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Electrical and Electronic Engineering

Highlights

- The Front Suspension
- Graphic Interface Applied
- Multilevel Unified Power
- Cylindrical Coaxial Cavity

Discovering Thoughts, Inventing Future

VOLUME 16 ISSUE 1 VERSION 1.0

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Graphic Interface Applied to the front Suspension Assembly Process for Automobile

By Francisco C. P. Bizarria, José W. P. Bizarria, Rogerio Oliveira de Paula & Ariadne Arrais Cruz
Taubate University (UNITAU), Brazil

Abstract- This paper proposes a graphical interface to be integrated into the physical architecture that has been established to receive a specific process of assembling the front suspension to the automobile. The physical architecture contains many cells with the necessary means to enable workers to carry out assemblies of various types of suspensions. In the development of the graphical interface are considered means for defining the formal sequence of assembly of each type of suspension in order to increase the production capacity and decrease losses by undue assemblies. The layout set for virtual components and also the choice of resources are planned to increase the expressiveness and ease of use of each window contained in the graphical interface. The validation of the operational features of the graphical interface is obtained by carrying out practical tests on a prototype that uses the basic elements that are specified in the aforementioned physical architecture.

Keywords: graphical interface, front suspension assembly, automobile.

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GRAPHICINTERFACEAPPLIEDTOTHEFRONTSUSPENSIONASSEMBLYPROCESSFORAUTOMOBILE

Graphic Interface Applied to the front Suspension Assembly Process for Automobile

Francisco C. P. Bizarria[α], José W. P. Bizarria[σ], Rogerio Oliveira de Paula[ρ] & Ariadne Arrais Cruz[ω]

Abstract- This paper proposes a graphical interface to be integrated into the physical architecture that has been established to receive a specific process of assembling the front suspension to the automobile. The physical architecture contains many cells with the necessary means to enable workers to carry out assemblies of various types of suspensions. In the development of the graphical interface are considered means for defining the formal sequence of assembly of each type of suspension in order to increase the production capacity and decrease losses by undue assemblies. The layout set for virtual components and also the choice of resources are planned to increase the expressiveness and ease of use of each window contained in the graphical interface. The validation of the operational features of the graphical interface is obtained by carrying out practical tests on a prototype that uses the basic elements that are specified in the aforementioned physical architecture. The positive results observed in practical tests suggest that the graphical interface will be able to increase productivity in the front suspension assembly process for automobile.

Keywords: graphical interface, front suspension assembly, automobile.

I. Introduction

The current scenario of the global economy establishes a condition in which the industries have to invest financial resources in the production lines to overcome seasonal variations of production demands that are imposed by consumer markets and also to maintain adequate quality standards, reduce losses in production, minimize lead times, lower costs and increase flexibility in manufacturing [1].

The management of a multinational company to meet the characteristics of the global economy and also keep the jobs, promoted the study to develop an assembly line of the front suspension for automobiles in order to supply the Latin American market.

The preservation of jobs is the requirement that aims at minimizing the social impact within the community in which the company operates, and improve local trade and also the infrastructure and also the and also the infrastructure as a whole. The very high initial financial cost was another important factor considered to limit the level of automation for production line.

In this context, this work proposes a graphical interface to be integrated into the physical architecture that has been established to receive a specific process of assembling the front suspension to the automobile.

The physical architecture was designed with many cells to meet production line. Each cell contains the necessary means so that a single worker performs assemblies of various types of suspensions that are produced by the company.

In developing the graphical interface are established every means to assist the worker who uses the resources of the physical architecture in conducting formal sequence to assemble each type of suspension in order to increase production capacity and reduce losses due to improper assembly.

The layout set for virtual components and also the choice of resources are planned to increase the expressiveness and ease of use of each window contained in the graphical interface by the worker.

The validation of the operational features of the graphical interface is obtained by carrying out practical tests on a prototype that uses the basic elements that are specified in the aforementioned physical architecture.

II. Objectives of the Work

The aim of this paper is to present a proposal for a graphical interface to be integrated into the physical architecture that has been established to receive a specific process of assembling the front suspension to the automobile.

Present the first results that were obtained on the practical tests performed with the prototype that adopts the basic elements contained in the aforementioned physical architecture.

III. Physical Architecture

Figure 1 shows the principal components of a production cell that belongs to the physical architecture that has been established to receive a specific process of mounting the front suspension to the automobile.

Author α: Asst. Professor in Electrical Engineering Department - Taubaté University (UNITAU), Brazil. e-mail: fcpbiz@gmail.com
Author σ: Asst. Professor in Computing Department - Taubaté University (UNITAU), Brazil. e-mail: jwpbiz@gmail.com
Author ρ: Tech. Professor in Federal Institute of Education, Science and Technology of São Paulo (IFSP), Brazil.
e-mail: rogerio.depaula@ifsp.edu.br
Author ω: Tech. Professor in Federal Institute of Education, Science and Technology of São Paulo (IFSP), Brazil.
e-mail: ariadne@ifsp.edu.br

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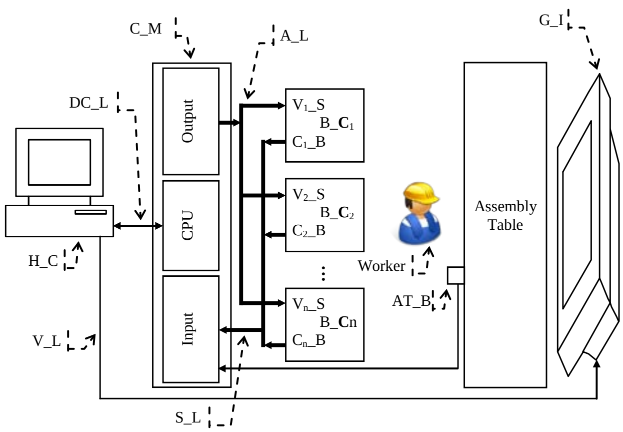

Fig.1: Physical architecture of the cell.

The acronyms contained in the physical architecture that is shown in Figure 1 have the following meanings:

a) Host Computer (H_C).
b) Graphical Interface (G_I).
c) Video Line (V_L).
d) Data Communication Line (DC_L).
e) Control Module (C_M).
f) Sensor Line (S_L).
g) Actuators Line (A_L).
h) Box Components (B_C).
i) Visual Signal (V_S).
j) Component Button (C_B).
k) Assembly Time Button (AT_B).

The function of the Control Module (M_C) can be performed by a Programmable Logic Controller (PLC) that is equipped with Central Processing Unit (CPU) capable of controlling the inputs and outputs, digital and / or analog, working with wide range amplitudes and frequencies of electrical signals [2].

In Control Module (C_M) is loaded the software that performs the management of the main activities planned for use of resources of the physical architecture [3]. The software performs all tasks in accordance with the parameter setting sequence which was held for the assembly of each type of suspension, including the activation of alarms and signals required for the process in question.

All control module outputs uses the Actuators Line (A_L) to control the activation of each Visual Signal (V_1_S, V_2_S, ..., V_n_S) that is installed in each Box Components (B_C_1, B_C_2, ..., B_C_n). The visual signal is activated with the purpose of assisting the worker in identifying which box has the component to be used in the present suspension assembly time. Each box components must store a single type of component that is used during assembly of the suspension.

Control module inputs receive the signals from each Component Button (C_1_B, C_2_B, ..., C_n_B) that is installed in each Box Components (B_C_1, B_C_2, ..., B_C_n), as well as the Assembly Time Button (AT_B). It is worth mentioning that the Assembly Time Button (AT_B) is used by the worker to start or stop or ending time count which is used for assembly each suspension.

The main functions of the Host Computer (H_C) are concentrated in hosting the Graphical Interface (G_I) and also make the transmission and reception of information that are related to the states of variables in the software installed on the Control Module (C_M).

The Graphical Interface (G_I) consists of several windows that should work with the resources available in the operating system of the Host Computer (H_C).

Within the windows contained in the Graphical Interface (G_I) are present virtual components that allow: access to the system, make changes, start the system, set the sequence for carrying out the assembly of each type of suspension, activate alarms and visual signals to be used during the production cycle. The Data Communication Line (DC_L) is the means that the Graphical Interface (G_I) uses to communicate with the Control Module (C_M).

IV. Prototype

A view of the prototype that was produced validate the graphical interface to be integrated on the physical architecture that has been established to receive a specific process of mounting the front suspension for the automobile is shown in Figure 2. The tests with the prototype were concentrated on the evaluation of the operational capacity of each virtual component contained in the graphical inter face.

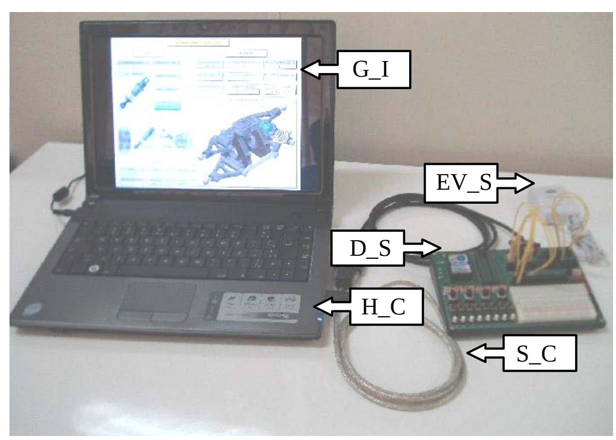

Fig.2 : Prototype view.

As shown in Figure 2, the main modules provided in the prototype are: graphical interface (G_I), host computer (H_C) development system (D_S), external voltage source (EV_S) and cable for serial communication (S_C).The number of modules contained in the prototype is lower when compared to the one defined for the physical architecture of Figure 1, but this condition is not sufficient to cause significant impact on the validation.The graphical interface (G_I) used in the prototype was developed through the resources contained in the Supervisory, Control and

Data Acquisition (SCADA) system, that is called by Elipse SCADA [4]

The host computer (H_C) used in practical tests is the portable type (notebook) with 64-bit, Intel architecture and Microsoft® Windows 7 operating system

The development system (D_S) chosen for the prototype is called by CUBLOC STUDY BOARD 1, as the same is capable of performing the cycle as well as the processing functions that are typical for Programmable Logic Controller (PLC), and can generate and receive electrical signals that are related to the sensors and actuators contained in the physical architecture [5]

The external voltage source (EV_S) has the function to provide electric power that is consumed for operating the development system (D_S) in direct current

The cable for serial communication (S_C) is the physical means by which the development system (D_S) and the graphical interface (G_I) transfer data with each other, through communication protocols defined by Electronic Industries Alliance (EIA).

a) Management software

The information management software is designed to meet the practical tests performed with the prototype. The software considers a sequence specific activity that the worker must perform to assemble a kind of suspension.

Each step in the assembly sequence is recognized by development system (D_S) by stimuli that are applied to the digital buttons (D_B), the digital key (D_K) and potentiometers (A_P), according to the details presented in Figure 3

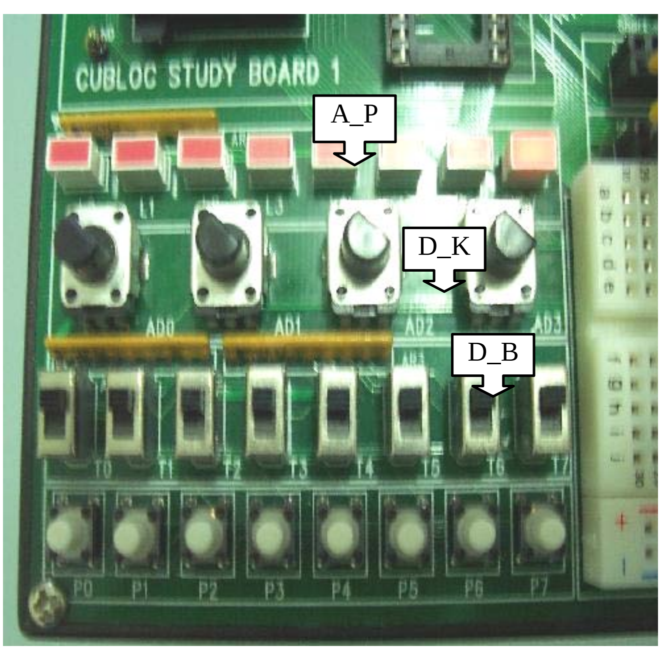

Fig.3 : Details development system.

In response to the stimuli applied to the buttons and switches, the graphical interface (G_I) presents the pictures and other details that are related to each phase of the suspension assembly sequence.

The analytical flowchart containing a specific sequence of actions foreseen in the management software that was used in carrying out practical tests of this work is shown in Figure 4

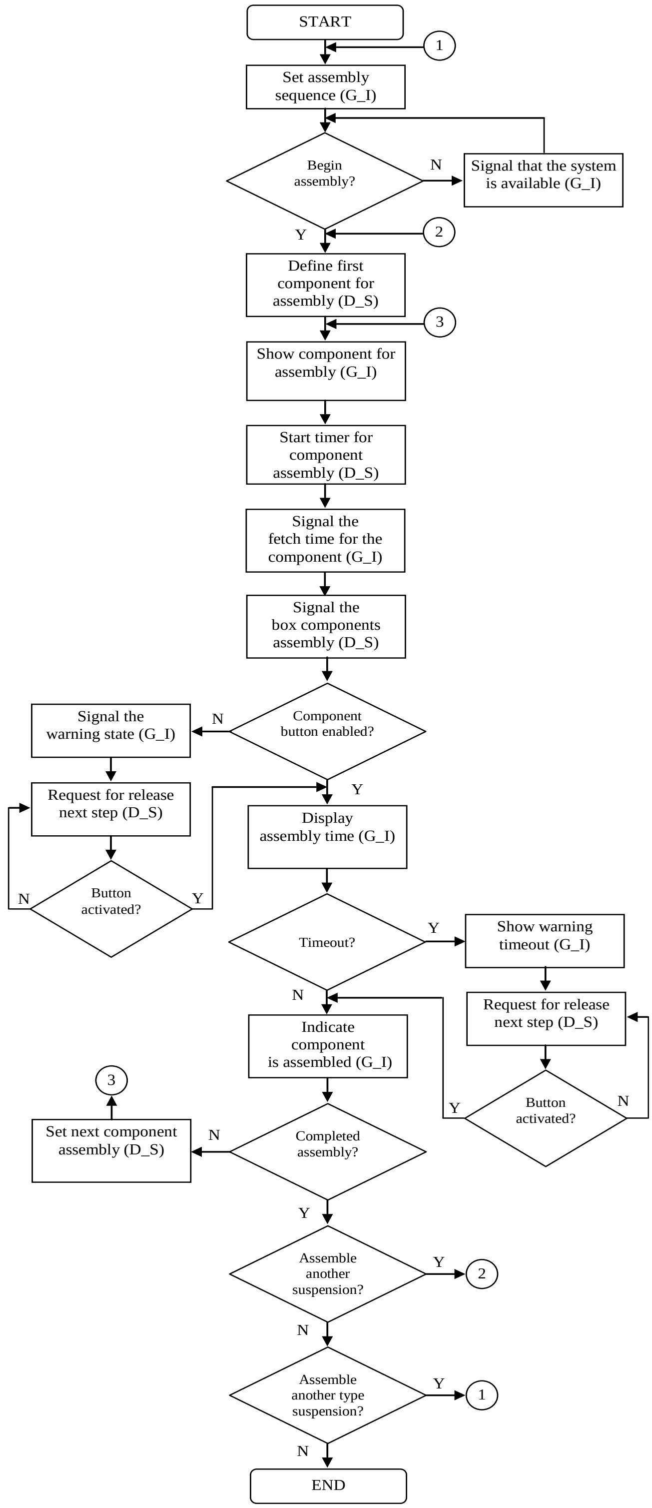

Fig.4 : Flowchart to test the graphical interface.

The acronyms contained in the flowchart shown in Figure 4 have the same meanings as those shown in the prototype view (Figure 2).

b) Graphical interface

The main function of the graphical interface (G_I) is concentrated in presenting visual signals in sufficient expressivity to assist the worker in the task of fetching items and also to assemble every suspension component. The main window of this interface is shown in Figure 5. It is worth mentioning that the figures of the suspension components used in the practice tests were obtained from the system called AUTODESK® [6].

The window shown in Figure 5 has two columns of virtual objects. The Column-1 is divided into groups which are called: FETCH, DETAILS and UTILITIES.

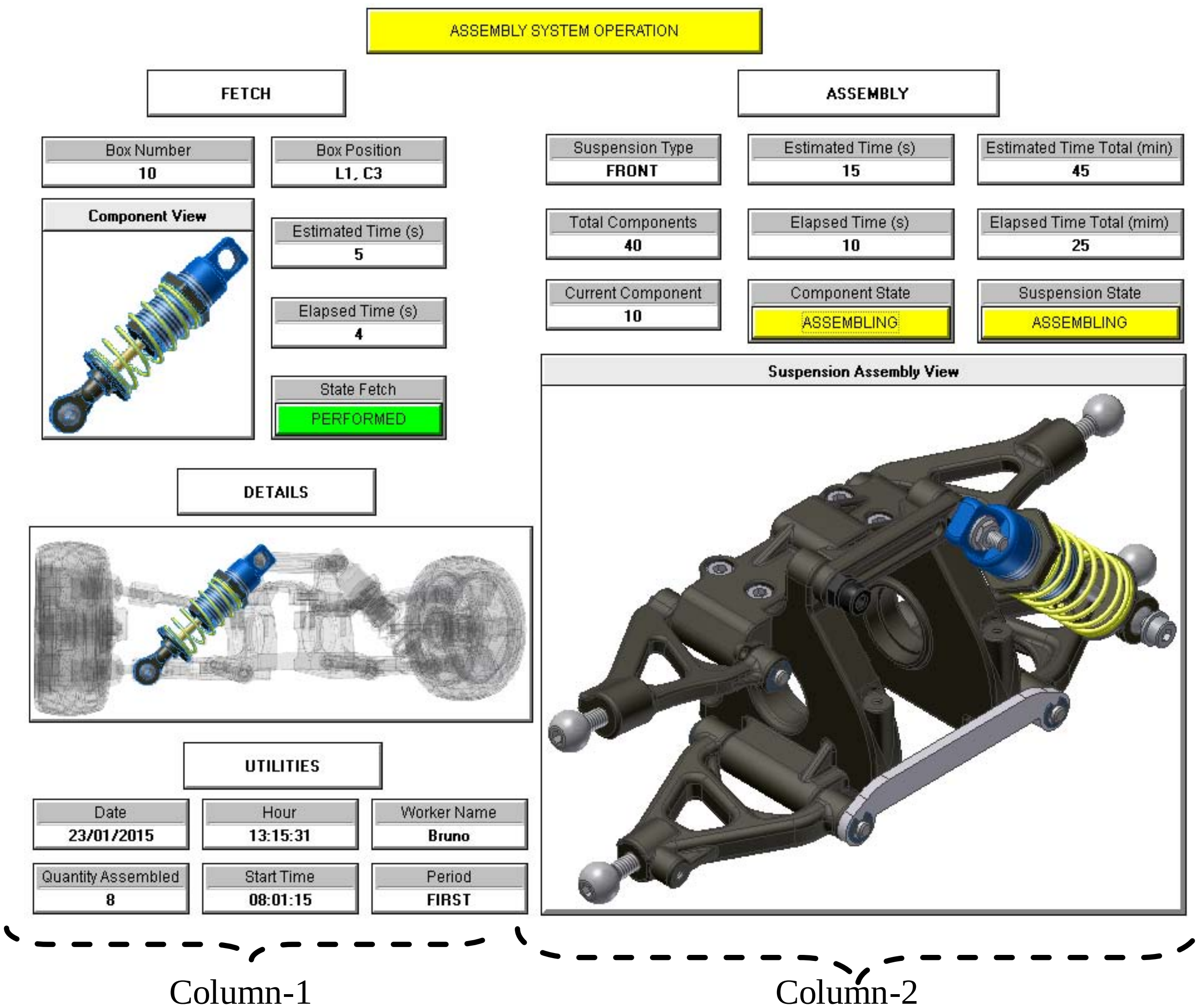

Fig.5 : Main window of the graphical interface.

The FETCH group contains means for the worker is able to identify the physical position of the box with the component to be assembled on the table, the removal of component of each component box, and also carry out the definition and measurement of the fetch time of each suspension component.

The virtual objects designed to meet the aforementioned purposes are designated:

a) Box Number.
b) Component View.
c) Box Position.
d) Estimated Time, in seconds.
e) Elapsed Time, in seconds.
f) State Fetch.

It is worth mentioning that the virtual object named by State Fetch shows the message "CURRENT", if the current step is the fetch component, and the indication "PERFORMED", if the Component Button (C_B) is activated by the worker to indicate that the fetch task was completed.

The intermediate stage between the fetch task and assembly of the component on the table is served by the DETAILS group, which may have a figure containing comments relevant to the realization of the assembly.

The additional information in the window is performed by UTILITIES group which has called virtual objects:

a) Date.
b) Hour.
c) Worker Name.
d) Quantity Assembled, this field is related to the current number of assembled suspensions.
e) Start Time.
f) Period, this field is related to the period that the worker is exercising activities in the company.

The information presented on the mentioned group are based on parameter values and obtained from the host computer (H_C).

It is worth mentioning that Start Time and Quantity Assembled display information which are related to the time elapsed from the activity start time of the worker and the amount of suspensions assembled at this time.

The Column-2 has virtual objects related to the type of suspension, the component to be assembled, the number of components assembled on the table, the assembly time for each component, the suspension assembly time, the component assembly signaling and also signaling for assembly the suspension.

The virtual objects designed to meet the mentioned signs are called:

a) Suspension Type.
b) Total Components.
c) Current Component.
d) Estimated Time, in seconds.
e) Elapsed Time, in seconds.
f) Component State.
g) Estimated Time Total, in minutes.
h) Elapsed Time Total, in minutes.
i) Suspension State.
j) Suspension Assembly View.

Due to the importance for the successful operation of the graphical interface (G_I), the virtual object named by the Suspension Assembly View occupies the largest area; it has the function to show the figures represented in three dimensions that are related to the components mounted on the table.

c) Practical tests

The procedures adopted in carrying out practical tests related to the graphical interface (G_I) that is proposed in this paper are as follows:

a) Make the connections of the modules contained in the prototype is shown in Figure 2.
b) Develop software in ladder language for development system (D_S), which follows the steps contained in the flowchart shown in Figure 4.
c) Prepare graphical interface containing the window shown in the Figure 4.

By means of the inputs contained in the development system (D_S) that is shown in Figure 3, the set of stimuli was applied to simulate the assembly sequence of the suspension in the physical architecture shown in Figure 1.

As consequence of applied stimuli was observed that the graphical interface (G_I) at the host computer (H_C) is able to properly display the visual signals expected for that type suspension assembly.

Some of the stimuli were applied with the goal of simulating an incorrect sequence of assembly in order to evaluate the system's ability to identify this situation, which actually occurred.

The results of the practical tests were positive because the graphical interface (G_I) was able to display all the virtual components in the correct sequence to assist the worker in the assembly task of the front suspension to the automobile.

It is very important to emphasize that the simulations with the incorrect assembly of components for the suspension were identified by the graphical interface (G_I), which allows the worker to correct and execute the exact sequence.

V. Conclusions

Satisfactory results observed in practical tests show that the proposal presented in this paper is feasible and can be carried out for the application to which it is intended. The objectives planned for this phase of the study were achieved, especially with regard to propose a graphical interface to assist the development of the activities performed by the worker in a physical architecture that was established to receive a specific process of assembling the front suspension to the automobile.

The graphical interface when integrated into a real physical system may contribute to increase production, to reduce the suspension assembly time, to minimize errors and also facilitate the implementation of activities by the worker.

The layout adopted, the quantity and clarity of the virtual objects provide an intuitive and meaningful environment for the worker carry out the suspension assembly.

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Simulation and Analysis of Power Quality Improvement using Multilevel Unified Power Quality Conditioner

By G. Annapurna & G. Tulasiramdas
G. Narayanamma Institute of Technology and Science, India

Abstract- Unified Power Quality Conditioner (UPQC) is an effective device to solve the power quality problems. The UPQC is a combination of series and shunt filters which simultaneously compensate load voltage and source current imperfections. This paper presents harmonic mitigation using three level Neutral Point Clamped inverter based Unified Power Quality Conditioner. The use of three level Neutral Point Clamped converters allows a better performance of equipment by reducing harmonics and the ripple of the generated oltages and currents. The performance of UPQC in the reduction of harmonics is evaluated when employed with Multi carrier based SPWM and three level novel SVPWM techniques. Simulation results based on MATLAB/SIMULINK are presented to verify the effective compensation of harmonics using the two different modulation techniques.

Keywords: active filters, neutral point clamped converters, total harmonic distortion, power quality, SVPWM.

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SIMULATIONANDANALYSISOFPOWERQUALITYIMPROVEMENTUSINGMULTILEVELUNIFIEDPOWERQUALITYCONDITIONER

Strictly as per the compliance and regulations of :

Simulation and Analysis of Power Quality Improvement using Multilevel Unified Power Quality Conditioner

G. Annapurna [α] & G. Tulasiramdas [σ]

Abstract- Unified Power Quality Conditioner (UPQC) is an effective device to solve the power quality problems. The UPQC is a combination of series and shunt filters which simultaneously compensate load voltage and source current imperfections. This paper presents harmonic mitigation using three level Neutral Point Clamped inverter based Unified Power Quality Conditioner. The use of three level Neutral Point Clamped converters allows a better performance of equipment by reducing harmonics and the ripple of the generated oltages and currents. The performance of UPQC in the reduction of harmonics is evaluated when employed with Multi carrier based SPWM and three level novel SVPWM techniques. Simulation results based on MATLAB/SIMULINK are presented to verify the effective compensation of harmonics using the two different modulation techniques.

Keywords: active filters, neutral point clamped converters, total harmonic distortion, power quality, SVPWM.

I. Introduction

The increased use of non-linear loads deteriorate power system voltage and current waveforms as they inject harmonics into the system. This results in increased losses, lower efficiency, failure of equipment etc. in the power system. Apart from voltage and current harmonics, voltage sag, voltage swell, voltage outage also can lead to poor quality of power [1]. Harmonic compensation and voltage regulation have become more important as imbalance in the voltage and presence of harmonics have been serious issues. Hence, there is a great need to mitigate these power quality issues.

The introduction of advanced power electronics technology has led to the development of active power filters which are viable solution to these power quality problems[1,2].

The general arrangement of Unified power quality conditioner is shown in Fig.1. The main function of a UPQC is to compensate voltage and current harmonics.

The UPQC combines series and shunt active filters with a common dc link. The series active filter suppresses voltage distortions while the shunt filter cancels current distortions such that this combination allows simultaneous compensation of voltages and currents supplied to the sensitive load to see that they are sinusoidal and balanced.

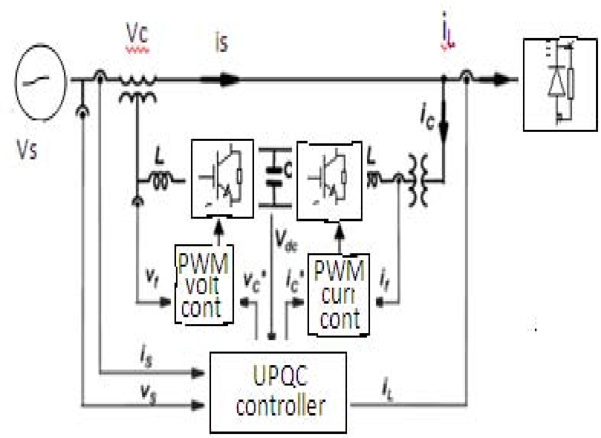


Fig.1 : General configuration of UPQC

Multilevel inverters play an important role in the reduction of harmonic content in the voltages and currents. The multilevel inverters can synthesize high output voltage from smaller voltage levels and thus the current ripples and voltage harmonics are reduced. The UPQC presented in this work consists of three level converter topology [3,4]. The performance of UPQC can be optimized because of reduction in the size of passive components and transformers [4].

II. The Upqc Controller

The UPQC controller is composed of PLL circuit, Reference Voltage Algorithm and Reference Current Algorithm [4,5,6].

The PLL circuit has the system voltages Vab and Vcb i.e (Vab =Vas – Vbs, Vcb = Vcs - Vbs) as inputs and the outputs are the signals Pll_a, Pll_b and Pll_c as shown in Fig.2.

Author α: e-mail: gootyanu@gmail.com

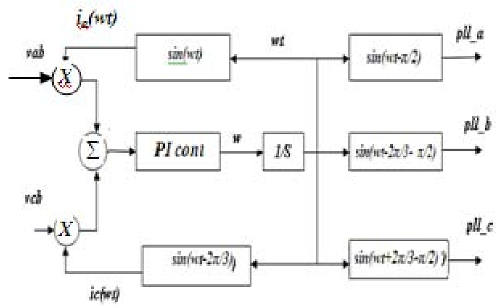


Fig. 2 : The synchronizing ciruit

The PLL circuit guarantees the load voltages and source currents to be balanced sinusoidal waveforms at fundamental frequency.

The reference current control strategy is shown in Fig.3. The reference currents algorithm control block determines six reference currents (i_{aref1},i_{bref1},i_{cref1}) and (i_{aref2},i_{bref2},i_{cref2}) by using the outputs of PLL (Pll-a,Pll-b,Pll-c) , the DC link voltages (V_{dc1},V_{dc2}) and the load currents (I_{al},I_{bl},I_{cl}) as inputs. The shunt active power filter will then synthesize the reference currents.

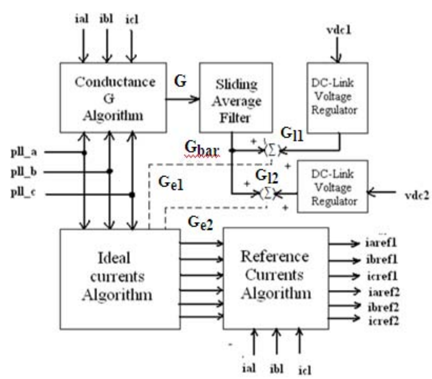


Fig. 3 : Reference current algorithm control strategy

The "reference voltage algorithm" shown in Fig.4 calculates, the reference voltages (V_{aref}, V_{bref}, V_{cref}) by using system input voltages (V_{as}, V_{bs}, V_{cs}) and PLL outputs(pll-a, pll-b, pll-c) that will be synthesized by the series power converter.

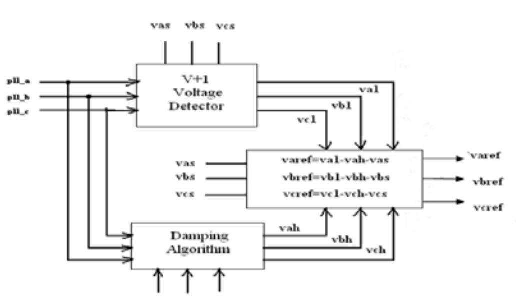


Fig. 4 : Reference voltage algorithm control strategy

III. Switching Strategy of Three Level Converters

In order to illustrate the switching control technique applied to the series and shunt active power converters, a basic three level NPC (Neutral Point Clamped) topology as shown in Fig. 5 is used [7,8].

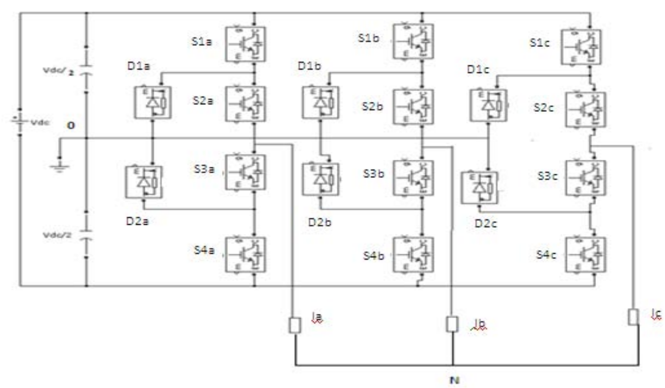


Fig. 5 : Three level Neutral point clamped converter

Each leg has four switching devices connected in series. As an example, phase "a" is considered to explain the behavior of the circuit.

The output of the inverter can take three voltage levels based on the switching states of the devices. The output Va is positive when switches S1a and S2a are ON, it is negative when S3a and S4a are turned ON, and it is '0' when switches S2a and S3a are ON. The switching states of the devices and the corresponding output voltages with respect to the dc mid-point are indicated in the following Table I.

The switching strategy of the series active filter is shown in Fig 6. In this technique, the reference signal is compared with measured signal, the error is amplified and processed by PWM generator to obtain V*a_PWM.* This signal is compared with two triangular waves of different limits having unit magnitude.

Table.I : Switching states and output voltages

SWITCHING STATES				OUTPUT VOLTAGE
S1a	S2a	S3a	S4a	Va
ON	ON	OFF	OFF	+Vdc/2
OFF	OFF	ON	ON	-Vdc/2
OFF	ON	ON	OFF	0

The switching control strategy of the shunt active converter is shown in Fig 7. This strategy compares the two reference signals Iaref1 and Iaref2 with measured currents, the errors are then amplified and processed by PWM generator to produce *I a1-pwm and I a2-pwm.* These signals are compared with two triangular trigger waves of different limits having unit magnitude.

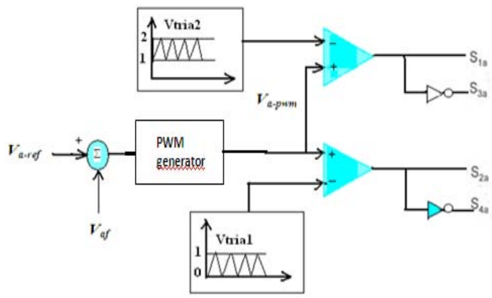


Fig. 6 : Series switching control strategy

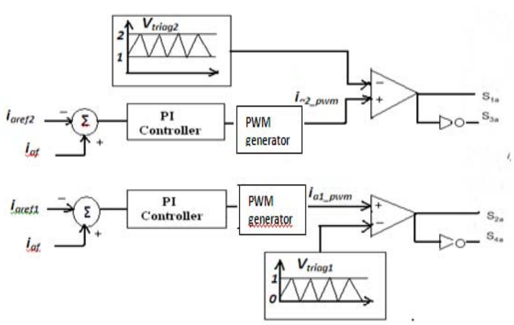


Fig. 7 : Shunt switching control strategy

IV. Modulation Strategy

a) *Sinusoidal Pulse Width Modulation*

i. *Carrier based PWM schemes*

In carrier based PWM schemes, for m- level inverter, (m-1) carrier waves are used. The carrier base PWM schemes are classified into two, they are,(i) Phase shifted multi carrier modulation,(ii) Level shifted multi carrier modulation. The level shifted multi carrier modulation schemes are again classified into three, they are,(i) In phase disposition method (ii)Alternative phase opposition disposition method and (iii) Phase opposition disposition method.

In this work, Phase Disposition multicarrier scheme is applied to Sinusoidal PWM. In this modulation, the reference sine wave is compared with the level shifted carrier triangular waves for producing the pulses. For a three level inverter, two triangular carrier waves of same frequency and amplitude are compared with the reference wave.

b) *Space Vector Pulse Width Modulation*

ii *Space Vector diagram of 3-level SVPWM inverter*

The space vector diagram of 3-level inverter is shown in Fig.8 [9,0,11].

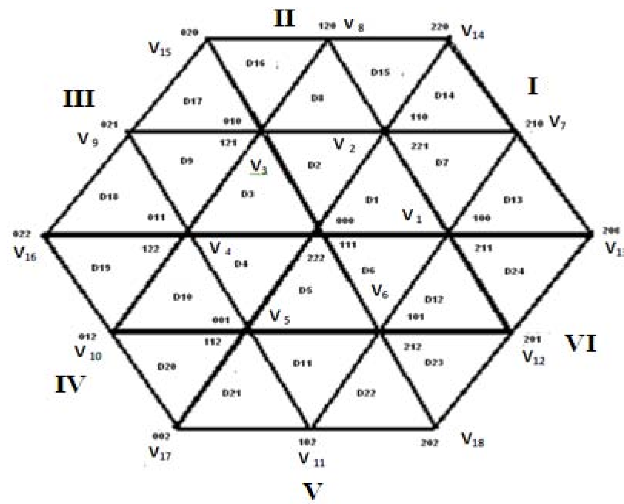


Fig.8 : Space vector diagram of three-level inverter

The plane is divided into 6 triangular major sectors numbered I to VI each of 60^0 of fundamental cycle. There are 4 minor sectors within each major sector such that 24 minor sectors are there in the plane.

The vertices of these minor sectors represent the voltage vectors. In the above plane, V0 is the zero voltage vector, large voltage vectors are represented by V13, V14, V15, V16, V17, V18 and V7, V8, V9, V10, V11, V12 are the medium voltage vectors. To determine the location of the command vector V* in a given major sector, first space vector phase angle' α' is calculated and then sector is determined. The determination of major sector is done as follows:

Table I : Determination of major sector

Range of 'α'	Major sector number
$0 \le \alpha < 60^0$	I
$60 \le \alpha < 120^0$	II
$120 \le \alpha < 180^0$	III
$180 \le \alpha < 240^0$	IV
$240 \le \alpha < 300^0$	V
$300 \le \alpha < 360^0$	VI

Let us consider space vector diagram of sector I as shown in Fig .9. It contains 4 minor triangles D1, D7, D13 and D14. The reference vector can be located in any of these 4 regions, where each region is limited by three adjacent vectors.

If the triangular sector where the command vector lies is defined by vectors Vx, Vy, and Vz assuming their durations Tx, Ty, and Tz respectively and Tx + Ty + Tz = Ts ,then V*= Vref can be synthesized by Vx, Vy, and Vz as follows :

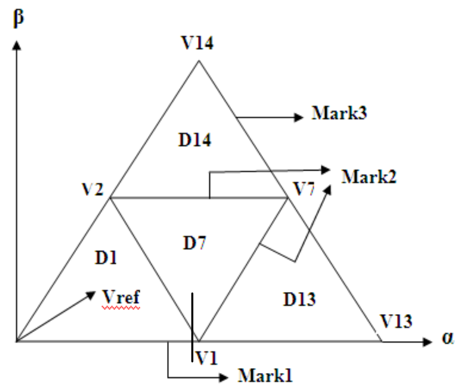


Fig.9 : Space vector diagram of Sector - I

$$V_{ref} = V^* = V_x (T_x/T_s) + V_y (T_y/T_s) + V_z (T_z/T_s)$$

$$T_x/T_s + T_y/T_s + T_z/T_s = 1,$$

$$T_x/T_s = X,\ T_y/T_s = Y \text{ and } T_z/T_s = Z$$

Where, T_S is the switching period.

Based on vector synthesis principle, the following equations can be written.

$$X + Y + Z = 1,\quad V_x X + V_y Y + V_z Z = V^*$$

The equations for the boundaries of modulation ratio Mark I, Mark 2, and Mark 3 can be obtained as follows:

$$\text{Mark 1} = \frac{\sqrt{3}/2}{\sqrt{3}\cos\theta + \sin\theta}$$

$$\text{Mark 2} = \frac{\sqrt{3}/2}{\sqrt{3}\cos\theta - \sin\theta},\ \theta \le \pi/6$$

$$= \frac{\sqrt{3}/4}{\sin\theta},\ \pi/6 \le \theta \le \pi/3$$

$$\text{Mark 3} = \frac{\sqrt{3}}{\sqrt{3}\cos\theta + \sin\theta}$$

Case 1 : If the modulation ratio m<Mark1, the rotating voltage vector V* lies in sector D1 and the same can be synthesized by vectors V0, V1, and V2. Then the following equation is obtained

$$\frac{1}{2}X + \frac{1}{2}(\cos 60^0 + j\sin 60^0)\,Y = m(\cos\theta + j\sin\theta)$$

We can obtain X, Y, and Z as follows:

$$X = 2m.\,[\cos\theta - \frac{\sin\theta}{\sqrt{3}}]$$

$$Y = m\frac{4\sin\theta}{\sqrt{3}}$$

$$Z = 1\text{-}2m\,[\cos(\theta) + \frac{\sin\theta}{\sqrt{3}}]$$

Case 2 : when (Mark1 < m < Mark2), V* lies in sector D7 and can be synthesized by vectors V1, V2, and V7 . The corresponding X, Y, and Z are:

$$X = 1 - m\frac{4\sin\theta}{\sqrt{3}}$$

$$Y = 1 - 2m.\,[\cos\theta - \frac{\sin\theta}{\sqrt{3}}\}]$$

$$Z = -1 + 2m\,[\cos(\theta) + \frac{\sin\theta}{\sqrt{3}}]$$

Case 3: When (Mark2<m<Mark3) and (0<θ<π/6), V* lies in sector D13 and can be synthesized by V1, V13, and V7. are selected to synthesize V*. The corresponding X, Y and Z are obtained as follows:

$$X = -1 + 2m\,[\cos(\theta) - \frac{\sin\theta}{\sqrt{3}}]$$

$$Y = m\frac{4\sin\theta}{\sqrt{3}}$$

$$Z = 2 - 2m\,[\cos(\theta) + \frac{\sin\theta}{\sqrt{3}}]$$

Case 4: When (Mark2 < m < Mark3) and (π/6<θ<π/3), V* lies in sector D14 and can be synthesized by Vectors V2. V7, and V14. X, Y, and Z can be determined as follows:

$$X = 2m\,[\cos(\theta) - \frac{\sin\theta}{\sqrt{3}}]$$

$$Y = -1 + m\frac{4\sin\theta}{\sqrt{3}} \qquad Z = 2 - 2m\,[\cos(\theta) + \frac{\sin\theta}{\sqrt{3}}]$$

Similar argument can be applied ,when the reference vector lies in the others major sectors. The above calculations for the entire coordinate plane can be obtained by replacing θ by $\theta - 60^0$, $\theta - 120^0$, $\theta - 180^0$, $\theta - 240^0$, and $\theta - 300^0$ respectively.

V. Simulation Results

Simulations were carried out in MATLAB/ SIMULINK on three-level Neutral Point Clamped Unified Power Quality Conditioner connected to a non-linear load employing Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation techniques and the results are presented below. FFT analysis is carried out in order to measure %THD in the load voltage and source current.

To study the performance of the UPQC, 5^{th} and 7^{th} harmonics are deliberately injected into the system and simulations were carried out to show the response of the UPQC.

a) Simulation results of 3level UPQC with SPWM

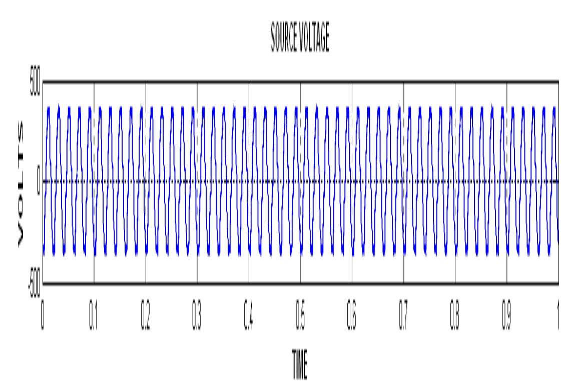


Fig.10 : Sourcevoltage

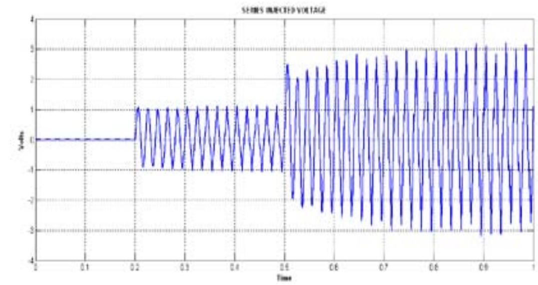


Fig. 11 : Voltage injected by the series inverter

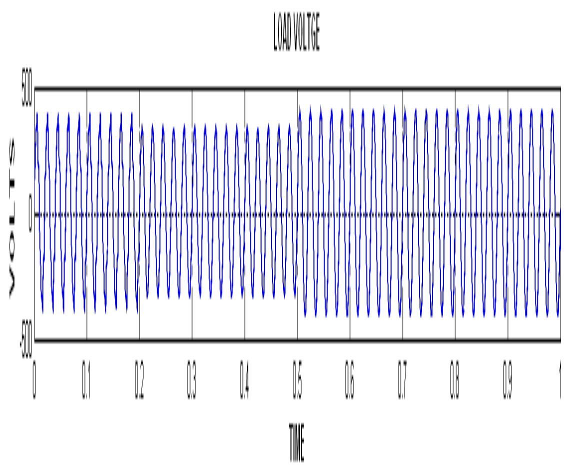


Fig. 12 : Load voltage after connecting UPQC

Fig. 10 shows source voltage where 5th and 7th harmonics are deliberately injected to study the ability of the UPQC in reducing the harmonics. Fig.11 indicates the voltage injected by the series inverter and Fig.12 shows the load voltage after compensation. If we observe Fig. 10 and Fig.12, the load voltage is same as source voltage till 0.2 sec where series filter is 'ON' and harmonics are reduced after 0.5 sec when both shunt and series filters are 'ON'.

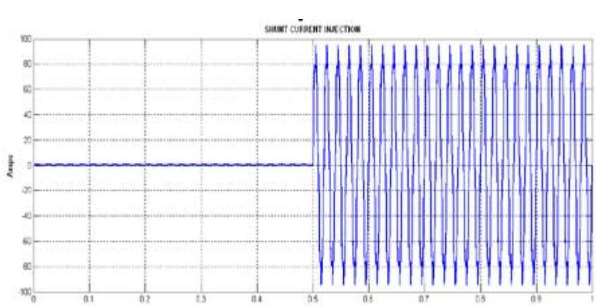


Fig. 13 : Current injected by shunt inverter

The shunt inverter is switched on at 0.5sec and it started injecting current as shown in Fig.13.

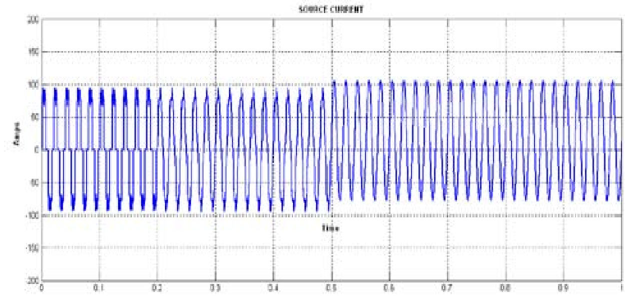
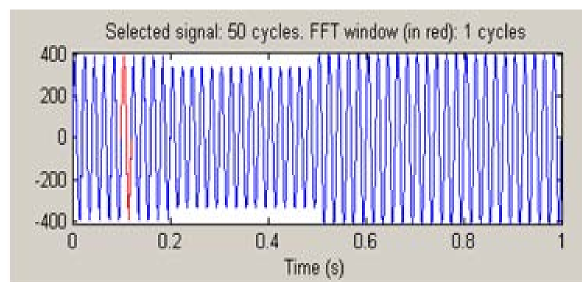
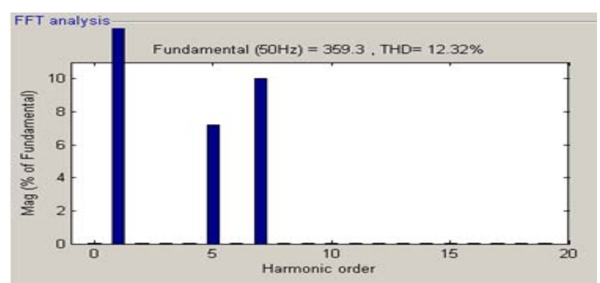


Fig. 14 : Source current

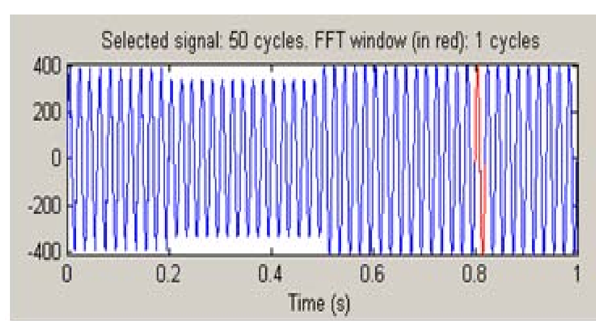
As it is seen in the above Fig.14, the source current harmonics are reduced from 0.5 sec when both filters started operating.

FFT analysis of load voltage





FFT analysis of load voltage before connecting UPQC



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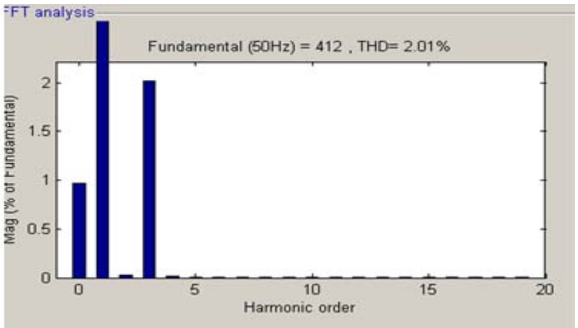
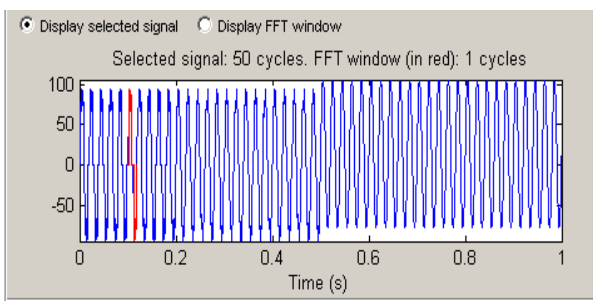
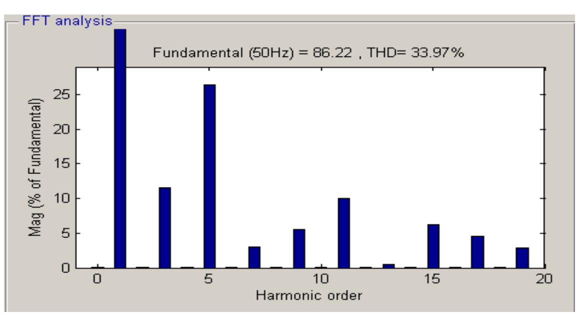


FFT analysis of load voltage after connecting UPQC

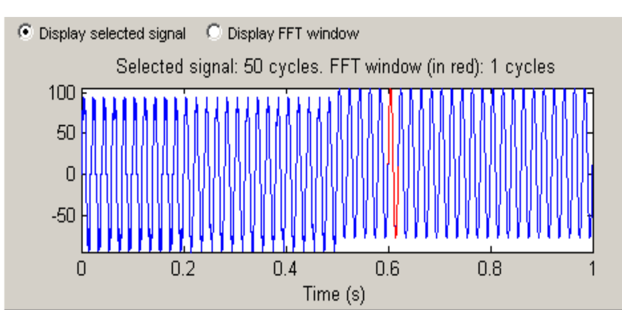
The series inverter is put into operation at 0.2sec and shunt inverter at 0.5sec.FFT analysis is carried out on the load voltage at 0.1sec and the THD is found to be 12.32%. In the second analysis, FFT is done at 0.8sec i.e. after connecting UPQC and THD is reduced to 2.01%



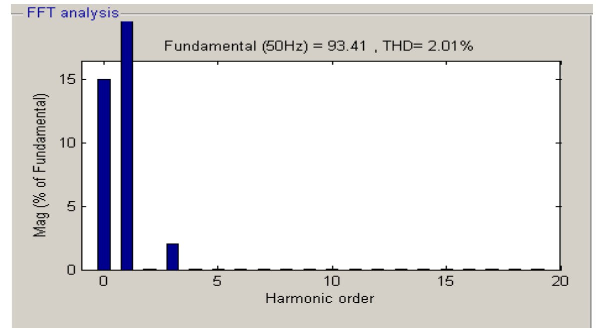
FFT analysis of source current



FFT analysis of source current before connecting UPQC



FFT analysis of source current after connecting UPQC



FFT analysis is carried out on the source current at 0.1sec before connecting UPQC and the THD is found to be 33.97%. In the second analysis, FFT is done at 0.6sec after connecting UPQC and THD is 2.01%

b) Simulation results of 3level UPQC with SVPWM

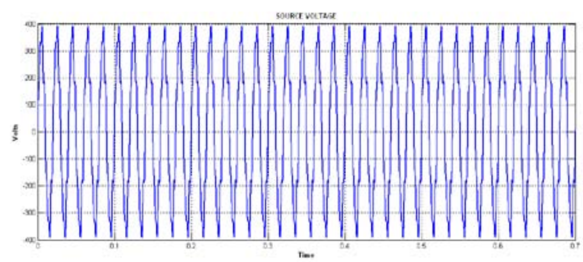


Fig.15 : Sourc Voltage

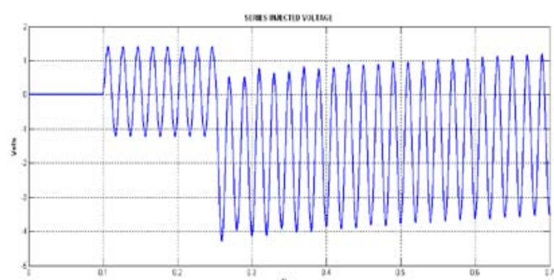


Fig.16 : Voltage injected by series inverter

The series filter is switched ON at 0.1 sec and it started injecting voltage.

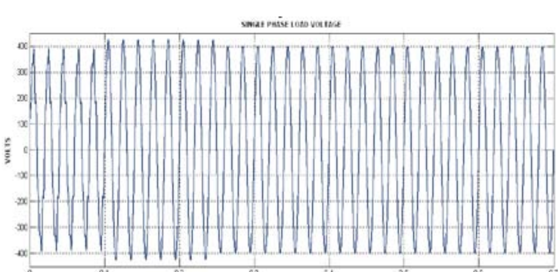


Fig.17 : Load voltage after connecting UPQC

Fig. 15 shows source voltage with 5^{th} and 7^{th} harmonic injection. Fig.16 indicates the voltage injected by the series inverter from 0.1 sec and Fig.17 shows the load voltage after compensation.

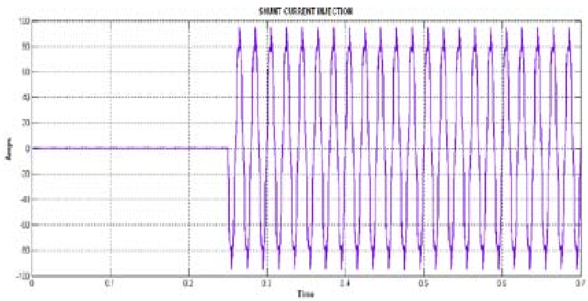


Fig.18 : Current injected by shunt inverter

The shunt filter is switched on at 0.25 sec and started injecting current

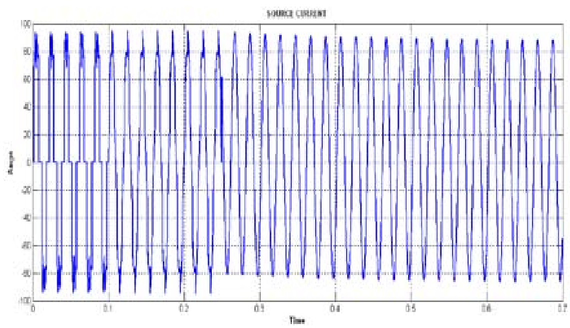
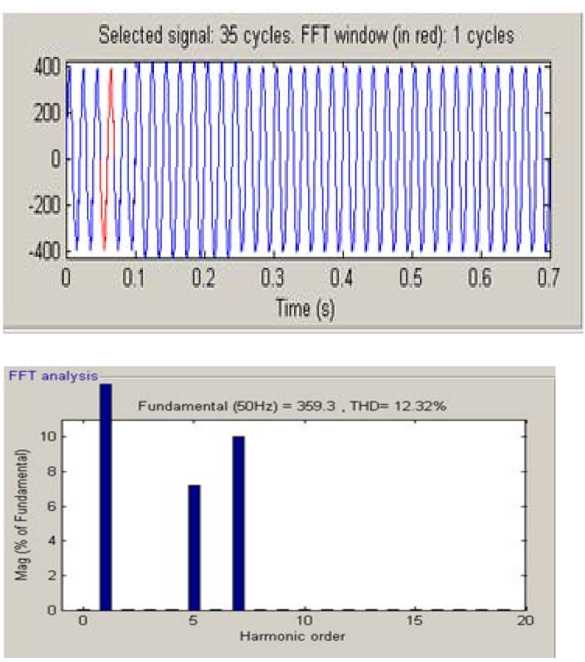


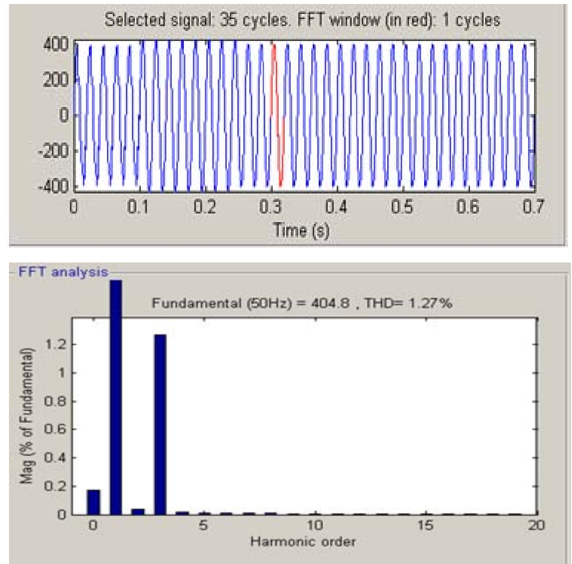
Fig.19 : Source current

From Fig. 19, it is clear that the harmonics are reduced to some extent after 0.1 sec where series filter is switched ON and from 0.25sec onwards there is a considerable reduction in the harmonics as both filters are in operation.

FFT analysis of load voltage



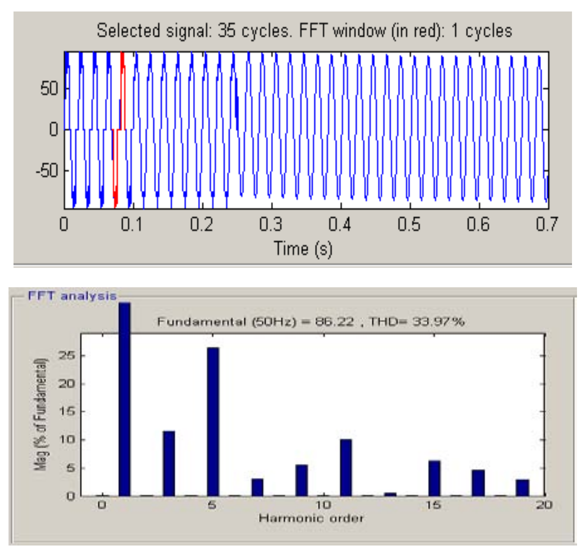
FFT analysis of load voltage before connecting UPQC



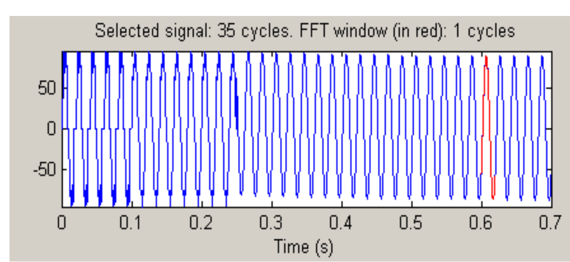
FFT analysis of load voltage after connecting UPQC

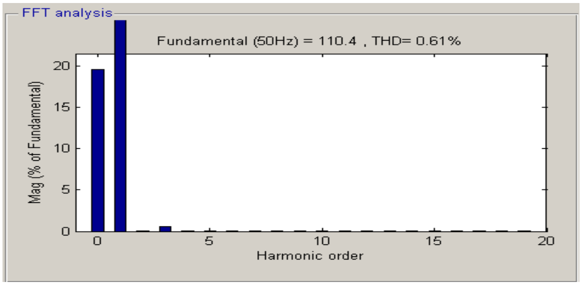
FFT analysis is carried out on the load voltage at 0.05sec before switching ON series and shunt inverters and the THD is found to be 12.32%. FFT analysis of load voltage again carried out at 0.3sec after connecting both series and shunt filters and THD is found to be 1.27%.

FFT analysis of source current



FFT analysis of source current before connecting UPQC





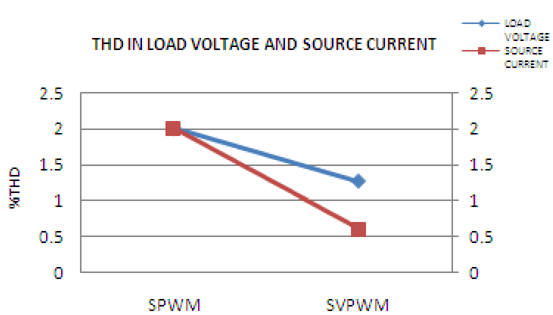
FFT analysis of source current after connecting UPQC

FFT analysis is carried out on the source current at 0.07sec before connecting UPQC and the THD is found to be 33.97%. In the second analysis, FFT is done at 0.6sec after connecting UPQC and measured THD is 0.61%

Table.II : Results of UPQC with SPWM and SVPWM

Control Scheme	Load voltage		Source current	
	%THD Before compensation	%THD After compensation	%THD Before compensation	%THD After compensation
SPWM	12.32	2.01	33.97	2.01
SVPWM	12.32	1.27	33.97	0.61

The above results are shown in the form of graphs for better understanding



The above table and graphs clearly show that the % THD of both load voltage and source current is less with SVPWM when compared to SPWM and within the prescribed limits of IEEE – 519.

VI. Conclusion

The performance of three level UPQC has been evaluated using Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation techniques. To prove the effective compensation by UPQC, harmonics are deliberately injected into the source voltage and the UPQC has successfully reduced harmonics from load voltage and source current. The %THD content in the load voltage and source current after compensation is very less and comply with IEEE-519. The simulation results show that the Total Harmonic Distortion of the load voltage after UPQC is put into operation is less in case of SVPWM compared to SPWM.

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A Study on the Eigen-Property of the Cylindrical Coaxial Cavity by FEM

By Yeong Min Kim
Kyonggi University, Korea

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Keywords: eigen-pair, FEM, Krylov-Schur iteration method, TM, TE, Galerkin method, Helmholtz equation.

GJRE-F Classification : *FOR Code: 090699*

ASTUDYONTHEEIGENPROPERTYOFTHECYLINDRICALCOAXIALCAVITYBYFEM

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Keywords: eigen-pair, FEM, Krylov-Schur iteration method, TM, TE, Galerkin method, Helmholtz equation

I. Introduction

It has been well known that the knowledge about eigen-mode is one of the most important thing designing the resonant cavity. Acquiring an information about the eigen-property is indispensable in the process of developing more valuable product. There are several factors influencing the eigen-property in the cavity. Among others, the geometrical structure has been considered as the most dominant factor influencing on the eigen-property. Its structure determines the eigen-mode which characterizes the resonant electromagnetic field. The cavity would be taken a variety of form in accordance with its applying purpose. Previously, we have studied the eigen-properties of cylindrical and rectangular resonant cavities using FEM (Finite Element method) [1] [2]. These studies have revealed the several prominent eigen-modes and corresponding eigen-values for each TM and TE modes. The spectra have been shown visually with the 3-Dim (Dimensional) schematic representation. These results have suggested that the similar method may be carried out on varied 3-dimensional cavities and give valuable information understanding the physical property of more complicating system. In this study, FEM has been performed on the cylindrical coaxial cavity as like the previous study. The mesh element was a simple tetrahedron and the shape functions were constructed with constant tangential edge vectors. The matrix eigen-equation was established basing on the vector Helmholtz equation. For a three-dimensional problem, the number of variables increases drastically comparing to a two-dimensional problem. It may be very difficult problem to calculate the huge dimensional matrix equation by common eigen-solving method. Krylov-Schur iteration method has been known as one of the most important and actively developing algorithms for calculating the large dimensional eigen-equation [3] [4]. This method compresses and transforms similarly the eigen-matrix into the Shur form. Even using personal computer, this method was easily carried out on the calculation obtaining the several prominent eigen-pairs. Accompanying with it, the shift-invert strategy add more helpful benefit to obtain the specific eigen-mode. So, Krylov-Schur iteration method has applied to the matrix eigen-equation in this study. As the results, the spectra for each eigen-pairs have been visualized with the schematic representations as like the previous study. The spectra were so complex that surface components of the field vector separated and presented side by side to each spectra.

Author : Dept. of Elecronic Physics, Kyonggi University, Korea. e-mail: kimym5418@hanmail.net

II. Finite Element Formulation

The calculation for the eigen-mode is the same as describing in previous studies. The formulation can be followed by using either $\vec{E}$(electric field strength) or $\vec{B}$(magnetic field strength) field. For a convenience of calculation, only $\vec{E}$ would be considered in the following discussion. The vector Helmholtz equation would be used in determining the wave property of the resonant cavity. It is described as following equation [5] [6]

$$\vec{\nabla} \times \left(\frac{1}{\mu_r}\vec{\nabla} \times \vec{E}\right) - k^2\varepsilon_r\vec{E} = 0(1)$$

where k, μ_r and ε_r is the wave number, relative permeability μ/μ_o and relative permittivity $\varepsilon/\varepsilon_o$ respectively. The eigen-equation is constructed from FEM basing on the tetrahedral elemental mesh. The cylindrical coaxial resonant cavity and the tetrahedral mesh is shown in the Fig.1. In the calculation, the lateral surface of the cavity has been assumed to be PEC (perfect electric conductor). This boundary condition makes TM and normal derivative for TE components to be vanished at the lateral surface. The Galerkin method of weighted residual has been used to construct a linear equation [7]. The equation resulting from this method is given as following

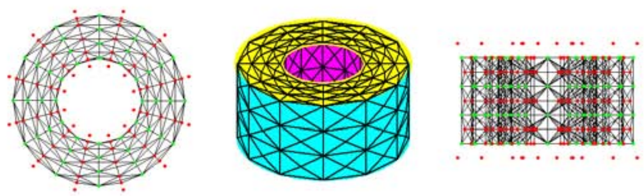


Fig. 1: Schematic representation of the 3-Dim mesh of the coaxial cylindrical cavity

$$\iiint \frac{1}{\mu_r}(\vec{\nabla}\times\vec{T})\cdot(\vec{\nabla}\times\vec{E})dV = k_o^2\varepsilon_r \iiint \vec{T}\cdot\vec{E}dV \quad (2)$$

Where $\vec{T}$ is a weighting function. To avoid the spurious solution attributed to the lack of enforcement of divergence condition for $\vec{E}$, basis functions have been constructed with constant tangential edge vectors $\vec{W}_m$ of the tetrahedral element

$$\vec{W}_m = l_m\left(N_{m1}\vec{\nabla}N_{m2} - N_{m2}\vec{\nabla}N_{m1}\right) \quad m = 1,2,3,4,5,6. \quad (3)$$

In this representation, N_{m1} and N_{m2} are the simplex coordinates associated with the 1st and 2nd nodes connected by edges m, and l_m is the length of edge m. The simplex coordinates for a given elementary mesh are

$$N_n = a_n + b_n x + c_n y + d_n z, \qquad n = 1,2,3,4 \quad (4)$$

And the gradient of any coordinate is

$$\vec{\nabla}N_n = b_n\hat{x} + c_n\hat{y} + d_n\hat{z} \quad (5)$$

The simplex coefficients are calculated by inverting the coordinate matrix

$$\begin{bmatrix} a_1 & b_1 & c_1 & d_1 \\ a_2 & b_2 & c_2 & d_2 \\ a_3 & b_3 & c_3 & d_3 \\ a_4 & b_4 & c_4 & d_4 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ x_1 & x_2 & x_3 & x_4 \\ y_1 & y_2 & y_3 & y_4 \\ z_1 & z_2 & z_3 & z_4 \end{bmatrix}^{-1} \quad (6)$$

Where (x_n, y_n, z_n) is a rectangular coordinate of the node n of the tetrahedral mesh. Each edge and node for element mesh are related with each other as illustrated in Fig.2. The electric field strength in a single tetrahedral element is calculated with the tangential edge vector as

$$\vec{E} = \sum_{m=1}^{m=6} e_m\vec{W}_m \quad (7)$$

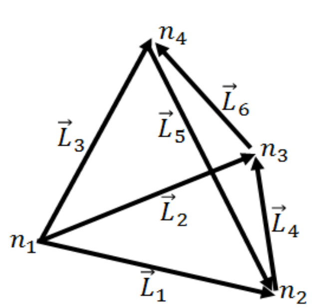


Fig.2 : The tetrahedral element mesh

The six unknown parameters $e_1, \dots, e_6$ are associate with tangential edges of the tetrahedral elemental mesh. Substituting equation (7) into equation (2), the eigen-equation of one tetrahedral element can be written in matrix form

$$[S_{el}][e] = k^2[T_{el}][e] \quad (8)$$

Where the element matrices are given by

$$[S_{el}] = \iiint \frac{1}{\mu_r}(\vec{\nabla}\times\vec{W})\cdot(\vec{\nabla}\times\vec{W})dV \quad (9)$$

$$[T_{el}] = \varepsilon_r \iiint \vec{W}\cdot\vec{W}dV \quad (10)$$

The evaluation of the element matrix requires the curl product for each basis function $\vec{W}_m$

$$\begin{aligned}\vec{\nabla}\times\vec{W}_m &= \vec{\nabla}\times l_m(N_{m1}\nabla N_{m2} - N_{m2}\nabla N_{m1}) \\ &= 2l_m\vec{\nabla}N_{m1}\times\vec{\nabla}N_{m2} \\ &= 2l_m\big((c_{m1}d_{m2} - c_{m2}d_{m1})\hat{x} + (b_{m2}d_{m1} - b_{m1}d_{m2})\hat{y} \\ &\quad + (b_{m1}c_{m2} - b_{m2}c_{m1})\hat{z}\big) \\ &\equiv 2l_m\vec{w}_m \end{aligned} \quad (11)$$

And from it

$$[S_{el}]_{mn} = 4l_m l_n V(\vec{w}_m\cdot\vec{w}_n) \quad (12)$$

To obtain the element matrix $[T_{el}]$, the scalar product between $\vec{W}_m$ and $\vec{W}_n$ may be calculated as

$$\vec{W}_m\cdot\vec{W}_n = l_m\left(N_{m1}\vec{\nabla}N_{m2} - N_{m2}\vec{\nabla}N_{m1}\right)\cdot l_n\left(N_{n1}\vec{\nabla}N_{n2} - N_{n2}\vec{\nabla}N_{n1}\right) \quad (13)$$

$$= l_m l_n\left[N_{m1}N_{n1}\varphi_{m2,n2} - N_{m1}N_{n2}\varphi_{m2,n1} - N_{m2}N_{n1}\varphi_{m1,n2} + N_{m2}N_{n2}\varphi_{m1,n1}\right] \quad (14)$$

Where $\varphi_{mi,nj} = \vec{\nabla}N_{mi}\cdot\vec{\nabla}N_{nj} = b_{mi}b_{nj} + c_{mi}c_{nj} + d_{mi}d_{nj}$

In the process of $[T_{el}]$ calculation, following volume integration for 3-Dim simplex coordinates may be used

$$\iiint (N_1)^i(N_2)^j(N_3)^k(N_4)^l dV = \frac{3!\,i!\,j!\,k!\,l!}{(3+i+j+k+l)!}V \quad (15)$$

These integrals can be simply summarized in the following matrix form [8]

$$[M_{ij}] = \frac{1}{V}\iiint N_iN_j\,dV = \frac{1}{20}\begin{bmatrix} 2 & 1 & 1 & 1 \\ 1 & 2 & 1 & 1 \\ 1 & 1 & 2 & 1 \\ 1 & 1 & 1 & 2 \end{bmatrix} \quad (16)$$

From the equations (13), (14) and (16), the element matrix can be written as following

$$[T_{el}]_{mn} = Vl_m l_n\left[\varphi_{m2,n2}M_{m1,n1} - \varphi_{m2,n1}M_{m1,n2} - \varphi_{m1,n2}M_{m2,n1} + \varphi_{m1,n1}M_{m2,n2}\right] \quad (17)$$

These element matrices are assembled over all tetrahedral elements in the 3-Dim cavity to obtain a global eigen-matrix equation.

$$[S][e] = k^2[T][e] \quad (18)$$

III. Results and Discussion

The following discussion is similar to the previous studies. The same FEM formulation was applied to the cylindrical coaxial cavity. But it is confirm that the mesh structure was differently constructed from these studies and the results sufficiently reflected on the characteristics of the present cavity.

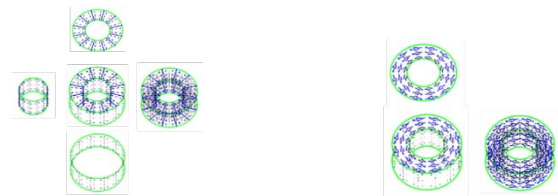
In this study,FEM has been used to construct the eigen-equation. The variable of vector Helmholtz equation was the vector edge of the tetrahedral mesh. The vertices of the tetrahedron were arranged following the right hand rule to obtain the positively determinant value of the element mesh. The dimension of the eigen-matrix equation was so large that the Krylov-Schur iteration method has been used to obtain several prominent eigen-modes. The calculation was more efficiently promoted in finding specific eigen-pairs by imploring the shift-invert strategy as following [9]

$$\lambda[e] = \frac{[T]}{[S]-\sigma[T]}[e] = [M][e] \qquad (19)$$

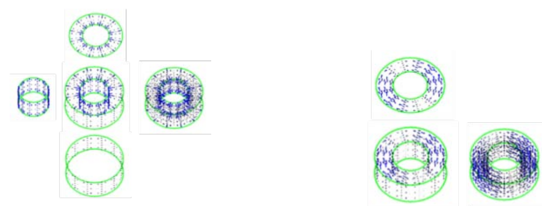
where $\lambda = \frac{1}{k^2-\sigma}$. As mentioned in the previous study, the sparsity and symmetry of the eigen-equation would be lost. But by this strategy, the convergent rate was further increased at the specific value σ. The Krylov-Schur iteration method has been performed on this square matrix $[M]$. By this iteration method, the matrix $[M]$ has been transformed into a Schur matrix. The eigen-modes were the column vectors of the similar transforming matrix which convert the square matrix $[M]$ to the Shure form. The wave numbers were calculated by converting each diagonal component of the Schur matrix into values$k^2 = \frac{1}{\lambda} - \sigma$. As a result, the eigen-pairs have been schematically represented in Fig. 3. The wave numbers were written in the blanket under each spectrum. As can be seen in the spectra, eigen-mode has shown the complicating distribution of electromagnetic fields. So, the surface components were separated from each spectra and positioned side by side to them. From these spectra, it could be identified that the field strength components were oriented to a specific direction. The mode type could be determined readily by investigating the direction of these field strength. These mode type are shown under each spectrum accompanying with a wave numbers. The lateral surface component of TM modes was not depicted definitely in the figure. The reason for it has been on PEC boundary condition which did not permitted tangential magnetic fields on the lateral surface.

IV. Conclusion

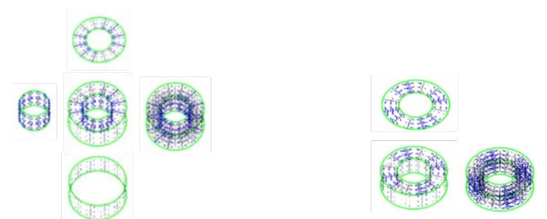
The 3-Dim eigen-equation of the cylindrical coaxial cavity has been constructed by FEM. Eigen-pairs have been calculated by applying the Krylov-Schur iteration method to the shift inverted matrix. As a result, the spectra have been represented schematically in the figure. To identify the mode type, the surface component were separated from the 3-Dim spectra. The mode type and wave numbers have been written under each spectra. From these results, it could be identified that the spectra reflect the characteristics of the coaxial cylindrical cavity.



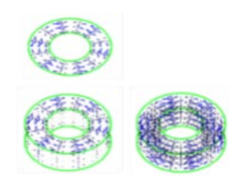
TE 101 (1.1561) TM 101 (0.6336)



TE 111 (2.1754) TM 111 (0.8175)



TE 111 (1.3726) TM 211 (1.2143)



TM 131 (1.6753)

Fig.3 : The schematic representation of the eigen-modes and corresponding wave numbers

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Maximum Power Point charge Controller for DCDC Power Conversion in Solar PV System

By Md. Nasir Uddin, M. M. Rashid, M. A. Aziz & N A Nithe
International Islamic University Malaysia, Malaysia

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Keywords: *charge controller, DC, AC, PV, Solar,PWM, MPPT, SHS.*

GJRE-F Classification : FOR Code: 090699

Maximum Power Point charge Controller for DC-DC Power Conversion in Solar PV System

Md. Nasir Uddin [α], M. M. Rashid [σ], M. A. Aziz [ρ] & N A Nithe [ω]

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I. Introduction

Photovoltaic production becomes double every two years, increasing by an average of 48 percent each year since 2002. For this reason it becomes the world's fastest-growing energy technology [1]. Photovoltaic efficiency is very important for solar application. Photo-voltaic (PV) panels (sometimes referred to as photovoltaic modules) produce current at a specific voltage depending on the amount of solar radiation hitting the cells of the panel. The theoretical maximum amount of power from the sun at the earth's surface is about 1 KW per square meter at the equator on a clear day. To make the electrical power useful when the sun is not available, it must be stored, typically in batteries. The nature of the PV panels is that they have a specific Voltage ×Current curve that changes with the temperature and on the amount of sunlight or the angle at which the sun strikes the panel. Higher temperatures lower the voltage and more sunlight increases the output current. Distributed photovoltaic generation, in the form of roof-top domestic systems, is being installed at an increasing scale [2-4]. Significant power quality issues, especially voltage rise and voltage unbalance have been widely studied [5, 6]. Higher penetrations or renewable generation within the distribution network can be achieved by the addition of intelligent control, storage or regulatory devices, [7].

In this case charge controller plays a vital role to protect the battery [8]. A series charge controller disables further current flow into batteries when they are full. A shunt charge controller diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full [8, 9].For increased system efficiency, it is desirable to operate PV panels at the voltage and current levels that produce the peak power, which is referred to as the Maximum Power Point [8, 10].The Proposed charge controller performs DC-DC power conversion typically utilizing Pulse Width Modulation (PWM) control of the electrical energy produced by the PV panels in order to transform such energy into a suitable form [11].

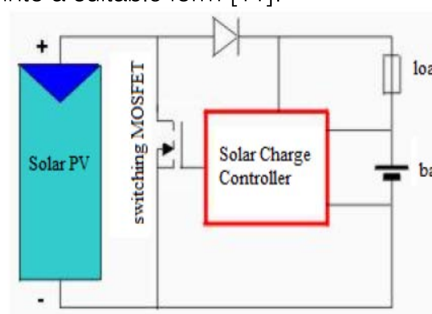

Figure iA : SHS with series controller[8]

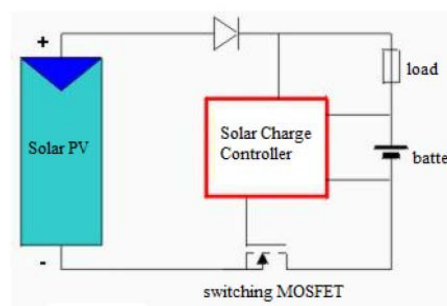

Figure iB : SHS with shunt controller Charge[8]

A charge controller is needed in photovoltaic system to safely charge sealed lead acid battery [12]. The most basic function of a charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced [13]. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough [14]. This is especially important with sealed lead acid battery where we cannot replace the water that is lost during overcharging. Unlike Wind or Hydro System charge controller, PV charge controller can open the circuit when the battery is full without any harm to the modules [15]. Most PV charge controller simply opens or restricts the circuit between the battery and PV array when the voltage rises to a set point [16]. Then, as the battery

Author α σ ρ ω : Department of Mechatronics Engineering, Faculty of Engineerin International Islamic University Malaysia.
e-mail: nasir.u@live.iium.edu.my

absorbs the excess electrons and voltage begins dropping, the controller will turn back on [17].

Figure iC : Basic image of controller and battery wiring[18]

Charge controller has been regarded as one of the important devices in stand-alone photovoltaic systems to prevent the battery from damage due to over-charging and over-discharging [20]. Besides that, the unstable voltage from photovoltaic systems may spoil the load [19]. Studies show that the life time of the battery is degraded without using charge controller [21]. Therefore, a charge controller should be designed to prolong the battery's life time and stabilize the voltage from photovoltaic panel [22].

II. Background of the Invention

a) Field of the Invention

This invention relates broadly to charge controllers that perform DC-DC power conversion. More particularly, this invention relates to charge controllers for solar applications, including converting DC electrical energy provided by photo-voltaic means for charging electrochemical batteries and for direct output [23-29].

b) State of the Art

Photo-voltaic (PV) panels (sometimes referred to as photovoltaic modules) produce current at a specific voltage depending on the amount of solar radiation hitting the cells of the panel. The theoretical maximum amount of power from the sun at the earth's surface is about 1 KW per square meter at the equator on a clear day. To make the electrical power useful when the sun is not available, it must be stored, typically in batteries. The nature of the PV panels is that they have a specific Voltage×Current curve that changes with the temperature and on the amount of sunlight or the angle at which the sun strikes the panel [30-36]. Higher temperatures lower the voltage and more sunlight increases the output current.

For increased system efficiency, it is desirable to operate PV panels at the voltage and current levels that produce the peak power, which is referred to as the Maximum Power Point. Loads such as batteries, on the other hand, have a need for voltage and current which is independent and often different from what the PV panel is producing. A charge controller (which can also be referred to as a charge regulator or regulator) is connected between the PV panel(s) and the batteries or load in order to deal with this miss-match. The charge controller performs DC-DC power conversion typically utilizing Pulse Width Modulation (PWM) control of the electrical energy produced by the PV panels in order to transform such energy into a suitable form. For example, for battery charging applications, the PWM control is used to adjust the voltage levels and current levels output the battery [37-42]. More particularly, as the battery reaches full charge, the PWM control is used to limit the voltage level supplied to the battery such a not to the harm the battery (i.e., inhibiting the boiling of the electrolyte of the battery, which can destroy the battery). Early charge controllers were only able to reduce the amount of voltage from the PV panels if too high for the batteries. Since the voltage from the PV panels would be lower at high temperatures, the PV panels had to be over sized to ensure that the minimum voltage at high temperatures would be at least as high as the battery to be charged plus voltage headroom enough to force current into the battery [43-48]. At any temperature lower than the maximum, the excess voltage from the PV panels would have to be discarded by the charge controllers. Because PV panels are the most expensive component of the system, the need for extra (or larger) PV panels negatively impacted the cost-effectiveness of such PV power systems [49-55].

Newer and more efficient charger controllers have emerged that provide a better match between the PV panels and their load. Their goal is to use all the power from the PV panel(s) regardless of the voltage and current at any amount of insolation or at any temperature. The newer charge controllers employ a DC to DC converter section that is adapted to dynamically charge the battery (or to directly power a load) at the exact voltage and current that is most appropriate for that battery (or load). Although the newer charge controllers provide improved system efficiencies relative to the older models, they too often suffer from several shortcomings. More particularly, the charge controllers are slow to adapt to changing conditions of the PV panel(s) over the course of any given day, including low light conditions in the morning, evening and during cloud cover and also temperature changes sometimes associated with the changes in insolation. The edges of clouds create particularly issues because they cause a rapid change in lighting which may be followed by a relatively rapid change in temperature. Because they do not quickly adapt to changing conditions, the charge controllers have limited efficiency, which results in the need for extra (or larger) PV panels to be used for a given power output and high costs.

III. Summary of the Invention

It is therefore an object of the invention to provide a charge controller that quickly adapts to changing conditions and thus affords improved energy conversion efficiencies.It is another object of the invention to provide such a charge controller which can be adapted for use with a wide range of PV panels.It is a further object of the invention to provide such a charge controller which can be adapted for use with a wide range of DC loads including batteries for energy storage and DC-AC inverters for direct output.In accord with these objects, which will be discussed in detail below, a charge controller is provided that includes an input interface that receives input DC electrical signals. A converter section converts the input DC electrical signals to output DC electrical signals. Control means is operably coupled to the converter section. The control means includes means for operating the converter section at an estimated maximum power point of the input DC electrical signals [56-62]. The estimated maximum power point is derived by a control scheme that includes the following operations:

i) storing an input voltage level corresponding to the estimated maximum power point;
ii) varying the input voltage of the input DC electrical signals over a sequence of sample points from a first voltage level to a second voltage level, and deriving and storing an output current value of the output DC electrical signals at each sample point;
iii) selecting the maximum output current value from the output current values stored in ii), and identifying the particular input voltage level corresponding thereto; and
iv) varying the input voltage of the input DC electrical signals over a sequence of sample points from the second voltage level to the particular input voltage level identified in iii); and
v) updating the stored input voltage level corresponding to the estimated maximum power point to the particular input voltage level identified in iv).

In the preferred embodiment, for each given sample point in ii), the output current value for the sample point is derived by averaging a plurality of output current measurements at the given sample point, and the first and second voltage levels of ii) are derived from the measured open circuit voltage.

In another aspect of the invention, the control scheme carried out by the charge controller derives the estimated maximum power point by the following operations:

a) storing an input voltage level corresponding to the estimated maximum power point;
b) varying the input voltage of the input DC electrical signals over a number of sample points around the input voltage level stored in a), and deriving and storing an
c) output current value of the output DC electrical signals at each sample point;
d) selecting the maximum output current value from the output current values stored in b) and identifying the particular input voltage level corresponding thereto; and
e) updating the stored input voltage level corresponding to the estimated maximum power point to the particular input voltage identified in c).
f) The number of sample points in b) include a first plurality of sample points at input voltage values less than the input voltage level stored in a) and a second plurality of sample points at input voltage values greater than the input voltage level stored in a).

In the preferred embodiment, for each given sample point in b), the output current value for the sample point is derived by averaging a plurality of output current measurements at the given sample point, and the voltage differences between the sample points of b) is on the order of 100 mill volts [63-69].

In yet another aspect of the present invention, the control scheme carried out by the charge controller updates an input voltage level corresponding to an estimated maximum power point at a frequency of at least 500 Hz.It will be appreciated that the maximum power point control operations of the present invention quickly adapt to changing conditions and thus afford improved energy conversion efficiencies.

In the illustrative embodiment, the converter section comprises a buck converter topology having input reservoir capacitance, at least one series switching element (e.g. an FET field effect transistor or IGBT insulated gate bipolar transistor), at least one synchronous rectifier switching element, at least one inductor, and gate drive circuitry that selectively switches the at least one series field effect transistor and the at least one synchronous rectifier field effect transistor between ON and OFF states in response to pulse width modulation control signals supplied thereto.

The control means (e.g., a microcontroller, microprocessor, digital signal processor or other control logic) is operably coupled to the gate drive circuitry for varying the duty cycle of the pulse width modulation control signals supplied to the gate drive circuitry in order to vary the input voltage level of the input DC electrical signals.In the preferred embodiment, the control scheme carried out by the control means includes an MPPT (Maximum Power Point Tracking) charging mode aswell as a bulk charging mode, an absorption charging mode, and a float charging mode.

In the MPPT charging mode, the control means regulates the input voltage of the input DC electrical

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signals such that it is maintained at the input voltage level corresponding to the estimated maximum power point as determined and stored by the control scheme. In the bulk charging mode, the control means regulates the output current of the output DC electrical signals such that it is limited to a predetermined maximum current limit.

In the absorption charging mode, the control means regulates the output voltage of the output DC electrical signals such that it is maintained at a predetermined absorption charging mode voltage level. In the float charging mode, the control means regulates the output voltage of the output DC electrical signals such that it is maintained at a predetermined float charging mode voltage level [70-72].

Additional objects and advantages of the invention will become apparent to those skilled in the art upon reference to the detailed description taken in conjunction with the provided figures.

IV. Description of the Drawings

FIG. 1

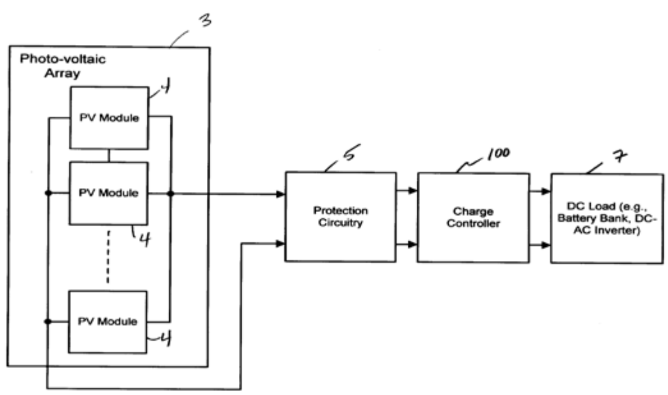


Fig. 1 : is a block diagram of a solar electric generator system in which the present invention can be embodied.

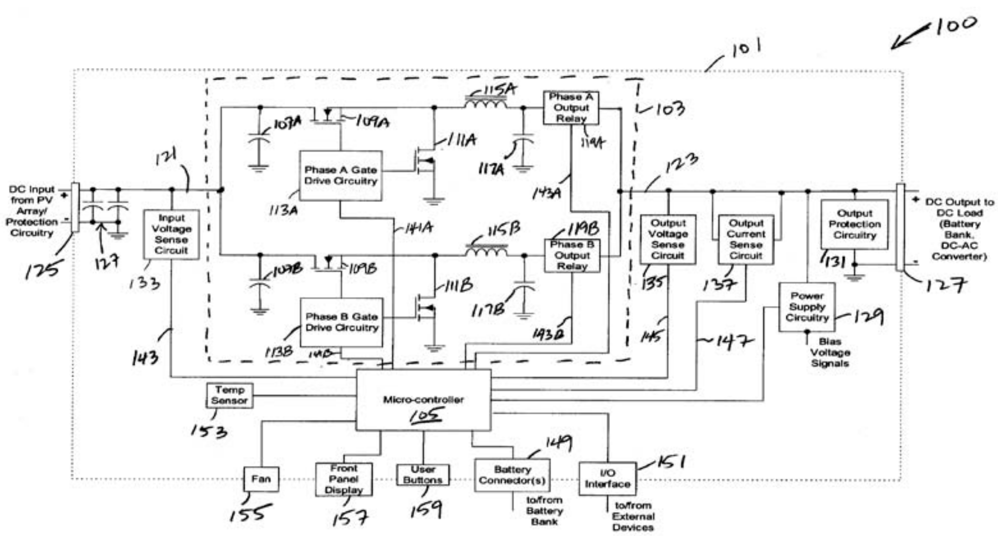
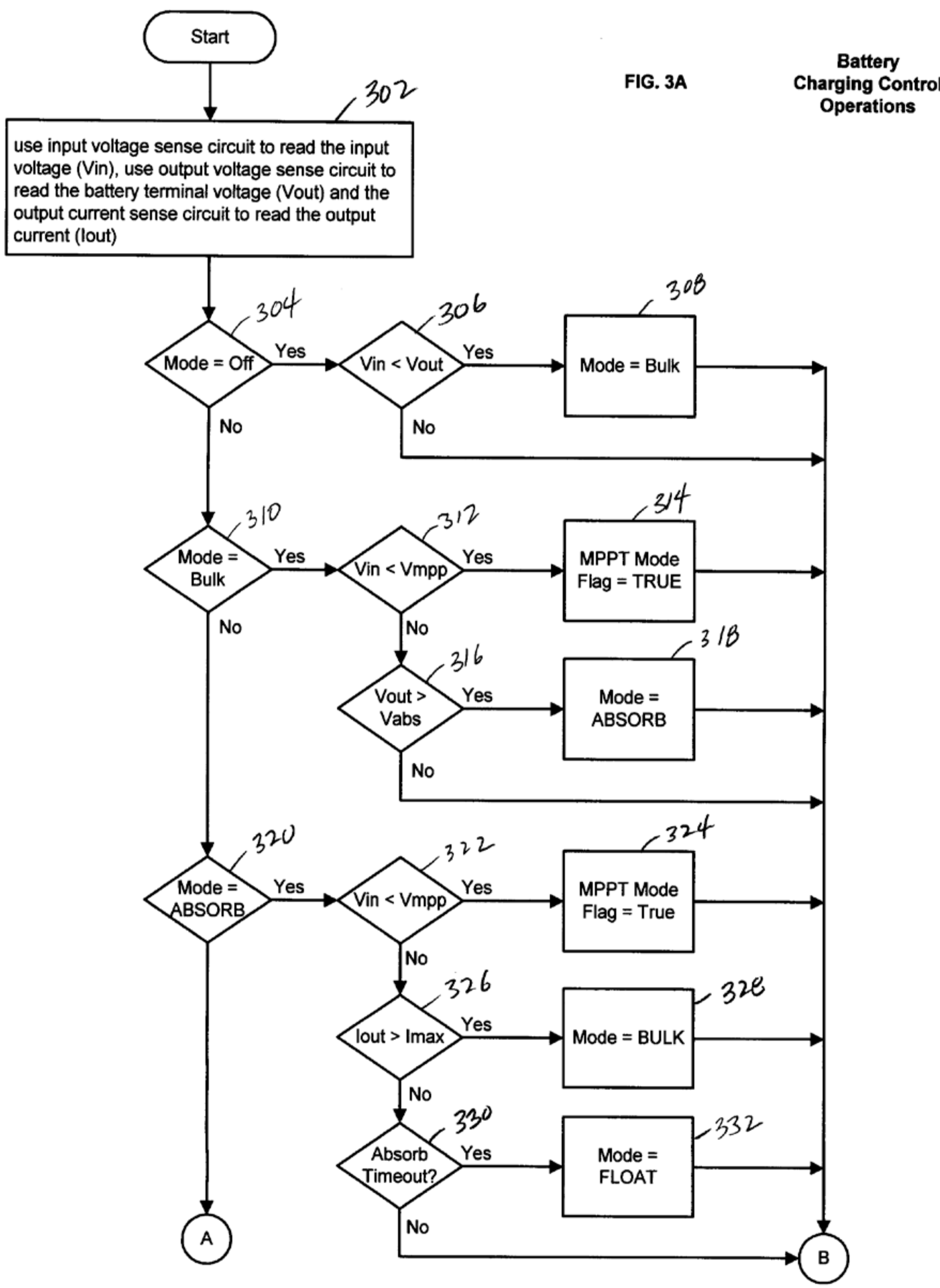


Fig. 2 : is a high-level schematic diagram of a charge controller in accordance with the present invention, which can be used as part of the solar electric generator system of FIG. 1 to convert the DC electrical signals generated by the photovoltaic array into a DC form suitable for supply to the DC load.



Figs. 3A and 3B : collectively, is a flow chart illustrating automatic battery charging operations carried out by the charge controller of FIG. 2 in accordance with the present invention;

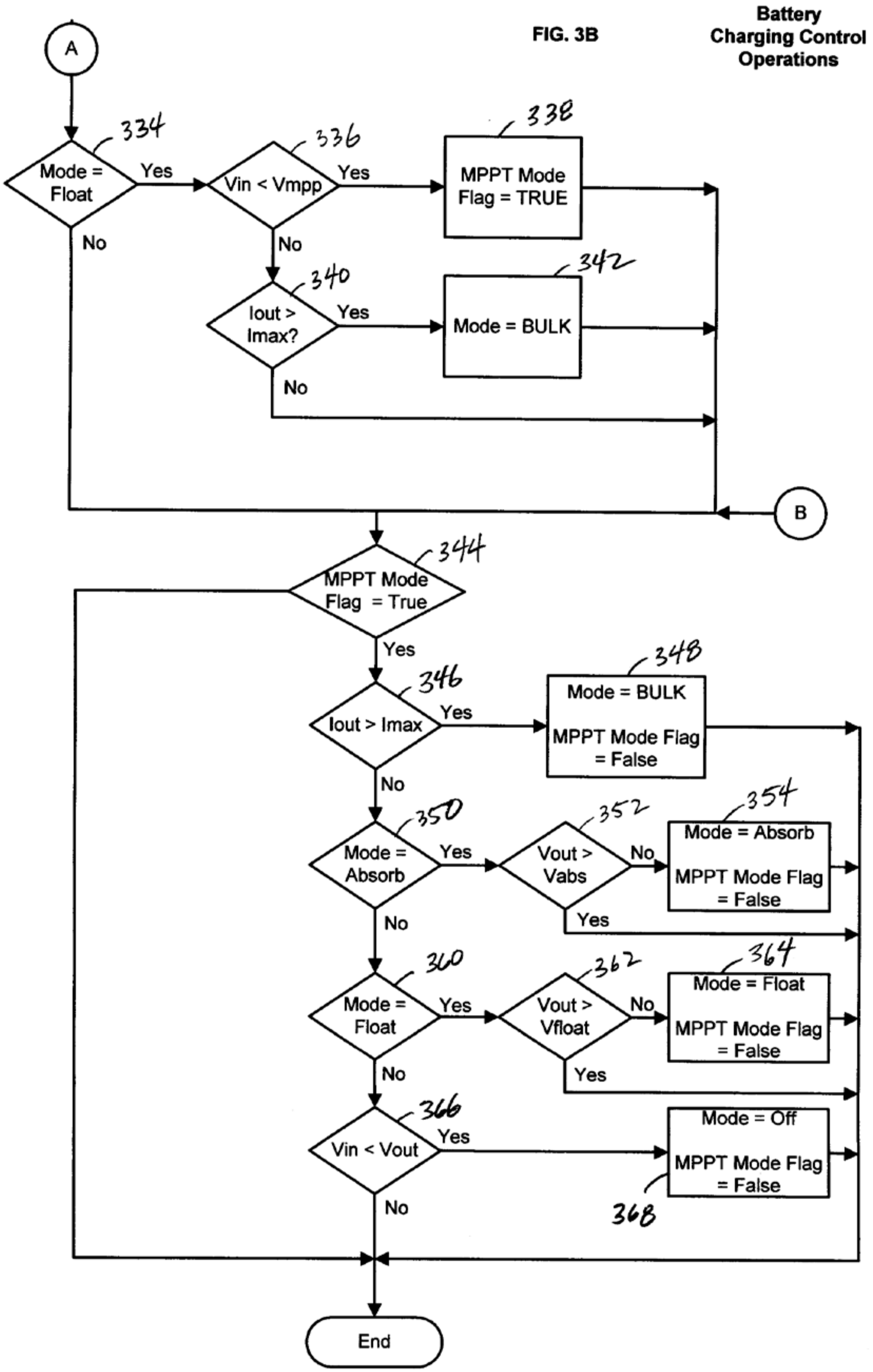


FIG. 3B
Battery Charging Control Operations
A
Mode = Float
334
Yes
No
Vin < Vmpp
336
Yes
No
MPPT Mode Flag = TRUE
338
Iout > Imax?
340
Yes
No
Mode = BULK
342
B
MPPT Mode Flag = True
344
Yes
Iout > Imax
346
Yes
No
Mode = BULK
MPPT Mode Flag = False
348
Mode = Absorb
350
Yes
No
Vout > Vabs
352
No
Yes
Mode = Absorb
MPPT Mode Flag = False
354
Mode = Float
360
Yes
No
Vout > Vfloat
362
No
Yes
Mode = Float
MPPT Mode Flag = False
364
Vin < Vout
366
Yes
No
Mode = Off
MPPT Mode Flag = False
368
End

FIG. 4A

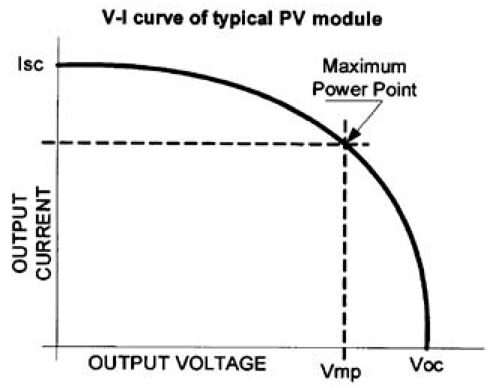


FIG. 4B

MPPT Scan

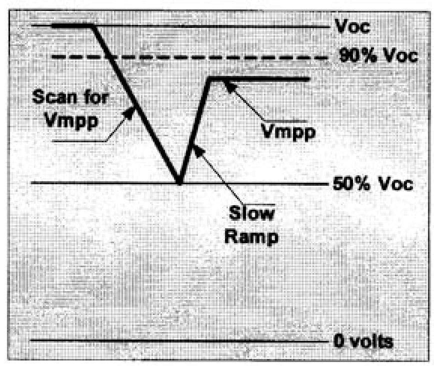


FIG. 4C

MPPT P&O

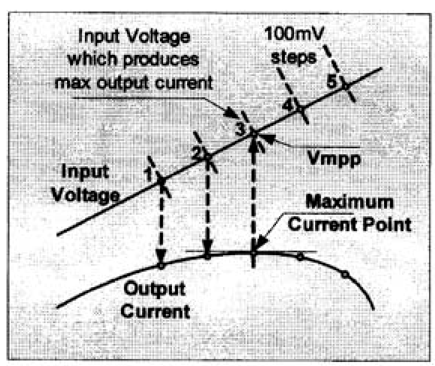


Fig 4a : is a pictorial illustration of the I-V curve of a typical photovoltaic module;

Fig 4b : is a pictorial illustration of exemplary scanning operations that are carried out by the charge controller of FIG. 2 for deriving an input voltage for estimated maximum power point conversion operations in accordance with the present invention;

Fig 4c : is a pictorial illustration of exemplary perturbation and observation operations that carried out by the charge controller of FIG. 2 for deriving the input voltage for estimated maximum power point conversion operations in accordance with the present invention;

FIG. 5 MPPT Mode Control

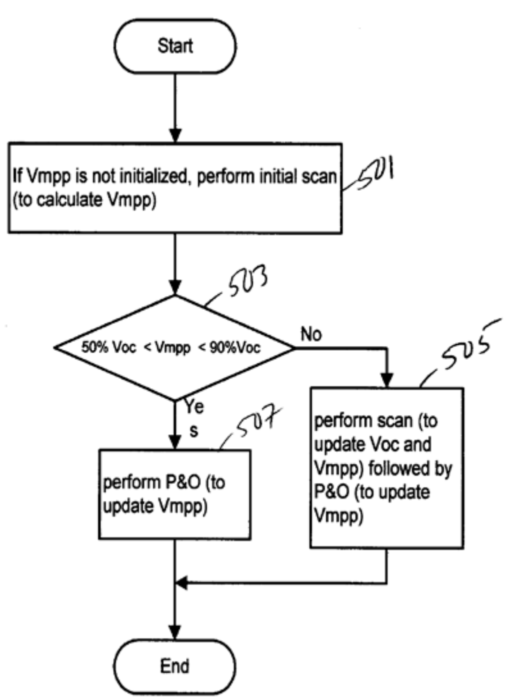


Fig. 5 : is a flow chart illustrating operations carried out by the charge controller of FIG. 2 for deriving the input voltage for estimated maximum power point conversion operations in accordance with the present invention.

V. Detailed Description of the Preferred Embodiments

Turning now to FIG. 1, there is shown a functional block diagram of a solar power conversion system **1** which includes a photo-voltaic (PV) array **3** capable of generating direct current electricity from incident solar radiation. The photo-voltaic array **3** typically includes a number of PV modules **4** each comprising a number of series-connected solar cells. The PV modules **4** can be connected in a parallel configuration as shown so that sufficient power can be generated under minimum radiation conditions. The DC electrical signals generated by the PV array **3** are supplied to a number of series-connected components including protection circuitry **5**, a charge controller **100** and a DC load **7**. The protection circuitry **5** provides for protection against lightning strikes and other faults (typically by shunting fault current to ground through MOVs and the like) and can also provide protection for reverse-polarity faults. The protection circuitry **5** may also be responsible for limiting the maximum voltage which can otherwise be higher than the maximum allowable voltage for the components in the next stage. The open-circuit voltage (Voc) of the PV array **3** is about 20% to 30% higher than the operating voltage of the same array and the increased voltages at low temperatures represent the worst case. The charge controller **100** converts the DC electrical signals generated by the PV array **3** into DC electrical signal suitable for output to the DC load **7**. The DC load **7** can be a bank of one or more batteries for energy storage and/or a DC-AC inverter for direct output.

As shown in FIG. 2, the charge controller **100** includes a system housing **101** supports a synchronous buck converter section **103** interfaced to a microcontroller **105**. The synchronous buck converter section **103** utilizes two switching elements (a series field effect transistor (FET) and a synchronous rectifier FET) to store energy into (and extract energy from) an inductor. The series FET and the synchronous rectifier FET are driven by gate drive circuitry to alternate between two states, a charging state and a discharging state. In the charging state, the series FET is turned ON and the synchronous rectifier FET is turned OFF such that the inductor is connected to a DC source voltage to store energy in the inductor. In the discharging state, the series FET is turned OFF and the synchronous rectifier FET is turned ON in order to discharge the energy stored in the inductor to the load. The gate drive circuitry that controls the operation of the series FET and the synchronous FET must prevent both switches from being turned on at the same time, which is a fault known as "shoot-through". During operation, the cooperation of the switching action of the series FET, synchronous rectifier FET and the inductor reduce the DC source voltage level by a factor which is controlled by the duty cycle for the charging state of both FETs. This duty cycle is controlled by pulse width modulation (PWM) control signals supplied to the gate drive circuitry as is well known.

A multiphase synchronous buck converter is a topology whereby multiple buck converter circuits as described above are placed in parallel between the source voltage and the load and controlled to out of phase with each other. For example, two parallel circuits are set to switch such that one circuit is ON while the other is OFF. In other words, the two circuits are 180 degrees out of phase with one another. The primary advantage of this multiphase topology is that the load current can be split among the circuits or phases, thus allowing for increased load currents. Another equally important advantage is that the output ripple is reduced by the number of phases, thus allowing for easier filtering and lower output ripple. Each of these "phases" is turned ON at predetermined intervals over the switching period.

In the illustrative embodiment shown, the buck converter section **103** employs a two phase topology with two high current paths (phases A and B) each having input capacitance **107**, a series FET **109**, a synchronous rectifier FET 111, gate drive circuitry 113, an inductor 115, output capacitance 117, and an output relay 119. The input capacitance 107 and the series FET 109 of the two phases are connected to an input path 121 as shown. The output relays 119 of the two phases are connected to an output path 123 as shown. The input capacitance 107 filters unwanted high frequency noise components. The output capacitance 117 filters the current flowing from the inductor in the discharge state with the series FET 109 turned OFF and the synchronous rectifier FET 111 turned ON. The output capacitance 117 also provides low impedance for transient load current changes, thus reducing steady-state output ripple.

An input connector 125 provides for supply of the positive (+) and negative (−) DC voltage signals generated by the PV array 3 of FIG. 1. Input reservoir capacitors 127 are connected between these two DC voltage signals via the input connector 125. The positive (+) terminal of the connector 125 and the positive terminal of the input reservoir capacitors 127 are connected to the input path 121 of the buck converter section 103 as shown. The input reservoir capacitors 127 are charged in the charging state (when the series FET 109 for the two phases is OFF) and discharged in the discharging state (when the series FET 109 for the two phases is OFF and the synchronous rectifier FET 111 for the two phases is ON). The input reservoir capacitors 127 witness pulsed current with an amplitude equal to the load current. It is common practice to select the input reservoir capacitance with an RMS current rating more than half the maximum current load. If multiple capacitors are paralleled, the RMS current for each input reservoir capacitor should be total current divided by the number of input reservoir capacitors.

The output path 123 of the buck converter section 103 is connected to the positive (+) terminal of an output connector 127. The negative (–) terminal of the output connector 127 is grounded as shown. The output connector 127 provides for supply of positive (+) and negative (–) DC voltage signals generated by the buck converter section 103 to the DC load of FIG. 1, which can be battery bank and/or an DC-AC Inverter or other DC load.

Power supply circuitry 129 can be connected to the positive (+) terminal of the output connector 127 as shown. The power supply terminal transforms the DC voltage signal carried by the positive (+) terminal of the output connector 127 to internal bias voltage levels for supply to electrical components of the converter 100 as needed. Output protection circuitry 129 can also be provided between the positive (+) and negative (−) terminals of the output connector 127 to provide for overvoltage protection and possibly backflow current protection.

The microcontroller 105 supplies PWM control signals to the gate drive circuitry 113A, 113B of the two phases via control lines 141A, 141B. These PWM control signals effectuate desired control over the duty cycle of the charging state of the series FETs 109A, 109B for the two phases. The gate drive circuitry 113A, 113B for the two phases also controls the operation of the synchronous rectifier FETS 111A, 111B for the two phases based upon the PWM control signals supplied thereto. In the preferred embodiment, the series FETs 109A, 109B and the synchronous rectifier FETs 111A, 111B of the two phases are switched at a frequency of 30 KHz or greater when combined in order to keep noise above human hearing

For battery charging operations (e.g., Bulk Charging, Absorption Charging, Float Charging), the microcontroller 105 controls duty cycle of the PWM control signals supplied to the gate drive circuitry 113A, 113B (and thus controls the duty cycle of the charging state of the series FETs 109A, 109B for the two phases) based upon the input voltage provided by the PV array, the output voltage level and the output current level supplied to the DC load (i.e., the battery bank), and the battery current produced by the battery bank. The input voltage is measured by the input voltage sense circuit 133, which supplies a signal representative of the input voltage to the microcontroller 105 via path 143 for conversion into digital form therein. The output voltage is measured by the output voltage sense circuit 135, which supplies a signal representative of the output voltage to the microcontroller 105 via path 145 for conversion into digital form therein. The output current is measured by the output current sense circuit 137, which supplies a signal representative of the output current to the microcontroller via path 147 for conversion into digital form therein. The battery current is measured either by an internal current sensing device such as a shunt resistor or hall effect device, or alternatively by an external shunt at the battery bank (not shown), which supplies a signal representative of the battery current to the microcontroller via connector 149 for conversion into digital form therein.

The microcontroller 105 can also measure and/or maintain information regarding other characteristics of the battery bank, such as temperature of the battery bank and the battery terminal voltage measured by Kelvin connections. In the exemplary embodiment, a temperature sensor at the battery bank supplies a signal representative of the battery bank temperature to the microcontroller 105 via connector 149 for conversion into digital form therein. Similarly, a Kelvin connection at the battery bank supplies a signal representative of the terminal voltage of the battery bank to the microcontroller 105 via connector 149 for conversion into digital form therein. The Kelvin connection allows for more accurate monitoring of the terminal voltage of the battery bank, especially during high current charging operations. In such high current charging operations, there can be a significant voltage drop across the output of the converter, which causes the output voltage sense circuit **135** to underestimate of the true battery voltage. The Kelvin bridge circuit eliminates these inaccuracies as it provides an accurate measurement of the terminal voltage of the battery bank during such high current charging operations. The high accuracy battery voltage measurements are used in the preferred embodiment to provide more accurate battery charging.

The microcontroller **105** also interfaces to a temperature sensor **153** internal to the system housing **101** to measure the internal temperature of the system housing **101**. This temperature can be used to activate, deactivate and control the speed of a fan **155** that blows air from outside the system housing to the interior space of the system housing for cooling as is well known. The microcontroller **105** can also interface to a temperature sensor (not shown) to measure the temperature on the interior or of the heat sink. This temperature too can be used to control the speed of the fan **155** (or additional fans) for cooling as needed.

The microprocessor **105** also interfaces to a front panel display and/or LED **157** and user input buttons **159** for presenting status information to the user as well as carrying out user interaction and control. The front panel display and/or LED **157** preferably presents status indications of a multiplicity of parameters including PV voltage, PV current, battery voltage, charging current, charging status, energy harvest history, battery energy status, energy used, etc.

In accordance with the present invention, the charge controller **100** of FIG. 2 can be adapted for use in a wide range of applications, including the charging of a battery bank for the storage of electrical energy therein and/or the direct output of electrical energy to a DC-AC inverter and the like. FIGS. 3A and 3B, collectively, is a flow chart illustrating exemplary control operations carried out by the microcontroller **105** for automatic charging of a battery bank. The control operations employ five charging modes: Off, Bulk Charging Mode (for a highly discharged battery), Absorption Charging Mode, Float Charging Mode, and Maximum Power Point Tracking (MPPT) mode.

a) Off Mode

In the Off mode, the microcontroller **105** opens the output relays **119** such that no current is passed through to the battery bank.

b) Bulk Charging Mode

In the bulk charging mode, the microcontroller **105** regulates the output current (as measured by the output current sense circuit **137**) such that it is at the maximum current limit of the converter (which is referred to herein as Imax and is designed to prevent overload). The maximum current Imax is preferably a parameter that is set and possibly updated by user input; alternatively, it can be stored as a constant value. The microcontroller **105** regulates the output current by controlling the duty cycle of the PMW control signals supplied to the gate drive circuitry **113**A, **113**B. The Bulk charging mode is used to charge a battery that is in a relatively low charge state.

c) Absorption Charging Mode

In the absorption charging mode, the microcontroller **105** regulates the output voltage level (as measured by the output voltage sense circuit **135** or by the Kelvin connection), such that it is maintained at a predetermined absorption voltage level (referred to herein as Vabs). The predetermined absorption voltage level is preferably a parameter that is set and possibly updated by user input; alternatively, it can be stored as a constant value. The microcontroller **105** regulates the output voltage by controlling the duty cycle of the PMW control signals supplied to the gate drive circuitry **113**A, **113**B. The Absorption charging mode is used to charge a battery at a relatively high charge state.

d) Float Charging Mode

In the float charging mode, the microcontroller **105** regulates the output voltage level (as measured by the output voltage sense circuit **135** or by the Kelvin connection), such that it is maintained at the predetermined float voltage level (referred to herein a Vfloat). The predetermined float voltage level is preferably a parameter that is set and possibly updated by user input; alternatively, it can be stored as a constant value. The microcontroller **105** regulates the output voltage by controlling the duty cycle of the PMW control signals supplied to the gate drive circuitry **113**A, **113**B. The float charging mode is used to charge a battery at a full or substantially full charge state

e) MPPT Mode

In the MPPT mode, the microcontroller **105** regulates the input voltage level such that it is maintained at or near the peak power point on the current-voltage curve for the PV array **3** connected thereto. This voltage level is referred to herein as "Vmpp". The microcontroller **105** regulates the input voltage by controlling the duty cycle of the PMW control signals supplied to the gate drive circuitry **113**A, **113**B.

The automatic battery charging operations of FIGS. 3A and 3B are performed on a periodic basis, preferably at least every 2 milliseconds or shorter. Such timing can be controlled by an interrupt timer or other timing circuitry. The operations are carried out using a state variable "Mode" that is set to correspond to the given operational mode, which can be either a predetermined value for the Off mode, a predetermined value for Bulk Charging, a predetermined value for Absorption Charging or a predetermined value for Float Charging. Because the MPPT mode can be used in conjunction with any one of the Bulk, Absorption and Float charging modes, a status flag ("MPPT mode

FLAG") is also used. The MPPT mode flag is set to true when the MPPT mode is active and set to false when the MPPT mode is inactive.

When the Mode variable is set, the microcontroller **105** automatically transitions to carry out the corresponding control operations for the particular mode as described above. In the Off mode, the microcontroller **105** opens the output relays **119** such that no current passes through from the input path **121** to the output path **123** and to the battery bank. In the Bulk charging mode, the microcontroller **105** regulates the output current such that it is at the maximum current limit Imax. In the Absorption charging mode, the microcontroller **105** regulates the output voltage level such that it is maintained at a predetermined absorption voltage level Vabs. In the Float charging mode, the microcontroller **105** regulates the output voltage level such that it is maintained at the predetermined float voltage level Vfloat.

When the MPPT mode flag is set to true, the MPPT mode operations override the charging mode operations (Bulk, Absorption or Float charging operations) as dictated by the Mode variable. Such override processing causes the microcontroller **105** to regulate the input voltage level such that it is maintained at or near the Vmpp value as described herein. When the MPPT mode flag is set to false, the override processing is avoided such that the charging mode operations dictated by the Mode variable are performed.

The operations begin in step **302** where the microcontroller **105** uses the input voltage sense circuit **133** to measure the input voltage (Vin), uses the output voltage sense circuit **135** to measure the output voltage (Vout), and uses the output current sense circuit **137** to measure the output current (Iout). For reverse current protection, the output relays **119** are switched OFF in the event that the output current Iout is less than a minimal threshold current, for example 2 amperes. The output relays **119** are switched ON for power conversion in the Bulk Charging, Absorption Charging, Float Charging and MPPT modes.

In step **304**, the microcontroller **105** determines if the Mode variable is set to the "Off" value. If the determination of step **304** is false, the operations continue to step **310**. If the determination of step **304** is true, the operations continue to step **306** where the microcontroller **105** checks whether the input voltage Vin is less than the output voltage Vout. If the decision of step **306** is true, the microcontroller **105** in step **308** sets the Mode variable to the "Bulk" value and the operations continue to step **344**. If the decision of step **304** is false, the microcontroller **105** continues to step **344**.

In step **310**, the microcontroller **105** determines if the Mode variable is set to the "Bulk" value. If the determination of step **310** is false, the operations continue to step **320**. If the determination of step **310** is true, the operations continue to step **312** where the microcontroller **105** checks whether the input voltage Vin is less than the maximum power point voltage Vmpp. If the decision of step **312** is true, the microcontroller **105** in step **314** sets the MPPT Mode flag to true and the operations continue to step **344**. If the decision of step **312** is false, the microcontroller **105** continues to step **316** to check whether the output voltage Vout is greater than the absorption voltage Vabs. If the decision of step **316** is true, the microcontroller **105** in step **318** sets the Mode variable to the "Absorb" value and the operations continue to step **344**. If the decision of step **316** is false, the operations continue to step **344**.

In step **320**, the microcontroller **105** determines if the Mode variable is set to the "Absorb" value. If the determination of step **320** is false, the operations continue to step **334**. If the determination of step **320** is true, the operations continue to step **322** where the microcontroller **105** checks whether the input voltage Vin is less than the maximum power point voltage Vmpp. If the decision of step **322** is true, the microcontroller **105** in step **324** sets the MPPT Mode flag to true and the operations continue to step **344**. If the decision of step **322** is false, the microcontroller **105** continues to step **326** to check whether the output current Iout is greater than the maximum output current Imax. If the decision of step **326** is true, the microcontroller **105** in step **328** sets the Mode variable to the "Bulk" value and the operations continue to step **344**. If the decision of step **326** is false, the operations continue to step **330** to check if an absorption timer has expired. The absorption timer is automatically set when the microcontroller **105** transitions from the Bulk mode to the Absorption mode. The initial absorption timer value is preferably a parameter that is set and possibly updated by user input; alternatively, it can be stored as a constant value. If the test of step **330** is true, the microcontroller **105** in step **332** sets the Mode variable to the "Float" value and the operations continue to step **344**.

In step **334**, the microcontroller **105** determines if the Mode variable is set to the "Float" value. If the determination of step **334** is false, the operations continue to step **344**. If the determination of step **334** is true, the operations continue to step **336** where the microcontroller **105** checks whether the input voltage Vin is less than the maximum power point voltage Vmpp. If the decision of step **336** is true, the microcontroller **105** in step **338** sets the MPPT Mode flag to true and the operations continue to step **344**. If the decision of step **336** is false, the microcontroller **105** continues to step **346** to check whether the output current Iout is greater than the maximum output current Imax. If the decision of step **346** is true, the microcontroller **105** in step **342** sets the Mode variable to the "Bulk" value and the operations continue to step **344**.

In step **344**, the microcontroller **105** checks whether the MPPT status flag is set to true. If the test of step **344** fails, the operations end. If the test of step **344**

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is true, the operations continue in step **346** to check whether the output current Iout is greater than the maximum output current Imax. If the decision of step **346** is true, the microcontroller **105** in step **348** sets the Mode variable to the "Bulk" value and clears the MPPT Mode flag to false and the operations end. If the decision of step **346** is false, the operations continue to step **350**.

In step **350**, the microcontroller **105** checks whether the Mode variable is set to the "Absorb" value. If the test of step **350** is false, the operations continue to step **360**. If the test of step **350** is true, the microcontroller **105** continues to step **352** to check whether the output voltage is greater than the Vabs. If so, the operations continue to step **354** to set the Mode variable to the "Absorb" value and clears the MPPT Mode flag to false and the operations end. If not, the operations end.

In step **360**, the microcontroller **105** checks whether the Mode variable is set to the "Float" value. If the test of step **360** is false, the operations continue to step **366**. If the test of step **360** is true, the microcontroller **105** continues to step **362** to check whether the output voltage is greater than Vfloat. If so, the operations continue to step **364** to set the Mode variable to the "Float" value and clears the MPPT Mode flag to false and the operations end. If not, the operations end.

In step **366**, the microcontroller **105** checks whether the input voltage is greater than the output voltage. If so, the Mode variable is set to the "Off" value and clears the MPPT Mode flag to false and the operations end. If not, the operations end.

In each one of the Bulk Charging Mode, Absorption Charging Mode and the Float Charging mode, the PV array may not be able to supply the required power to achieve the desired voltage or current limits set by the charging operations. Under these conditions, the microcontroller **105** transitions to the MPPT mode. For example, for the Bulk Charging Mode, the microcontroller **105** automatically transitions to the MPPT mode in steps **312** and **314**. In the Absorption Charging Mode, the microcontroller **105** automatically transitions to the MPPT mode in steps **322** and **324**. In the Float Charging Mode, the microcontroller **105** automatically transitions to the MPPT mode in steps **336** and **338**.

For the MPPT mode, the microcontroller **105** regulates the input voltage level such that it is maintained at or near the peak power point on the current-voltage curve for the PV array as shown graphically in FIG. 4A. This voltage level is referred to herein as "Vmpp". In the preferred embodiment, the Vmpp voltage level is derived from a scanning step as well as perturbation and observation steps. The scanning step is graphically illustrated in FIG. 4B and the perturbation and observation steps are graphically illustrated in FIG. 4C.

The scanning step establishes the open circuit voltage of the PV array together with an initial value for Vmpp. The perturbation and observation steps vary the input voltage to multiple sample points about the initial "Vmpp" value established by scanning and measures the output current at each sample point. The sample point with maximum output current is selected as the new "Vmpp" value.

In the illustrative embodiment, the scanning steps include the following sequence of operations:

the duty cycle of the converter section **103** is reduced to zero such that the switching devices remain OFF for a predetermined sampling period such that the input voltage sense circuit measures the open circuit voltage Voc of the PV panel. The microcontroller **105** reads this measurement via input path **143**.

i) the microcontroller **105** sweeps the input voltage over sample points within a predetermined voltage range based on the Voc measured in i); for example, the predetermined voltage range can be from Voc to 50% to 60% Voc (or to 130% of the battery terminal voltage, whichever is greater); in the preferred embodiment, the microcontroller **105** ramps down the input voltage on 1 volt steps every 400 milliseconds.
ii) at each one of the sample points in ii), the microcontroller **105** measures and stores the output current; and
iii) the microcontroller **105** analyzes the stored output current values over the sample points of the scan to identify the sample point with the maximum output current value. This highest output current value, denoted Impp establishes the initial voltage level "Vmpp" that provides peak power; and
iv) the microcontroller **105** then slowly increases the input voltage level from the floor (low point) of the scan to the "Vmpp" level. The slow adjustment to the input voltage level (which is preferably on the order of **1** volt every 200 milliseconds) prevents rapid changes in current which can cause overshoot and errors in the control routine.

In alternative embodiments, it is contemplated that the scanning operations can start at the bottom of the range and sweep the input voltage by ramping up the input voltage. At the top of the range, the microcontroller can then ramp down the input voltage to the Vmpp voltage level.

In the illustrative embodiment, the perturbation and observation steps include the following sequence of operations:

i) the output current is measured a number of times (for example, 128 times in one embodiment) to reduce any inaccuracies due to noise and the average is stored as the maximum current point

Impp (which is labeled P3 for purposes of illustration in FIG. 4C);

ii) the input voltage is reduced by 200 mV by adjusting the duty cycle of the PWM control signals supplied to the gate driver circuitry **113** and the output current is again measured many times, averaged and recorded (this point is labeled P1 for purposes of illustration in FIG. 4C);

iii) the input voltage is increased by 100 mV by adjusting the duty cycle of the PWM control signals supplied to the gate driver circuitry **113** and the output current is again measured many times, averaged and recorded (this point is labeled P2 for purposes of illustration in FIG. 4C);

iv) the input voltage is increased to 100 mV above the voltage value for the Impp point in i) by adjusting the duty cycle of the PWM control signals supplied to the gate driver circuitry **113** and the current is again measured many times, averaged and recorded (this point is labeled P4 for purposes of illustration in FIG. 4C);

v) the input voltage is increased to 100 mV by adjusting the duty cycle of the PWM control signals supplied to the gate driver circuitry **113** and the current is measured again many times, averaged and recorded (this point is labeled P5 for purposes of illustration in FIG. 4C); and

vi) The stored output current values for the steps i)-v) above are processed to select the highest output current value and the voltage value for that selected sample point is stored as the new Vmpp value.

Note that for the perturbation and observation step described above, the number of sample points, the voltage difference between the sample points, and the order in which the sample points are measured can be changed as desired and are proved for illustrative purposes.

Also note that for the perturbation and observation step described above, one of the sample points is the Vmpp point itself, multiple sample points are provided at voltage levels above the Vmpp point, and multiple sample points are provided at voltage levels below the Vmpp point. Such sampling quickly locates the maximum power point and thus reduces the processing time and delays associated therewith. Such reduction in processing time improves the efficiency of the power conversion process, especially in dynamic conditions (e.g., changing sunlight due to moving cloud cover and the like).

FIG. 5 is a flow chart illustrating exemplary control operations that are carried out by the microcontroller **105** in order to calculate and update the Vmpp value as described herein. Such operations are preferably performed on a periodic basis when the MPPT mode flag is activated in accordance with the operations of FIG. 3 as described above. Such timing can be controlled by an interrupt timer or other timing circuitry. In the illustrative embodiment, the operations of FIG. 5 are performed on a period basis every 2 milliseconds or shorter, which corresponds to a frequency of 500 Hz or greater. In this manner, the Vmpp values are updated at least every 2 milliseconds or less (or at a frequency of 500 Hz or greater), which enhances the efficiency of the conversion process especially during dynamic conditions.

In step **501**, the microcontroller **105** checks whether the Vmpp has been initialized. If no, the microcontroller **105** performs as initial scanning step as described above with respect to FIG. 5B. This scanning step calculates the initial Vmpp value for the MPPT mode processing.

In step **503**, the microcontroller **105** checks whether the input voltage Vin is within a predetermined voltage range (for example between 50% Voc and 90% Voc. If not, the operations continue to step **505** to perform a scanning step as described above with respect to FIG. 5B followed by a perturbation and observation step as described above with respect to FIG. 5C. The scanning of step **505** updates the open circuit voltage Voc and the Vmpp value, and the perturbation and observation of step **505** updates the Vmpp value. From step **505**, the operations end.

If the results of step **503** indicate that the input voltage Vin is within the predetermined voltage range, the operations continue to step **507** to perform a perturbation and observation step as described above with respect to FIG. 5C. The perturbation and observation of step **507** updates the Vmpp value. From step **507**, the operations end.

There have been described and illustrated herein an embodiment of charge controller for solar applications and methods of operating same. While a particular embodiment of the invention have been described, it is not intended that the invention be limited thereto, as it is intended that the invention be as broad in scope as the art will allow and that the specification be read likewise. Thus, while particular control operations (including particular control states and transitions between control states) have been disclosed, it will be appreciated that other control operations can be used as well. In addition, while particular buck-type converter topologies have been disclosed, it will be understood that the general control operations described herein can be used with other PWM-controlled converter topologies or other non-PWM converter topologies.

Also, while it is preferred that the control operations of the charge controller be carried out by a microcontroller element, it will be recognized that other control elements and control systems can be used (such as a microprocessor, a digital signal processor, an ASIC, a CPLD, an FPGA, or other digital logic device).

VI. Conclusion

It is preferably that the control operations be realized as a program of instructions that are loaded into the firmware of the microcontroller or other programmed logic device. Furthermore, while the embodiments described above utilize field effect transistors as switching devices, it will be understood that other switching devices such as IGBT insulated gate bipolar transistors can be similarly used. In addition, while particular solar applications have been disclosed, it will be understood that the charge controller described herein can be adapted for other energy conversion applications such as wind energy harvesting, wave-energy harvesting, hydroelectric energy harvesting, thermoelectric energy harvesting, etc. It will therefore be appreciated by those skilled in the art that yet other modifications could be made to the provided invention without deviating from its spirit and scope as claimed.

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Global Energy: Need, Present Status, Future Trend and key Issues

By Md. Nasir Uddin MM Rashid, MG Mostafa, Belayet H, SM Salam & NA Nithe
International Islamic University Malaysia, Malaysia

Abstract- Human beings, unlike other biological species, had always and still have the universal desire or instinct of improving quality of life. This inherent instinct has caused previously unimagined explosion of amenities of life, change in life style, improvement of standard of living and resulted sharp growth of global population and life expectancy. Better quality of life requires more works to be done to cook food, build housing, construct roads, and produce clothes and lighting and primarily to generate motive power to produce present day goods and services. Energy sources are needed to fulfill the ever-increasing human needs.

Traditional sources of energy e.g. firewood and vegetable wastes, animal power, wind, sun and the traditional ways of using these sources could not match with the increased energy demand. Commercial energy sources: coal, oil and gas are presently playing the dominant role. But the reserves of these sources are finite. New and renewable energy sources like: hydro, nuclear, solar, wind, hydrogen, synthetic oils etc. are also contributing to meet the rising global energy demand but the contribution of these sources is still very limited..

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Electricity is the most preferred from of energy to meet the end use. The growth rate of electricity is the highest and is likely remain so in the coming years. The paper primarily discusses, in brief, the global energy need, present status, future trend and the key issues involved with energy development that have to be confronted in meeting the sustainable development as well as to achieve the Millennium Development Goals (MDGs).

I. Introduction

Energy is the capacity to do work. It is an essential element to produce the goods and services required for higher quality of life. Energy in various forms is needed to grow food crops to cook food, to produce clothes, to build houses, construct roads and bridges, for transportation, for lighting and even to compute and send information and signals in the present day of information and communication technology. All these activities need sources of energy to perform the desired activities.

The primary energy sources are geographically unevenly distributed. Economic development depends on the available opportunities. Availability of final energy increases or widens the choices or opportunities. The explosion of global population and the economic activities have created tremendous pressure on the commercial sources. Use of fossil fuels is causing global warming and environmental degradation. The cost of large-scale use of renewable energy sources is still economically prohibitive.

Energy affects health and environment. Global warming and climatic change and the environmental pollution are linked with energy. Commercial sources are finite. The question of sustainable development as such is a challenge before the world community.

Wide disparities exist among states and among communities within a state. "Today, citizens of the ten wealthiest countries are at least 75 times richer than those who live in the ten poorest ones, and the chasm is widening" [1]. Millennium Development Goals (MDGs) have been set to reduce poverty, hunger, and diseases to half by 2015 [Annex- I]. Energy is linked with the fulfillment of MDGs [2].

Comprehensive assessment and analyses with knowledge and wisdom from the perspective of present and future global and regional needs are essential to address energy related issues.

II. Energy

The universe constitutes of two fundamental things: matter and energy. These are inter- convertible. The dynamic universe is evolving at the expense of energy. The paper deals with human centered energy only. Lots of works are and have to be carried out in order to maintain and improve quality of life. Without energy no work can be done.

a) *Energy Terms*

While the subject is being explored further, the meaning and perceptions of some (the reaming ones may be seen at Annex – II) of the terms that are often used in energy domain should be clear. Some of these terms are discussed below[3].

Energy System: may be defined as all the activities starting form the exploration of the primary energy sources to the end use including processing, transportation, conversion, distribution etc. The Fig.1 shown below helps to understand the energy system [4].

Author α σ ρ: Department of Mechatronics Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia.
e-mail: nasir.u@live.iium.edu.my
Author ω ¥ §: Department of Electrical & Electronics Engineering, ADUST, BUET, I&E, Dhaka, Bangladesh.

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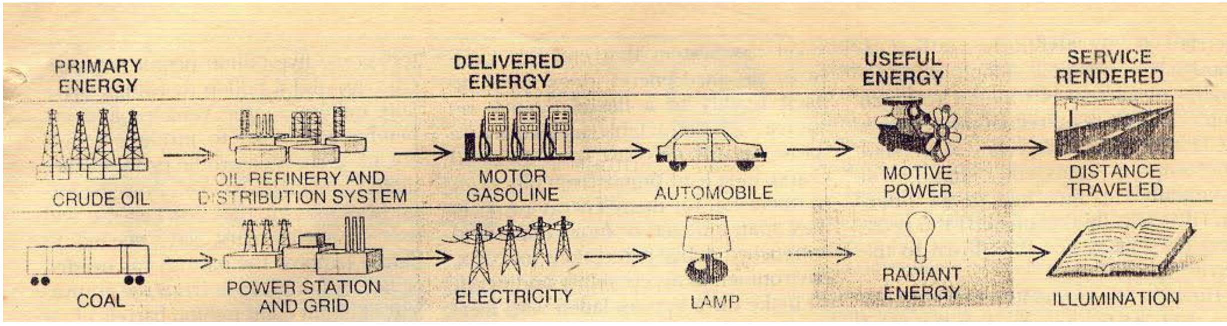


Fig. 1: Energy System, Source: p.22 Scientific American, September 1990

Energy Services: are used to describe consumer benefits, which include: lighting, air- conditioning, refrigeration, cooking, transportation, providing motive power etc.

Energy Chain: includes activities that link the primary energy to deliver energy services.

Energy Security: may be defined as the national policy actions assuring the availability of all energy forms at affordable prices and in sufficient quantities for a reasonable future period (30 to 50 years, depending on many factors).

Energy Intensity: is the ratio of the quantity of energy consumed for producing unit of gross domestic product.

Commercial Energy: is the energy that is subject to a commercial transaction and thus can be accounted for.

Biomass: is the organic non-fossil material oil or gas of biological origin, which constitutes an exploitable energy resource.

Primary Energy: is the energy extracted directly from nature e.g. crude oil, hard coal, natural gas, wood, solar-wind-hydro power, uranium (as we receive from nature) etc.

Final Energy: is the energy delivered to the customer often after processing e.g. electricity, gasoline, diesel, coal, gas, compressed natural gas etc. The primary and final energy situation of France shown in Fig.2 may help in clearing the ideas behind the terminology [5].

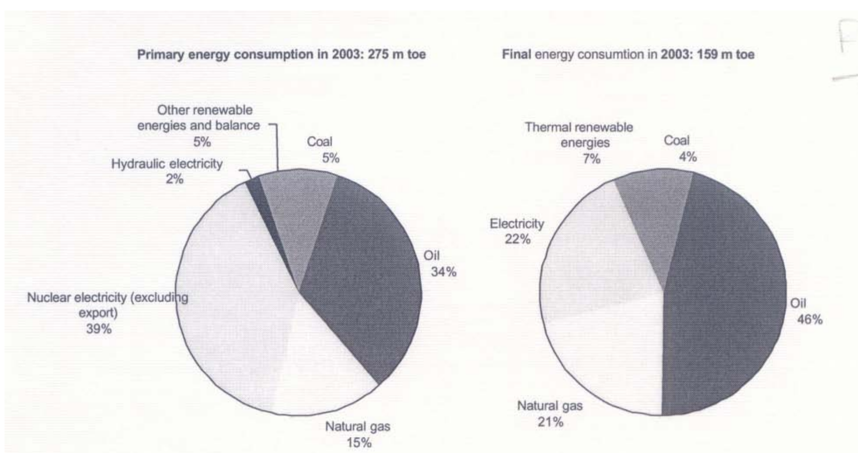


Fig. 2 : Primary and Final Energy , Source: [5]

Reserves : are those occurrences of energy sources or minerals that are identified and measured as economically and technically recoverable with current technology and prices [5].

Resources : are those occurrences of energy sources or minerals with less certain geological and/or economic/technical recoverability characteristics, but that are considered to become potentially recoverable with foreseeable economic and technological development.

b) *Sustainable Development*

The world community committed (Agenda 21) for achieving human centered Sustainable Development at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. More than 175 states are now parties to this programme [6].

The World Commission on Environment and Development defines sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (p.8.); also "as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potentials to meet human needs and aspirations" (p.46). In broad sense the report notes, "the strategy for sustain able development aims to promote harmony among human beings and between humanity and nature" [7].

c) Energy Forms

There are different forms of energy, gas, coal, oil, hydro, nuclear, electricity, light, heat, potential, kinetic etc. The selection or suitability of the form will depend on the end use. Electricity is the most preferred form.

III. Energy Need

a) Population Growth

It took about 600 thousand years (form early Java man) for the human population to cross the limit of 1 billion around 1800 AD, but the same increased by 4 billions in just 55 years (from 2.48 billions in 1950 to 6.46 billions in 2005). The 2^{nd} and the 5^{th} billion were added to the global population in just 123 and 13 years respectively [8].

The population growth is much more significant in the developing countries (90% growth is taking place in this region) than the developed world [8]. This trend will remain so in the coming years. The world population, though the growth rate is declining due to fall in reproduction and fertility rates, is expected to rise to 10.1 billion by 2050 [8]. More energy will therefore be needed for the expanding global population.

b) Quality Living

A full grown person needs about 2200 kilocalorie of energy per day, which is generated through food intakes. Human beings are the only bio-species, which presently consume on the average about 75 gigajoule of energy which, is about 22 times more energy than what is required for living. The excess amount is required to maintain the life style and the standard of living. The urge for better living is a universal human instinct. Easy availability of plentiful and affordable different forms of energy allows many people to enjoy unprecedented comfort, mobility and productivity. Consequently the quality of living is improving and the energy consumption rate per person is also increasing.

The desire for the improvement of quality of life is universal. The effect of globalization, particularly the, electronic media and information and communication technology has strengthened this urge of better life. Energy is needed to fulfill this urge.

c) Knowledge Explosion

The ever expanding knowledge and understanding of physical laws and chemical behavior of matter, the application of more and more sophisticated technology in production and services led to the previously unthinkable living standard (at least for those living in the developed world), higher life expectancy and a consequent sharp rise of global population. The world knowledge is doubling every five years as more and more persons are engaged in research and development works [9].

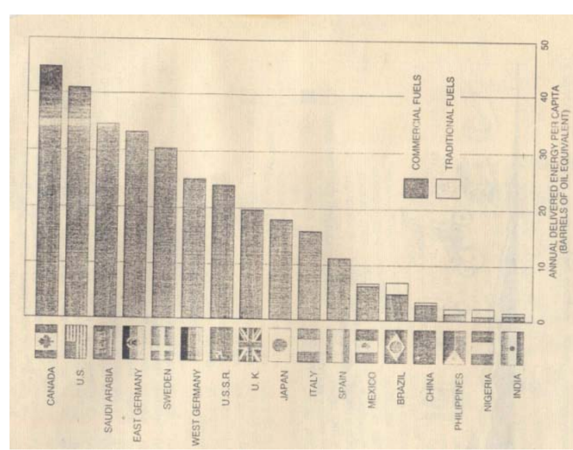
d) Demographic Transition

Just over 100 years ago 95 % of the USA population were engaged in agriculture and food related activities. The percentage has dropped to 5% now [9]. The process of urbanization and social transition is a logical trend to support the changed economic activities. This trend is true for the developing world as well. Besides, people living in areas with lesser economic opportunities have a general tendency of migration to areas of better economic opportunities.

e) Disparities

Wide disparities exist among the states as well as within communities or groups of a state. The world's richest 500 hundred individuals have a combined income greater than that of the poorest 416 million [10]. The 2.5 billion people living on less than 2$ a day and comprising 40% of the global population –account for only 5% of the global income while the richest 10% mostly living in developed countries account for 54%. More than 1 billion people live in acute poverty and hunger with less than 1$ a day [11].

The disparity in energy consumption between developed and developing countries is actually a reflection of economic development status [Fig.3]. Ensuring energy availability and affordability to the population at large living in rural areas of the developing world is one of the important challenges which has to be addressed. This is required for removing disparities and ensuring sustainable growth. About 2 billion global populations do not have access to even electricity. These people live almost entirely on traditional energy sources.



Source: p.23 Scientific American, September 1990

Fig. 3 : Disparity in Energy Consumption between Developed and Developing Countries

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f) Consumption Limit and Conservation

There is still (although there was and still there is an effort in some developed countries like to limit the energy consumption rate to 1500 watt per capita) no limit set or established for the human consumption of energy. Efforts are on for quite some time to conserve energy sources by improving efficiency and avoiding wastage. But the savings due to conservation measures are largely offset by the growing demand.

g) MDGs

"When we consider The Millennium Development Goals….. such as the eradication of poverty and hunger, universal access for fresh water, and improved health care – it is quickly evident that the availability of energy overall, and electricity in particular is central to our ability as an international community to deliver on each of these goals" [12]. The fulfill ment of MDGs are closely linked with availability and affordability of final energy sources. Please see **Annex-III [13].**

h) Energy-Economy Linkage

The economy is directly linked with energy. The global economy is expanding and will continue to expand. So the energy demand will also increase. Among the different forms of energy electricity is the most preferred form and it will remain so in the coming years. The **Fig.4** shows the changes in gross domestic product, population, primary energy use and electricity use by region for the period 1971 to 1997 [14]. The figure reveals how the economic growth is linked with energy particularly electricity. The energy demand growth of developing regions in the Asia and Pacific regions, specifically of China is clearly significant.

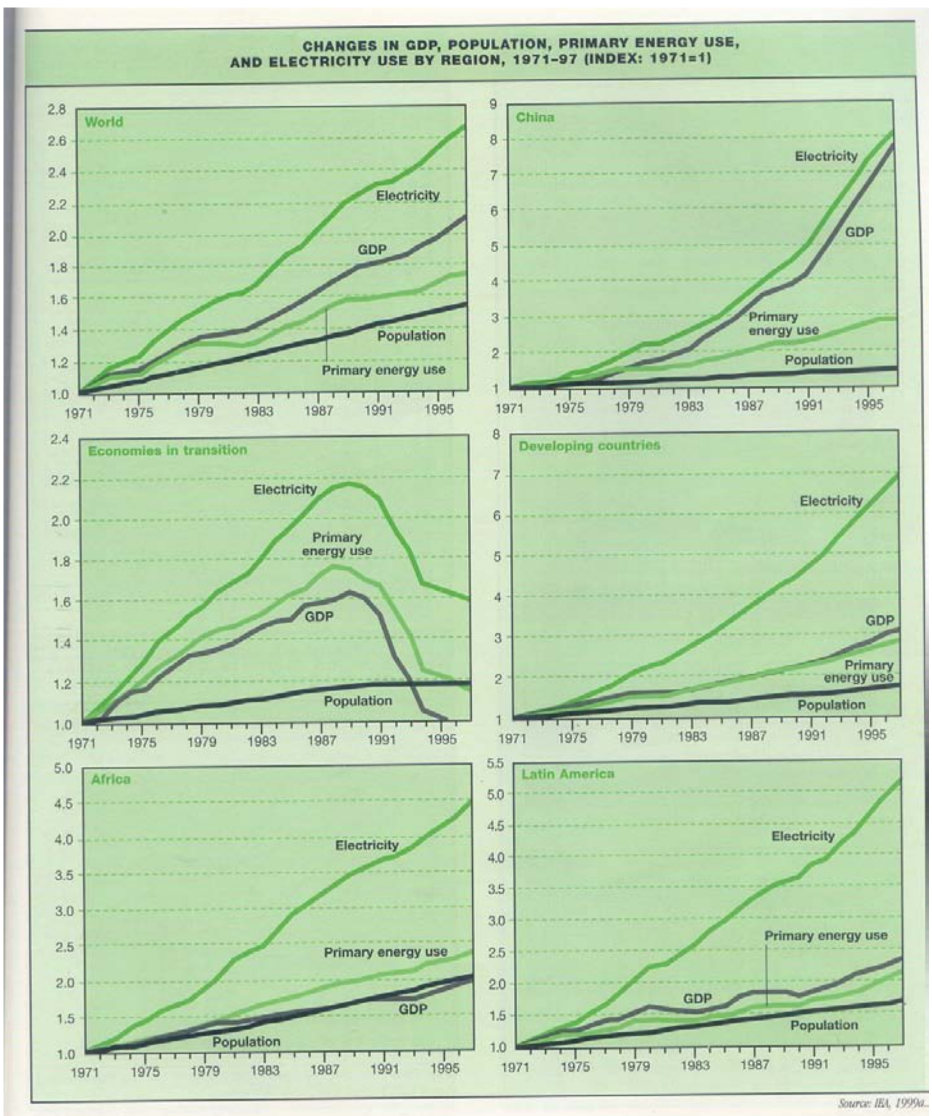

Fig. 4 : Changes in Gross Domestic Product, Population, Primary Energy Use and Electricity Use by Region for the Period 1971 to 1997, Source:[23]

i) Driving Force

The prime driving force is economy and market forces. The rate of growth and energy supply scenario as well as the relative share of the constituting energy sources may, however, be affected or changed due to geopolitical situation and the technological inventions and innovations. The growth rates may also be affected by country's regulatory framework and environmental considerations.

The demand of energy will therefore continue to rise to fulfill the growing economic needs of expanding global population and for meeting other global and the United Nations' goals discussed in the preceding paragraphs.

IV. Evolution of Energy Scenario

a) Evolution

The 'use of oxen multiplied the power available to a human being by a factor of 10. The invention of the vertical wheel increased productivity by another factor of 6; the steam engine by another order of magnitude'[14].

The energy scenario with the consequent growth of types and quantities of primary energy sources actually evolved over the years as the world economy evolved with technological inventions and innovations. The scientific knowledge and the technology also affected the transition of economic activities from predominantly agricultural to production sector during post industrial revolution period and now to service sectors. This evolution is shown in the Fig. 5 [4].

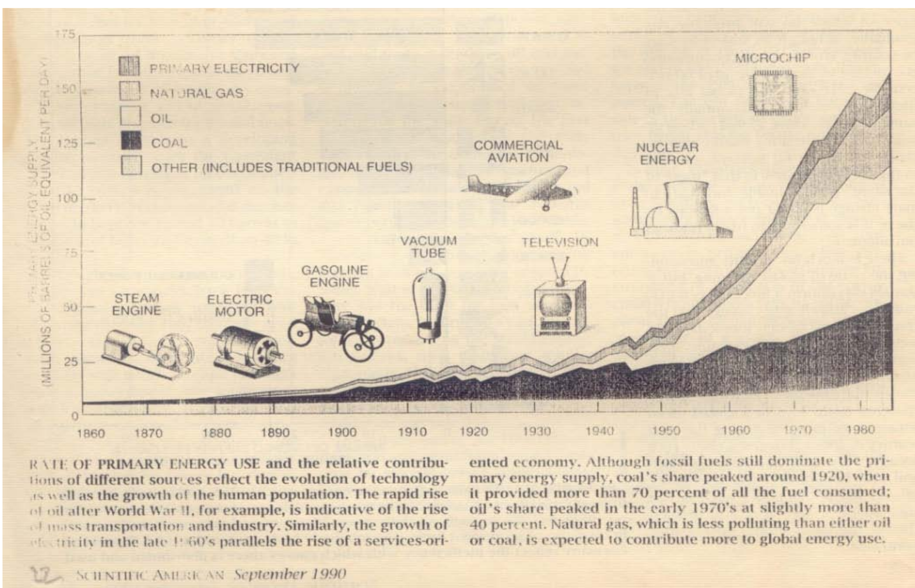

Fig. 5 : Evolution of Energy, Source: [4]

Motor vehicles and airplanes reduced transportation time and the cost. Recent explosion of information and communication technology (ICT) resulted electronic speed in exchange of data and information. The barrier of distances has greatly been reduced. The earth is becoming smaller and smaller.

b) Resource Constraints

It may be seen that the use of traditional fuels remained static since 1880 as the industrial revolution started. The fossil fuels dominated and still dominate the primary energy supply. Coal's share peaked around 1920, when it provided more than 70% of all fuel consumed; oil's share peaked in the early 1970's at slightly more than 40% [4]. In the recent background of price hike of oil the share of gas, which is the least polluting, is increasing fast. The share of coal may also peak as the gas and oil reserves are stressed and the prices of these two sources compared to coal are escalating.

The fissile or nuclear sources however remained largely untapped. There are issues of safety, safeguards, proliferation and waste management. But the principal reason appears to be geo-politics.

c) Energy Intensity

The energy intensity is decreasing globally particularly in developed countries as the economy is gradually shifting from predominantly production oriented to service oriented activities. The increased efficiency of the energy systems also contributes to this end. Yet the rate of expansion is higher than the effect of decline due to the lessened energy intensity. This may be seen at Fig. 6.

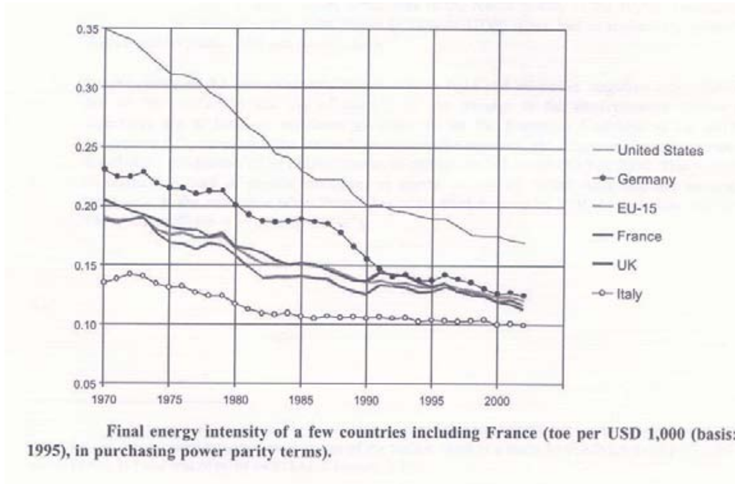

Fig. 6 : Final Energy Intensity of a few Countries, Source: [5]

V. Present Status

a) Energy Sources

The energy sources are usually categorized into: primary, final and commercial groups.

i. *Primary Sources*

The **primary energy** sources consists of the following –

- Traditional sources (fire woods, vegetable wastes etc.);
- Commercial sources or the fossil fuels (coal, oil and gas);
- Renewables (solar, wind, tide, geothermal etc.) and
- Nuclear/Fissile sources (Uranium and Thorium)

ii. *Final Sources*

The **final energy** sources are processed oil, coal, gas, heat, light, radiation, electricity etc. The most important and preferred one of the final energy sources is **electricity**.

iii. *Commercial Sources*

The commercial sources: oil, gas and coal are presently the dominant types of energy sources. The trend will continue in the coming years (at least in the next 2 to 3 decades). The energy use pattern is primarily dependent on the demand and supply situation (profit) and the market forces. The regulatory frame works and the environmental effects of the use of these source influence the use. The geopolitical situation also affects the energy scenario. The reserves are **maturing** i.e. the discovery now fails to match with the consumptions rate.

b) Energy Reserves and Resources

Nature took more than 3 million years to produce the fossil fuels. The fossil fuels are now being depleted at a rate that is 100,000 times faster than they are being formed [4]. This is not sustainable. The reserves depend on various factors: available technology, demand and the economic cost. The **Fig. 7** reproduced below will help in understanding the dynamics of energy reserve and resource situations.

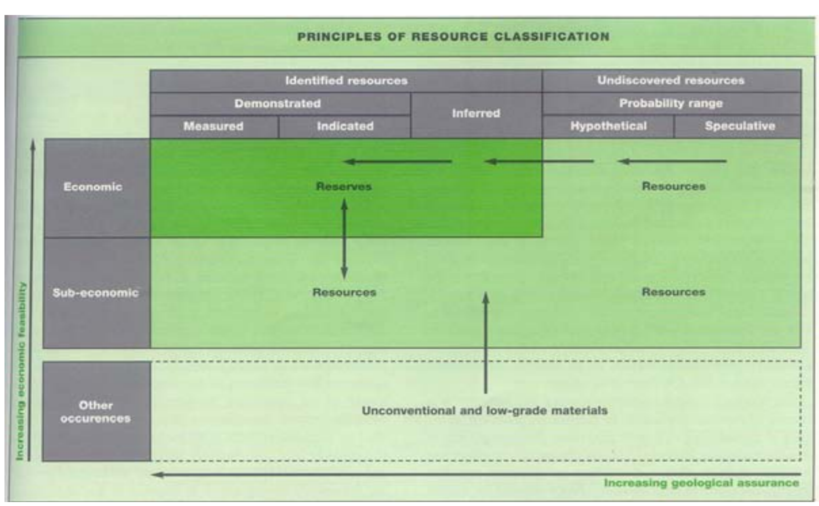

Fig. 7 : Principles of Reserve & Resource Classification, Source: [23]

i. *Fossil and Nuclear Fuels*

The summary of the world fossil fuels and nuclear fuel reserves are shown in Table-2 .The nuclear source in the table does not include the fissile materials that exist in seawater. It may be noted that nuclear source is still very much untapped. The proper use of this source may ease the global energy supply situation for transition to a pseudo infinite source like fusion source.

Table-2 : Summary of Global Fossil & Nuclear Sources, Source: [23]

SUMMARY OF GLOBAL FOSSILE AND FISSILE RESOURSES (THOUSANDS OF EXAJOULES)						
Resource	**Consumed by end 1998**	**Consumed in 1998**	**Reserves**	**Resources**	**Resource base[a]**	**Additional occurrences**
Oil	5.14	0.14	11.11	21.31	32.42	45
Conventional	4.85	0.13	6.00	6.07	12.08	
Unconventional	0.29	0.01	5.11	15.24	20.35	45
Gas	2.38	0.08	14.88	34.93	49.81	930
Conventional	2.35	0.08	5.45	11.11	16.57	
Unconventional	0.03	0.00	9.42	23.81	33.24	930
Coal	5.99	0.09	20.67	179.00	199.67	
Fossile total	**13.51**	**0.32**	**46.66**	**235.24**	**281.89**	**975**
Uranium						
Open cycle in thermal reactors[b]	n.e.	0.04	1.89	3.52	5.41	7.1[c]
Closed cycle with fast reactors[d]	—	—	113	211	325	426[b]
Fossile and fissile total[e]	**n.e.**	**0.36**	**48**	**446**	**575**	**1,400**

n.e. Not estimated. — Negligible.
a. Sum of reserves and resources. b. Calculated from the amount in tonnes of uranium, assuming 1 tonne = 589 terajoules (IPCC, 1996a). c. Does not include uranium from seawater or other fissile materials. d. Calculated assuming a 60-fold increase relative to the open cycle, with 1 tonne = 35,340 terajoules. e. All totals are rounded.
Source: Author's calculations from previous chapter tables.

ii. *Renewable Energy Sources*

The summary of the global potential of renewable sources is shown in Table-3. The share of these sources in the global energy demand is likely to remain low key because of many technical and economic reasons. But this is undoubtedly a vast untapped area.

Table-3 : Summary of the Renewable Energy Potential, Source: [23]

SUMMARY OF THE RENEWABLE RESOURCE BASE (EXAJOULES A YEAR)			
Resource	**Current use[a]**	**Technical potential**	**Theoretical potential**
Hydropower	9	50	147
Biomass energy	50	> 276	2,900
Solar energy	0.1	> 1,575	3,900,000
Wind energy	0.12	640	6,000
Geothermal energy	0.6	5,000	140,000,000
Ocean energy	n.e.	n.e.	7,400
Total	**56**	**> 7,600**	**> 144,000,000**

n.e. Not estimated.
a. The electricity part of current use is converted to primary energy with an average factor of 0.385. *Source: Author's calculations from previous chapter tables.*

c) *Geographical Distribution, Production and Replenishments*

The world fossil fuels are geographically very much unevenly distributed. Some countries like Japan, France, Italy etc. are largely dependent on imported energy sources and others like Middle East Russia sell the excess energy[15]. This necessitated a flourishing worldwide trade in energy commodities. The distribution networks [pipe lines for gas and oil, processing facilities for CNG, LPG, oil distillates, transmission and distribution lines] had to be developed and are still required to be developed to deliver desired forms of energy to the customers or users.

i. *Oil*

The global distribution of oil and the flow of the sources from the producing to consuming regions are shown in Figs.8 & 9 respectively. The oil production or demand in different years is shown in Fig. 10. The replenishments of the sources in USA and in the world are shown in Fig. 11 and Fig.12 respectively.

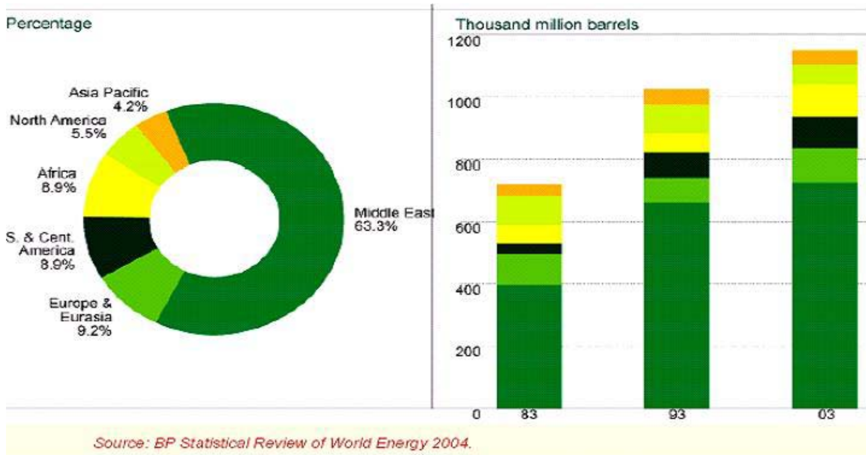

Fig. 8 : Oil Energy Reserve & Geographical Distribution

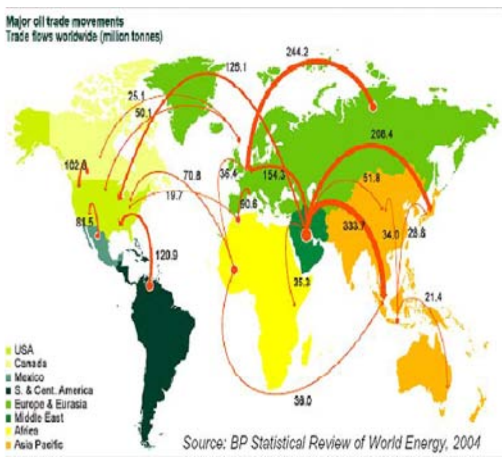

Fig. 9 : Global Oil Trade

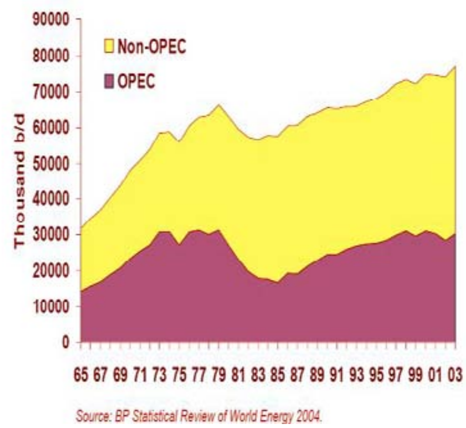

Fig. 10 : Oil Demand Scenario

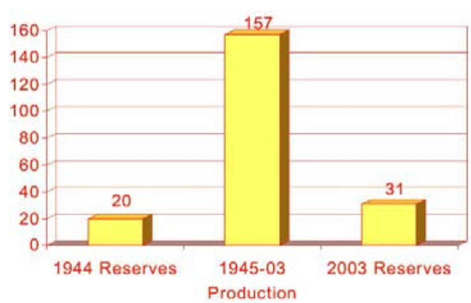

Fig. 11 : U.S.Oil Production& Replenish ment

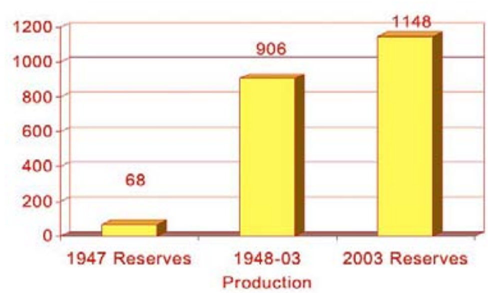

Fig. 12 : World Oil Production & Replenish ment

Source: [21]

ii. *Gas*

The global gas reserves and the gas producing regions are shown in Fig.13. The gas production or demand in different years is shown in Fig.14. The replenishments of the sources in USA and in the world are shown in Fig.15 and Fig.16 respectively.

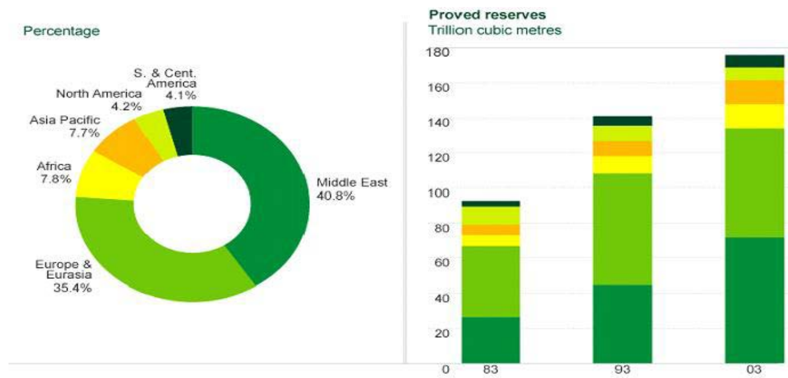

Fig. 13 : Gas Energy Reserve & Geographical Distribution, Source: [21]

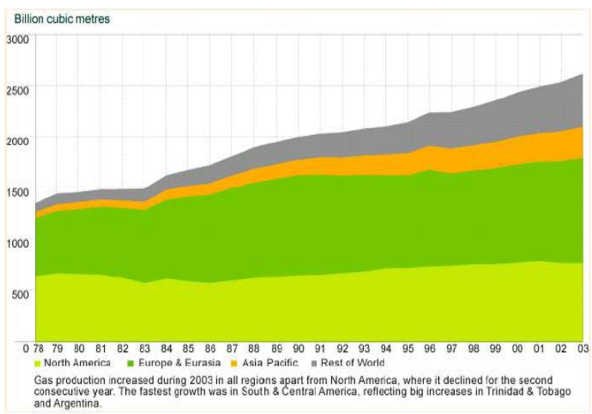

Fig. 14 : Gas Demand Scenario

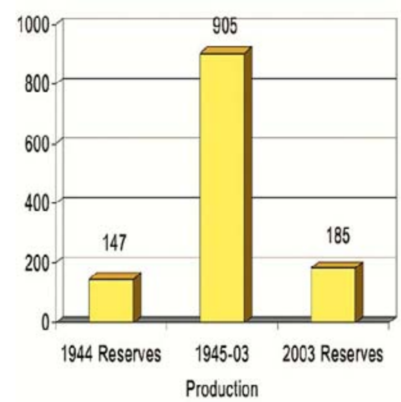

Fig. 15 : U.S. Gas Production & Replenishment

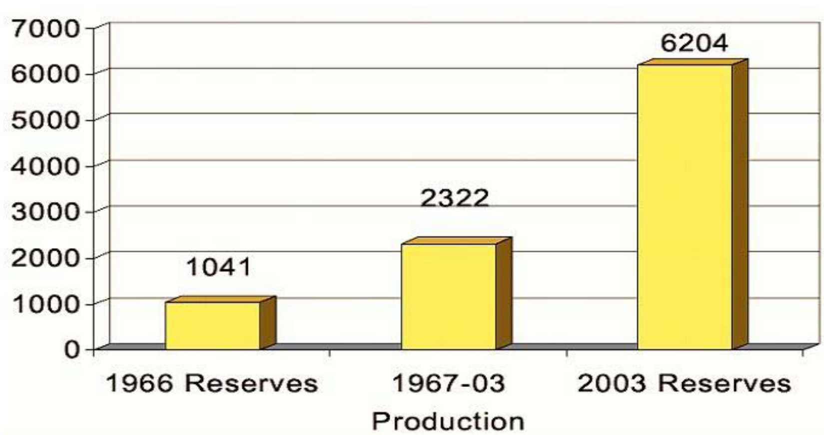

Fig 16 : World Gas Oil Production & Replenishment, Source: [21]

iii. *Coal*

The global estimated reserves and resource of coal and the distribution shown at Tables 4 & 5 respectively.

Table 4 : World Estimated Coal Reserve

ESTIMATED COAL RESERVES (MILLIONS OF TONNES)				
Region	Bituminous (incl. anthracite)	Sub-bituminous	Lignite	Total (exajoules)
North America	115,600	103,300	36,200	6,065
Latin America and Caribbean	8,700	13,900	200	533
Western Europe	26,300	600	47,700	1,178
Central and Eastern Europe	15,400	5,500	10,700	744
Former Soviet Union	97,500	113,500	36,700	4,981
Middle East and North Africa	200	20	0	6
Sub-Saharan Africa	61,000	200	< 100	1,465
Pacific Asia	900	1,600	5,100	10
South Asia	72,800	3,000	2,000	1,611
Centrally planned Asia	62,700	34,000	18,600	2,344
Pacific OECD	48,100	2,000	41,600	1,729
Total	**509,200**	**277,600**	**198,900**	**20,666**

Source: WEC, 1998

Table 5 : World Estimated Coal Resource

ESTIMATED COAL RESOURCES (BILLIONS OF TONNES OF COAL EQUIVALENT)			
Region	Hard coal	Soft coal/ lignite	Total (exajoules)
North America	674	201	25,638
Latin America and Caribbean	37	2	1,143
Western Europe	337	11	10,196
Central and Eastern Europe	106	14	3,516
Former Soviet Union	3,025	751	110,637
Middle East and North Africa	1	1	58
Sub-Saharan Africa	181	< 1	5,303
Pacific Asia	7	5	352
South Asia	84	1	2,491
Centrally planned Asia	429	35	13,595
Pacific OECD	139	67	6,030
Total	**5,021**	**1,089**	**178,959**

Note: Includes reserves. *Source: BGR, 1998.*

Source: [23]

VI. Electricity

a) Growth Trend

Electricity as stated earlier is the most preferred form of energy. The electricity demand is growing at much faster rate compared to other final energies. Yet, 2 billion people or every 2nd person out of the 6 persons of the world do not have any access to electricity. 'Energy analysts are looking at the pace and price of progress-at a time when electricity demand is rising ever higher' [16]. The world net electricity production and the past trend of growth as well as the contribution of different sources are shown in the Fig.17.

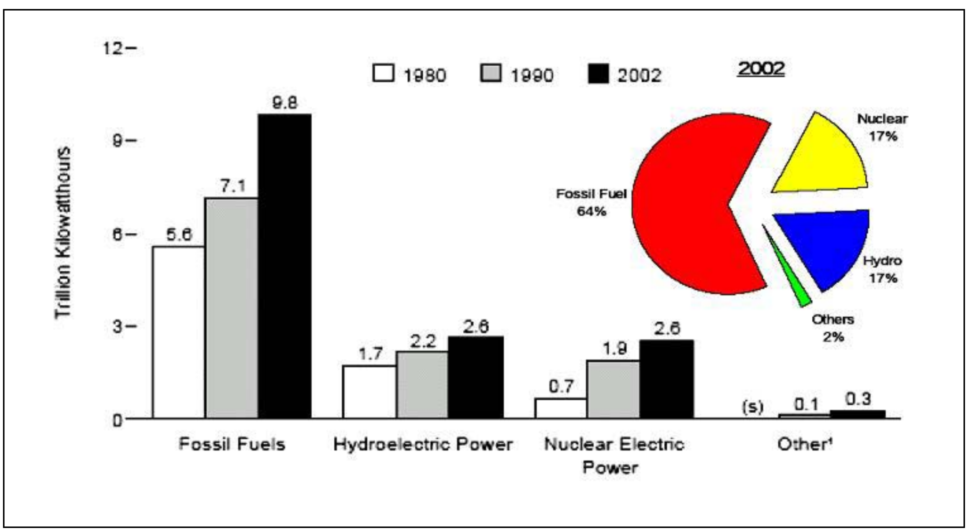

Fig. 17 : World Electricity Production & Growth Rate, Source: [21]

b) Investment Outlook

The World Energy Investment Outlook of the International Energy Agency EIA projects an investment of $16 trillion (about 1% of the global GDP) over the period 2001-2030 to meet primary energy demand growth of 1.7% and electricity demand of 2.4%. Electricity will require 60% of the total investment. Compared to the estimated annual investment of $410 billion in 2000, it will rise $ 550 billion in the current decade and to $630 billion during 2021 to 2030 [16]. The summary of electricity investment, as projected is shown in Fig.18. The cumulative investment in energy by fuel is shown in Fig. 19.

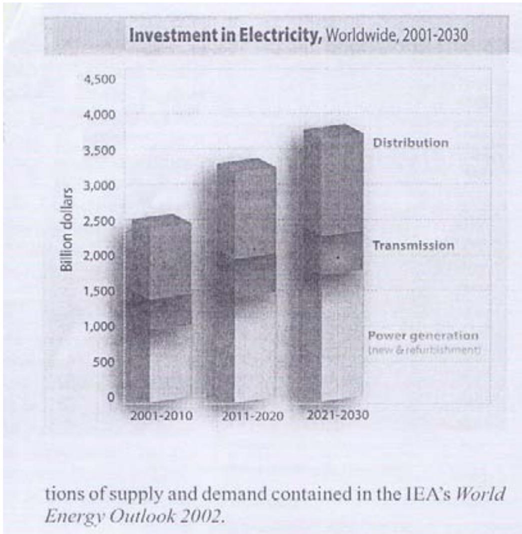

Fig. 18 : World Investment in Electricity Source: [18]

The fuel wise generation of electricity is shown in **Table-6**.

Table 6 : World Electricity Balance, Source: [18]

Electricity Balance,* Worldwide, 2000-2030

	2000	2010	2020	2030	Average annual growth 2000-2030 (%)
Gross generation (TWh)	15,391	20,037	25,578	31,524	2.4
Coal	5,989	7,143	9,075	11,590	2.2
Oil	1,241	1,348	1,371	1,326	0.2
Gas	2,676	4,947	7,696	9,923	4.5
Hydrogen-fuel cells	0	0	15	349	n.a.
Nuclear	2,586	2,889	2,758	2,697	0.1
Hydro	2,650	3,188	3,800	4,259	1.6
Other renewables	249	521	863	1,381	5.9
Own use and losses (Mtoe)	235	304	388	476	2.4

*Includes transport, agriculture and non-specified uses of electricity.

c) Supply Reliability

Uninterrupted and quality power supply at an affordable price is a key component for smooth economic growth of a country. In industrialized countries, consumers demand 100% reliability, while the power supply systems in developing countries suffer frequent disruptions as well as poor quality (voltage and frequency fluctuations). The cost burden of the disruptions is enormous.

The electricity blackouts make headlines in Europe and North America. But such blackouts are common in any developing countries. The reliability of electricity supply,therefore, was highlighted as a priority issue in the Sydney World Energy Congress of September 2004 [Annex-V].

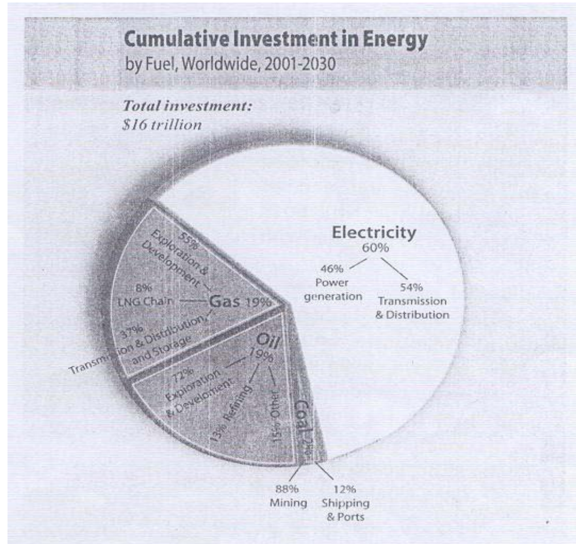

Fig. 19 : World Cumulative Investment in Energy Source: [18]

VII. Future Trend

a) Market Forces

The development of energy industry depends on many factors: economy, advances in technology related to energy production, distribution and consumption, policy decisions, regulations and environmental effects and global demand and supply position. The key is profit and market force. This is also dependent on geo-political dynamics. Recently unthinkable price hike took place in oil sector. The oil price, which dipped to $10.29 in December 1998 remained stable between $ 20 to 30 for a certain period and then, crossed $ 70 in August 2005.

b) Energy Outlook

i. *USA*

The energy trend is presented from the overview of the Annual Energy Outlook 2005 document published by Energy Information Administration of the USA [24]. The overview presented the historical growth (from 1970 to 2003) of energy prices and projections for the period up to 2025 **[Fig.20]**, delivered energy consumption by sectors [**Fig. 21**], energy consumption by fuel [**Fig. 22]**, energy use per capita and per dollar of GDP [**Fig.23**], electricity generation by fuel [**Fig. 24**], total energy production and consumption [**Fig.25**], energy production by fuel [**Fig. 26**] and the projected CO2 emissions by sector of fuels [**Fig. 27**].

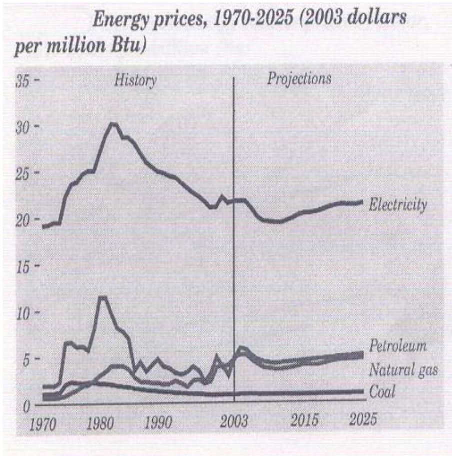

Fig. 20 : Energy Prices & Projection

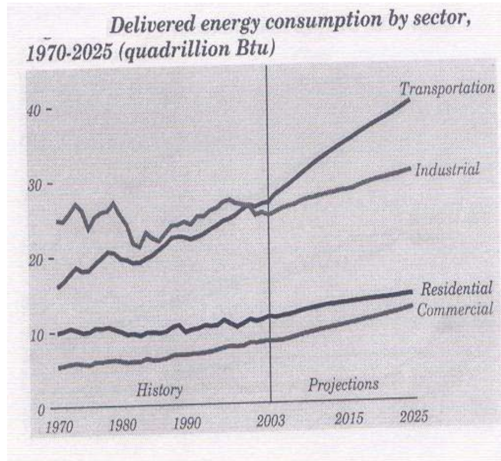

Fig. 21: Delivered Energy Consumption

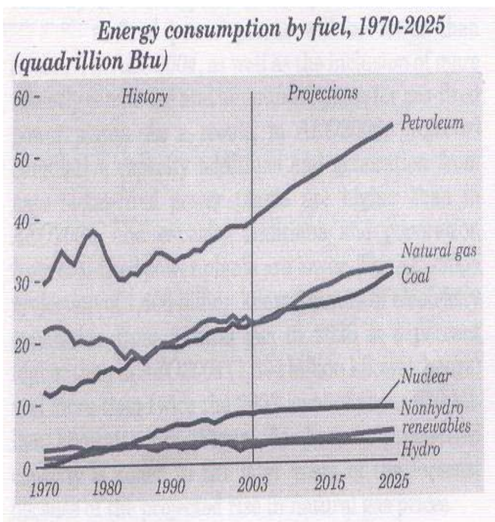

Fig. 22 : Energy Consumption by Fuel

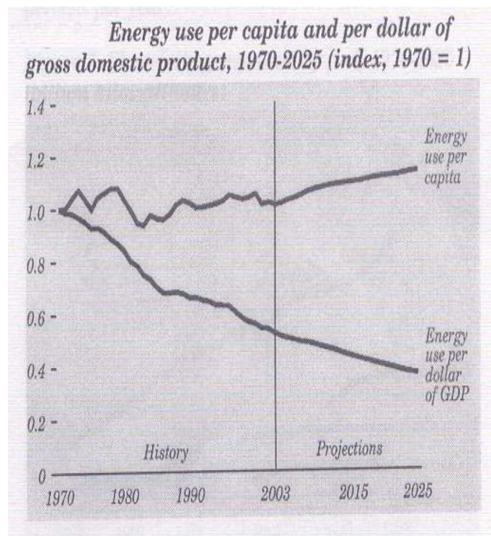

Fig. 23 : Energy Use per Capita & per Dollar of GDP

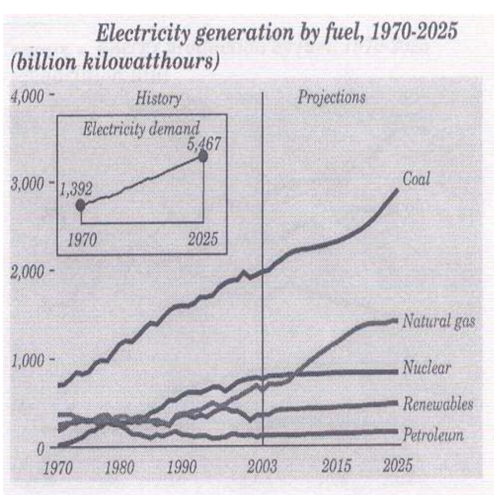

Fig. 24 : Electricity Generation by Fuel

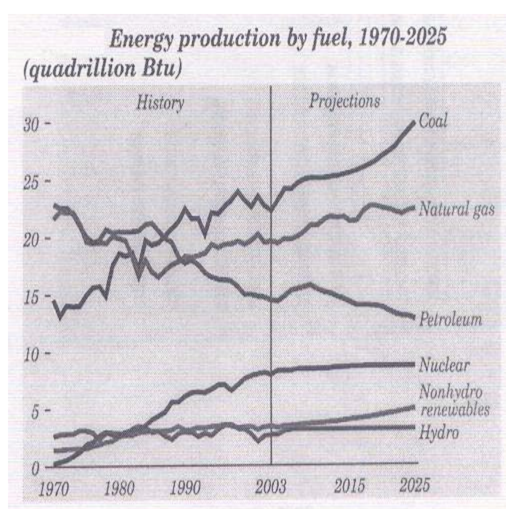

Fig. 25 : Total Energy Production & Consumption

Source: [24]

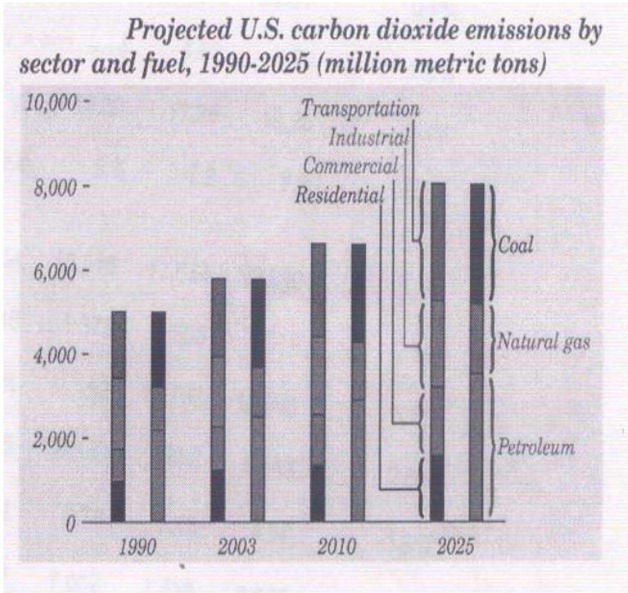

Fig. 26 : The Projected CO_2 Emission by Sectors of Fuels, Source: [24]

The summary of the overview is shown in Table7. The energy trend presented above is designed for the USA. The oil price forecast for the coming years ($ 28.50 in 2020 and $30.31 in 2025) from the present day perspectives appears to be highly optimistic. But there must have been in depth analyses behind these optimistic forecasts. The information throws light on future energy trend.

Table-7 : EIA/DOE Energy Forecast

Total energy supply and disposition in the *AEO2005* reference case: summary, 2002-2025

Energy and economic factors	2002	2003	2010	2015	2020	2025	Average annual change, 2003-2025
Primary energy production (quadrillion Btu)							
Petroleum	14.71	14.38	15.41	14.31	13.83	12.82	-0.5%
Dry natural gas	19.48	19.58	20.97	21.33	22.48	22.42	0.6%
Coal	22.70	22.66	25.10	25.56	27.04	29.90	1.3%
Nuclear power	8.14	7.97	8.49	8.62	8.67	8.67	0.4%
Renewable energy	5.79	5.89	6.85	7.13	7.57	8.10	1.5%
Other	1.12	0.93	0.97	0.78	0.77	0.82	-0.5%
Total	**71.94**	**71.42**	**77.79**	**77.73**	**80.35**	**82.73**	**0.7%**
Net imports (quadrillion Btu)							
Petroleum	22.64	24.10	28.61	33.10	36.87	41.11	2.5%
Natural gas	3.59	3.32	5.06	7.19	8.08	8.87	4.6%
Coal/other (- indicates export)	-0.47	-0.43	-0.14	0.19	0.25	0.58	NA
Total	**25.75**	**26.99**	**33.53**	**40.47**	**45.21**	**50.55**	**2.9%**
Consumption (quadrillion Btu)							
Petroleum products	38.41	39.09	44.84	48.07	51.30	54.42	1.5%
Natural gas	23.59	22.54	26.11	28.69	30.73	31.47	1.5%
Coal	21.98	22.71	24.95	25.71	27.27	30.48	1.3%
Nuclear power	8.14	7.97	8.49	8.62	8.67	8.67	0.4%
Renewable energy	5.79	5.89	6.85	7.13	7.57	8.10	1.5%
Other	0.07	0.02	0.03	0.07	0.05	0.04	4.1%
Total	**97.99**	**98.22**	**111.27**	**118.29**	**125.60**	**133.18**	**1.4%**
Petroleum (million barrels per day)							
Domestic crude production	5.74	5.68	6.02	5.49	5.21	4.73	-0.8%
Other domestic production	3.60	3.38	3.59	3.77	4.00	4.10	0.9%
Net imports	10.54	11.24	13.37	15.40	17.11	19.11	2.4%
Consumption	19.71	20.00	22.98	24.67	26.32	27.93	1.5%
Natural gas (trillion cubic feet)							
Production	19.03	19.13	20.49	20.85	21.97	21.91	0.6%
Net imports	3.50	3.24	4.94	7.02	7.89	8.66	4.6%
Consumption	22.98	21.95	25.44	27.96	29.95	30.67	1.5%
Coal (million short tons)							
Production	1,105	1,083	1,238	1,270	1,345	1,488	1.5%
Net imports	-23	-18	-9	3	7	20	NA
Consumption	1,066	1,095	1,229	1,273	1,352	1,508	1.5%
Prices (2003 dollars)							
World oil price (dollars per barrel)	24.10	27.73	25.00	26.75	28.50	30.31	0.4%
Domestic natural gas at wellhead (dollars per thousand cubic feet)	3.06	4.98	3.64	4.16	4.53	4.79	-0.2%
Domestic coal at minemouth (dollars per short ton)	18.23	17.93	17.30	16.89	17.25	18.26	0.1%
Average electricity price (cents per kilowatthour)	7.4	7.4	6.6	6.9	7.2	7.3	-0.1%
Economic indicators							
Real gross domestic product (billion 2000 dollars)	10,075	10,381	13,084	15,216	17,634	20,292	3.1%
GDP chain-type price index (index, 2000=1.000)	1.041	1.060	1.218	1.373	1.563	1.814	2.5%
Real disposable personal income (billion 2000 dollars)	7,560	7,734	9,594	11,192	12,783	14,990	3.1%
Value of manufacturing shipments (billion 1996 dollars)	5,067	5,105	6,165	6,850	7,633	8,469	2.3%
Energy intensity (thousand Btu per 2000 dollar of GDP)	**9.73**	**9.47**	**8.51**	**7.78**	**7.13**	**6.57**	**-1.6%**
Carbon dioxide emissions (million metric tons)	**5,751**	**5,789**	**6,627**	**7,052**	**7,520**	**8,062**	**1.5%**

Notes: Quantities are derived from historical volumes and assumed thermal conversion factors. Other production includes liquid hydrogen, methanol, supplemental natural gas, and some inputs to refineries. Net imports of petroleum include crude oil, petroleum products, unfinished oils, alcohols, ethers, and blending components. Other net imports include coal coke and electricity. Some refinery inputs appear as petroleum product consumption. Other consumption includes net electricity imports, liquid hydrogen, and methanol.
Source: AEO2005 National Energy Modeling System, run AEO2005.D102004A.

Energy Information Administration / Annual Energy Outlook 2005

ii. *World*

The summary of the UNDP World Assessment report (2000) about the energy projections up to 2100 are shown at **Annex- IV [17].** The UNDP projections may be compared and verified with the EIA/DOE energy outlook.

iii. *Energy System Integration and Cooperation*

The word is moving though slowly towards cross –boundary integration of energy distribution networks of electrical grids and gas and oil pipelines. Such integration is likely to make energy systems more efficient, accessible and affordable. The EU countries in the past has taken and are taking steps towards this direction. But for the developing countries will require more transparency, understanding, consensus of people and parties at stake for energy system integration. The actions have to be based mutual trust, cooperation and ethics.

VIII. Bangladesh Perspective

a) Energy Status

Bangladesh is the most densely populated country (among the comparable sized ones) of the world. Population wise (about146 million) it is the eighth largest country with an area of only 147570 sq kms. The impor- tance of energy, particularly electricity is recognized in the Constitution (Article - 16) [19]. Yet, more than 66% of the people do not have access to electricity. Besides the electrical supply system suffers from frequent load shedding and low quality. The per capita energy consumption rate is also very low. The **Table-8** shows energy scenario of some selected countries and the regions. Most of the people (79.9%) living in the rural areas depend mostly on primary energy sources.

Table 8 : Energy Scenario of Some Selected Regional Countries and Economic Areas

Sl. No.	Country	+Traditional Fuel Consumption (% of total) 2002	+Per Capita Electricity Consumption (kwh/yr.	Installed Capacity (Mega Watt)	Electricity Access to Population (%)
1.	Bangladesh	61.6	140	4710	40
2.	Bhutan	87.8	241	445	30
3.	India	20	561	112,058	56
4.	Nepal	-	63	522	40
5.	Pakistan	-	479	17,953	56
6.	Sri Lanka	41.6	354	1,615	64
9.	China	5.3	1484		
10.	Malaysia	1.5	3234		
11.	Iran	0.1	2,075		
12.	OECD	3	8615		
13.	High Income	4.5	10,198		
14.	Middle Income	17	1,653		
15.	Developing	24.5	1,155		
16.	Low Income	42.2	399		
17	World	7.6	2456		40

+Source: UNDP Human Development Report 2005

b) Energy Sources

The country has very little energy reserves even compared to South Asian countries [**Table-9**]. The most important commercial energy source is gas (very high quality). Gas is used for production of 89 % of electricity of the country [20]. The rationality may be assessed.

Table 9 : Energy Reserve Base of South Asian Countries

Sl.No.	Country	Population Million	Oil Reserve (GigaTons)	Gas Reserve (Trillion m3)	Hydro Potential 10^{12} watt hr/Yr.	Coal Giga Tons
1.	Bangladesh	145	0.007	0.3	2	2.5
2.	Bhutan	2	-	-	70	-
3.	India	1085	0.671	0.77	660	84
4.	Nepal	28	-	-	158	-
5.	Pakistan	164	0.026	0.75	130	2
6.	Srilanka	20	-		8	-
7.	World	6465	295	502	13945	5579

Source : Oil and Gas Journal, World Energy Council (Energy & Power, p.9, 01.02.05)

c) Energy Management

The country has notified the Energy Policy in 1995[22]. Several energy studies have been carried out since 1975. But the recommendations of the national policy or the studies are not duly reflected in the policy decisions of energy development. Consensus on the energy reserve-resources (particularly on gas) is lacking. The coordination of the activities of the interdependent energy and consumer sectors is also weak.

The energy demand and supply issues, as these are closely linked with sustainable development [Agenda 21], are required to be routinely studied and assessed with due depth from the energy security perspectives. The Japanese, South Koreans, French, Malaysian national energy policies may be examined for guidance. The uniqueness of Bangladesh in the context of geo-socio-economic situation are also required to be critically and routinely examined. Such studies may help in achieving smooth and sustainable development as well as to fulfill the country's constitutional obligations (Articles 16 and 19).

IX. Key Issues

The issues that are confronted by the world community were elaborately discussed in the World Energy Conference held in Sydney, Australia in September 2004.

a) Goal

While the message of the World Energy Council (WEC) Conference held in September 1989 in Montreal, Canada was "Find **more energy or perish";** the key issue of the last WEC Conference held in Sydney was **energy sustainability**. But the achievement of sustainable development in energy sector demands that the access and security of supply is ensured while avoiding environmental impacts, which would compromise future social and economic development.

b) Focal Areas

The increase in energy prices and supply disruptions and their effects on different energy development aspects were subjects of discussions and redress. The conclusions of the Sydney World Congress are given in **Annex-V.** Some of the key conclusions are highlighted below: -

- All energy options must be open
- More pragmatic market reform
- Reliability of electricity supply
- Regional integration of energy supply
- Research and development
- Climate change
- Public trust and understanding
- Energy security
- Energy accessibility and affordability

c) MDGs and Sustainable Development

Particularly the accessibility and affordability of the useful forms of final energy are essential to fulfill the millennium development goals (MDGs). World is very much diverse. Each country, particularly the developing one, has its unique socio-politico- geo-economic position. The unique features shall have to be taken into consideration by the policy makers for achieving the sustainable development.

d) Global Consensus

Global consensus and cooperation among the states are needed to resolve global warming and climatic changes and environmental pollution issues and for more future friendly use of fissile and renewable sources.

X. Conclusion

Energy is essential for continued human development and economic growth. It 'is central to achieving the interrelated economic, social, and environmental aims of sustainable human development'.

Electricity and final energies are not accessible or affordable to more than 2 billion people who live in acute poverty and deprivation. The energy need of this deprived group has to be addressed in order to achieve the MDGs.

Energy will be needed in much larger quantities in the coming years to meet the need of the expanding global population as well as to meet the growing need of goods and services are required for better quality of life. But the reserves of the commercial sources are finite.

"Much of the world's energy.... is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to remain substantially the same".

Proper understanding and consensus among the parties at stakes on national energy issues from the country's energy reserve/resource base and socio-geo-economic condition are essential for energy security and sustainable development. The planned energy mix has to be optimized in the context of the national needs and aspirations and global perspectives.

Comprehensive assessments and analyses with knowledge and reliable data and actions with wisdom will be necessary to address energy related issues. This is essential for a more stable and livable world, particularly in this age of globalization and information and communication technology and expanding global unrest and terrorism.

The goal is of course achievable if the ethics based strong commitment, mutual trust and active support and cooperation of the world leaders and the multinational economic-giants could be ensured.

XI. Annexes

Annex-I: Millennium Development Goals
Annex-II: Glossary-selected terminology
Annex-III: Matrix of Energy and the Millennium Development Goals
Annex-IV: Summary of three Energy Development Cases in 2050 and 2100 compared with 1990
Annex-V: Conclusions of World Energy Congress, Sydney, Australia, 5-9 September 2004

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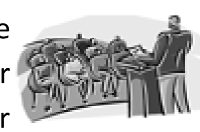

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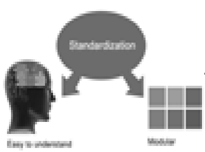

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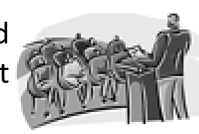

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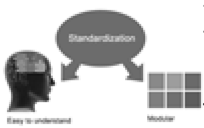

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27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

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29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

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Key points to remember:

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- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

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- Fundamental goal
- To the point depiction of the research
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- Significant conclusions or questions that track from the research(es)

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Approach:

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- 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.

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- Leave out information that is immaterial to a third party.

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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.

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	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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