eight devices branches,
* safe data record.
* The measured data on each branch are the following:
* input, output and reflected power,
* output power variation in RF pulse ,
* device biasing current,
* temperature.

All data necessary to keep track of each device degradation evolution in real time are secured thanks to the rack. Life-tests are run in the working conditions (pulsed RF) using various device base plate temperatures (10°C, and 150°C) and a high drain–source voltage (44 V) in order to get more power from the device for radar applications.

The RF transistors (8 samples) have been submitted during 3000 hours to ageing test on the reliability bench. This bench operates in radiofrequency pulse mode. During the life test, the goal is to study the component performances in actual working situation to ensure that it will maintain a good performance level. The device under test is placed on a thermal module in order to maintain a constant flange temperature. The command unit manages DC supply voltage, temperature regulation and RF signal monitoring.

The picture of 50Ω-matched test fixture on thermal support using the Peltier effect for power LDMOS amplifier in S-band radar application.

The component is in centre of support of test specifically designed for operation at full power in pulsed mode (2.9 GHz and 44 V). These values (frequency and tension) are particularly high compared to nominal values given by the manufacturer (2.2 GHz under 26 V). The power RF-LDMOS device under test is a commercial telecom dedicated transistor (encapsulated in a 2-lead flange package with a ceramic cap) S-band operating in class B at saturation and 65 V DC biasing. Indeed, these performances are given in conditions of width pulse 500 μs with a duty cycle of 50%. The gate length is equal to 0.8μm.

The Power density is equal to 1.89 W/mm. More than 61% of drain efficiency, and a gain More than of 11 dB can be obtained around the S band frequency at 2200 MHz in a common source test circuit. The junction temperature does not exceed 150° C for a flange temperature equal to 65° C. The thermal resistance is 0.2 C/W.

A modified structure of RF power N channel LDMOS, previously developed by Raman et al [15], was implemented and simulated using the physical simulator Atlas of Silvaco [16]. Fig. 3 shows the device's structure with approximate doping wells. The main geometrical and technological parameters are given in Table 1. The implemented structure is typically similar to our tested device. Consequently the qualitative understanding of physical phenomenon will be studied. The suggested structure has a Gaussian doping profile along LDD and channel surface. The doping profile was optimized using a technological process simulation carried out by SSUPREM3 [16], see Fig. 3.

III. Results And Discussion

The bench allows to record temperature, currents and voltages (gate and drain), the input power, reflective and output powers. After RF life-tests, the degraded device under test was characterized at ambient temperature, and then a parameter set is extracted.

The current I_{ds} measured is average and in order to have the correct peak current, the duty cycle is needed on the expression of DE. During all the life tests, threshold voltage V_{th}, drain-source current I_{ds} and feedback capacitance C_{rss} are shifted. We can partially conclude that these three DC critical parameters are affected by the RF life test. The increase of the V_{th} was detected and it presented a good correlation with the I_{ds} slump (decrease of the I_{ds} corresponded to increase of the $R_{ds\text{-}on}$). The shift after and before life tests of device threshold voltage V_{th} is presented in fig.4. An interpretation is proposed to explain the discernable change observed on the feedback capacitance, once again more noticeable at 10°C. The C_{rss} at zero drain-source bias is reduced from 2.6pF to 1.8pF at 10 °C, indicating a shift of 30%. Even at 26V bias, the C_{rss} is reduced from 0.43pF to 0.34pF (shift 21%), see fig.5.

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Fig. 6 displays changes of S-parameter (S_{21}) before and after RF life-tests at 10°C and 150°C. The gate–source voltage for S-parameters measurement was 4.7 V, and the drain–source voltage was 28 V. The devices are operated in the saturation region. Ideally the I_{GSS} value would be zero for voltage levels that are less than the voltage required to reach the dielectric strength of the gate oxide. In the data sheet the value is less than 40 nA (Table 2). Fig.7-a shows the gate leakage current (I_{GSS}) measured of three samples power RF LDMOS before ageing test.

Overstressing the gate either periodically with RF or statically with DC can also cause an increase of I_{GSS} and thus degrades device performance with respect to RF power gain. Fig.7-b shows the increase Gate leakage current (I_{GSS}) measured of three samples power RF LDMOS after ageing test but still far from the total limit of device failure. I_{GSS} due to many factors that are related to the integrity of gate oxide and surrounding regions. I_{GSS} can be used to evaluate reliability of this integral component of the MOSFET. Increase of this parameter with a particular device stress can be used to extrapolate the mean time failure (MTTF) of the gate oxide [12]. Other considerations for the gate oxide include careful electrostatic-discharge (ESD) precautions since the gate oxide is easily damaged [12].

A higher junction temperature will increase the leakage current [9,10] which may lead to thermal runaway phenomenon [13]. The electrical parameters are shown in Table 2, in which the measured and the manufacturer's data sheet values of the power MOSFET are compared.

The breakdown voltage as per the manufacturer's data sheet (Vgs=0; I_{ds}=0.2mA) is higher than 75 V. The value of this voltage $V_{(BR)DSS}$ was found 86 V in the case virgin and 81 V after ageing. I_{DSS} include minority carrier injection from the source due to carriers overcoming the energy barrier resulting from surface band bending and also from sub-critical avalanching caused by high electric fields due to a non-ideal body as well as the Laterally-Diffused-Drain (LDD) doping profile [12].

After accelerated RF pulsed life test, the degradation of leakage current can be explained by the increase of V_{th} and C_{rss}. These parameters are degraded due to the interface state generation after stress, device performances should be degraded due to the same degradation mechanism. This indicates that the performance degradation is mainly due to the hot carrier induced interface state generation [17,18]. The Miller capacitance C_{rss} is composed of two parts, the oxide capacitance (C_{OX}) and the drift region capacitance (C_{SI}) [19].

The electric parameters of MOS transistor are more and more sensitive to defects bound to the presence of charges in the gate oxide and at the Si/SiO_2 interface [10].

The origin of the observed shift could be related to the presence of very high electric field, which increases carrier injection into the grown silicon dioxide layer (SiO_2) and into interface state Si/SiO_2 [10,19]. The detail of the lateral electric field distribution of the active silicon layer in channel and drift regions is shown in Fig. 8.

The hot carriers produce an additional interface trap density and trapped electron charge which results in a build up of negative charge at Si/SiO_2 interface [20]. This negative charge attracts holes depleting the negative charge in the power LDMOS N-drift region and by consequent increasing the $R_{ds\text{-}on}$ device resistance. Hence, $R_{ds\text{-}on}$, C_{rss} and I_{dsat} variations are more remarkable at 10°C, due to the fact that the maximum impact ionization rate is located near the gate edge, see Fig. 9.

The aggressive gate leakage current due to the carrier direct tunneling has become as ultimate limit for gate oxide down scaling [6]. The RF performances are not stable during all 3000 h the life test; we see a variation of I_{ds}. This variation affects the RF performances. According to the literature [19,20], the most probable cause of degradation for power RF LDMOS technology is attributed to hot electron-induced interface state generation and/or impact ionization. May be state interface Si/SiO_2 between drain and gate are responsible of this phenomenon. In order to explain this behaviour, the characterisation of these defects should be investigated. Particularly, the distribution of the data in the figures shows that the aging of the transistor is relatively dependent of the temperature.

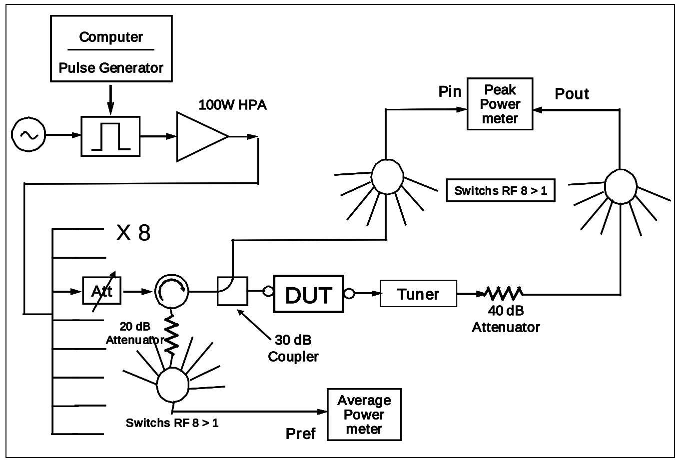

Fig. 1: Synoptic of a RF pulsed life test bench

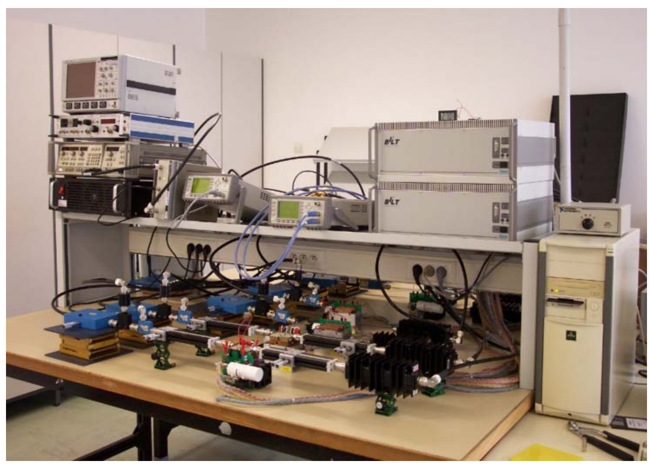

Fig. 2: Photography of the RF pulsed life test bench

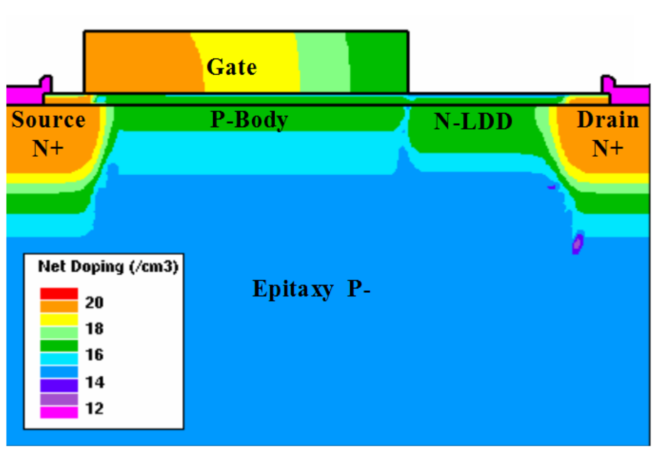

Fig. 3: Cross-section view of power RF N-LDMOS device with Net doping profile along silicon surface implemented in Silvaco-Atlas

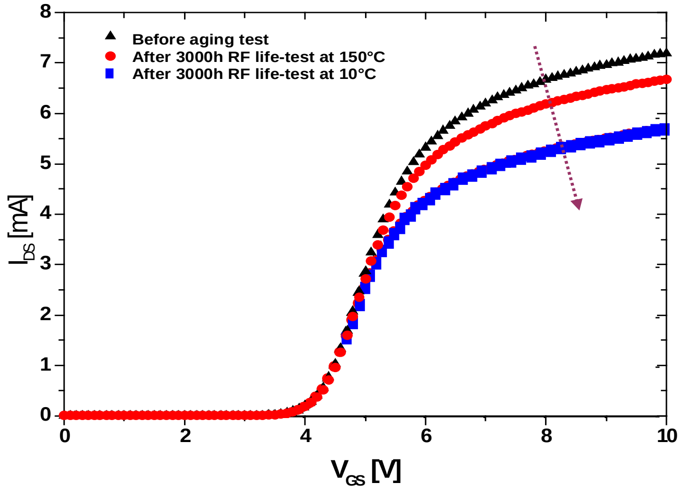

Fig .4: V_{th} evolution before and after ageing RF Life tests with V_{DS}=10mV

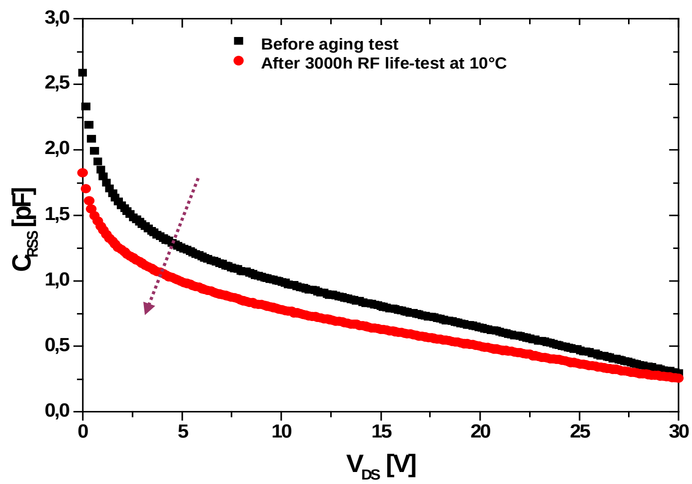

Fig. 5: C_{RSS} profile before and after 3000h RF Life test (10°C) with Freq=1MHz

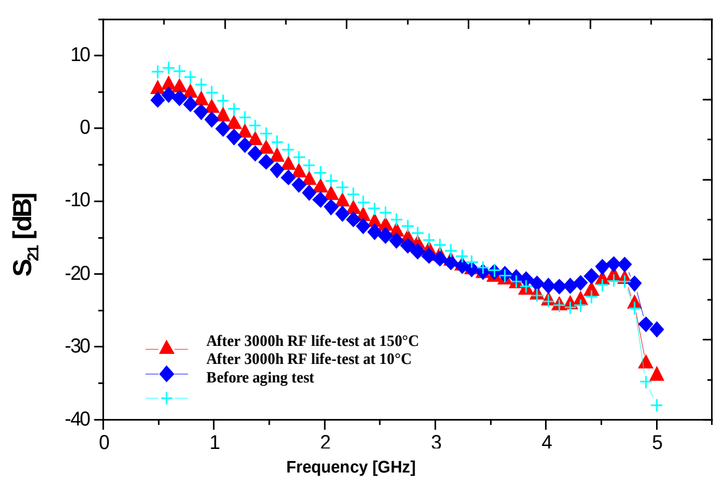

Fig. 6: S-parameter (S_{21}) degradations of the power RF LDMOS before and after RF Life-test, with V_{ds}= 28V, V_{gs}=4.7V and Freq=[0.5GHz, 5GHz]

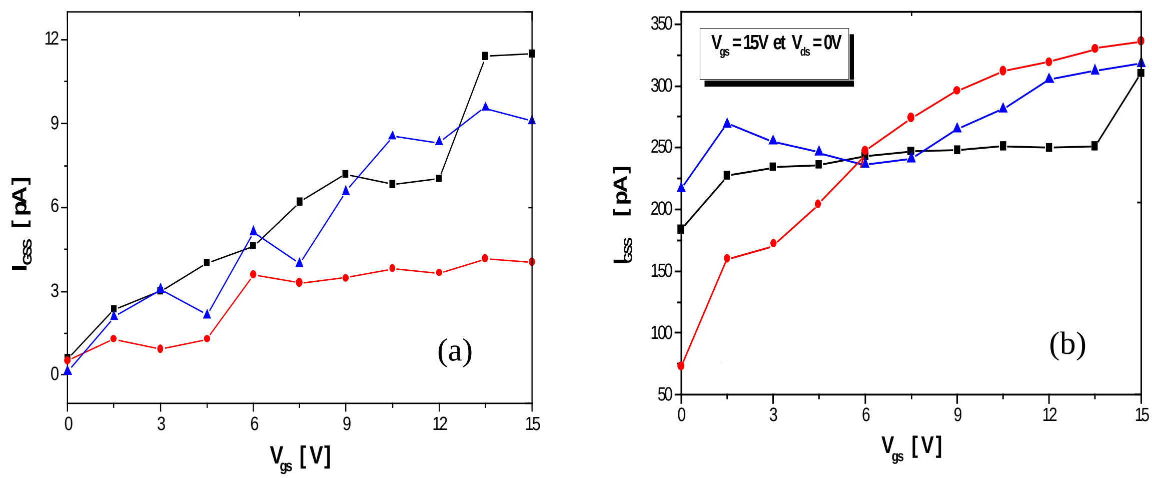

Fig. 7: Variations of Gate leakage current (I_{GSS}) measured of three samples power RF LDMOS before and after ageing test

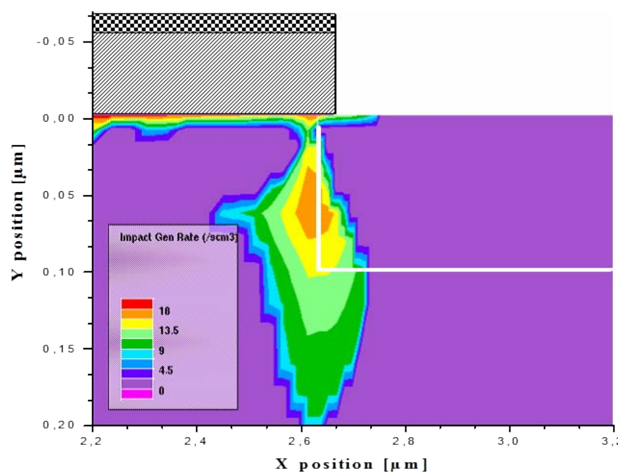

Fig. 8: Simulated impact ionization rate distribution, at bias conditions (Vds = 44 V and Vgs = 3.8 V)

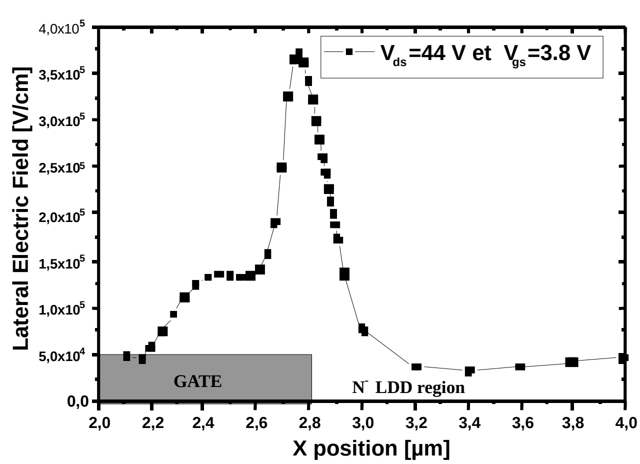

Fig. 9: Lateral electric field distribution in power N-LDMOS structure, with Vds=44V and Vgs=3.8V bias

Table 1: Device dimensions

Parameter	Value (μm)
Source length	1.1
Source-gate spacing	1
Gate length	0.8
Gate-drain spacing	3
Drain length	1.1
Gate oxide thickness	0.065

Table 2: Measured and data sheet values of the electrical parameters

Parameter measured	Measured value			Data sheet value
	Virgin	Degraded shift%		
I_{GSS}	12 pA	340 pA >100		‹ 40 nA
I_{DSS}	2 nA	90 nA >100		‹ 1.5 μA
V_{th}	4.1 V	4.83 V	17	4v ≤ ; ≥ 5v
$V_{(BR)DSS}$	86 V	81 V	6	75V ≤
Crss	0.43pF	0.34 pF 21		typ. 0.5 pF
S_{21}	-7.3 dB	-10 dB 36		‹ 11 dB

IV. Conclusions and Prospects

This objective constitutes an investigation to clarify the problems related of Hot Carrier Injection effects for reliability exerted on power RF LDMOS under operating conditions of radar application (stress: electrical, thermal and RF). The reliability is shown by monitoring I_{ds}, V_{th}, C_{rss}, S_{21}, T°C and I_{GSS} parameters in order to put in evidence the device performances. The simulation approach helps to assess the device robustness under critical conditions by means of the temperature evaluation, RF and current distributions in LDMOS structures operating. The results obtained highlighted a degradation caused primarily by the mechanism of hot carrier injected in oxide layer and in channel interface states (i.e. hot-electron-induced interface state generation and/or impact ionization), and in turn its effect on critical parameter drifts (I-V, C-V and RF). These are sensitive parameters to the electrons injected in gate/SiO_2 interface traps.

This paper represents the starting point for the development of an accurate and more complex FEM based simulation concept which would correctly include electro-thermal effects. Further failure mechanisms, e.g. the possible activation of the CEM will be integrated within the simulation condition. Moreover, it would be interesting to make the connection with the normal life of a component, through an aging model or MTTF (Mean Time To Failure). The comparison of this study with other technologies such as IGBT and VDMOS is underway.

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Investigating Impact and Viability of Hostile Weather Conditions on Solar Farm Establishment in Nigeria: A Case Study

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Abstract- The study investigates impact of hostile weather conditions on performance and viability of solar farm establishment in Nigeria. This was done on two different PV Modules of 10MW capacity using NASA radiation data for six (6) different locations (Abuja, Birnin-Kebbi, Enugu, Lagos, Port Harcourt and Maiduguri) in Nigeria. RET Screen clean energy software was used in the simulation. The results show dependence of Capacity Utilization Factor (CUF) on Solar Irradiation among other design and technological factors like Controlled tracking of PV Module and type. Other Factors like air temperature, wind speed, elevation from horizon and latitude of the location that affect irradiation are also investigated. The findings showed that increasing the output of the system by increasing the capacity of PV module does not affect CUF but attract additional cost, thus making solar farm in hostile environment costly.

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INVESTIGATINGIMPACTANDVIABILITYOFHOSTILEWEATHERCONDITIONSONSOLARFARMESTABLISHMENTINNIGERIAACASESTUDY

Strictly as per the compliance and regulations of:

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Omorogiuwa Eseosa [α] & Martins Enebieyi William [σ]

Abstract- The study investigates impact of hostile weather conditions on performance and viability of solar farm establishment in Nigeria. This was done on two different PV Modules of 10MW capacity using NASA radiation data for six (6) different locations (Abuja, Birnin-Kebbi, Enugu, Lagos, Port Harcourt and Maiduguri) in Nigeria. RET Screen clean energy software was used in the simulation. The results show dependence of Capacity Utilization Factor (CUF) on Solar Irradiation among other design and technological factors like Controlled tracking of PV Module and type. Other Factors like air temperature, wind speed, elevation from horizon and latitude of the location that affect irradiation are also investigated. The findings showed that increasing the output of the system by increasing the capacity of PV module does not affect CUF but attract additional cost, thus making solar farm in hostile environment costly.

I. Introduction

Generating power by converting sunlight into electricity is not a new concept; neither is generating solar power at the utility scale. What is new, however, is the accelerating demand for clean energy, particularly PV solar energy. Solar energy as one of the many sources of renewable energy-based off-grid electricity supply is traditionally considered as an expensive and unreliable source of power. But as technology improves over the years, renewable energy sources are beginning to take the stage of modern energy divide (Omorogiuwa Eseosa and Ekiyor Martin Thompson 2017).The modern surge for solar is, in part, driven by rising demand for electricity and increasing environmental costs associated with conventional fuels. In recent years, large-scale solar energy development has also been invigorated by the economic forces of technological innovation, falling costs of production, and political support in the way of renewable energy standards and goals. As a result, numerous large-scale solar projects have taken root domestically and internationally, and are continuing to grow. However, solar energy usage has not gained much popularity in Nigeria as it is majorly limited to pilot and demonstration projects even with abundant available solar renewable energy. Solar energy applications serve various energy needs among rural dwellers because of obvious deprivation of grid supply. Solar PV technologies are growing, though awareness is relatively low. PV installations are commonly found in street lighting, rural electrification projects as well as low and medium level uses such as solar pumps. PV cells have been installed to serve rural clinic and schools. Understandably, many of the earliest projects were developed in areas where sun shines the most. Northern Region of Nigeria is certainly very viable for solar development for many reasons: land is relatively cheap, environmental impacts tend to be less complex, population is comparatively less dense, high solar irradiance, low humidity, and the weather is predictably cloudless for most part of the year. Though the conditions in the North are rather ideal, large-scale solar power is still very much a viable source of renewable energy in a myriad of conditions and locations. In other regions of Nigeria, particularly in the South, for instance, the conditions are dramatically different from the North—land tends to be expensive, very complex environmental impacts, denser population, solar irradiance is comparatively less, humidity can soar, and the weather is highly variable and extremely difficult to predict. Even though the conditions may not be as ideal as those found in the North, economic forces are spurring the feasibility of PV solar power development in other regions of Nigeria. However, a predictive study of the performance of solar PV system in various locations in Nigeria will result in correct investment decisions, better regulatory framework and favorable government policies. Accurate and consistent evaluation of PV system performance allows detection of operational problem, facilitate the comparison of system that may differ with respect to design, technology, or geographic location and validate model for system performance and cost estimation during the design phase. A comparative analysis of the meteorological Data across regions in Nigeria is necessary to determine variation of solar irradiation and its effect on solar energy utilization in Nigeria. Solar Energy depends on solar radiation which is a lot more complex than human perception of solar potential from sunshine and may require sophisticated instrument for measurement. Moreover, to successfully investigate the distribution of solar resources in Nigeria, more regions than North and South will be under

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studied. Optimum Solar PV system is derived with regard to various designs and technologies, thus resulting to correct investment decision and performance improvement. It will also facilitate comparison of systems that may defer with respect to geographic location among others and validate models for system performance. This work overviews environmental constraint of utility solar PV energy utilization in Nigeria in an attempt to achieve the following:

- Review design and technological criteria for better performance of solar power plants.
- Determination of viability of solar power potentials at different locations in Nigeria
- Modeling of PV systems using RETScreen renewable energy software and make possible recommendation for future work in the field of solar energy

II. Review of Related Work

PV panels have been used to collect photons for decades with the sole purpose of generating power for utilities since the first megawatt- scale solar farm was built in Sacramento, California, in 1984 (Green Energy News 2009) as cited by Robert and Anders (2013). From the location of Nigeria, it can actually produce appreciable amount of solar energy radiation as this value varies across the country from 3.5kWh/m^2 per day in the coaster latitude to 7kWh/m^2 per day in the far North; giving an annual average solar intensity estimated to be 1934.5kWh/m^2. (Akindele, 2014). According to Sambo, 2009 as cited by Akindele (2014), with 1% of Nigeria's land area covered by solar collectors, given prevailing efficiencies and average radiation of 5.5kWh/m^2/day, it will be possible to generate 1850x10^3 GWh of electricity per year, which is over 100 times grid consumption level. However, there is currently no grid input from solar source in Nigeria. In recent years, studies of solar energy technology are on the rise as it becomes more readily deployable as in the case of Ethiopia rural electrification where SPV account for 95% electrical energy of HPS (Zelalem, 2013). In the author's methodology, to obtain PV arrays/size that will satisfy energy demand, parameters used include lifetime PV array of 25 years, 90% derating factor and ground reflectance of 20% and was simulated with homer optimization software. The results showed that the site has tremendous solar resource potential, with average radiation of 6kWh/m^2/day (insolation). This is the reason 95% of electrical energy is from PV array while the rest 5% is obtained from diesel Generator in optimum system. The author also concluded that incentives from state and federal government are critical to the widespread deployment of such system due to high net present cost. The method adopted by Emmanuel (2009) to analytically calculate various losses of PV Park considered in-plane solar radiation, ambient daytime temperature, array DC power as well as park AC output power averaged with 10 min frequency during a typical day per month. The nominal instantaneous array DC power per 10 min and total annual array output energy were computed using solar radiation data as well as technical specifications of photovoltaic panels. Real array output power obtained by gradually adding various losses of array comprising of degradation modulus, temperature and soiling losses. The same method is adopted for calculation of interconnection, inverter and transformer losses by correlating real array power output with PV park power output with a 10 min frequency. This method gives realistic estimate, since various losses are interrelated and directly linked with instantaneous real power output of both PV panels and park.

The efficiency of PV panel depends on the operating temperature and power density of solar radiation. As its temperature increases, efficiency decreases linearly, since peak power PV panels refers to Standard Test Condition (STC). In different temperatures, output power of PV panels depends on difference of panel temperature, STC temperature (TC - TSTC) and power density (G) of the incident solar radiation. The following variables were defined by the researcher; final yield (YF), reference yield (YR), performance ratio (PR) and capacity factor (CF) and were calculated as defined by IEC Standard 61724. The final yield is annual, monthly or daily net AC energy output of the system divided by peak power of installed PV array at STC of 1000 W/m^2 solar irradiance and 25-degree cell temperature.

$$YF = \frac{E[KWh_{A,C}]}{P_r[KW_{DC}]} \tag{1}$$

Reference yield is the total in-plane solar insolation Ht (kWh/m^2) divided by the array reference irradiance (1 kW/m^2); therefore, the reference yield is the number of peak sun-hours.

$$Y_R = \frac{Ht[\text{KWh}/\text{m}^2]}{1\text{KW}/\text{m}^2} \tag{2}$$

Performance ratio is the final yield divided by reference yield. It represents the total system losses when converting from name plate DC rating to AC output. The typical losses of PV park include losses due to panel degradation(ɧdeg), temperature(ɧtem), soiling(ɧsoil), internal network(ɧnet), inverter(ɧinv), transformer (ɧtran), system availability and grid connection network (ɧppc), Therefore, PR can be expressed as

$$p_R = \frac{Y_F}{Y_R} = \text{ɧdeg}.\text{ɧtem}.\text{ɧsoil}.\text{ɧnet}.\text{ɧinv}.\text{ɧtran}.\text{ɧppc} \tag{3}$$

Array yield (YA) is defined as annual or daily energy output of the PV array divided by the peak power of the installed PV. System losses (LS) are gained from the inverter and trans- former conversion losses, and the array capture losses (LC) are due to the PV array losses

$$Y_A = \frac{E_A}{Pr} \quad (4)$$

$$Lc = Y_R - Y_A \quad (5)$$

$$Ls = Y_A - Y_F \quad (6)$$

Finally, capacity factor (CF) is defined as the ratio of actual annual energy output to the amount of energy PV Park would generate if operated at full power (Pr) for 24hr/day for a year.

$$C_F = \frac{Y_F}{8760} = \frac{E}{P_r \text{ x } 8760} = \frac{\text{Ht x } p_R}{\text{Pr x } 8760} \quad (7)$$

Performance ratio and various power losses associated with 5MW Grid connected solar PV power plant in Karnataka were evaluated over 7-months period. Manually extracted parameter through SCADA system was compared with simulated result from PVsyst software. The closeness of the result proves the method satisfactory for determining possible plant capacity for an arbitrary chosen area. (Bharathkumar and Byregowda, 2007).

Hakeem in 2013 categorized PV systems on the basis of their functional operational requirements, component configuration and equipment connection to other power sources and electrical loads. On these basis, PV systems are rather classified as grid–connected/utility–interactive systems and stand–alone systems. Marion et al (2005) presented a paper to illustrate the extent to which the performance parameters of grid connected solar PV plant might be influenced by weather. PV system performance was modeled using PV form for 30-year period. The hourly solar radiation and meteorological data input to PV form was for the boulder, CO, Station in the National solar radiation Data base. Final yield (Yf) shows the greatest variability and the PVUSA rating at PTC shows the least. The variability of the reference yield (Yr) is similar to the final yield because of Yr dependence on solar irradiance. Performance Ratio (PR) values exhibit the influence of temperature, with smaller values in summer than winter for every yearly values. Both PVUSA, AC power rating at PTC and yearly PR values should be able to detect degradation of system performance over time.

Dirk and Sarah (2012) presented a report on 40-year field test on module degradation rate. Nearly 2000 degradation rate measured on individual module or entire system, have been assembled from literatures and showed mean degradation rate of 0.8%/year and a median value of 0.5%/year. The majority (78%) of all data reported a degradation rate of <1%/year. Significant differences between module and system degradation rates observed earlier on has narrowed, implying that substantial improvement towards stability of the balance of system components has been a choice. Despite the progress achieved in the last decade, linearity and precise impact of climate have not been satisfactorily determined.

III. Methodology

RET Screen is the choice software used for the study. It is clean energy project analysis software used in energy decision making and allows engineers, architects, and financial planners to model and analyze any clean energy project. It allows five step standard analyses. These include energy analysis, cost analysis, emission analysis, financial analysis and sensitivity/risk analysis. RETScreen is used in this report to predict the output from 10MW power plant using satellite data from National Aeronautics and Space Administration (NASA) in the absence of real time measurement from solar plant and metrological site in Nigeria. In order to determine environmental hostilities of solar PV performance in Nigeria, information and data from a wide variety of sources (primary and secondary) such as Data from solar radiation was obtained from NASA and analyzed using RETScreen software to determine irradiation levels from different sources, and power output from solar plants.

a) *Data Collection*

The following data were collected from NASA.

- ✓ Geographical and environmental variables associated with solar PV Module in the locations. These include: Latitude & Longitude, Climate Zone, Elevation, Heating Design Temperature, cooling design temperature, Earth Temperature Amplitude, Air Temperature, Relative Humidity, Precipitation, Daily Solar Radiation, Atmospheric Pressure, Wind Speed, Earth Temperature, Heating Degree-Days and Cooling Degree-days.
- ✓ Manufacturers' specification Data for two different PV Module (mono crystalline silicon & amorphous silicon) of 10MW each.

b) *Data Analysis*

RET Screen software was used to simulate the geographical, environmental and solar PV module parameters. Data for six locations which uses radiation data from NASA and Ground measurement was obtained and analyzed. It was found that NASA source data varies over a wide range depending on whether it is collected from monitoring stations, extrapolated, or derived from satellite information. In order to evaluate the environmental factors associated with Solar PV performance, technological and design factors are kept constant while factors that are specific to geographical locations are varied. One Location is taken from each of the six geographical zones in Nigeria as climatic variation is minimal within a region. The latitudes at the locations are used as the optimum tilt angle for the PV module in fixed tilt orientation to maximize Irradiation and to ensure same condition for all locations. Simulations was done for both Fixed tilt and Single axis tracking Scheme, leading to a total of 24 simulations with 4 in each location. These include Abuja, Birnin-Kebbi, Enugu, Lagos, Port Harcourt and Maiduguri as highlighted in Figure 3.0. Assumption used in RETScreen for Mono-Silicon and Amorphous Silicon modules are given in Table 3a and 3b respectively.

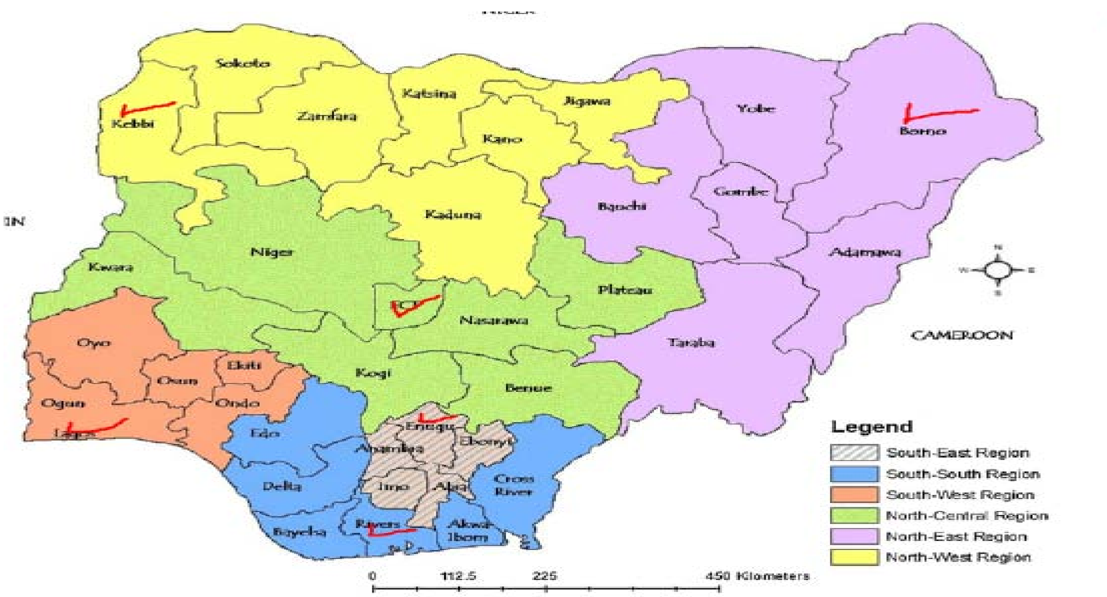


Figure 3.0: Regional Map of Nigeria

Table 3a: Mono-Silicon Module and inverters parameters

Photovoltaic		
Type		mono-Si
Power capacity	MW	10
Manufacturer		BP Solar
Model		mono-Si - BP 1210
Number of units		1,000,000
Efficiency	%	7.75%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.4%
Solar collector area	m²	129,032
Miscellaneous losses	%	7.5%
Inverter		
Efficiency	%	96%
Capacity	kW	10,000
Miscellaneous losses	%	0%
Resource Assessment		
Solar Tracking Mode		Fixed and one - Axis
Slope		Latitude of the location
Azimuth		0

Table 3b: Amorphous Silicon and inverter parameters

Photovoltaic		
Type		a-Si
Power capacity	MW	10
Manufacturer		BP Solar
Model		a-Si - BP Millenia MST 50 MV
Number of units		200,000
Efficiency	%	6.1%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.11%
Solar collector area	m²	163,934
Miscellaneous losses	%	7.5%
Inverter		
Efficiency	%	96%
Capacity	kW	10,000
Miscellaneous losses	%	0%
Resource Assessment		
Solar Tracking Mode		Fixed and one - Axis
Slope		Latitude of the location
Azimuth		0

IV. Result and Discussions

RET Screen Simulation result in Table 4.0 shows the trend of improvement CUF from fixed tilt to single axis tracking and from mono-silicon to amorphous silicon module

Table 4.0: CUF and annual output for tilt and one axis tracking method at various locations

		Annual Average Radiation KWh/m²/d		Mono Silicon Annual Output MWh		Amorphous silicon Annual Output MWh		m-Si CUF		a-Si CUF				
S/N	location	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Amb Temp °c	Wind Speed(M/s)	Optimum Tilt Degree
1	Abuja	5.45	6.88	16,460	20,423	17,555	21,791	18.8	23.3	20	24.9	24.7	2.4	9.2
2	Birnin Kebbi	5.97	7.75	17,758	22,599	19,199	24,436	20.3	25.8	21.9	27.9	27.6	2.3	12.5
3	Enugu	4.92	5.97	14,804	17,795	15,733	18,917	16.9	20.3	18	21.6	25.2	2.1	6.3
4	Lagos	4.74	5.69	14,260	16,962	15,155	18,032	16.3	19.4	17.3	20.6	25.7	2.8	6.5
5	Port Harcourt	3.96	4.48	11,907	13,435	12,603	14,222	13.6	15.3	14.4	16.2	26.7	2	4.9
6	Maiduguri	5.89	7.63	17,599	22,313	18,974	24,059	20.1	25.5	21.7	27.5	27	3.8	11.9

The trend is also repetitive in the average radiation across the locations. Average radiation is directly proportional to CUF. Air temperature does not have linear relationship with solar radiation (irradiation) as seen in cases of Port Harcourt and Lagos with lower irradiation despite having higher air Temperature than Abuja and Enugu. Other geographical factors like location latitude, elevation from the horizon and wind velocity also affect the irradiation level. From the meteorological resource data in Appendix A and B, Port Harcourt and Lagos have the lowest elevation with values of 18m and 32m respectively. The irradiation is also observed to have direct variation with the nearness of the latitude to north with exception to Enugu and Lagos. Lagos is 0.2 degree more elevated than Enugu but 155m lower from the horizon. Their latitudes are 6.5 degree and 6.3 degree due north respectively. The irradiation of Enugu is higher than Lagos despite trailing Lagos by 0.2 degree north. The pattern is sustained as the difference in their latitude is small as compared to the difference in their elevation from the horizon.

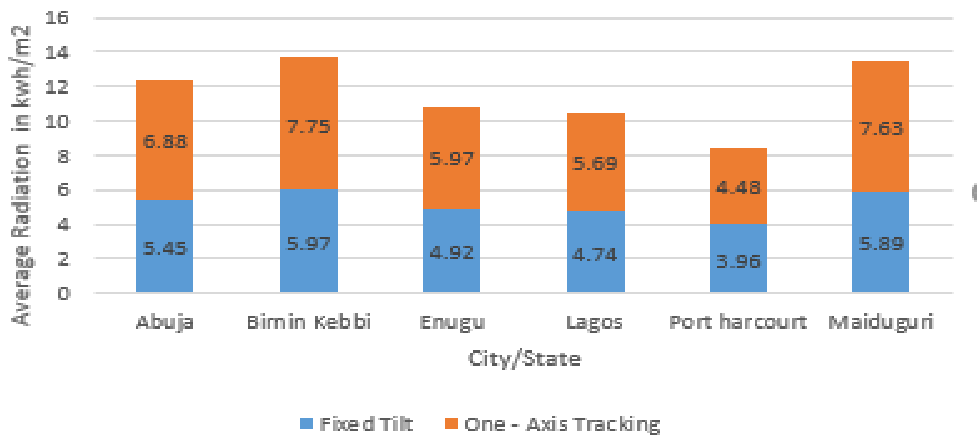
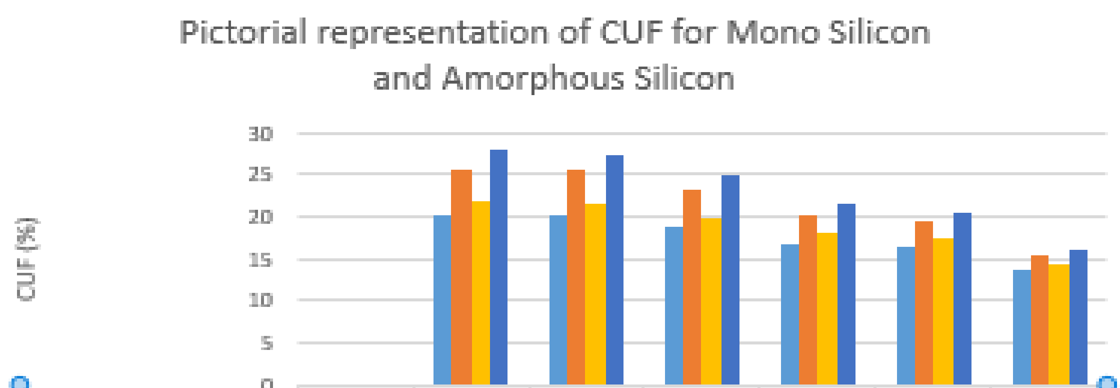


Figure 4.0: Average Radiation for fixed tilt and one axis tracking system on the various locations

There is significant improvement on the annual average radiation by the used of one axis tracking control method in all location as shown in Figure 4.0. Port Harcourt recorded 13.1% increase while Birnin Kebbi shows an increase of 29.8%. Percentage increase is seen to rise from the least average radiation to the highest average radiation. The increase obtained by the use of one axis tracking control is proportional to the magnitude of the fixed tilt average radiation.



	City/State	Birnin Kebbi	Maiduguri	Abuja	Enugu	Lagos	Port harcourt
m-si fixed tilt	0	20.3	20.1	18.8	16.9	16.3	13.6
M-Si single axis tracking	0	25.8	25.5	23.3	20.3	19.4	15.3
A-Si fixed tilt	0	21.9	21.7	20	18	17.3	14.4
A-Si single axis tracking	0	27.9	27.5	24.9	21.6	20.6	16.2

m-si fixed tilt · M-Si single axis tracking · A-Si fixed tilt · A-Si single axis tracking

Figure 4.1: Shows CUF for various location, PV Module type and tracking mechanism

The difference of CUF brought about by PV module type is minimal compare to change in CUF due to the use of tracking scheme. Figure 4.1 shows variation of CUF from the highest to the least across different locations and variations of CUF due to tracking technique and PV module type within a location. Birnin-Kebbi has the highest CUF while Port Harcourt has the lowest CUF. The initial cost, operational and maintenance cost for fixed tilt and single axis tracking scheme are shown in Table 4.1. From the investigation, tracking scheme is more expensive than fixed tilt system both in terms of cost and maintenance.

Table 4.1: Economic Analysis

Cost Summary	Fixed Tilt	Single Axis tracking
Initial cost/KW	$ 2800	$ 3400
O & M cost/KW-Year	$ 38	$ 44
10MW Initial Cost	$28,000,000	$38,000,000
10MW O & M Cost/year	$380,000	$440,000

V. Conclusion and Recommendation

Solar Farm investment will play an important role in the overall energy supply in Nigeria because of its great potential in most location. Among the six towns selected from each of the geopolitical zones only Port Harcourt and Lagos shows low solar potential as determined from their CUF. This depends on several factors including Solar Radiation, Temperature, Air Velocity, apart from technological and design Parameters like, PV Module type and quality, angle of tilt (or tracking), Cable losses, efficiencies of Inverter and Transformers. Amorphous Silicon PV Module performed better than Mono Silicon PV Module in all the locations but did not improve the CUF as much as the variation of tracking mechanism, from fixed tilt to single axis tracking scheme. Annual output of Solar PV farm can be improved considerably by increasing the capacity of Solar PV Module and reducing losses in cable, inverter, transformer and soiling. In the case of Port Harcourt, to achieve an output of 28,444MWh/year, Solar PV Module capacity will be increased to 20MW, which is twice the initial capacity. Simulation results for 20MW in Port Harcourt are shown in Appendix C and D. This will require an additional initial and maintenance cost of $38,000,000 and $440,000/year respectively. The overall effect results in increasing cost. Furthermore, the use of storage facility to compliment the output in period of low solar irradiation will also attract additional cost, thereby making solar farm in hostile environment feasible but costlier.

It will be desirable to monitor solar radiation data from ground base weather station in order to determine the inaccuracies associated with satellite measured data such as that provided by NASA, NREL and WRDC. This work is essential in providing useful proposition to the application of solar energy technology to meet the millennium development Goal (MDG) of clean energy deployment in Nigeria. This paper is limited to investigation of Environmental factors affecting Solar PV performance in Nigeria. The factors considered are those specific to a given geographic location. It also encompasses models for system comparison, performance analysis and cost estimation during the design phase. It does not include other factors like module degradation, capture losses, and losses in system inter-connectivity. It is also recommended to carry out detailed study for several locations with active involvement of existing Solar plant in the region.

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Appendix A

Enugu, Port Harcourt and Lagos Meteorological Resource Data

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Enugu	
Latitude	°N	6.3	
Longitude	°E	7.5	Source
Climate zone	1A	Very hot - Humid	NASA
Elevation	m	187	NASA
Heating design temperature	°C	20.2	NASA
Cooling design temperature	°C	31.1	NASA
Earth temperature amplitude	°C	10.5	NASA

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Port Harcourt	
Latitude	°N	4.9	
Longitude	°E	7.0	Source
Climate zone	0A	Extremely hot - Humid	Ground+NASA
Elevation	m	18	Ground
Heating design temperature	°C	22.3	NASA
Cooling design temperature	°C	28.3	NASA
Earth temperature amplitude	°C	4.2	NASA

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Lagos	
Latitude	°N	6.5	
Longitude	°E	3.5	Source
Climate zone	1A	Very hot - Humid	NASA
Elevation	m	32.2	NASA
Heating design temperature	°C	22.4	NASA
Cooling design temperature	°C	29.0	NASA
Earth temperature amplitude	°C	5.2	NASA

Appendix B

Meteorological Resource Data for Maiduguri, Birnin Kebbi & Abuja

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Maiduguri	
Latitude	°N	11.9	
Longitude	°E	13.2	Source
Climate zone	0B	Extremely hot - Dry	NASA
Elevation	m	337	NASA
Heating design temperature	°C	17.4	NASA
Cooling design temperature	°C	36.8	NASA
Earth temperature amplitude	°C	18.5	NASA

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Birnin Kebbi	
Latitude	°N	12.5	
Longitude	°E	4.2	Source
Climate zone	0B	Extremely hot - Dry	NASA
Elevation	m	263	NASA
Heating design temperature	°C	18.3	NASA
Cooling design temperature	°C	37.7	NASA
Earth temperature amplitude	°C	18.1	NASA

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Birnin Kebbi	
Latitude	°N	12.5	
Longitude	°E	4.2	Source
Climate zone	0B	Extremely hot - Dry	NASA
Elevation	m	263	NASA
Heating design temperature	°C	18.3	NASA
Cooling design temperature	°C	37.7	NASA
Earth temperature amplitude	°C	18.1	NASA

RETScreen - Climate database			
Country		Nigeria	
Province/State			
Climate data location	See map	Abuja	
Latitude	°N	9.2	
Longitude	°E	7.2	Source
Climate zone	1A	Very hot - Humid	NASA
Elevation	m	573	NASA
Heating design temperature	°C	18.3	NASA
Cooling design temperature	°C	32.8	NASA
Earth temperature amplitude	°C	13.6	NASA

Appendix C

Port Harcourt Simulation Parameters for 20MW

Photovoltaic		
Type		a-Si
Power capacity	MW	20
Manufacturer		BP Solar
Model		a-Si - BP Millenia MST 50 MV
Number of units		400,000
Efficiency	%	6.1%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.11%
Solar collector area	m²	327,869
Miscellaneous losses	%	7.5%
Inverter		
Efficiency	%	96%
Capacity	kW	20,000
Miscellaneous losses	%	0%
Summary		
Capacity factor	%	16.2%
Initial costs	$/kW	3,400
	$	68,000,000
O&M costs (savings)	$/kW-year	44
	$	880,000
Electricity export rate		Electricity exported to grid - annual
	$/kWh	0.10
Electricity exported to grid	MWh	28,444
Electricity export revenue	$	2,844,393

Appendix D

Port Harcourt simulation Result for 20MW

Resource assessment		
Solar tracking mode		One-axis
Slope	°	4.9
Azimuth	°	

Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/kWh	Electricity exported to grid MWh
January	4.13	4.90	0.10	2,639.005
February	4.32	5.06	0.10	2,456.673
March	4.23	4.81	0.10	2,591.109
April	4.29	4.84	0.10	2,521.848
May	4.13	4.61	0.10	2,482.108
June	3.82	4.19	0.10	2,185.119
July	3.51	3.76	0.10	2,034.927
August	3.29	3.46	0.10	1,873.910
September	3.79	4.17	0.10	2,180.834
October	3.89	4.39	0.10	2,372.921
November	3.98	4.64	0.10	2,423.037
December	4.15	4.98	0.10	2,682.441
Annual	**3.96**	**4.48**	**0.10**	**28,443.934**

Annual solar radiation - horizontal	MWh/m²	1.44
Annual solar radiation - tilted	MWh/m²	1.64

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Study of Two-Dimensional Open EWOD System using Printed Circuit Board Technology

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Abstract- Digital micro fluidics (DMF) emerged as a popular technology for lab on chip (LOC) application, which allows full and independent control over droplets on an array of electrodes. In this work, open electro wetting on dielectric technique (EWOD) based on printed circuit board has been investigated, which has a wide range of applications. The most of the traditional EWOD chips array of electrode pads typically in 1-D (one-dimensional) line pattern designed for specific operation at a time, limit the utilization of estate. In the proposed system, 2-D (two-dimensional) array of 22 electrodes, controlled by 8 control signals designed and fabricated to enhance reconfigurable paths. Bio-compatible polydimethylsiloxane (PDMS) is used as a dielectric as well as a hydrophobic layer. The controlled droplet transport and mixing are successfully done on the fabricated device. The effect of ground wire configuration on droplet velocity is investigated and results are verified with estimated droplet velocity.

Keywords: digital microfluidics· electrowetting-on-dielectric (EWOD)· polydimethylsiloxane (pdms)· printed circuit board (PCB)· open source computer vision (OPENCV).

GJRE-F Classification: *FOR Code: 290901p*

STUDYOFTWODIMENSIONALOPENEWODSYSTEMUSINGPRINTEDCIRCUITBOARDTECHNOLOGY

Strictly as per the compliance and regulations of:

Study of Two-Dimensional Open EWOD System using Printed Circuit Board Technology

Vandana Jain [α], Vasavi Devarasetty [σ] & Rajendra Patrikar [ρ]

Abstract- Digital micro fluidics (DMF) emerged as a popular technology for lab on chip (LOC) application, which allows full and independent control over droplets on an array of electrodes. In this work, open electro wetting on dielectric technique (EWOD) based on printed circuit board has been investigated, which has a wide range of applications. The most of the traditional EWOD chips array of electrode pads typically in 1-D (one-dimensional) line pattern designed for specific operation at a time, limit the utilization of estate. In the proposed system, 2-D (two-dimensional) array of 22 electrodes, controlled by 8 control signals designed and fabricated to enhance reconfigurable paths. Bio-compatible polydimethylsiloxane (PDMS) is used as a dielectric as well as a hydrophobic layer. The controlled droplet transport and mixing are successfully done on the fabricated device. The effect of ground wire configuration on droplet velocity is investigated and results are verified with estimated droplet velocity. The maximum velocity points are correlated with maximum electric field obtained by electromagnetic simulations for all ground wire configurations. The detection of milk adulteration is successfully demonstrated using open EWOD device. This work illustrates the promise of open two-dimensional EWOD device for digital micro fluidics applications.

Keywords: digital microfluidics· electro wetting-on-dielectric (EWOD)· polydimethylsiloxane (pdms)· printed circuit board (PCB)· open source computer vision (OPENCV).

I. Introduction

Many micro fluidics tools are developed to control fluidics on the micro scale level. The first generation is continuous micro fluidics and the second generation is digital micro fluidics [1]. In continuous micro fluidics for liquid flow, we need external components like micro pumps and micro valves and also very difficult to manage many operations at a time [2]. Whereas in digital micro fluidics on a single chip can perform parallel various fluidic operations like dispense, transport, splitting, and merging [3], which offers advantages of portability, automation, higher sensitivity and high throughput in diagnosis applications [4]. This chip can perform clinical diagnostics for human physiological fluid [5], polymer chain reaction [6], proteomics [7] and glucose detection [8].

The manipulation of droplets in digital micro fluidic has been achieved using various techniques like temperature gradient [9], acoustic wave [10], dielectrophoretic (DEP) [11], Op to-electro-wetting (OEW) [12], electro wetting (EW) and electro wetting on dielectric (EWOD) [13]. EWOD outwits all the other methods because of recon figure ability, flexibility, dynamic nature and signal processing ability using optical and electrical techniques. EWOD is essentially the phenomenon where the wetting behavior of a conductive droplet placed on a dielectric surface can be modified by application of electric field across the dielectric below the droplet [14]. The contact angle change is predominantly because of accumulation of charge carriers at the solid and liquid interface.

We have seen that most reported EWOD chips use a series of electrode pads essentially in a one-dimensional line pattern, designed for a specific task by using highly sophisticated lithography for electrode patterning [13] and expensive dielectric materials like Teflon-AF or paralene-C [15]. In our previous works, we have demonstrated low-cost one- dimensional EWOD chip using PCB (Printed Circuit Board) technology [16]. But for desired universal chips allowing reconfigurable user paths would require the electrode pads in a two-dimensional pattern [14,17]. Compared to conventional lithography technique, PCB technology allows high recon figure ability and reusability at lower manufacturing cost [18,19]. However, the PCB-PDMS based inexpensive approach for two-dimensional EWOD system fabrication is not studied much. Also very less cost effective EWOD systems are available for the continuous monitoring of droplet parameter with accuracy [20], which is essential for precise control and accurate manipulation of droplet for enhancing the system performance.

In this work, the development of a PCB-PDMS based two-dimensional open EWOD system with continuous monitoring of droplet parameter using open source computer vision (OpenCV) is discussed. The effect of different ground wire configuration on droplet velocity is investigated. The detection of milk adulteration is demonstrated by the mixing of two droplets on the device.

The rest of the paper is organized as follows; in section 2 experimental aspects of device fabrication is discussed. The measurement setup is discussed in section 3. Results obtained are presented in section 4 followed by conclusions in section 5.

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II. Device Fabrication

The proposed open EWOD device in this work has dimensions of 3 X 3 cm2 PCB, consists of 22 copper electrodes (2mm X 2mm) separated by 155μm gap. Each electrode pad is connected by eight control signals through a 160μm wide line. The PCB is designed in such a way that when one electrode is activated it will not affect the adjacent electrode. The pictorial view of PCB is shown in Fig. 1, where the same color regions are representing electrodes are activated by the same control signal, and black dot is a PTH (Plated through hole) hole which allows the electrode to connect from the bottom side of PCB. The physical design of PCB is shown in Fig. 2 in which backside PTH hole (300μm) is filled with soldering paste to avoid leakage through the hole. Then we have coated PCB with PDMS, which acts as both a dielectric as well as a hydrophobic layer using spin coater system. Note that the PDMS is a biocompatible polymer which has an average static contact angle of 1100, which is capable of easing the droplet operation [21]. After spin coating and testing of this device, we have found that water hydrolysis is occurred, which is creating a problem for the droplet motion. We have observed that this is happening due to the improper dielectric coating on the device because of copper thickness (35μm) and the PTH hole. So avoiding this we have coated device two times with different speed. In first time device is coated with 1500rpm and allowed to cure for 45mins at 100oC and second time device is coated with 2500 rpm and then cured at 100oC for 45mins. The PDMS coatings are removed from contact pads by gentle scraping with a scalpel to facilitate electrical contact for droplet actuation. The electrode pad contact is provided through the female connector.

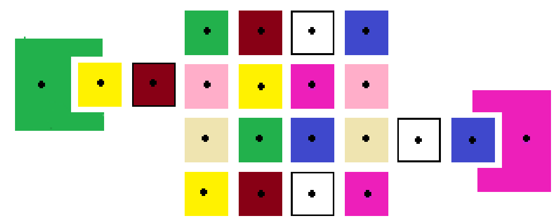

Fig. 1: Pictorial image of EWOD PCB

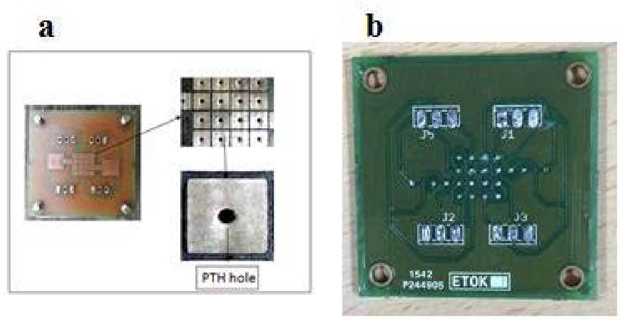

Fig. 2: Fabricated Device (a) Front view (b) Back view

For ground connection of droplet, we have used four aluminum wire catena (diameter 100μm) attached to separate PCB as shown in Fig. 3(a). The ground electrode wires are carefully arranged along the centerline of control electrode array on fabricated open EWOD device as shown in Fig. 3(b).

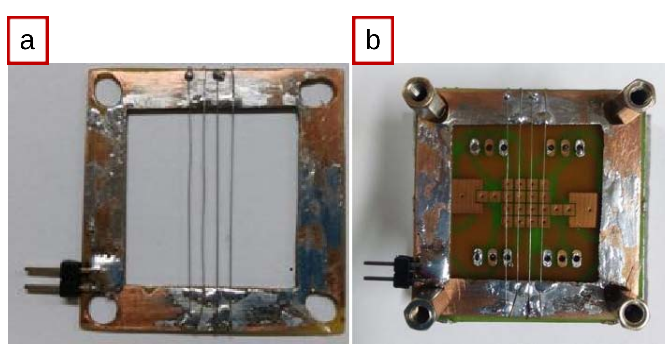

Fig. 3: (a) Catena arrangement on PCB (b) Final open EWOD device

III. System Description

A novel and precise droplet handling system is developed as shown in Fig. 4. A high voltage source is obtained from a DC boost converter. The application of high voltage is programmed by a microcontroller, which actuates a specific electrode through an electromagnetic relay. The complete setup consists of USB digital camera for capturing image/video in real time, XYZ stage for holding the sample, Arm7 based electronic system which has standard circuits for providing actuation of voltage and handling image processing along with HDMI display. The system is designed to achieve precise real-time control over the movement of the droplet in real time embedded Linux platform. The C++ and python codes are developed in Qt software for precise control of droplet on the electrode. Ground and a positive voltage of power supply are connected respectively to the ground wire and the contact pads of the glass plate [16].

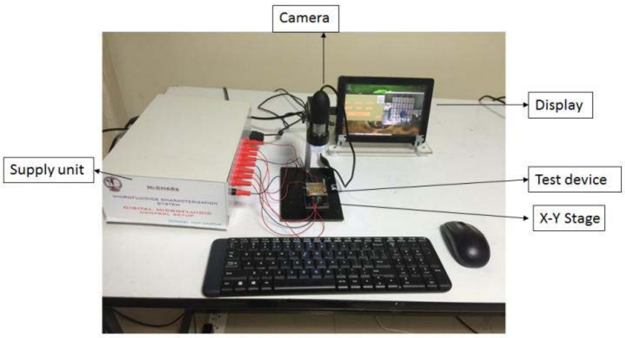

Fig. 4: Test setup

a) Image processing

The developed system is combined with integrated development environment (IDE) software with Open CV libraries for continuous mentoring of droplet velocity measurement and position detection. The functionalities of Open CV library are enhancing the image processing analysis. To characterize the developed DMF device, we have performed droplet transporting with velocity measurement in open EWOD system.

IV. Results and Discussions

a) Droplet transport by EWOD

The droplet transport under electrostatic force is studied in the device. The pictorial view of droplet motion in the open configuration is shown in Fig. 5. The droplet motion occurs as a result of capillary force which sequels an apparent wettability gradient between actuated and non-actuated electrode. Using Lippmann-Young law, we can translate that electro wetting effect into a capillary effect. So the net capillary force or electro wetting force is rewritten in the following expression [22].

Where ε0 is the permittivity of free space, εr is its relative dielectric constant, d is the thickness of the dielectric layer, V is the applied voltage, L is the effective contact line length. The contact line length L is determined by the boundary structure formation of the adjacent electrode.

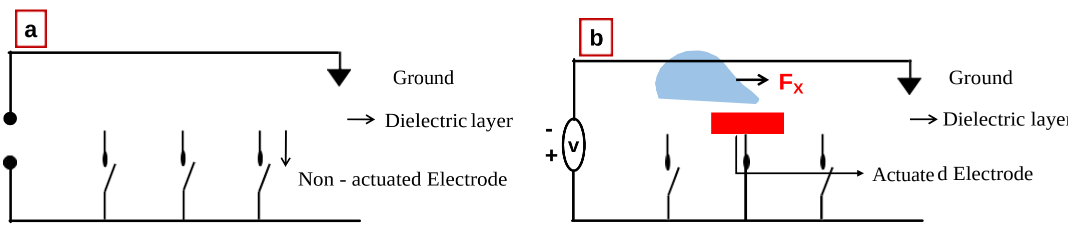

Fig. 5: Pictorial representation of open EWOD operation (a) without voltage (yellow color indicate no actuation) (b) With voltage (Red color indicate actuation)

The velocity of the droplet in the open EWOD device is derived for 1100 static contact angle of droplet by using [23].

$$U = \frac{\frac{\varepsilon_r \varepsilon_0 L}{d} \cdot V^2}{\pi K_1 K_2 K_c C_V \mu R \left(5.248 + \frac{\varepsilon_r \varepsilon_0 L}{d \gamma_{LG}} \cdot V^2\right)} \qquad (2)$$

Where KC is the damp factor caused by the pinning effect in the triangle region, K1 is acceleration and deceleration time process factor, K2 is the considering dragging effect due to the ground wire, R is the radius of the droplet CV is an empirical consta the solid– liquid surface tension and μ is the viscosity of the fluid.

A 5μL DI water droplet with 0.1M KCL is placed on electrode pad with the top ground and transport is realized by sequentially energizing the adjacent electrode pad. But high pinning effects and sticky nature of PDMS, transportation of droplet from one pad to another pad is not observed. For getting a proper droplet motion very thin layer of silicone oil (350mPa.s) is spread on the PDMS coated device. We have noted that with and without oil film there is no change in initial contact angle of the droplet. On the other hand, oil film reduces the minimum electrical field required to move the droplet. Thus all the experiments reported in this paper are performed with PDMS layer covered with silicone oil film. The vertical and horizontal movement of droplet on different electrodes as shown in Fig. 6

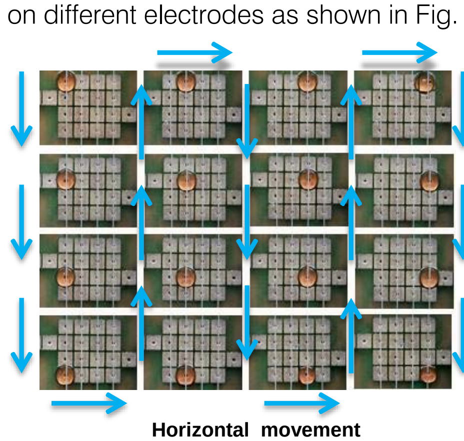

Fig. 6: Droplet transport vertically and horizontally on electrodes pads

b) Droplet position detection

The position of a droplet on electrode pads is monitored continuously using Open CV. Each frame of the live stream is correlated through image processing algorithm. Open CV libraries and IDE platform are combined using C++ codes. The written code, along with HSV values of the droplet tincture, plays a vital role in the detection of centroid pixel coordinate of a droplet through color thresholding as shown in Fig. 7(b). If the droplet centroid pixel coordinates lie within the respective limits of the coordinates of the electrode pads, the position of the droplet is printed on the terminal as shown in Fig. 7(c).

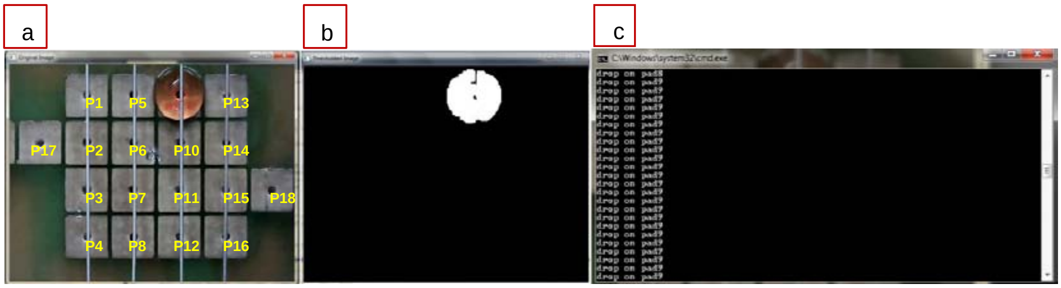

Fig. 7: Droplet position detection (a) Original image (b) Threshold image (c)) Terminal image with droplet position

c) Droplet velocity measurement

The velocity of the droplet is a vital parameter for various applications of LOC device and observing and controlling this key parameter in real time is one of the challenging tasks. In this work, we have successfully measured the droplet velocity between electrode pads in real time using the Open CV libraries. The timer count 1 starts when the centroid of droplet acquiesces with pad1 centroid and the timer count 2 starts when the centroid of the droplet coincides with pad 2 centroid. The difference between the two timer's times is measured. The difference between two centroid pads is calculated and multiplied by calibration factor for getting the actual distance in mm units. The droplet velocity is given as the ratio of distance to time; droplet velocity result is shown in Fig. 8b. Using this technique, we can track efficiently droplet parameter for multiple droplets. In our system image processing tools and high voltage control unit functionality works parallel, this makes EWOD system a smart system to perform various tasks on single platform simultaneously.

i. *Droplet velocity measurement by varying the ground configuration*

By using the developed velocity measurement system as described above, it becomes easy to analyze the velocity of the droplet at different voltages. In this section, we have investigated the effect of ground wire configuration on droplet velocity with respect to different voltages. In this paper we have taken three ground wire configurations namely; meshed, single line and diagonal which is shown in fig. 8.

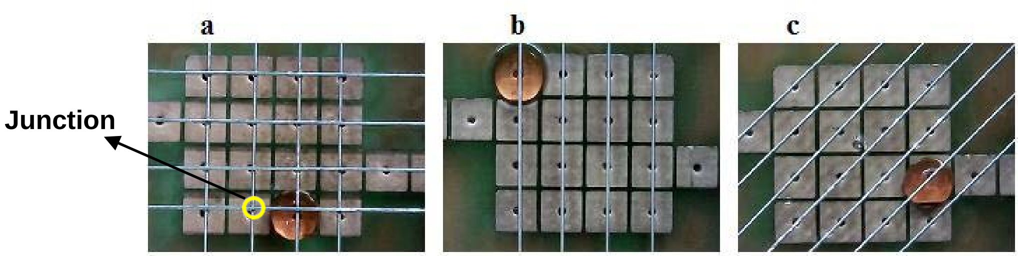

Fig. 8: Different ground configuration (a) Meshed (b) single line (c) Diagonal

The horizontal and vertical velocity of the droplet for the voltage range of 200V to 400 V at 155μm gap for all configurations is extensively studied in this work and summarized in Fig. 9. We have found that up to threshold voltage Vth, no droplet movement is observed. In these experiments, it is noted that up to 200V for all configuration, droplets are not moving. After that, any increment in the voltage beyond Vth, the significant movement of the drop, proportional to the applied voltage is noticed. To move the drop from its initial rest position sufficient electric field has to be built within the drop to reduce the interfacial energy [25,26]. The horizontal droplet velocity at 400V for meshed, single line and diagonal cases are 5.92mm/sec, 5.43mm/sec, and 5.18mm/sec respectively. The vertically droplet velocity at 400V for meshed, single line and diagonal cases are 5.1mm/sec, 5.43mm/sec, and 4.84mm/sec respectively.

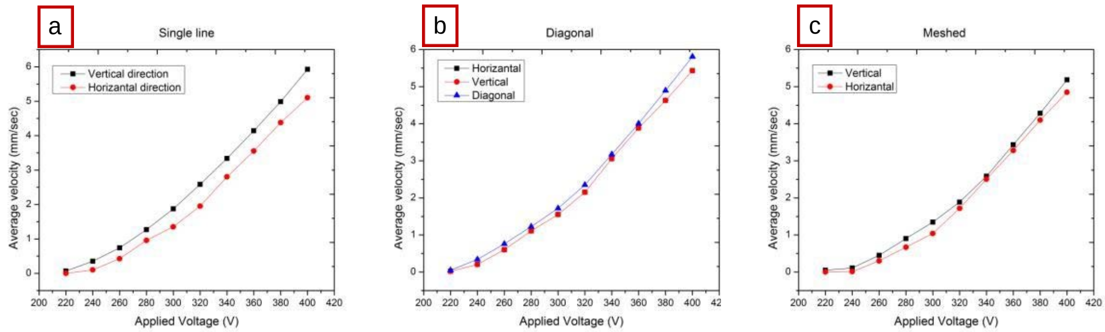

Fig. 9: Velocity of droplet (a) Meshed (b) Single line (c) Diagonal

We have observed that in meshed configuration velocity of the droplet is more in the vertical direction as compared with the horizontal direction; because vertical catena wires have been placed first then over that horizontal catena which makes the junction, and it is affecting the horizontal movement of the droplet shown in Fig. 9(a)

In the single ground line configuration, ground lines are arranged vertically as shown in Fig. 8(b). In this configuration, we have observed that velocity of the droplet is more in the vertical direction as compared with the horizontal direction because droplet gets proper grounding along the direction of the catena.

In the diagonal ground configuration, the ground lines are arranged diagonally as shown in Fig. 8 (c). In this configuration, we have observed the droplet velocity is same in both horizontal and vertical direction and more in a diagonal direction. In this configuration, we can transport the droplet in all direction.

We have compared the droplet velocity in all configurations for both horizontal and vertical directions as shown in Fig. 10. We have found that the horizontal droplet velocity is more in diagonal configuration and droplet vertical velocity is more in single line configuration.

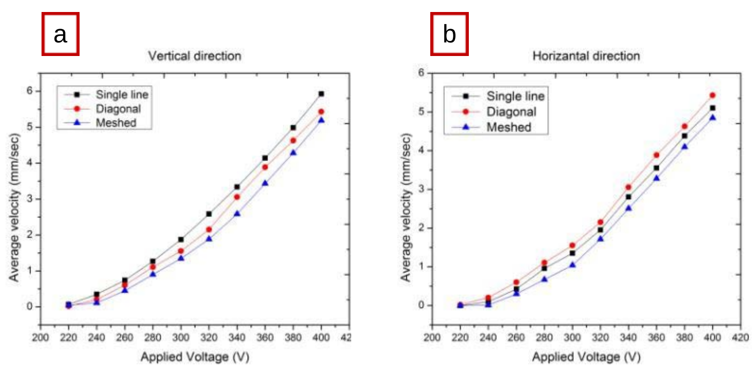

Fig. 10: Velocity of droplet (a) Horizontal direction (b) Vertical direction

To validate the experiment results with analytical results, we have plotted droplet velocity for vertical single line ground configuration with analytical value as shown in Fig. 11. We have calculated the analytical droplet velocity using Eq. 2 with adjusting the empirical parameter and taking K2 (4-6) into account. It is observed that the average droplet velocity is proportional to the square of the applied voltage (with R2 is 0.99) which is in good agreement with the analytically calculated droplet velocity. The obtained relationship between droplet velocity and applied voltage is in good agreement with the analytical EWOD model [2,27] which relates the average velocity using Eq. 3

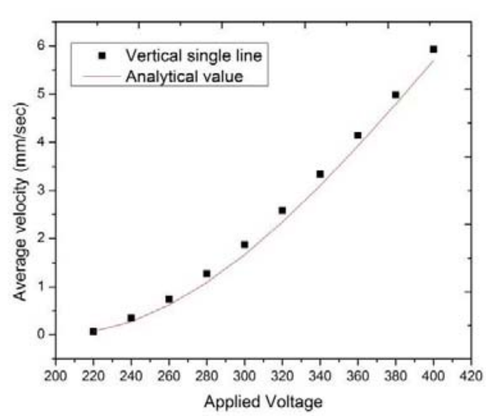

Fig .11: Comparison between experimental vertical single line and analytical value of droplet velocity

Also to validate the effect of ground wire configuration on droplet velocity; we have measured the maximum electric field in all configurations for both horizontal and vertical directions using COMSOL Multi physics. The estimation of the electric field is related to electro wetting force acting on the droplet. The electro wetting forces directly influence the droplet velocity.

Table 1: Maximum electric field for all configurations

S. No.	Configuration type	E_x (V/m)	E_y (V/m)
1	Meshed Ground	7.201 X 10^5	7.235 X 10^5
2	Single line Ground	7.24 X 10^5	7.327 X 10^5
3	Diagonal Ground	7.268 X 10^5	7.268 X 10^5

The resultant maximum electric field in horizontal and vertical directions for all configurations is given in Table 1. We have observed that single ground configuration is offering a more electric field in the vertical direction as compared to other configurations and a diagonal ground configuration having a more electric field in the horizontal direction as compared to other, which is well satisfied with our experimental results.

ii. *Droplet velocity with different liquids*

In this section, we have analyzed the effect of droplet viscosity on velocity. We have taken three different liquid sample; 0.1M KCL solution (1 Cps), 0.1M Potassium buffer (1.4-1.6 Cps) [28] and milk (3 Cps). The velocity comparison for different liquids is shown in Fig.12. It is observed that velocity of the water droplet is more compared to all. The experimental results are well in agreement with an analytical expression of droplet velocity given in Eq. 3, which shows droplet velocity is inversely proportional to the viscosity of the droplet.

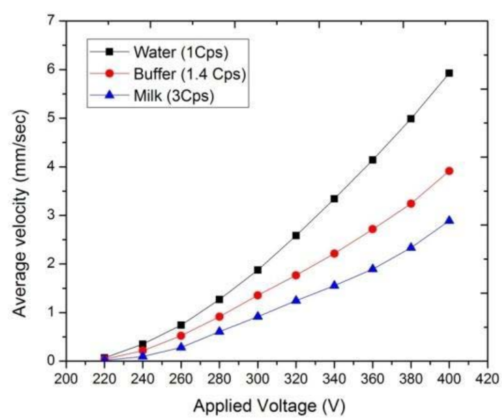

Fig. 12: The droplet velocity with different viscosity

d) Detection of Milk adulteration

One of the significant problems in the lab on chip area is merging and mixing of the two droplets dynamically using EWOD [29]. In this work we have demonstrated, mixing of two different droplets for one of milk adulteration application using two-dimensional open EWOD device which detects the starch existence in the milk. Starch is one such component that is added to adulterate milk for making milk fat [30]. We have used iodine solution for detection of starch in milk [31]. If starch content present in the milk sample, milk color becomes dark blue due to the formation of starch- iodo complex otherwise it turns into pale yellow color [32].

The 5μL milk droplet is first allowed to merge with a 1μl droplet of iodine solution on the open EWOD device by actuating the middle electrode between these droplets. Then coalesced droplet is repeatedly moved along the electrode pattern for proper mixing. After some movement on the different electrodes pads, it will turn into pale yellow color if there is no starch content present as shown in Fig. 13b. Otherwise, it turns into blue color as shown in Fig. 13c.

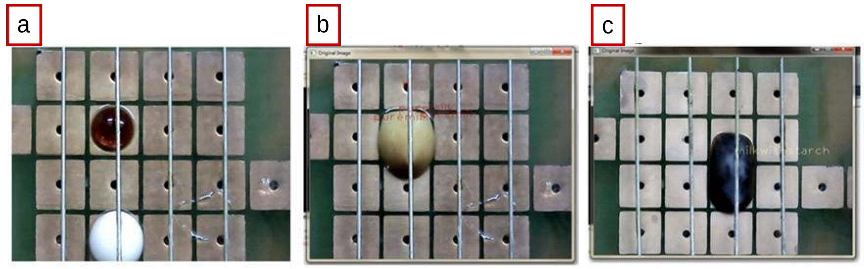

Fig. 13: Identification of pure milk a. before mixing b. after mixing along with result in Open CV

V. Conclusion

A low-cost reconfigurable open two-dimensional EWOD device has been demonstrated. A droplet transport is performed in both horizontal and vertical directions on the proposed device. The droplet position detection and droplet velocity measurement by varying the ground configuration are obtained, by using the open source computer vision (Open CV) platform. The electromagnetic simulations are done to measure the effect of electric field distribution by varying the ground configuration, which is well matching with experimental results. The testing of milk adulterations is successfully demonstrated. This work shows the potential for low-cost, rapid DMF device design and fabrication for future lab on chip applications.

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A Novel Hybrid Symbiotic Organism Search for Solving Generator Maintenance Scheduling in a Power System

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Keywords: *generator maintenance scheduling, hybrid symbiotic organism search, overall operational cost minimization, optimal generator maintenance schedule.*

GJRE-F Classification: *FOR Code: 290901p*

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Keywords: generator maintenance scheduling, hybrid symbiotic organism search, overall operational cost minimization, optimal generator maintenance schedule.

Nomenclature

i - Power generating unit index
I - Total number of generating units
t - Time period index (week)
T - Total number of sub periods (weeks) in the planning horizon
nc - Constraint index
NC - Total number of constraints
k - Population index
K - Iteration index in Lagrange Multiplier method
NP - Population Size
a_i, b_i, c_i - Fuel cost coefficients of unit *i*
CV - Constraint violation
v_i - Variable operation and maintenance cost of unit *i* in $/MWh
H - Number of hours in a sub-period (week) = 168
X - Vector of variables

P_{it} - Power output from generating unit *i* in sub-period *t*, MW
$P_i^{min.}$ - Minimum limit generating unit *i*, MW
$P_i^{max.}$ - Maximum limit generating unit *i*, MW
R_i - Rating of unit *i*
U_{it} - State variable equal to 0 if the unit *i* in sub-period *t* is offline for maintenance and 1 otherwise
S_{Ei} - Earliest period in which maintenance of unit *i* can start
S_{Li} - Latest period in which maintenance of unit *i* can start
S_i - Starting period of maintenance of unit $i \in [S_{Li}, S_{Ei}]$
M_i - Maintenance duration of unit *i*
PD_t - Active power load demand in week *t*
ω - Penalty factor
ψ - Fitness function to be minimized

I. Introduction

The generator maintenance scheduling problem is a large scale, stochastic, nonlinear combinatorial optimization problem which is a sub problem of integrated long term operations planning problem. The objective of the GMS problem is to find the exact time interval for preventive maintenance of power generating units with the intention of minimizing the operating cost, maximizing the system reliability and extending the life time of it. In earlier literature, mathematical approaches have been used for solving GMS [1, 2, 3]. These methods are limited to small size systems having few numbers of generators. For the case of large size systems, the number of intermediate solutions exponentially increases known as curse of dimensionality that restricts the use of mathematical methods to solve GMS. Local search methods such as Simulated annealing (SA) [4], Tabu search (TS) algorithm [5] has been proposed for the solution of GMS problem. For obtaining timetable for the purpose of maintenance of generators, nature inspired algorithms like Particle swarm optimization (PSO) [6], Artificial bee colony (ABC) algorithm [7], Ant colony optimization (ACO) [8], Shuffled frog leaping algorithm (SFLA) [9] have been used. Evolutionary algorithms such as Genetic algorithm (GA) [10], Evolutionary programming (EP) [11], Differential evolution (DE) [12]

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and other meta heuristic approaches such as Harmony Search (HS) [13], Teaching Learning Based Optimization (TLBO) [14] have also been applied for the solution of GMS.

In this paper, to solve the GMS problem, a new nature inspired algorithm; Symbiotic Organism Search (SOS) [15] is proposed. To get exact production cost that is to be spent by generating company to meet the weekly active peak load demand, Lagrange multiplier method (LMM) is hybridized with SOS, which helps SOS in finding minimum production cost based maintenance schedule for GMS. To examine the efficacy of the proposed approach, a small size system having 4 generating units and a medium size system having 22 generating units are considered and simulation results are compared with that obtained using well admired techniques such as PSO and TS.

The paper is organized as follows. In section 2, GMS problem formulation is discussed. Section 3 presents the detailed explanation of proposed SOS for solving GMS. The simulation results and discussions of using the proposed technique to solve GMS for 4- and 22- units system are included in Sections 4. Section 5 ends with the concluding remarks and future scope of the work.

II. GMS Problem Formulation

The cost objective considered here is to minimize the overall operational cost over a planning horizon is stated as

$$F = \sum_{t=1}^{T}\sum_{i=1}^{I} H.\left(a_i P_{it}^2 + b_i P_{it} + c_i\right).U_{it} + \sum_{i=1}^{I} H.P_{it}.v_i.U_{it} \tag{1}$$

The first part of (1) is production cost and second part signifies the variable operation and maintenance cost. The fixed maintenance cost is constant and does not have influence on maintenance schedule and hence it is neglected in the formulation.

The solution obtained for the GMS problem must satisfy the following set of system and operational constraints.

$$U_{it} = \begin{cases} 0 & t = S_i, \dots, S_i + M_i - 1 \\ 1 & otherwise \end{cases} \tag{2}$$

$$\sum_{t=S_{i1}}^{S_{i1}+M_{i1}-1} U_{i2,t} = 1 \tag{3}$$

$$S_2 \geq S_1 + M_1 \tag{4}$$

$$\sum_{i=1}^{I} R_i.\left(1 - U_{it}\right) \leq \left(\sum_{i=1}^{I} P_i^{\max} - PD_t\right) \tag{5}$$

$$P_i^{\min} \leq P_{it} \leq P_i^{\max} \tag{6}$$

$$\sum_{i=1}^{I} P_{it}.U_{it} \geq PD_t \tag{7}$$

The constraint (2) is the maintenance window constraint which ensures that once maintenance of the unit *i* begins, the work have to be continued without any break off for the time period that is exactly equal to maintenance duration of unit *i*. To ensure no two generators is maintained by same crew, it is stated in terms of U_{it} variables of second unit i2 as in (3). Crew constraint restricts maintenance of unit 1 and 2 in unison. In some situation, the maintenance works on some of the power producing units should be initiated only after the completion of maintenance activities of other generators. This can be achieved with the inclusion of precedence constraint. For instance, if maintenance of unit '2' is to be started only after the completion of maintenance of unit '1', then this constraint is given by (4). In every sub-period of planning horizon, the sum of capacity of generating units that are switched off for maintenance must be lesser than gross reserve in that sub-period. This can be achieved by using resource constraint as given in (5). Constraint (6) guarantees the real power output from every generator is within its minimum and maximum limits. Load balance constraint is given by (7).

III. Proposed Solution Methodology

The GMS problem have two types of variables; continuous and binary integer variables. The continuous variables denote the power output from the online generating units and binary integer variables indicates the on/off status of power producing units. Here, as in most of the literature, the staring period for maintenance of each generator is considered as variables which are integers. The number of integer variables is exactly equal to number of generators present in the system. To solve the problem, symbiotic organism search (SOS) a population based new meta-heuristic nature inspired algorithm is proposed. The SOS is initially developed by Cheng and Prayogo in 2014 [15]. Basically SOS has been proposed for solving the problem in continuous domain. This algorithm requires only common control parameter such as population size and maximum number of generations to be tuned and does not have any algorithm specific control parameters. It mimics the symbiotic interaction strategies adopted by two organisms to stay alive and propagate in the ecosystem. To evolve to a good solution, SOS uses three important phases; mutualism, commensalism and parasitism. The flowchart of the SOS is shown in Fig. 1.

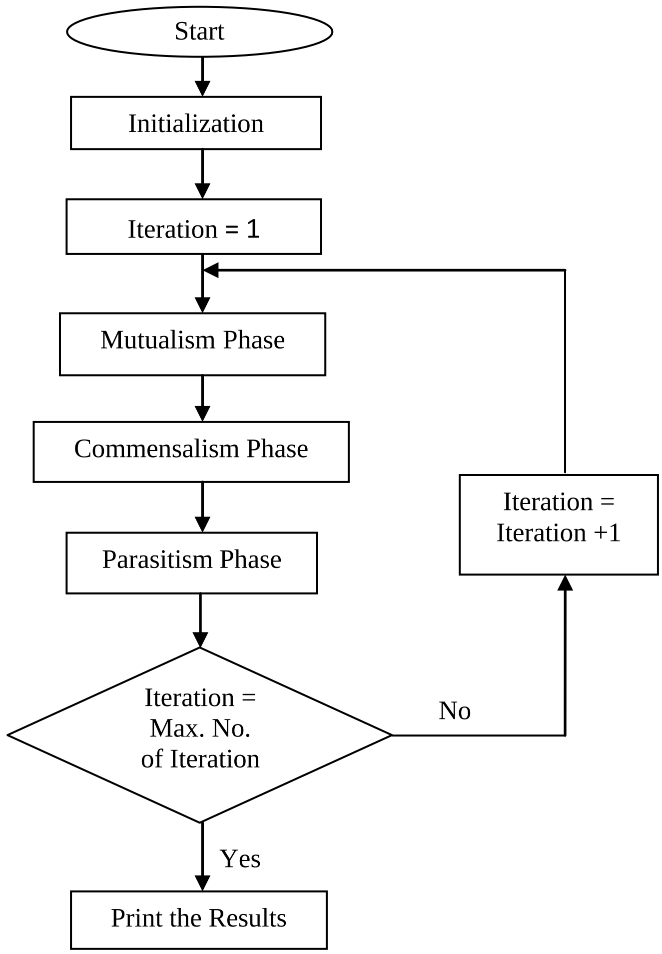

Fig. 1: Flowchart of Symbiotic Organism Search

To deal with integers, a rounding off operator is used in SOS called integer coded symbiotic organism search (ICSOS). The detailed explanation of proposed solution methodology for solving GMS problem is given below.

a) Hybrid SOS for Cost based GMS

The cost objective is given in (1). The aim is to obtain a maintenance schedule for the GMS problem such that the overall operation cost should be minimized. To obtain the exact production cost involved to meet the weekly peak load demand, a LMM is hybridized with ICSOS called hybrid SOS (HSOS). The following are the steps involved in HSOS for solving cost based GMS.

i. *Initialization*

Initialize NP population called ecosystem. Each vector of ecosystem called organism represents one candidate solution of the problem. Each organism (X^k) has integers decision variables equal to number of generators present in the system which is generated randomly between every generator's earliest and latest allowed starting period for maintenance as follows

$$\left(X_i^k\right) = round\ \left(S_{Ei}^k + random(0,1).\left(S_{Li}^k - S_{Ei}^k\right)\right) \quad (8)$$

The integer variables are checked for precedence and crew constraints. If any of the above constraint is violated for a particular generator, the corresponding integer variable is chosen randomly until the constraints are satisfied and then the integer variables are checked for maintenance window constraint. After satisfying all the constraints, the status of each unit is set at '0' from the starting period up to its corresponding maintenance duration period to indicate that the unit *i* is switched off for preventive maintenance and '1' during other periods. The LMM is used to achieve optimal generation schedule from the online generators in every week to meet the weekly load demand as follows.

Step 1: With initial value of λ, power output from each committed generator (P_i) in sub-period *t* can be calculated using

$$P_{it} = \frac{\lambda - b_i}{2c_i} \quad (9)$$

The generated output power is checked to satisfy constraint (6).

Step 2: The change in power output (ΔP) can be calculated using

$$\Delta P^K = PD_t - \sum_{i=1}^{NCG} P_{it} \tag{10}$$

Step 3: The change in λ (Δλ) can be found as follows

$$\Delta\lambda^K = \frac{\Delta P^K}{\sum_{i=1}^{NCG} \frac{1}{2c_i}} \tag{11}$$

Step 4: The new value of λ for the next iteration (K+1) can be found by adding change in λ with previous value of λ as follows

$$\lambda^{K+1} = \lambda^K + \Delta\lambda^{K+1} \tag{12}$$

The above steps are repeated until ΔP becomes zero. Thus constraint (7) is satisfied. The fitness function of the GMS problem to be minimized by HSOS is

$$\psi = \sum_{t=1}^{T}\sum_{i=1}^{I} H.\left(a_i P_{it}^2 + b_i P_{it} + c_i\right).U_{it} + \sum_{nc=1}^{NC} \omega_{nc}\left|CV_{nc}\right| \tag{13}$$

ii. *Mutualism Phase*

In mutualism phase, two participating organisms of the ecosystem get benefited. In SOS, two organisms X_y and X_z are selected. They interacts each other with the aim of increasing mutual survival advantage in the ecosystem. The new solution after mutual relationship is given by

$$X_{y\,new} = X_y + round\left(random(0,1).\left(X_{best} - \left(\frac{X_y + X_z}{2}\right).BF_1\right)\right) \tag{14}$$

$$X_{z\,new} = X_z + round\left(random(0,1).\left(X_{best} - \left(\frac{X_y + X_z}{2}\right).BF_2\right)\right) \tag{15}$$

where X_{best} is the best organism in the ecosystem which is used in SOS to model the highest degree of adaptation, that is the objective of both organisms. After creating the starting period for maintenance of each generator using equations (14) and (15) they are checked for any constraints violation. If all the constraints are satisfied, the status of each unit is set at '0' from the starting period up to its corresponding maintenance duration period to indicate that the unit *i* is taken out for preventive overhauling work and '1' during other periods. The minimum production cost for new organisms that denotes the starting period for maintenance of thermal units is calculated with the help of LMM. The fitness function is calculated for new organisms using equation (13). If these organisms have better fitness, the current organism is replaced by the new one.

iii. *Commensalism Phase*

During this phase, an organism X_y gets benefited by interacting with randomly generated another organism X_z in the ecosystem. But X_z is neither suffered nor benefited. A new solution of X_y is determined based on the commensalism operation among the organisms X_y and X_z, which can be expressed as

$$X_{y\,new} = X_y + round\left(rand(-1,1).\left(X_{best} - X_z\right)\right) \tag{16}$$

Once the new organism that indicates the starting period for maintenance of power generating units is determined, it is checked in order to satisfy constraints (2) – (5). After satisfying all the constraints, the status of each unit is set at '0' from the starting period up to its corresponding maintenance duration period to indicate that the unit *i* is taken out for planned preventive maintenance and '1' during other periods.

Then LMM is used to obtain optimum generation schedule from the online generators in every sub-period to meet the weekly peak load demand with minimum production cost. The fitness function is calculated for new organisms using equation (13). The new organism $X_{y,new}$ is accepted, if it has better fitness, than the current organism.

iv. *Parasitism Phase*

In this phase, a parasite vector $X_{y,new}$ is created in the search space by duplicating organism X_y and its dimensions are perturbed using a random number as follows

$$X_{y,\,new} = round\left(random(0,1).\,X_y\right) \tag{17}$$

The parasite vector that indicates the starting period for maintenance of generating units is checked in order to satisfy constraints (2) – (5). After satisfying all the constraints, the status of each unit is set at '0' from the starting period up to its corresponding maintenance duration period to indicate that the unit *i* is taken offline for maintenance and '1' during other periods. Then LMM is used to obtain optimum generation schedule from the online generators in every sub-period to meet the weekly peak load demand with minimum production cost thus satisfying generator limit and load balance constraints given by equations (6) and (7). The fitness function is calculated for new organisms using equation (13). An organism X_z is chosen randomly from the ecosystem that serves as a host for the parasite vector $X_{y,new}$. If the parasite vector has better fitness function value, then it occupies the space of its corresponding host by killing them. The above phases are repeated until maximum number of generations.

IV. Simulation Results And Discussions

In order to prove the superiority of the proposed HSOS algorithm, two test systems; one is small system having 4 generators and another one is medium size system having 22 power generating units are considered [5, 12]. In the proposed approach, Lagrange Multiplier method is hybridized with ICSOS in order to solve large scale generator maintenance scheduling problem. In HSOS approach, ICSOS tries to find an optimal starting period for maintenance of power generating units with the help of LMM which tries to economically dispatch the available generation from committed generators to meet the weekly peak active load demand with minimum production cost. The program is developed using MATLAB on a personal computer with 3 GHz core i5 CPU. The simulation results are compared with that achieved via particle swarm optimization scheme.

a) *Test System 1: 4 Units System*

There are 4 thermal generating units to be maintained within a planning period of 8 weeks. Among 4 generating units, due to precedence constraint, the maintenance of unit 1 must be completed before the starting of maintenance of unit 2. Due to crew constraint, units 1 and 2 should not be under maintenance simultaneously. The generator data is given in [12]. The gross reserve in every week can be calculated by taking difference between installed capacity and load demand in that week. The weekly peak load data is given in Table 1.

Table 1: Load data of 4 units system

Week	1	2	3	4	5	6	7	8
Load (MW)	249	265	276	279	256	307	187	295

In order to compare the results of proposed HSOS and mathematical approach assisted particle swarm optimization (MAPSO) [12], the population size and maximum number of generations for both the algorithms are set at 10 and 500 respectively. Since the test system 1 is a small system, both the algorithms produce the same maintenance schedule. Table 2 shows the maintenance schedule of 4 units system. Here, '0' indicates the unit is taken out for maintenance and '1' indicates that the unit is available to serve the load. From the table, it can be seen that unit 1 and 2 are not under maintenance in unison, thereby satisfying crew constraints. Also, the maintenance of unit 2 begins only after the completion of maintenance of unit 1, thereby satisfying precedence constraint. In Table 2, it is clear that each generator is under maintenance only once during the planning period and is equal to corresponding maintenance duration week, thereby satisfying maintenance window constraint.

Table 2: Maintenance Schedule of 4 Units System

Unit/Week	1	2	3	4	5	6	7	8
1	1	1	0	0	0	0	1	1
2	1	1	1	1	1	1	0	0
3	0	0	1	1	1	1	1	1
4	1	1	1	1	1	1	0	1

Fig. 2. shows the capacity on maintenance in every week. From the figure, it can be seen that, in every week, the capacity of units that are taken out for maintenance is lesser than the gross reserve in that week, thereby satisfying resource constraint.

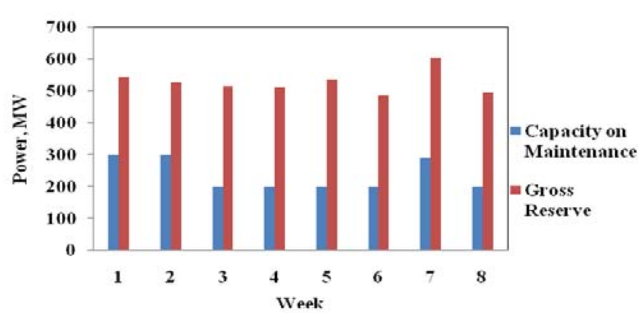

Fig. 2: Capacity on Maintenance

Table 3 shows the power output from online generators obtained using LMM. From the table, it can be seen that power output from committed generators are within their lower and upper bounds, thereby satisfying generator limit constraint. The sum of the power output from available generators in every week is exactly equal to corresponding active power load demand, thus satisfying load balance constraint.

Table 3: Power Output from Committed Generators

Unit/Week	1	2	3	4	5	6	7	8
1	102.5031	108.1499	0	0	0	0	85.4857	120.9644
2	125.3387	131.23	129.1009	130.1914	121.8306	140.3698	0	0
3	0	0	122.8916	123.9751	115.6682	134.0878	101.5143	138.29
4	21.1582	25.6201	24.0075	24.8335	18.5012	32.5424	0	35.7456

For the maintenance schedule of 4 unit system that is obtained through Tabu Search (TS) algorithm [5], the authors have not given the overall production cost. For the same schedule, using LMM the overall operation cost is found. Table 4 shows the comparison of overall operational cost between proposed method with other existing methods.

Table 4: Overall Operational Cost

	Cost ($)
HSOS	3391993.59
MAPSO	3391993.59
TS	3392728.13

The available reserve in every week can be calculated by taking difference between installed capacity and sum of capacity on maintenance and weekly load demand. The minimum reserve obtained for the above maintenance schedule is 225 MW in 2[nd] week.

b) Test System 2: 22 Units System

In this system, there are 22 generating units that have to be maintained once within a planning horizon of one year. The planning period is divided into 52 sub-periods (weeks). The generator data is provided in [12]. The weekly load data is given in Fig. 3.

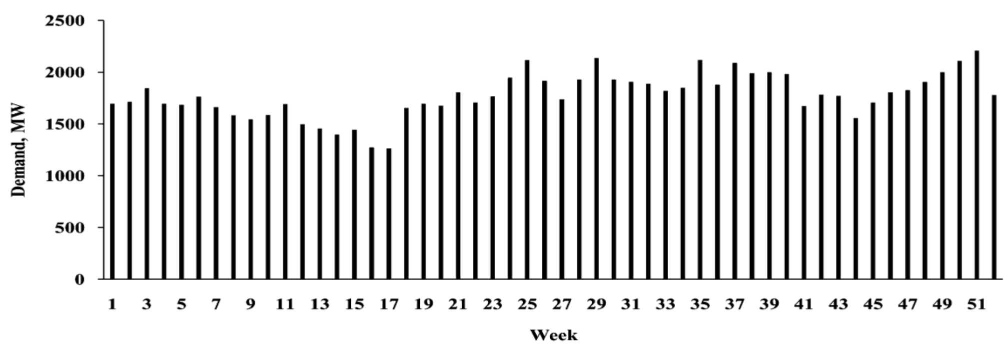

Fig. 3: Load Data of 22 units system

Due to precedence constraint, units 2 and 5 should be taken out for maintenance before the commencement of maintenance of units 3 and 6 respectively. Due to crew constraints, units 15 and 16, units 21 and 22 should not be under maintenance at the same time.

To make the comparison between proposed HSOS and MAPSO, population size and maximum number of iterations are fixed at 50 and 2500 respectively. The convergence characteristics of 22 units system is shown in Fig. 4.

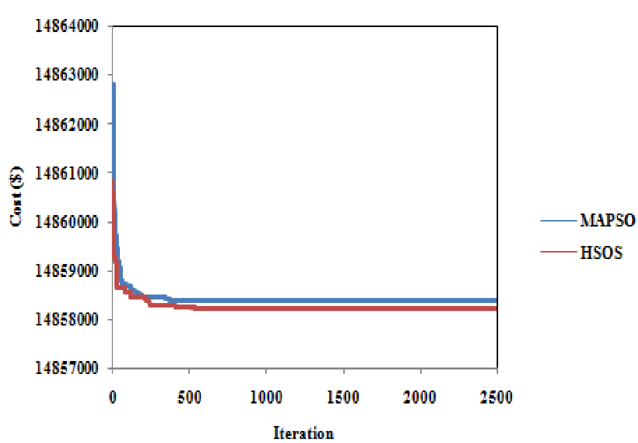

Fig. 4: Convergence Characteristics of 22 units system

From the characteristics, it can be seen that though HSOS have speed of convergence lower than MAPSO, it produces better maintenance schedule in terms of overall operational cost which includes production as well as variable operation and maintenance costs than MAPSO. Table 5 and 6 shows the maintenance schedule obtained through proposed HSOS algorithm and MAPSO. From Table 5 and 6, it can be seen that in both the schedules, each unit is taken out for maintenance only once during the planning horizon and is under maintenance without any interruption for the period equal to corresponding maintenance duration weeks. Thus, the maintenance window constraint gets satisfied. The gross reserve in every week is given in [5]. In every week, the capacity on maintenance is lesser than the gross reserve in that week. Thus resource constraint is satisfied. In Table 5 and 6, it is evident that the maintenance on units 2 and 5 gets completed before the starting of maintenance on units 3 and 6 respectively satisfying precedence constraint. Also units 15 and 16, units 21 and 22 are not under maintenance in same duration satisfying crew constraint.

The comparison of overall operational cost for 22 units system satisfying generator limit and load balance constraints are given Table 7.

Table 7: Overall Operational Cost

	Cost ($)
HSOS	148582246.21
MAPSO	148584093.45
TS	148705625.34

V. Conclusion

A new nature inspired algorithm for the optimization of generator maintenance scheduling problem in vertically integrated system is presented in this paper. In the proposed approach, conventional lambda iteration approach or Lagrange Multiplier method is hybridized with integer coded symbiotic organism search algorithm. The lambda iteration approach assists symbiotic organism search algorithm in finding optimal starting period for maintenance of generating units. The proposed approach provides a feasible maintenance schedule for the generating units by considering minimization of overall generator operation cost as objective which includes production and variable operation and maintenance cost while satisfying system and operational constraints. The proposed method is validated by considering two test systems. The superiority of the proposed HSOS algorithm is demonstrated by comparing the results with the results obtained from MAPSO algorithm. The results conclude that both HSOS and MAPSO are well suited for solving generator maintenance scheduling of small system. For solving large scale generator maintenance scheduling problem, HSOS outperforms MAPSO in terms of finding the overall generation operation cost. Thus, test results reveal the capability of the proposed algorithm in finding the optimal solution for the GMS problem. The proposed approach can be extended for the solution of GMS problem in the competitive environment without any difficulty.

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Table 5: Maintenance Schedule (HSOS)

Weeks	Load	Maintenance Capacity	Units on Maintenance
1	1694	585	1,5,7,8,17,18
2	1714	585	1,5,7,8,17,18
3	1844	585	1,5,7,8,17,18
4	1694	810	1,4,5,8,17,18,19
5	1684	710	1,4,5,17,18,19
6	1763	510	1,4,5,19
7	1663	610	10
8	1583	610	10
9	1543	610	10
10	1586	610	10
11	1690	610	10
12	1496	910	2,10,13,14
13	1456	910	2,10,13,14
14	1396	1001	2,10,11,13,14
15	1443	1041	10,11,14,21
16	1273	1261	10,11,14,15,21
17	1263	1261	10,11,14,15,21

18	1655	830	10,15
19	1695	460	15,22
20	1675	560	12,15,22
21	1805	440	3,12,22
22	1705	440	3,12,22
23	1766	440	3,12,22
24	1946	100	12
25	2116	100	12
26	1916	320	12,20
27	1737	320	12,20
28	1927	220	20
29	2137	0	-----
30	1927	0	-----
31	1907	220	16
32	1888	220	16
33	1818	220	16
34	1848	220	16
35	2118	220	16
36	1879	220	16
37	2089	0	-----
38	1989	0	-----
39	1999	0	-----
40	1982	0	-----
41	1672	650	9
42	1782	650	9
43	1772	650	9
44	1556	650	9
45	1706	650	9
46	1806	90	6
47	1826	90	6
48	1906	90	6
49	1999	90	6
50	2109	0	-----
51	2209	0	-----
52	1779	0	-----

Table 6: Maintenance Schedule (MAPSO)

Weeks	Load	Maintenance Capacity	Units on Maintenance
1	1694	511	8,11,15,17
2	1714	511	8,11,15,17
3	1844	511	8,11,15,17
4	1694	511	8,11,15,17
5	1684	320	15,17
6	1763	610	10
7	1663	610	10
8	1583	610	10
9	1543	610	10
10	1586	610	10
11	1690	610	10
12	1496	710	10,14
13	1456	950	10,14,21
14	1396	950	10,14,21
15	1443	950	10,14,21
16	1273	1350	4,10,12,13,14,18,22

17	1263	1350	4,10,12,13,14,18,22
18	1655	730	4,5,12,13,18,22
19	1695	630	1,5,12,18,22
20	1675	730	1,2,5,12,18,22
21	1805	610	1,2,5,12,19
22	1705	610	1,2,5,12,19
23	1766	510	1,5,12,19
24	1946	100	1
25	2116	0	-----
26	1916	320	3,20
27	1737	320	3,20
28	1927	320	3,20
29	2137	0	-----
30	1927	0	-----
31	1907	90	6
32	1888	185	6,7
33	1818	185	6,7
34	1848	185	6,7
35	2118	0	-----
36	1879	0	-----
37	2089	0	-----
38	1989	0	-----
39	1999	0	-----
40	1982	0	-----
41	1672	650	9
42	1782	650	9
43	1772	650	9
44	1556	650	9
45	1706	650	9
46	1806	0	-----
47	1826	220	16
48	1906	220	16
49	1999	220	16
50	2109	220	16
51	2209	220	16
52	1779	220	16

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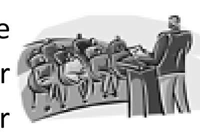

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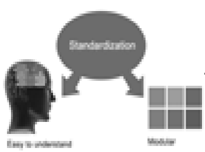

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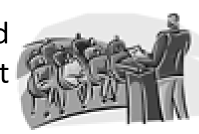

The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

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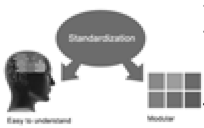

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The board can also take up the additional allied activities for betterment after our consultation.

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Note :

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- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
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2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript's Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

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- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Please carefully note down following rules and regulation before submitting your Research Paper to Global Journals Inc. (US):

Segment Draft and Final Research Paper: You have to strictly follow the template of research paper. If it is not done your paper may get rejected.

- The **major constraint** is that you must independently make all content, tables, graphs, and facts that are offered in the paper. You must write each part of the paper wholly on your own. The Peer-reviewers need to identify your own perceptive of the concepts in your own terms. NEVER extract straight from any foundation, and never rephrase someone else's analysis.
- Do not give permission to anyone else to "PROOFREAD" your manuscript.
- Methods to avoid Plagiarism is applied by us on every paper, if found guilty, you will be blacklisted by all of our collaborated research groups, your institution will be informed for this and strict legal actions will be taken immediately.)
- To guard yourself and others from possible illegal use please do not permit anyone right to use to your paper and files.

Criterion for Grading a Research Paper (Compilation) by Global Journals Inc. (US)

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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