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Adaptive Control Method for Output Voltage of a Three-Phase Multilevel Inverter Considering For Fluctuation in DC Voltage

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Abstract— In this paper, a new control approach for closed loop feedback control (CLFB) multilevel inverter of the output voltage using space vector pulse width modulation (SVPWM) is presented. The DC sources input to the inverter circuit are directly connected without energy storage devices considering solar, wind and fuel cell cogeneration systems. The Proportional plus Integral control (PI), Fuzzy Logic Control (FLC) and Particle Swarm Optimization (PSO) has been applied, the main role of these control techniques is to make improvement in the controllability and absorption of the fluctuations of DC voltages, Using three level inverters with static and dynamic loads has been examined. This paper gives a detailed analysis and comparison of control techniques simulated by MATLAB environment.

Index Terms— Closed Loop Feed Back Control(CLFB), Fuzzy Logic Control (FLC), Particle Swarm Optimization (PSO), Proportional plus Integral control (PI), Space Vector Pulse Width Modulation (SVPWM)

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1 INTRODUCTION

The world electricity demand is increasing day by day. To meet electricity demands with help of natural energy source are not a only sufficient to meet this loads. In extant to meet the load demands by using renewable energy sources and cogeneration systems are one solution. The multilevel inverter is a DC to AC converter circuit that generates the voltage without resort to energy storage device and transformers by using multiple DC sources and witching elements. In conventional inverter circuits, the suppression of harmonics is possible by pulse width modulation, and the harmonic contents can be reduced when using a multilevel configuration [3].

The cogeneration systems using Solar, wind energy and fuel cells have become widespread. In such systems, the generated power is converted into a DC voltage, stored in batteries, and then converted into an AC voltage by inverter circuits [18].

In these type of power plants, the generated power is not constant always and unsteady, and large voltage fluctuations .Thus far, voltage stabilization has been achieved by the introduction of booster circuits, and maintain the inverter output voltage magnitude constant or rated value even though input DC voltage magnitude fluctuating condition[3],[4,[5],][6].

In this paper, we analyzed the control method for the simplification of control calculations, improving the voltage
Utilization factor of multilevel inverters without transformer and reduce the total harmonic distortions.

And also we have introduced a new control algorithm in which the superposition ratio is varied according to DC voltage fluctuations. An approach [19],[20] to determine the optimum switching angles in varying DC sources is to calculate the switching angles using PI, Fuzzy logic control and PSO control using SVPWM.

2. PROPORTIONAL-PLUS-INTEGRAL CONTROL

This is the combination of proportional and integral control action. Mathematically it can be represented by equation [2]

$m(t)=Kp\, e(t)+KpKi\int_0^1 e(t)dt$………………..(1)

Laplace transform of equation (1)

$M(s)=KpE(s)+\frac{Kp}{STi}E(s)=E(s)\left[1+\frac{1}{STi}\right]Kp$

$\frac{M(s)}{E(s)}= Kp\left[1+\frac{1}{STi}\right]$ ………………………….. (2)

In equation (2) both parameters Kp and Ti are adjustable. Ti is called integral time, Kp is proportional coefficient. In integral control action the actuating signal consists of proportional error signal with integral of the error signal.

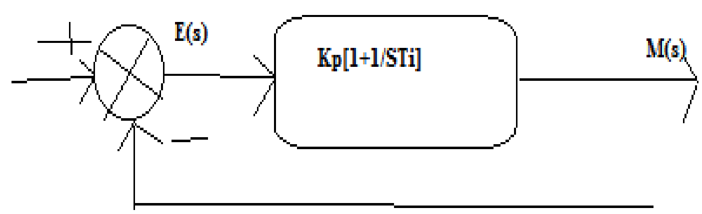

Fig1.Block diagram of PI control

In proportional control action, the output of the controller is proportional to error[2]. When the error is zero, the controller output is constant. In this action the gain kp and proportional band are inversely proportional to each other. In integral control action, the output of the controller is changed at a rate which is proportional to the actuating error signal e(t).

2.1 Output voltage tracking control

The following has been obtained from the fundamental
Equations for a three-phase three-wire system, and from the
Relationship between the line voltages and phase voltages [8],[18].

$V_{ab}+V_{bc}+V_{ca}=0$ .... (3)

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$V_{an} + V_{bn} + V_{cn} = 0$ .... (4)

Relational expression between line voltage and phase voltages the following equations are obtained.

$V_{ab} = V_{an} - V_{bn}$

$V_{bc} = V_{bn} - V_{cn}$ .... (5)

$V_{ca} = V_{cn} - V_{an}$

When (3) (4) and (5) are arranged in V_{an} they become as follows

$V_{an} = -V_{bn} - V_{cn}$ .... (6)

$V_{an} = V_{bn} + V_{ab}$ .... (7)

$V_{an} = V_{cn} - V_{ca}$

By adding both sides of three equations following equation is deduced.

$3V_{an} = V_{ab} - V_{ca}$

By similarly operation on other phase

$V_{an} = \frac{1}{3}(V_{ab} - V_{ca})$

$V_{bn} = \frac{1}{3}(V_{bc} - V_{ab})$ .... (8)

$V_{cn} = \frac{1}{3}(V_{ca} - V_{bc})$

Phase voltage of V_{an}, V_{bn}, V_{cn} are converted into two phase AC V_{α} and V_{β} by using following matrix.

$$\begin{bmatrix} V_{\alpha} \\ V_{\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad \text{.................... (9)}$$

In addition V_{out} is calculated by synthesizing the vector of V_{α}, V_{β}.

$$V_{out} = \sqrt{|V_{\alpha}|^2 + |V_{\beta}|^2} \quad \text{.............................. (10)}$$

V_a, V_b, V_c *of* each phase are expressed by following equations

$V_a = V_{pi}[(1+\alpha)sin\Theta + \alpha sin3\Theta]$

$V_b = V_{pi}\left[(1+\alpha)\sin\left(\Theta - \frac{2}{3}\prod\right) + \alpha sin3\Theta\right]$ .... (11)

$V_c = V_{pi}\left[(1+\alpha)\sin\left(\Theta + \frac{2}{3}\prod\right) + \alpha sin3\Theta\right]$

From equations (10), the magnitude V_{out} corresponds to the effective value of the output line voltage, which is a DC value in the case of a three-phase balanced voltage without fluctuation. Therefore, tracking control of the output voltage can be implemented by maintaining this value at a constant level.

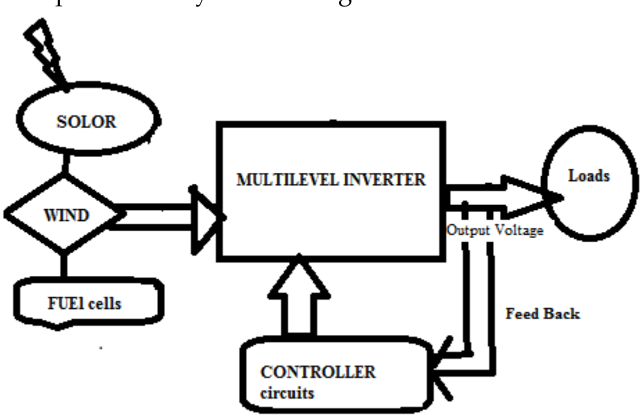

Fig2. Block diagram of the output voltage feedback control

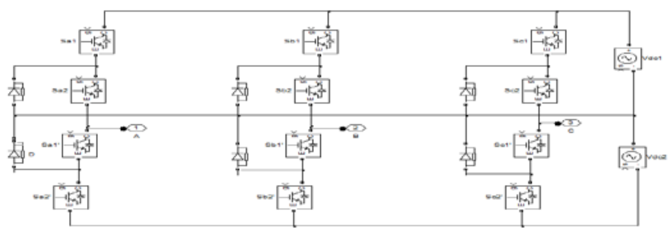

Fig.3: Three-level diode clamped inverter

3. FUZZY LOGIC CONTROL

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 controller we use the 4 rules.

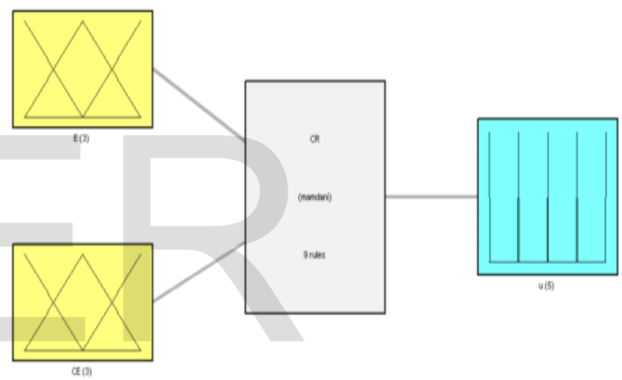

Fig.4..Rules of fuzzy logic controller

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[7],[16]

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 unit, this fuzzy controller is based on the input errors [15].

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4. PRATTICLE SWARM OPTIMIZATION (PSO)

A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solutions (called particles). These particles are moved around in the search-space according to a few simple formulae [1]. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered [13].

```
  n = 3;   %No. of iterations. = n^3
    kp1=1;
ki1=1;
simopt
simset('solver','ode23t','SrcWorkspace','Current','DstWorkspac
[tout,xout,current_fitness] = sim('Inverter_5',[0 0.5],simopt);
local_best_fitness = current_fitness;
 for i=1:n
   for j=1:n
      kp1=i/1000;
      ki1=j/10;
    if current_fitness(975,:) < local_best_fitness(975,:)   %local
best fitness
      local_best_fitness = current_fitness;
      kp_best = i/1000;
      ki_best = j/10;
   end
   [global_best_fitness] = min(local_best_fitness(970:980,:);
   end
end
```

N represents the number of iterations , n=3 it means 3*3 plane is taken, total 9 times system is running and get the best value[9],[10],[11],[12],[13]. In this PSO method we use the PI controller so we fix the kp and ki values, means initiation the values of kp and ki. Simopt means simulation optimization it has the simulation set in this simulation set has different types of commands, Src Workspace - Where to evaluate expressions [{base} | current | parent] This property specifies the workspace in which to evaluate MATLAB expressions defined In the model. The default is the base workspace.

Where to assign variables [base|{current}|parent] This property specifies the workspace in which to assign any variables defined in the model. The default is the current workspace. tout, xout means save time and save state.

Local best fitness=current fitness it means local best value is consider as present best value. i, j are variables these are use to variable names in mat-lab. i=1:n , j=1:n these statement represents the i and j values are 1 to n, n means number of iterations.

if current_fitness(975,:)<local_best_fitness (975), local_best_fitness = current_fitness; these statements are if statements the standard comparison can be made. After this compression variables find the kp best and ki best values. These values are equal to global best values.

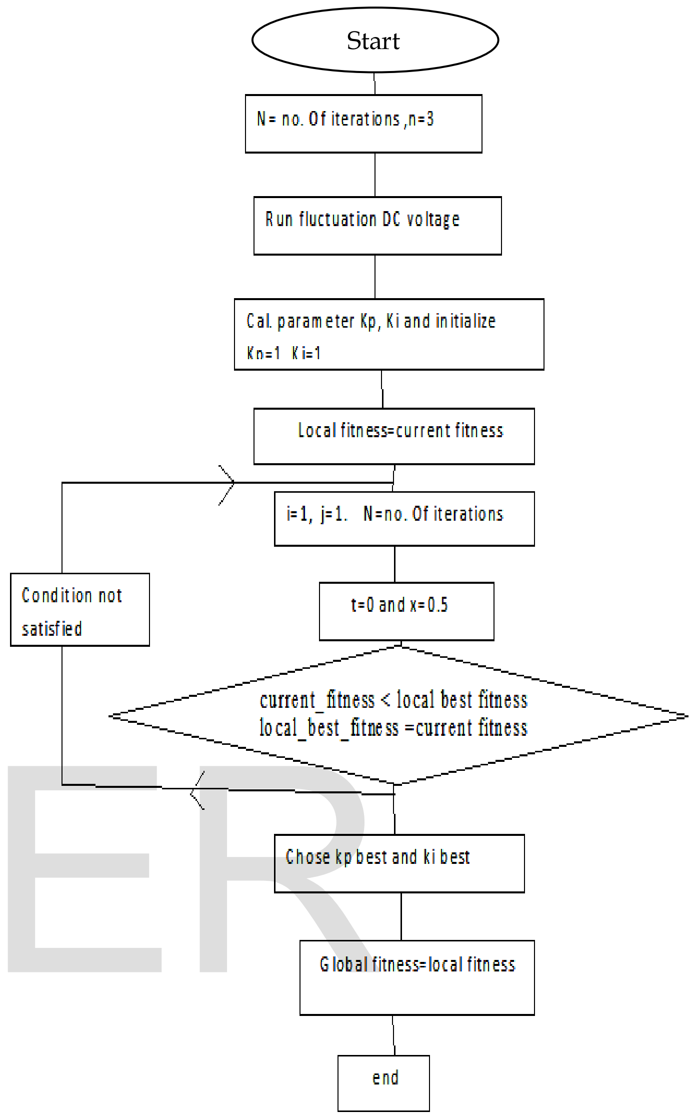

Fig5. Flow chart of PSO method

5. Simulation Results

5.1) PI Controller

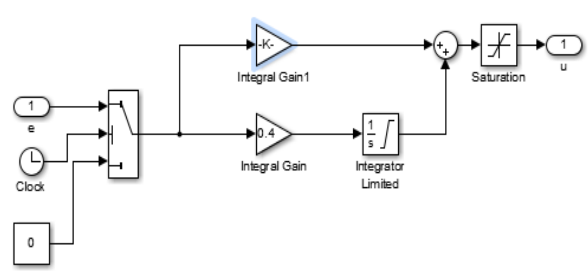

Fig6.Simulation diagram of PI controller

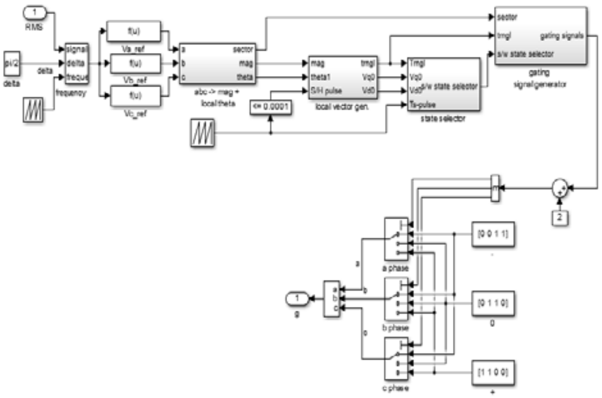

Fig.7. Space vector pulse width modulation simulation diagram

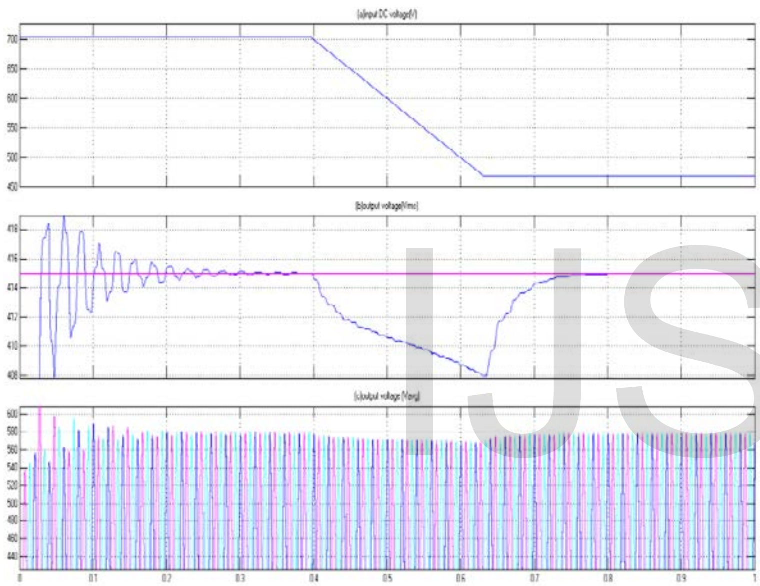

Fig.8:Simulation results of 3level inverter using PI controller .(a) Input fluctuated DC voltage, (b)Inverter output voltage(Vrms) (c) The output voltage(Vavg)

From fig 8.(a) The constant input DC voltage is applied from 0sec. to 0.4sec(i.e 20% more than the rated value). Then the time scale from 0.4sec. to 0.5sec.the input DC voltage is decreased from704.29V to 586v. Then 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 (i.e20% lesser than the rated value).

From fig8.(b) it shows the output (Vrms) voltage from 0sec. to 0.4sec. the DC voltage magnitude is constant, voltage (Vrms) is oscillated nature settled up to 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 decreased up to 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.8(c) we 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 helps to improve the output voltage magnitude to maintain rated voltage with fast switching cycles.

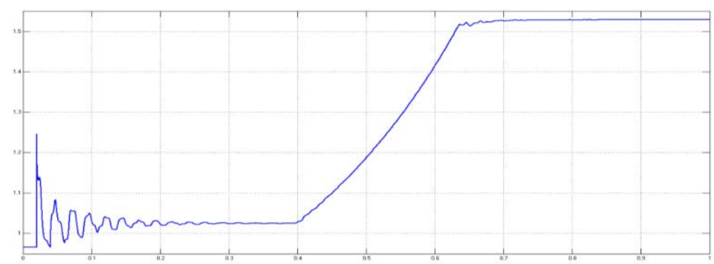

Fig9. PI controller error signal

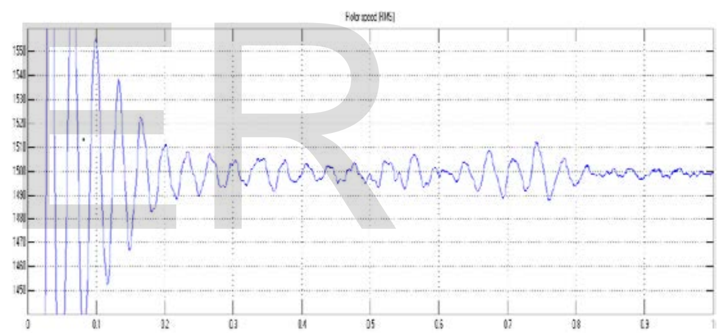

Fig10.Rotor speed of induction motor (rpm)

5.2) Fuzzy logic controller

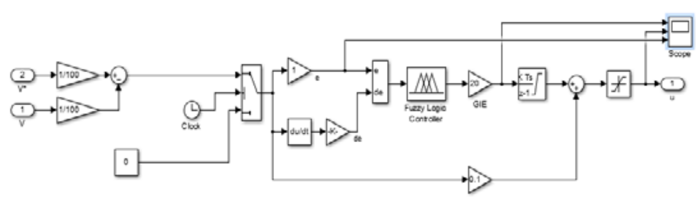

Fig11.Simulation diagram of Fuzzy controller

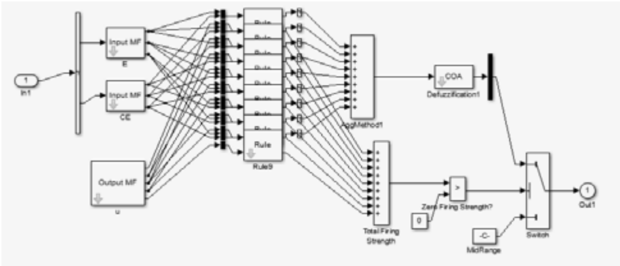

Fig12. Sub system of Fuzzy logic simulation block

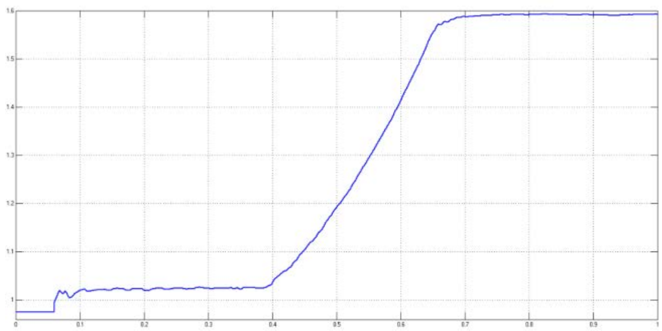

Fig15.Fuzy controller error signal

Figure13.Simulation results of 3level inverter using Fuzzy controller with 22% DC voltage fluctuation
.(a) input DC voltage,(b) Inverter output voltage(Vrms) (c) the output voltage(Vavg)

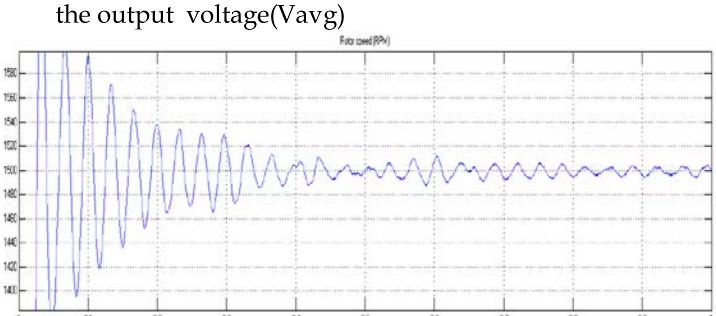

Fig14. Simulation results of dynamic load rotor speed using fuzzy-control

From fig13.We can observe that the time scale 0sec. to 0.1sec. Input DC voltage is 716v fixed (i.e 22% more than the rated value) and RMS voltage get the small fluctuations shown in fig 13(b). And load voltage is 580v. From 0.1sec. To 0.36sec. the DC voltage is decreases from 716v to 457.78v (i.e 22% of fluctuation and RMS voltage is decreases from 415v to 400.8v and load voltage is decreases to 565v voltage magnitude as shown in fig13(c). In the scale from 0.36sec. to 1sec. DC voltage is maintain constant voltage magnitude of 457.78v(i.e 22% lesser than the rated value) and RMS voltage is increases to upto 415v and maintain constant voltage magnitude and load voltage also increases to 585v and maintain constant voltage magnitude accordingly as shown in fig13(a),(b)and(c).

The fig13 shows (a) input DC voltage,(b) Inverter output voltage(Vmrs) (c) the output voltage(Vavg) with fuzzy controller ha been reaches the constant RMS voltage within very less time with THD of 0.22%, as shown in fig13 and fig14.

5.3) Particle swarm optimization(PSO)

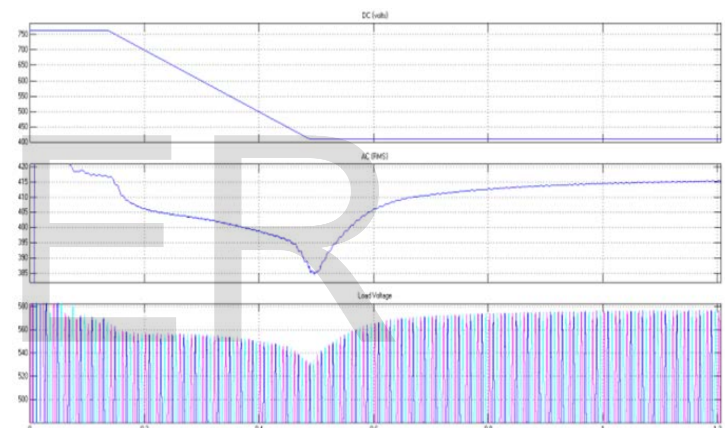

Figure16. Simulation results of 3level inverter using PSO- controller with 31% of DC voltage fluctuation
(a) input DC voltage,(b) Inverter output voltage(Vrms) (c) the output voltage(Vavg)

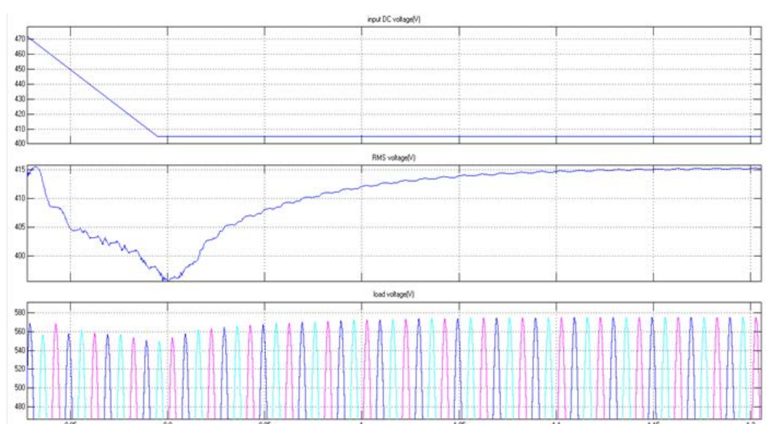

Fig 17. Simulation results of multilevel inverter using PSO-controller with zoom scale of fig16.

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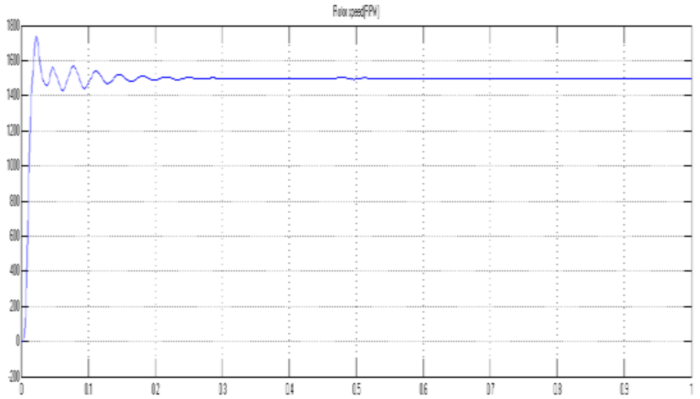

Fig18.Simulation results of dynamic load rotor speed using PSO-controller.

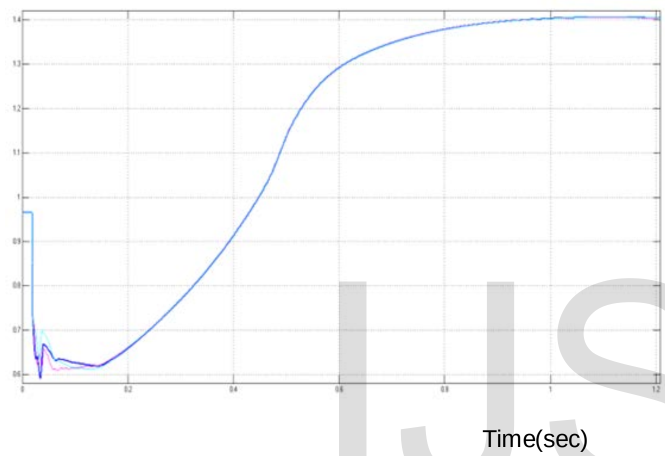

Fig19. PSO- controller error signal

From fig16. We can observe that time scale 0sec. to 0.1sec. Input DC voltage is 768.82v fixed (i.e 31% is more than the rated value) and RMS voltage have constant magnitude and load voltage is 575v. From 0.1sec to 0.5sec, the DC voltage has the smooth decreeing from 768.82v to 404.96v (i.e 31% of fluctuation of DC magnitude) and RMS voltage is decreases from 415v to 382.7v and load voltage is also decreases to 529v voltage magnitude, in the time scale from 0.5sec to 1.2sec. Input DC voltage is maintain constant voltage magnitude of 404.96v (i.e 31% less magnitude of initial value) and instantly RMS voltage is increases to 415v with smoothly and maintain constant voltage magnitude and load voltage also increases to rated value and maintain constant voltage magnitude. By implementing PSO method with 5HP IM & Resistive- load is reaches the constant RMS voltage within less time with final output voltage wich containTHD of 0.71%.

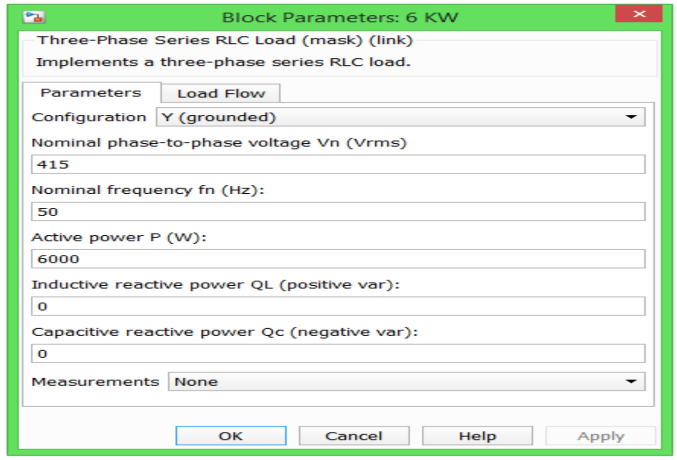

Fig.20. Three phase Static Load parameters

From fig10, 14, and 18 Simulation results of dynamic load rotor speed using PI, Fuzzy and PSO-controllers correspondingly shown, from this analysis the PI & Fuzzy controller results have the fluctuating speed behaviors. By using PSO controller motor speed is very smoothly controlling in case of DC voltage fluctuating cases. From Table1 we can validate the effectiveness of controllers.

From fig 22. Indicate the Total Harmonic Distortion of the voltage wave forms after reach the rated value by implementing the control techniques.

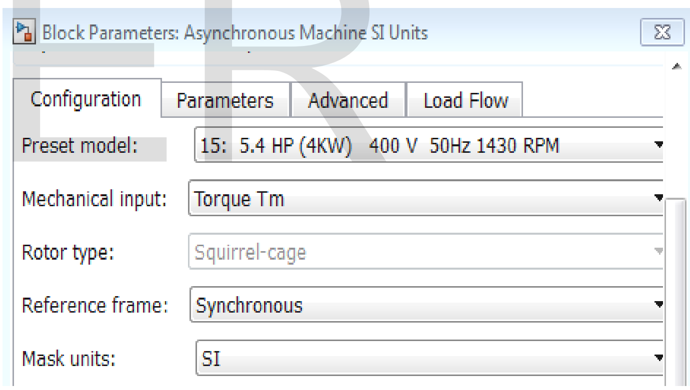

Fig21. Three phase Dynamic Load parameters

Table1.Results comparison between PI, Fuzzy and PSO controller

Input DC voltage control and absorption rate (%)	**Control Methods**	**Total Harmonic Distortion (%)**
20	Proportional plus Integral control	0.28
22	Fuzzy Logic Control	0.22
31	Particle Swarm Optimization	0.71

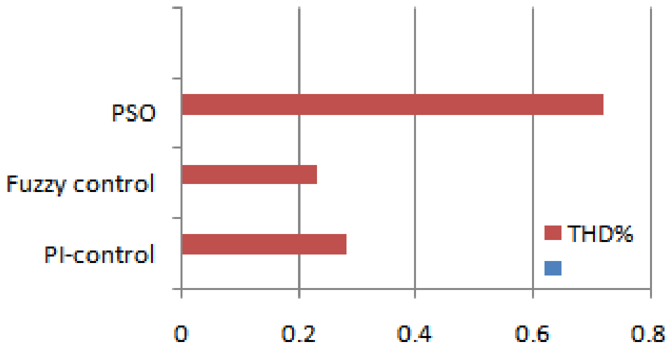

Fig 22. Total Harmonic Distortion Analysis.

6. CONCLUSION

This paper has presented new control methods for output voltage of a three phase multilevel inverter considering the fluctuated DC voltage. The comparison of PI, FUZZY and PSO controllers, the PSO controller is effective than other controllers, we confirmed that, the control and absorption of DC voltage fluctuation of about 31%, this is 10% of voltage fluctuation absorption more than the PI and FUZZY controllers dynamic load response also very well in this control method. The disadvantage of the PSO controller is time consuming more than PI and FUZZY controllers. The advantage of PI controller is less THD and advantage of FUZZY-controller is taking less number of cycles to reach the rated value after the voltage disturbance and fast controlling. In these paper we conclude that the PSO-control technique is an effective one considering DC voltage fluctuation cases.

Future work will focus on further reduction of output voltage distortion. For improving the voltage utilization factor

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