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A Novel Control Method for Improvement of Voltage Utilization Factor in Three-Phase Multilevel Inverter Considering the Input Voltage Fluctuation

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Abstract- In This paper wind, solar and fuel cells based stand alone cogeneration systems are presented for remote area utilities applications. This type of co generation system output voltages are not constant or stable in always. The generated output voltages are directly connected to the loads, without battery bank or energy storage devices. The PI, fuzzy control method was proposed in this paper using svpwm, such that the output voltage of converter circuit is constant even though input voltages are fluctuation conditions. A three phase multilevel inverter with static and dynamic load was examined to validate for proposed work in MATLAB environment.

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Abstract- In This paper wind, solar and fuel cells based stand alone cogeneration systems are presented for remote area utilities applications. This type of co generation system output voltages are not constant or stable in always. The generated output voltages are directly connected to the loads, without battery bank or energy storage devices. The PI, fuzzy control method was proposed in this paper using svpwm, such that the output voltage of converter circuit is constant even though input voltages are fluctuation conditions. A three phase multilevel inverter with static and dynamic load was examined to validate for proposed work in MATLAB environment.

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I. Introduction

The last decades growth in the production of electric energy from renewable energy sources has led to an increased focus on power electronics. Renewable energy sources like photovoltaic, wind and wave energy are relying on power converters in order to exchange power with the grid. Anyone who wants to produce power for the grid has to make sure that their facilities are complying with national grid codes. The grid codes has strict regulations when it comes to the voltage quality, including limits for rapid voltage variations, flicker and harmonic distortion. Rapid voltage variations and flicker are matters of control of the inverter system, but harmonic distortion is created by the pulse width modulated switching of the converter. Different filters topologies can be used in order to reduce the harmonics generated by the switching action in the converter.

The technology growth in the recent years, most of the electrical and electronics equipments are playing the major role in the social growth. Accordingly more and more amount of power demand has an increased. One solution that to meet the power demands in rural and remote area are cogeneration systems, witch an includes hybrid renewable energy sources. In case of the system power generation with natural energy and fuel cell, comparatively large amount of fluctuation is generated at the DC voltage.

The circuit wich converts the DC power in to AC power using multilevel inverter circuit was implemented considering the input dc voltage fluctuations. However the space vector pulse width modulation method was applied in order to improve the voltage utilization factor and stabilization of output voltage.

In this paper, the new control method which an introduced the control of the output voltage feedback control is proposed. It applied to the control circuit, multilevel inverter and operational principle with are explained.

II. Diode Clamped Multilevel Inverter

The diode-clamped inverter provides multiple voltage levels through connection of the phases to a series bank of capacitors. According to the original invention, the concept can be extended to any number of levels by increasing the number of capacitors. Early descriptions of this topology were limited to three-levels where two capacitors are connected across the dc bus resulting in one additional level. The additional level was the neutral point of the dc bus, so the terminology neutral point clamped (NPC) inverter was introduced. However with an even number of voltage levels, the neutral point is not accessible, and the term multiple point clamped (MPC) is sometimes applied. Due to capacitor voltage balancing issues, the diode-clamped inverter implementation has been mostly limited to the three level. Because of industrial developments over the past several years, the three level inverter is now used extensively in industry applications. Although most applications are medium-voltage, a three-level inverter for 480V is on the market.

The three phase 3-level diode clamped multilevel inverter is the common multilevel inverter used for various applications. A three phase 3-level diode clamped multilevel inverter is adopted in this project. It is obtained from a configuration of twelve switching devices and six clamping diodes as shown in figure.

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The pairs Sa1 Sa1', Sa2 Sa2', Sb1 Sb1', Sb2 Sb2', Sc1 Sc1' and Sc2 Sc2' are complementary. Therefore, Sa1'=1–Sa1, Sa2'=1– Sa2, Sb1'=1–Sb1,Sb2'=1–Sb2,Sc1'=1–Sc1 and Sc2'=1–Sc2. There are twelve active combinations were taken using these switching states which produce twelve active voltage vectors. The nonzero voltage vectors are from V1 to V12.

The sector is identified from three phase reference voltage and the corresponding voltage vector is selected from the switching table to generate the gating pulses for the inverter. The vector sequence is V1, V2 , V3 , V4 , V5 , V6 ,V7 , V8 , V9 , V10 , V11 , V12 , V1 each for 30°.

The angle of reference is found using equation $= \tan^{-1}\left(\frac{v_{ld}}{v_{lq}}\right)$. In 3-level inverter one cycle is split into twelve sectors with each 30°. Sector 1 is from 0 to +30°, sector 2 is from +30° to +60°, sector 3 is from +60° to +90°, sector 4 is from +90° to +120°, sector 5 is from +120° to +150° and the sector 6 is from +150° to +180°, Sector 7 is from -180° to 150°,sector 8 is from -150° to -120°, sector 9 is from - 120° to -90°, sector 10 is from -90° to -60°, sector 11 is from -60° to -30° and the sector 6 is from -30° to 0°.

The switching table is formed using the sector, the corresponding voltage vector and the switch state. For example, the angle of the reference voltage is between 0° and 30°, it is in sector 1 and it selects the voltage vector V1. The corresponding switching state is 110000. Switches Sa1 and Sa2 are in on state. Switches Sb1, Sb2, Sc1and Sc2 are in off state. Switches Sa1', Sa2', Sb1', Sb2', Sc1'and Sc2' are complementary.

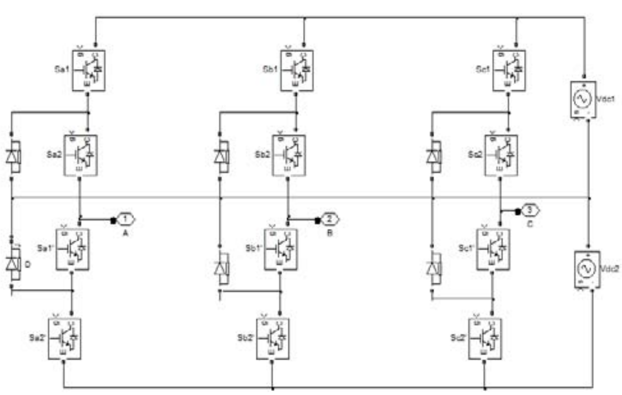

Figure 1 : 3-level diode clamped inverter

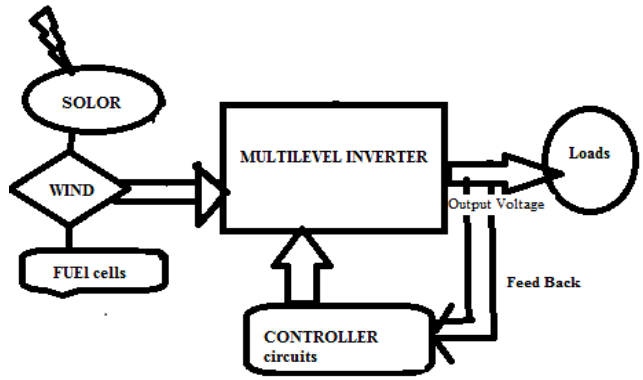

Figure 2 : Block diagram of the output voltage control system

From fig 2. It represent the combined generation systems of the solar energy, wind power and fuel cell systems are consider for the input source to the inverter circuit, these are generated power is not constant in always. In such cases output voltage suffers from its input. In this paper we developed a control circuit with PI, Fuzzy controller logic which absolves the output voltages, generates the equalant correction signal to the pwm circuits.

III. Space-Vector Pwm

One of the features of two parallel connected inverters is the ability to obtain three levels of voltage (phase to neutral) P = VDC, H = $\frac{1}{2}$VDC and O = 0. Describing system in the meaning of three voltage levels provides similarity to Three-Level Neutral Point Clamped Inverter. This similarity allows to approach Space Vector Modulation in the same way like for Neutral Point Clamped Inverter [1].

The large vectors divides the plane into six sectors. Each of these sectors can be split into four regions as it is depicted in Fig. 3. Combination of vectors which should be used to synthesize Vref is based on its position. For example, when Vref is in region four of sector I, V2, V7 and V14 are used.

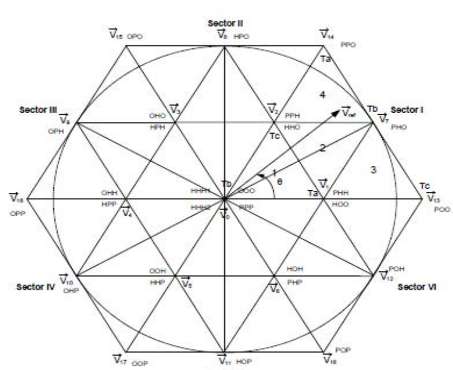

Figure 3 : 3-level space vector modulation sectors

a) Dwell Times

The following Figure presents reference vector transition from sector I to sector II:

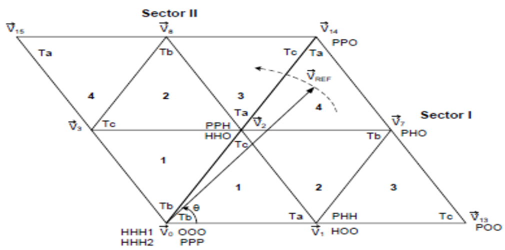

Figure 4 : Voltage reference transition between two sectors

where:

$$V14 = \tfrac{2}{3}VDCe^{j\frac{\Pi}{3}}e^{j\frac{\Pi}{3}};\ V7 = \tfrac{2}{3}VDCe^{j\frac{\Pi}{6}};\ V2 = \tfrac{1}{3}VDCe^{j\frac{\Pi}{3}};\quad \tfrac{2}{3}[\cos(\tfrac{\Pi}{3}) + j\sin(\tfrac{\Pi}{3})]T_a + \tfrac{\sqrt{3}}{3}[\cos\left(\tfrac{\Pi}{6}\right) + j\sin(\tfrac{\Pi}{6})]T_b + \tfrac{1}{3}[\cos(\tfrac{\Pi}{6}) + j\sin(\tfrac{\Pi}{6})]T_C = \tfrac{Vref}{VDC}[\cos(\Theta) + j\sin(\Theta)]T_s \qquad (2)$$

The dwell times calculation for three level SVM is similar to two level SVM. Vectors: V2, V7 and V14 are used when Vref is in region four of sector I:

$$V14Ta + V7Tb + V2Tc = Vref\ Ts \qquad (1)$$

And splitting into real and imaginary part:

b) Real

$$\frac{1}{3}T_a + \frac{1}{2}T_b + \frac{1}{6}T_c = \frac{Vref}{VDC}\cos(\Theta)T_s \qquad (3)$$

c) Imaginary

$$\frac{\sqrt{3}}{3}T_a + \frac{\sqrt{3}}{6}T_b + \frac{\sqrt{3}}{6}T_c = \frac{Vref}{VDC}\sin(\Theta)T_s \qquad (4)$$

d) Together with

$$T_a + T_b + T_c = T_s \qquad (5)$$

a set of equations real and imaginary can be created to calculate dwell times: Ta, Tb, Tc. The dwell times for every region in sector I are presented in Table1.

Table 1 : Switching pattern for sector

SECTOR -1				
Segments	1	2	3	4
1	[OOO]	[HOO]	[HOO]	[HHO]
2	[HOO]	[HHO]	[POO]	[PHO]
3	[HHO]	[PHO]	[PHO]	[PPO]
4	[HHH]	[PHH]	[PHH]	[PPH]
5	[HHO]	[PHO]	[PHO]	[PPO]
6	[HOO]	[HHO]	[POO]	[PHO]
7	[OOO]	[HOO]	[HOO]	[HHO]

O-lower switching, H-upper switching, P-both upper and lower switching.

IV. Pi Controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response [5]. It can be expected since PI controller does not have means to predict what will happen with the error in near future [1] [2]. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when

a) Fast response of the system is not required
b) large disturbances and noise are present during operation of the process
c) There is only one energy storage in process (capacitive or inductive)
d) There are large transport delays in the system

The pi controller basic mathematical equation is

$$U = Kpe_k + Ki\sum_{j=0}^{k} e_k + u_0 \qquad (6)$$

$$u_k = \begin{Bmatrix} Umax(U \geq Umax) \\ Umin(U \leq Umin) \end{Bmatrix}$$

Kp=proportional coefficient

Ki=integral coefficient

e_k =K-th sampling time

u_0=initial value

V. Fuzzy Controller

The most commonly used fuzzy inference technique is the so-called Mamdani method, as the very first attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Their work was inspired by an equally influential Interest in fuzzy control has continued ever since, and the literature on the subject has grown rapidly [2]. In this model the fuzzy implication is modeling by Mamdani's minimum operator, the conjunction operator is min, the t-norm from compositional rule is min and for the aggregation of the rules the max operator is used. In order to explain the working with this model of FLC will be considered the example. Where a simple two-input one-output problem that includes three rules is examined

Rule 1 : IF x is A3 OR y is B1 THEN z is C1

Rule 2 : IF x is A2 AND y is B2 THEN z is C2

Rule 3 : IF x is A1 THEN z is C3.

Step 1: Fuzzification

The first step is to take the crisp inputs, x0 and y0, and determine the degree to which these inputs belong to each of the appropriate fuzzy sets. According to Fig 5 one obtains.

$$\mu A1(x0) = 0.5, \mu A2\ (x0) = 0.2, \mu B1\ (y0) = 0.1, \mu B2\ (y0) = 0.7 \quad (7)$$

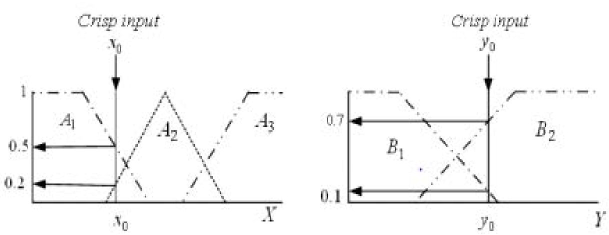

Figure 5 : Fuzzification

Step 2: Rules evaluation

The fuzzified inputs are applied to the antecedents of the fuzzy rules. If a given fuzzy rule has multiple antecedents, the fuzzy operator (AND or OR) is used to obtain a single number that represents the result of the antecedent evaluation. To evaluate the disjunction of the rule antecedents, one uses the OR fuzzy operation. Typically, the classical fuzzy operation unions used.

$$\mu A \cup B(x) = \max\{\mu A(x), \mu B(x)\} \quad (8)$$

Similarly, in order to evaluate the conjunction of the rule antecedents, the AND fuzzy operation intersection is applied.

$$\mu A \cap B(x) = \min\{\mu A(x), \mu B(x)\} \quad (9)$$

The result is given in this Figures

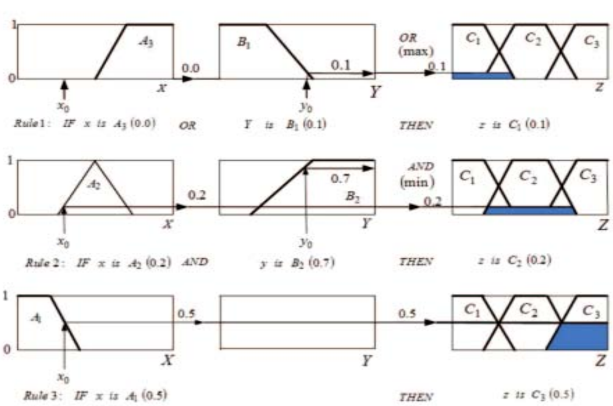

Figure 6 : Rules evaluation

Now the result of the antecedent evaluation can be applied to the membership function of the consequent. The most common method is to cut the consequent membership function at the level of the antecedent truth; this method is called clipping. Because top of the membership function is sliced, the clipped fuzzy set loses some information. However, clipping is preferred because it involves less complex and generates an aggregated output surface that is easier to defuzzify. Another method, named scaling, offers a better approach for preserving the original shape of the fuzzy set [3][9]. The original membership function of the rule consequent is adjusted by multiplying all its membership degrees by the truth value of the rule antecedent see in fig 7.

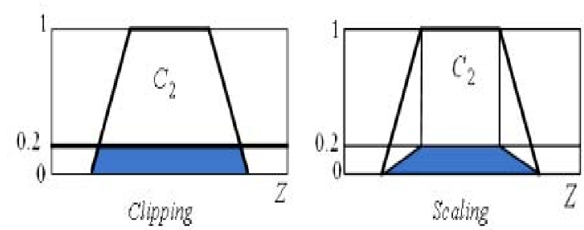

Figure 7 : Clipping and scaling

Step 3: Aggregation of the rule outputs

The membership functions of all rule consequents previously clipped or scaled are combined into a single fuzzy set. fig 8.

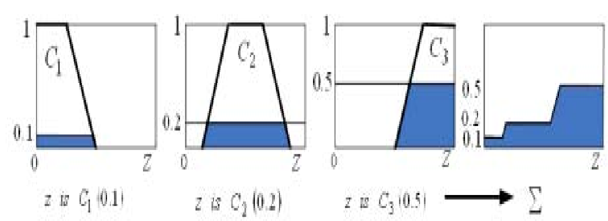

Figure 8 : Aggregation of the rule outputs

Step 4: Defuzzification

The most popular defuzzification method is the centroid technique used in this paper. It finds a point representing the center of gravity (COG) of the aggregated fuzzy set A, on the interval [a, b].

A reasonable estimate can be obtained by calculating it over a sample of points. This fuzzy logic controller is 3- level system so it has two inputs, n-level system has (n-1) inputs and $(n-1)^2$ rules are used so in this fuzzy logic controllers.

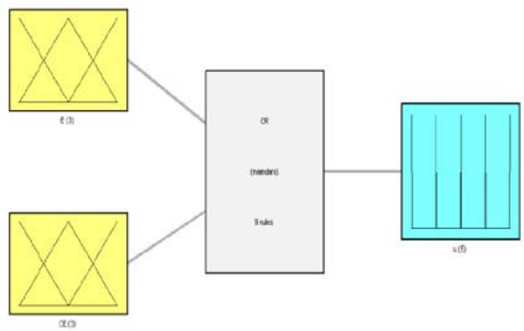

Figure 9 : Rules of the fuzzy logic controller

This fuzzy controller has two errors one is (E) error another one is (CE) counter error both are called input layer these are connected to hidden layer it means both inputs are compared as following rules

If (E is Negative) and (CE is Negative) then (u is Min)

If (E is Negative) and (CE is Positive) then (u is Zero)

If (E is Positive) and (CE is Negative) then (u is Zero)

If (E is Positive) and (CE is Positive) then (u is Max)

U id the output of fuzzy controller it is giving the pulses to pwm, this fuzzy controller is based on the input errors.

VI. Results

a) PI controller

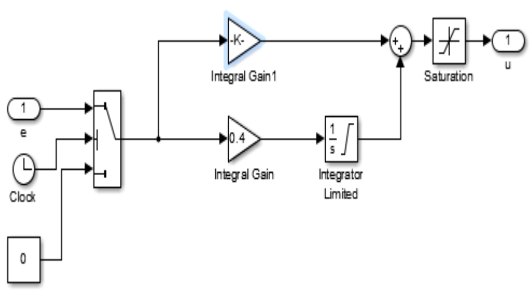

Figure 10 : Simulation diagram of PI controller

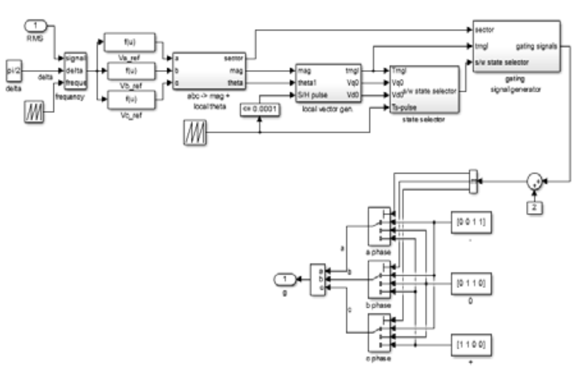

Figure 11 : Space vector pulse width modulation simulation diagram

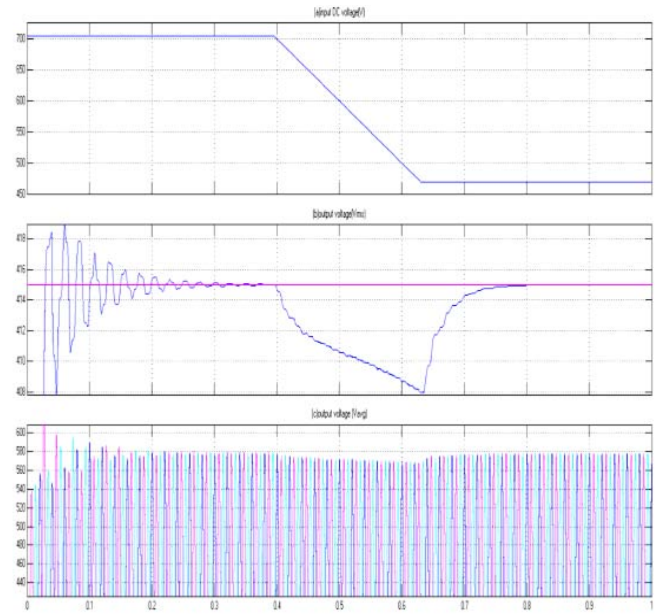

Figure 12 : Simulation results of Multilevel inverter using PI controller. (a) Input fluctuated DC voltage, (b) Inverter output voltage (Vrms) (c) The output voltage (Vavg)

From fig. no. 12. (a) The constant input DC voltage is applied from 0sec. to 0.4sec. then the time scale from 0.4sec. to 0.5sec.the input voltage is decreased from704.29V to 586v. then the time scale from 0.5sec. to 0.62sec. the DC voltage is gradually decreases from586v to 469.49V. Then after the input DC voltage magnitude is remains constant from 0.62sec. to 1sec.

From fig. no. 12. (b) it shows the output (Vrms) voltage from 0sec. to 0.4sec. the DC voltage magnitude is constant, voltage (Vrms) is oscillated nature settiled upto 0.3sec, then from 0.4sec.to 0.5sec.DC voltage is gradually decreases but output voltage (Vrms) fluctuated from 415v to 411v. Then after input DC voltage is decreased from 0.5sec. to 0.62sec. The voltage (Vrms) is also decresed upto 408V. Then from the time scale 0.62sec. to 1sec, input DC voltage is remains constant 469.49v and output (Vrms) voltage reaches the constant magnitude of 415v.

From fig.no.12(c) we can observe that 0sec. to 0.4sec. input DC is constant, output voltage is maintain constant magnitude. From 0.4sec. to 0.62sec. the input DC voltage is decreases. in this case the output voltage magnitude is small decreased. Than after time scale from 0.62sec. to 0.8sec.the output voltage has increased to meet the rated value of magnitude. after 0.62sec. to 1sec. DC voltage is 20% lesser than the applied voltage magnitude even through this period output voltage magnitude is reached the rated voltage and remains constant voltage magnitude. Using SVPWM method which is helps to improve the output voltage magnitude to maintain rated voltage with fast switching cycles.

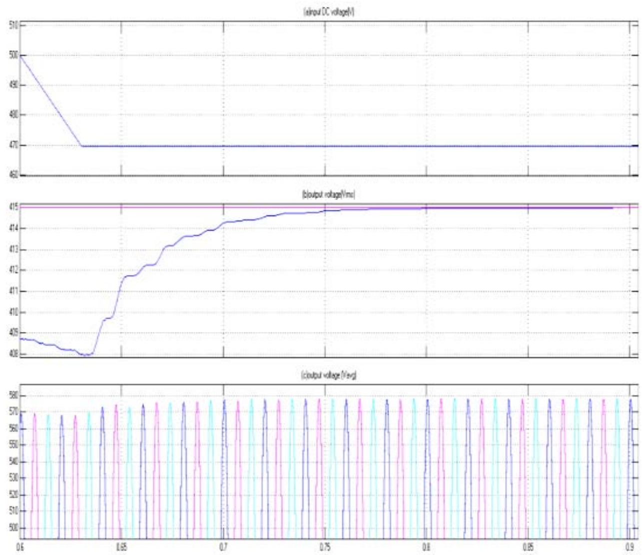

Figure 13 : Simulation results of Multilevel inverter using PI controller with zoom scale of fig12. (a) input DC voltage,(b) Inverter output voltage (Vms) (c) the output voltage (Vavg)

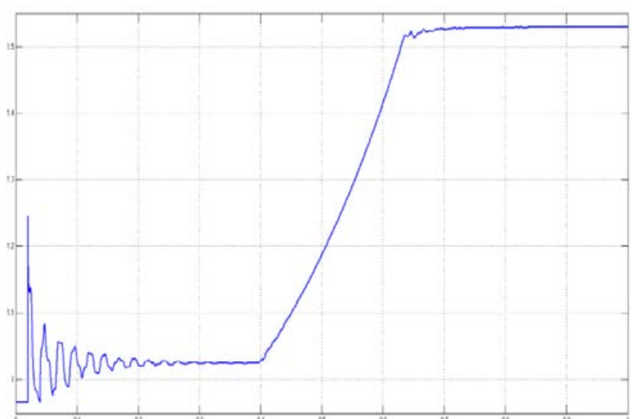

Figure 14 : PI controller error signal

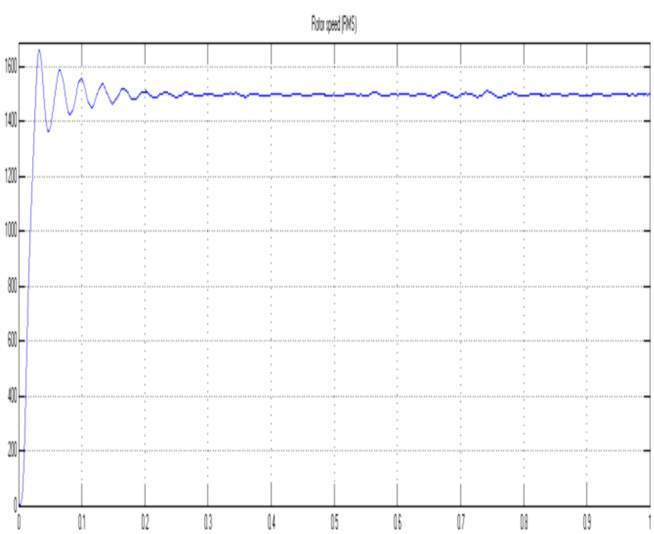

Figure 15 : Rotor speed of induction motor (rpm)

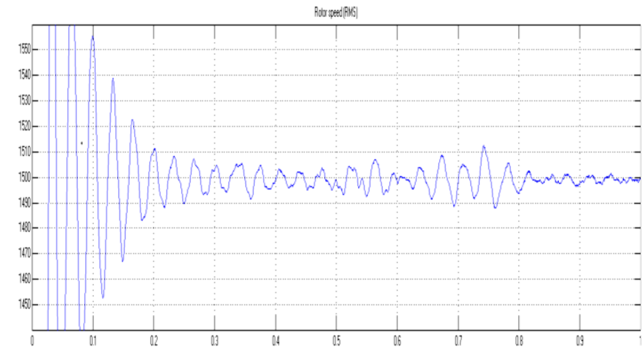

Figure 16 : Rotor speed of induction motor with zoom scale(rpm)

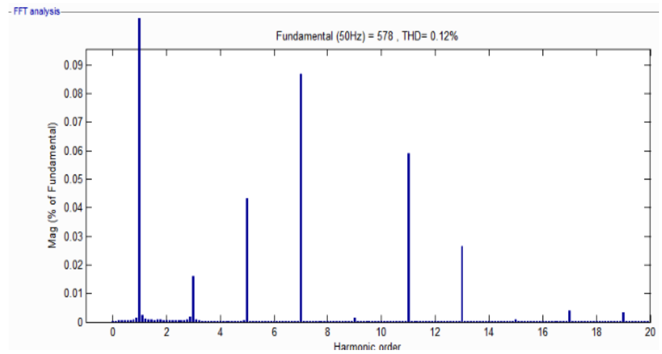

Figure 17 : THD with static load

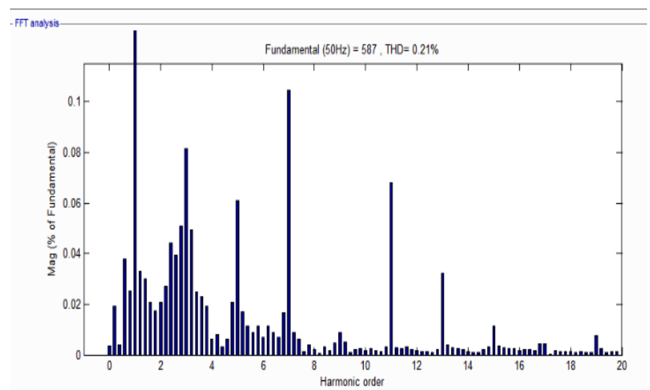

Figure 18 : THD with Induction motor load

From fig. no. 15, we conclude that using PI control method the 20% input DC voltage fluctuation was an effectively absorbed and improved the output rated voltage magnitude considering dc voltage fluctuation, induction motor load was running with constant rotor speed even though dc voltage fluctuation cases.

b) Fuzzy logic controller

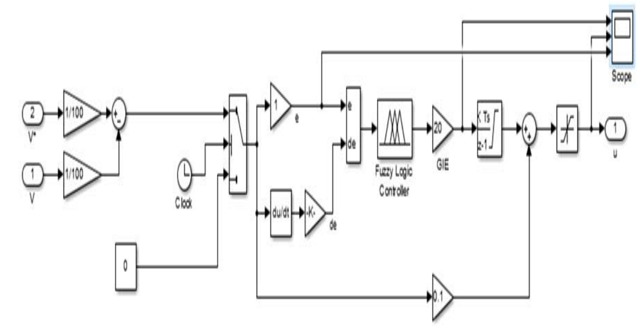

Figure 19 : Simulation diagram of Fuzzy- controller

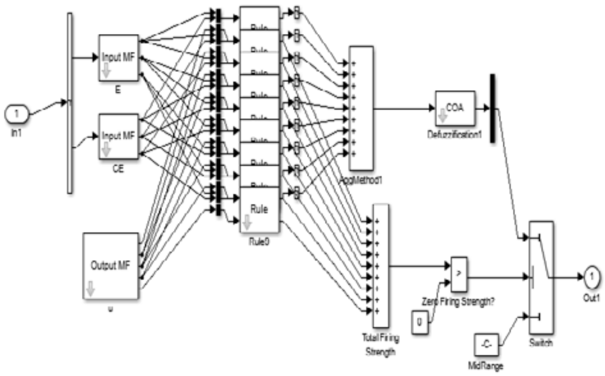

Figure 20 : Sub system diagram of Fuzzy logic simulation block

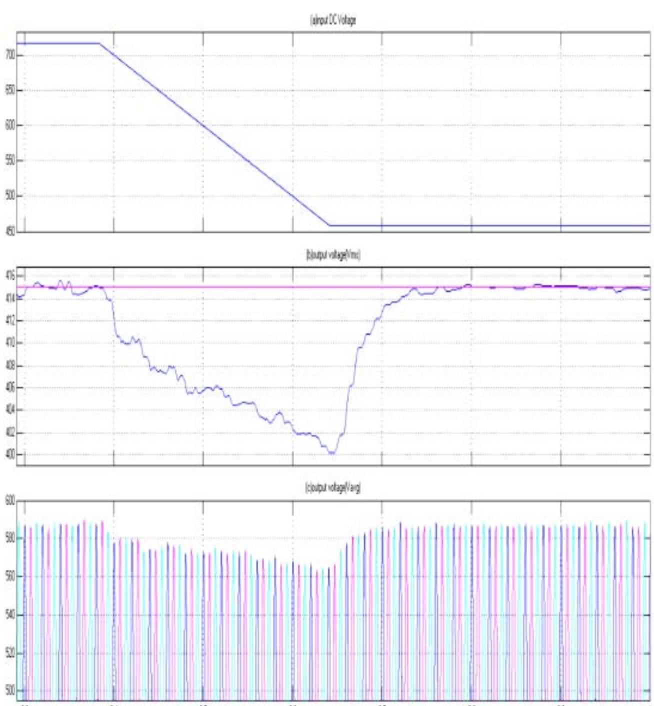

Figure 21 : Simulation results of Multilevel inverter using Fuzzy controller with 22% dc voltage fluctuation.(a) input DC voltage,(b) Inverter output voltage (Vrms) (c) the output voltage (Vavg)

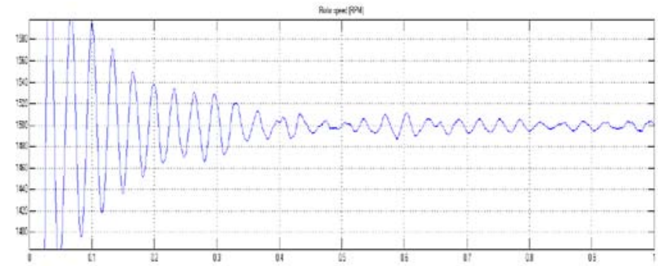

Figure 22 : Imulation results of dynamic load rotor speed using fuzzy-controller

From fig. no. 21. (b) it shows the output (Vrms) voltage from 0sec. to 0.4sec. the DC voltage magnitude is constant, voltage (Vrms) is less oscillated. Then from 0.4sec.to 0.62sec.DC voltage is gradually decreases but output voltage (Vrms) also decresed very smoothly. Then after input DC voltage is constant magnitude with 22% lesser value. From 0.62sec. to max time scale, the voltage (Vrms) is has an increased to reached the rated value magnitude of 417v within very less time comparatevily PI control method.

From fig.no.21(c) we can observe that 0sec. to 0.4sec. input DC is constant, and the output voltage is maintain constant magnitude. From 0.4sec. to 0.62sec. the input DC voltage is decreases. In this case the output voltage magnitude is small decreased. Than after time scale from 0.62sec. to 0.8sec. the output voltage has increased to reach the rated value of magnitude. after 0.62sec. to 1sec. DC voltage is 22% lesser than the applied voltage magnitude even through this period output voltage magnitude is remains constant voltage magnitude.

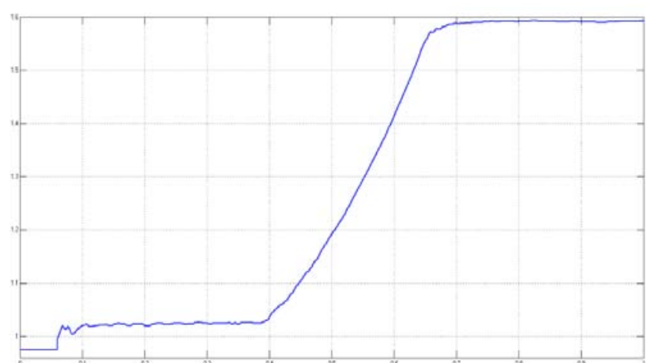

Figure 23 : Fuzy controller error signal

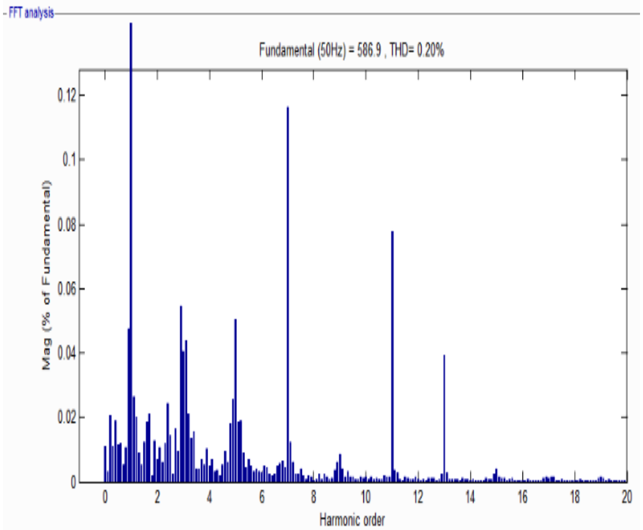

Figure 24 : THD of the dynamic load using Fuzzy controller

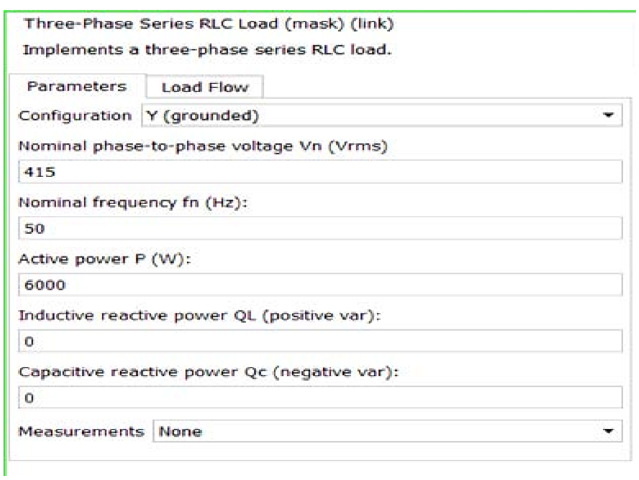

Figure 25 : Static load parameters(6Kw)

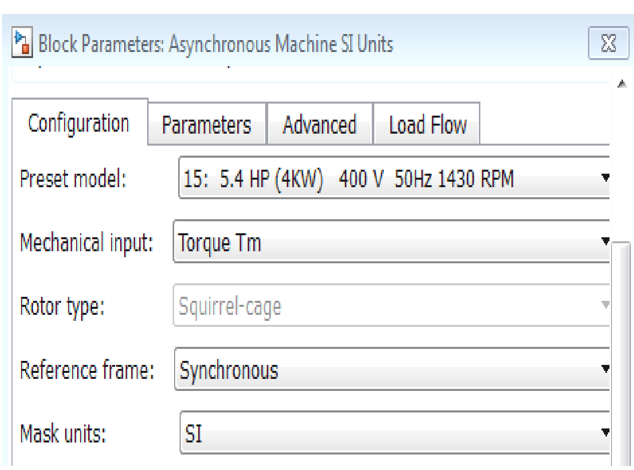

Figure 26 : Dynamic load parameters

Table 2 : Results comparison between PI and Fuzzy controller

Input DC voltage fluctuation (%)	Control methods with Load	Total Harmonic Distortion (%)	No. of cycles to reach rated voltage
20	PI with Resistive	0.12	12
20	PI with Induction motor	0.21	12
22	Fuzzy with Resistive	0.20	8
22	Fuzzy with Induction motor	0.20	8

VII. Conclusion

From table 2. Comparison of PI and FUZZY-controllers, The advantage of PI controller is less THD than fuzzy. The advantage of Fuzzy -controller is taking the less number of cycles to reach the rated output voltage magnitude considering input dc voltage flutuation. Fuzzy control is 22% of voltage fluctuation more DC voltage utilization and dynamic, static load response is very smooth manner than the PI control. So that fuzzy-control method is an effective one considering dc voltage fluctuation cases to improve the output voltages of converters with very fast response time, low THD value, and the supporting results are an examined in this paper with 6Kw resistive and 5HP induction motor loads.

VIII. Feature Scope

Future work will focus on the fast response time to reach the rated voltage magnitude considering input DC voltage fluctuation, low value of THD. Can be an implement the other hybrid techniques control algorithm. For improving the voltage utilization factor and power quality.

References Références Referencias

1. Biji Jacob, and M. R. Baiju, "A New Space Vector Modulation Scheme for Multilevel Inverters Which Directly Vector Quantize the Reference Space Vector" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 62, NO. 1, page.no.88-95, JANUARY 2015.
2. Azuki Abdul Salam1, Nik Azran Ab Hadi "Fuzzy Logic Controller for Shunt Active Power Filter" 4th International Conference on Engineering Technology and Technopreneuship (ICE2T), pp. no. 256-259, 2014.

3. N. Madhanakkumar, T. S. Sivakumaran and D. Divya sri "Performance Analysis of PI and Fuzzy Control for Resonant Converter Incorporating Boost" International Conference on Science, Engineering and Management Research (ICSEMR 2014).
4. Ritu Sharma, Alka Singh, A.N. Jha "Performance Evaluation of Tuned PI Controller for Power Quality Enhancement for Linear and Non Linear Loads" IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014), May 09-11, 2014, Jaipur, India.
5. Amei, K.; Tanizaki, Y.; Ohji, T.; Sakui, M. "A Control Method of Superposition Ratio in the Improvement of Voltage Utilization Factor in Three phase Multilevel Inverter considering the DC Voltage Fluctuation" Power Conversion Conference - Nagoya, 2007.7Publication Year: 2007, Page(s): 37 – 142.
6. High Performance Direct Power Control of Three-Phase PWM Boost Rectifier under Different Supply Voltage Conditions. 2014.
7. Jin-Woo Jung, Nga Thi-Thuy Vu, Dong Quang Dang, Ton Duc Do, Young-Sik Choi, and Han Ho Choi, "Three-Phase Inverter for a Standalone Distributed Generation System: Adaptive Voltage Control Design and Stability Analysis, Energy Conversion, IEEE Transactions Volume: 29, Issue: 1 Page(s): 46 – 56, 2014.
8. Bayat, Z.; Babaei, E.; Badamchizadeh, M. "Low Order Harmonics Elimination in Multilevel Inverters Using Fuzzy Logic Controller Considering the Variations of DC Voltage Sources" Electrical Machines and Systems (ICEMS), 2011 International Conference, Page(s): 1 – 6, 2011.
9. Lin Chengwu, Zhang Xiaomin, Jiang Qiguang "Research on SVPWM inverter output control technology" Fifth International Conference on Measuring Technology and Mechatronics Automation (ICMTMA), Page(s): 927 – 929, 2013.

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