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ANALYSIS OF SUPERPOSITION RATIO CONTROL METHOD FOR THE IMPROVEMENT OF VOLTAGE UTILIZATION FACTOR IN THREE PHASE MULTILEVEL INVERTER

S. Narasimha and M. Sushama
Department of Electrical and Electronics Engineering, JNTUH College of Engineering, Hyderabad, India
E-Mail: snarasimha.999@gmail.com

ABSTRACT

In this paper, a new approach for the control of superposition ratio of odd harmonic wave into output voltage feedback control and improvement on voltage utilization factor is presented. The input DC voltages sources are feeding to the multilevel inverters are directly connected from cogeneration systems. In case of solar, wind and fuel cell applications, the generated voltage from these sources are not constant always and unsteady, it's mainly depends on solar radiation and wind characteristics. But the aim is to get stabilized AC voltages of multilevel inverter even though input DC voltage fluctuations. This paper gives detailed analysis of the improvement on the controllability and absorption of the DC voltage fluctuation by superimposing the moderate odd harmonic wave using proportional plus integral, Artificial Neural Network controllers. The results obtained with 5,7level diode clamped inverters connected to static and dynamic loads. Using simulink/MATLAB software.

Keywords: Superposition ratio control, closed loop PI control, Sinusoidal pulse width modulation. Artificial Neural Network control

I. INTRODUCTION

The last decade's growth in the production of electric energy from renewable energy sources has led to an increased focus on power electronics systems. Renewable energy sources like photovoltaic, wind and wave energy are relying on power converters in order to exchange power with the grid [1]. These inputs are not constant with time always in fluctuating nature and 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 have 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. However [2][3], filters for high power converters can be of substantial size and weight and therefore also of great cost since they are made of several expensive metals. Therefore, a lot of effort is made in order to improve the converter system so that the filter can be reduced while the cried codes and system specifications are still met. There are mainly two ways of reducing the harmonic distortion. One way is to optimize the switching sequence, with harmonics as the most important constraint. Another way is to use several levels to build the fundamental voltage i.e. converters with three levels or more [4][5].

In an effort to improve voltage quality and efficiency, a simple control method for improving the voltage utilization factor of multilevel inverter [9][11]. In this paper a control method which introduced the control of superposition ratio of third harmonic wave into output voltage feedback control and improvement on voltage utilization factor is proposed.

It is applied to the multilevel inverter, and the operation principle and features are explained in Figure-1. Which including Solar, and fuel cells system.The fluctuated inputs are converted to stable output by using Multilevel inverter. By simulation the validity of proposed control analysis has been confirmed.

II.PROPORTIONAL PLUS INTEGRAL CONTROL

A) Proportional term

To control the system speed Proportional and integral (PI) controller is used. PI is a generic control loop feedback mechanism controller widely used in industrial control system. A PI controller calculates error values as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant KPcalled the proportional gain [12]. The proportional term is given is by:

$U_P(\text{t}) = K_P \text{e}(\text{t})$ ...(1)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become

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unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

B) Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error.

The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously [12]. The accumulated error is then multiplied by the integral gain (K_I) and added to the controller output. The integral term is given by

$$U_I(t)= K_I \int_0^t e(t)dt...(2)$$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value.

In the proposed control method, the basic PWM control block used conventionally for multilevel inverters is implemented by output voltage feedback and improvement of the voltage utilization factor [9]. we aimed at the more improvement in absorption and controllability of input DC voltage fluctuations. A block diagram of the proposed control method is shown in

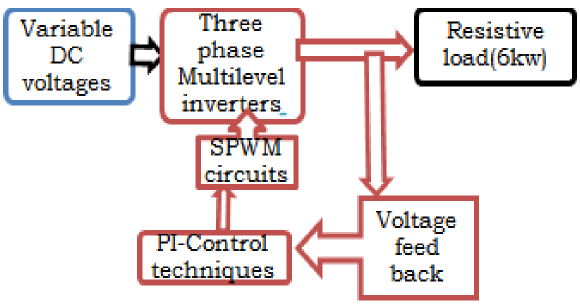

Figure-1, and detailed explanations are given below.

Figure-1. Block diagram of closed loop voltage control of multilevel inverter method.

III.OUTPUT VOLTAGE TRACKING CONTROL

Two phase output line voltages $V_{RY}$and V_{BR} are taken into the Simulation the following can be obtained from the fundamental equations for a three-phase three-wire system, and from the relationship between the line voltages and phase voltages [8]:

$$V_{RY}+V_{YB}+V_{BR}=0$$
$$V_{RY}=V_{BN}-V_{YN}$$
$$V_{YB}=V_{YN}-V_{BN}$$
$$V_{BR}=V_{BN}-V_{RN} \quad ...(3)$$

Therefore,

$$V_{BN}=1/3(V_{RY}-V_{BR})$$
$$V_{YN}=1/3(V_{YB}-V_{RY})$$
$$V_{BN}=1/3(V_{BR}-V_{YB})(4)$$

Three phase voltages V_{RN},V_{YN} and V_{BN} *are* converted into two-phase AC voltages $V\alpha$ and $V\beta$ by using the following:

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \frac{\sqrt{3}}{2}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{RN} \\ V_{YN} \\ V_{BN} \end{bmatrix} ....(5)$$

Now the magnitude $V_{out}$of the resultant output vector is calculated as follows:

$$V_{out} = \sqrt{\left|\dot{V}_\alpha\right|^2 + \left|\dot{V}_\beta\right|^2} ....(6)$$

The magnitude Vout 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 stable level [8].

The difference between the output voltage references V*out and the resultant vector magnitude Vout is given to the proportional integrator, and the DC voltage compensation on V_{pi} is calculated. A coefficient related to the superposition ratio α is applied to this value, and then a sinusoidal reference is obtained by multiplying by a three-phase sine Wave with amplitude of one[7][8].

The advantage of this system is obtaining the fixed control characteristic, when the AC voltage of any frequency is output, because the signal input to the proportional integrator is the instant DC voltage which does not depend on the frequency of the output Voltage. That is, the method can be applied to variable speed drive of electric motors and to other cases when a variable-frequency source is required.

C) Sinusoidal pulse width modulation

The method for improving the utilization factor of the output voltage by superimposing a third harmonic on every phase signal of a three-phase inverter. In this study, we describe the application of this method to a multilevel inverter.

Sine + 3rdharmonic PWM technique

The idea of Sine+3rdharmonic modulation technique is based on the fact that the 3-phase inverter-bridge feeding a 3-phase ac load does not provide a path for zero-sequence component of load current. Only three output points are brought out from a three-phase inverter-bridge. These output points are connected to the three supply terminals of the load. Such an arrangement does not cause any confusion for the delta connected load but for a star connected load the neutral point remains floating. However for a balanced, three-phase, star-connected load this should not be a drawback as the fundamental component in the load phase voltage is identical to the fundamental component of inverter's pole voltage[6].

In fact, the floating neutral point has the advantage that no zero sequence current (which includes dc, third and integer multiples of third harmonics) will be able to flow through the load and hence even if the pole voltage is distorted by, say, 3rdand integral multiples of third harmonics the load side phase and line voltages will not be affected by these distortions [10]. Accordingly a suitable amount of third harmonic signal is added to the sinusoidal modulating signal of fundamental frequency. Now, the resultant waveform (modified modulating signal) is compared with the high frequency triangular carrier waveform. The comparator output is used for controlling the inverter switches exactly as in SPWM inverter. the low frequency component of the pole voltage will be a replica of the modified modulating signal provided (i) The instantaneous magnitude of the modified modulating signal is always less than or equal to the peak magnitude of the carrier signal and (ii) the carrier frequency is significantly higher than the frequency of modulating signal[6].

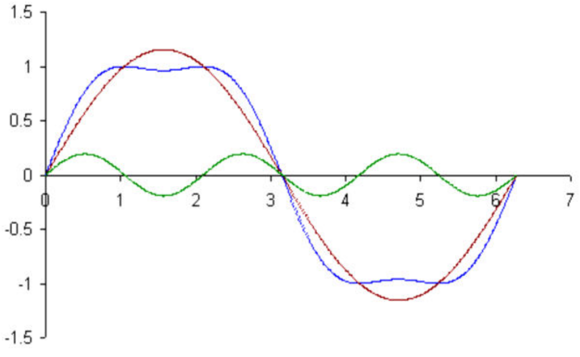

Figure-2. The modulating signal for Sine+3rd Harmonic modulation.

The addition of small percentage of 3rdharmonic to the fundamental wave causes the peak magnitude of the combined signal to become lower than triangle wave's peak magnitude [6].In other words, a fundamental frequency signal having peak magnitude slightly higher than the peak magnitude of the carrier signal, if mixed with suitable amount of 3rdharmonic may result in a modified signal of peak magnitude not exceeding that of the carrier signal.

Thus the peak of the modulating signal remains lower than the peak of triangular carrier signal and still the fundamental component of output voltage has a magnitude higher than what a SPWM can output with m = 1.0. Thus the fundamental voltage output by the inverter employing Sine+3rdharmonic modulation technique can be higher [6].

IV.IMPROVEMENT OF VOLTAGE UTILIZATION FACTOR

The utilization factor of the output voltage by superimposing a third harmonic on every phase signal of a 3 phase inverter.In this analysis and application of this method to a multilevel inverter [8][9].

We introduce variable superposition ratio control, so that the superposition ratio of the third harmonic can be adjusted to the DC voltage fluctuation. The input signal of proportional integrator PI_1 reflects the control state of output voltage, and its value is employed for calculation of the appropriate superposition ratio of the third harmonic [8].

When the DC voltage is sufficient to output the rated voltage of 415V, the input signal of PI_1 is 0, and the output of LIM_1 is below V_{tri}. Therefore, the input of PI_2 becomes negative. As a result, the output of LIM_2 is 0, and the superposition amount is likewise 0. On the other hand, when the DC voltage is Deficient, the output LIM_1 is limited by V_{tri}, and the input of PI_2 becomes positive. As a result, the output of LIM_2 is somewhere between 0 and V_{out}, and the superposition amount is adjusted to the shortfall of the DC voltage as shown in Figure-3.

The superposition ratio α is obtained by dividing the output value by $6V_{out}$, and the superposition signal is generated by applying the ratio to the sine wave of the third harmonic[8]. The signal is added to the three phase sine wave reference multiplied by (1 + α) in order to calculate the output $V_{out}$of PI_1. As a result, the following phase signals are obtained [8].

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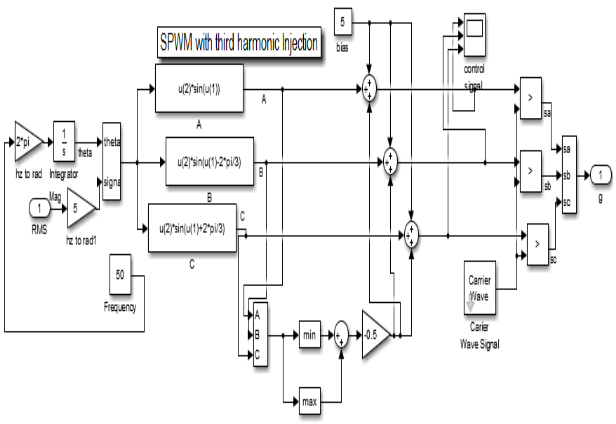

Figure-3. Simulation block diagram of Sine+3rd Harmonic modulation.

V.SIMULATION RESULTS

D) Using PI controller

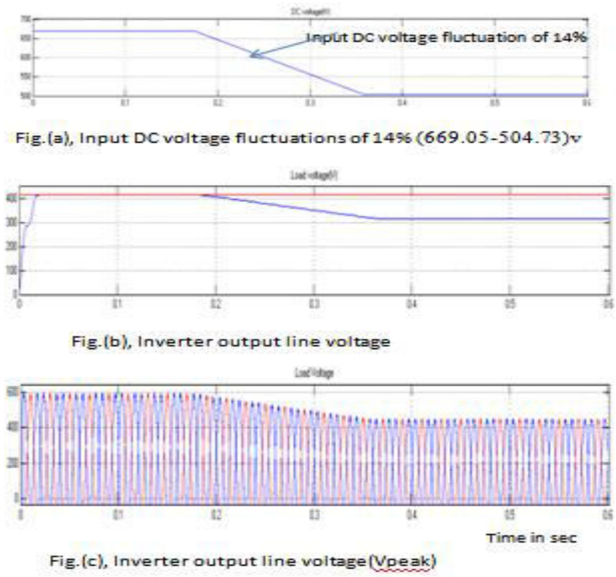

Figure-4. Simulation results of Output voltage control of 5level inverter connected to 6kw resistive load, input DC voltage fluctuation of 14%. ***With out using PI controller.***

fig(a) Input DC voltage fluctuation of 14%. Fig(b) Inverter ouput line voltage response(Vrms).fig(c) Inverter output line voltage(Vpeak)

In the Figure-4. We can observe that simulation results has been anlysed without using PI control performance of inveter,in fig(a) input DC voltage has been fluctuated 14% value,from fig(b)andfig(c) shows the output line voltage and peak voltages are also follows to input voltage.

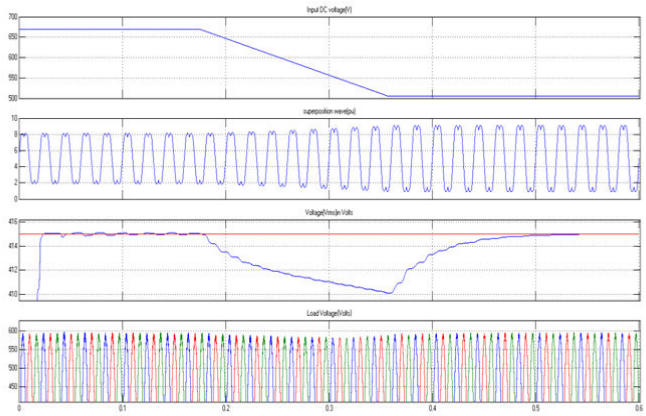

Figure-5. Simulation results of Output voltage control of 5level inverter connected to 6kw resistive load, input DC voltage fluctuation of 14%. *With using PI controller.*

Fig(a) Input DC voltage fluctuation of 14%. Fig(b) the superposition signal wave (pu).fig(c) Inverter output line voltage(Vrms).fig(d) Inverter output line voltage(Vpeak)

From Figure-5, can obsrved that input DC voltage is fluctuating from 0.18sec to 0.35sec, the voltage has been dercesed from initial magnitude. From fig(b) the superposition wave has been incresing acordingly input voltage fluctuations,In fig(c),(d) the inverter out put line voltage(Vrms) and peak voltages response as shows that inverter output line voltages are constant magnitude with PI control implimenting even thought input voltage fluctuating cases. In this case the PI gains are consider Kp=0.01and Ki=0.3 using by trail and error method.

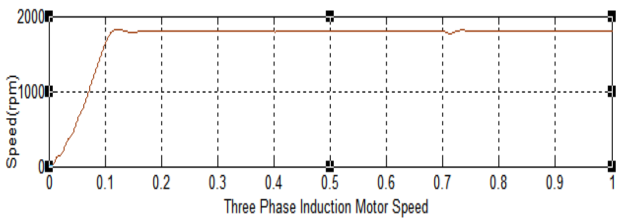

Figure-6. Simulation results of 5level inverter connected to induction motor(5hp), rotor speed response with input DC voltage fluctuation of 14%.

From the Figure-6, Can observed that the rotor speed response of induction motor is constant i.e1500 r.p.m even thought input DC voltages of inverter is fluctuating(14%) conditions with spwm method.

From the Figure-7, can analysed that input voltage is fluctuating from reference voltage to 20% of fluctuations in linearly and sudden as shown in fig.7(a). From fig7(b)shown the super position wave response is varied according to input voltage fluctuations, if input voltage is decreasing than superposition wave is increasing accordingly vice versa. Such that the output voltage of inverter maintain stable voltage and speed as shown in fig7(c) at DC voltage fluctuation of 20%.

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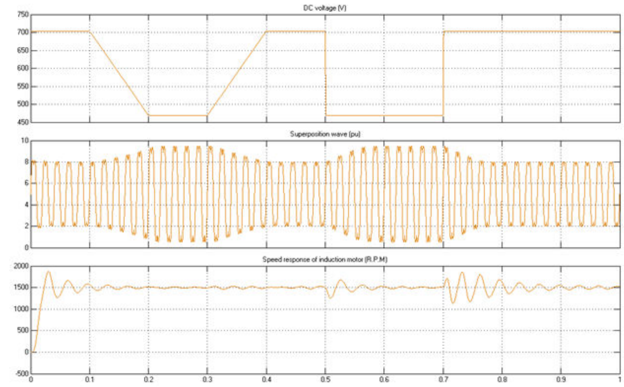

Figure-7. Simulation results of speed response of induction motor connected to 5level inverter with input DC voltage fluctuation of 20%. ***using PI controller*** with SVPWM method.

Fig(a) DC voltage fluctuation of 20%. Fig(b) the superposition signal wave (pu).fig(c) Speed response of induction motor

E) Using 7Level inverter

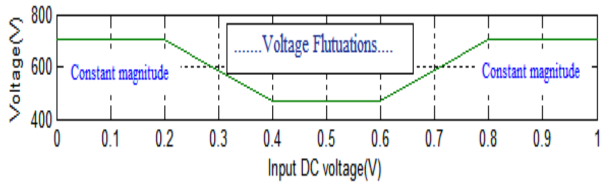

Figure-8. Input DC voltage fluctuation of 20% (469.5V-704V).

In the Figure-8. The time scale from 0sec to 0.2sec the input DC voltage is constant magnitude i.e 20%more than the reference value. And from 0.2sec to 0.4 sec the input DC voltage has gradually decresing from 704V to 469V i.e. 20% voltage lesser than the reference value and incresing the same to 0.8sec.

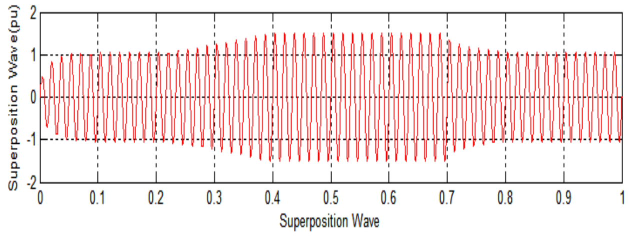

Figure-9. Super position wave(pu).

From Figure-9, can obsrved that input DC voltage is constant magnitude i.e. 704V upto 0.2sec at the same time the superposition signal is also maintaining constant magnitude. Than after o.2sec the input DC voltage is decresing from 704V to 469V at this time the superpsition signal is gradually incresing to improve the output voltge to meet the desire value and vice versa. Such that stabilized the line voltage of inverters as shown in fig10.

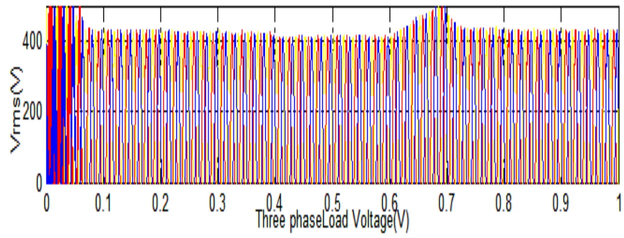

Figure-10. Simulation results of 7level inverter connected to resistive load(6kw) line voltage responseVrms.

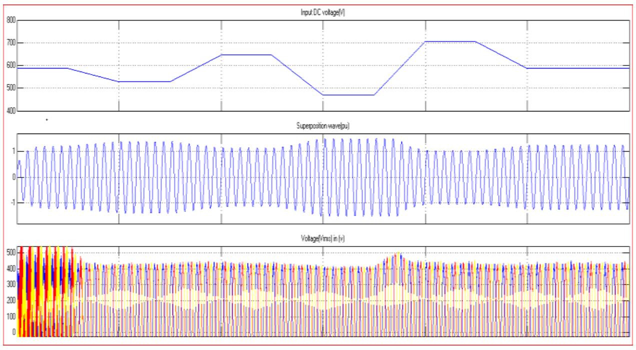

Figure-11. Simulation results of 7level inverter connected to resistive load with input DC voltage fluctuation of 20%

Fig.11(a)A step change in Vdc, (b) Superposition signal wave(Pu) (c) Inverter output line voltage (Vrms)

From the Figure-11, can observe that input DC voltage fluctuation response to a step changing as shown in Figure-16 (b) correspondingly superposition signal wave has been improving to maintain the inverter output voltage is constant or rated value (i.e.415Vrms), considering the input DC voltage fluctuations as shown in Figure-16 (b) and (c).

(F) Using Artificial Neural Networks (ANN) controller

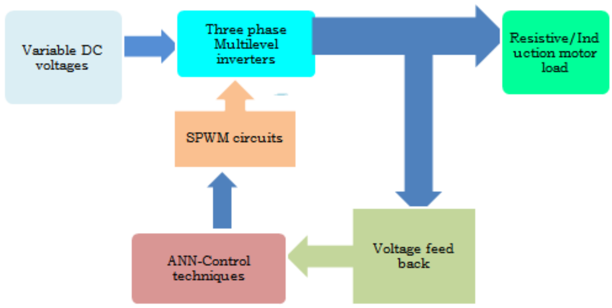

Figure-12.the block diagram of ANN controller for output voltage stabilization in multilevel inverters

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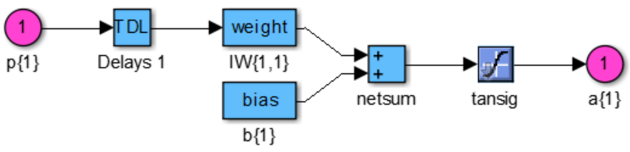

Figure-13.Simulation subsystem block diagram of ANN training .

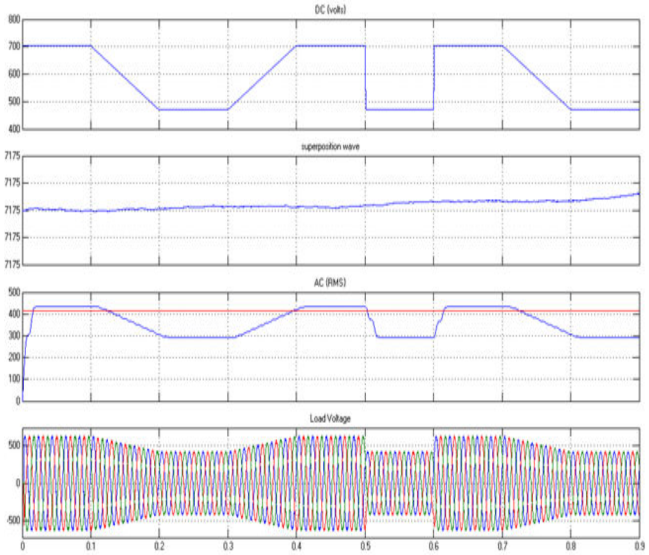

Figure-14.Simulation results of 5level inverter connected to resistive load ***without ANN controller*** with input DC voltage fluctuation of 20% .

Fig(a) DC voltage fluctuation of 20%. Fig(b) the superposition signal wave (pu).fig(c) Inverter output line voltage response

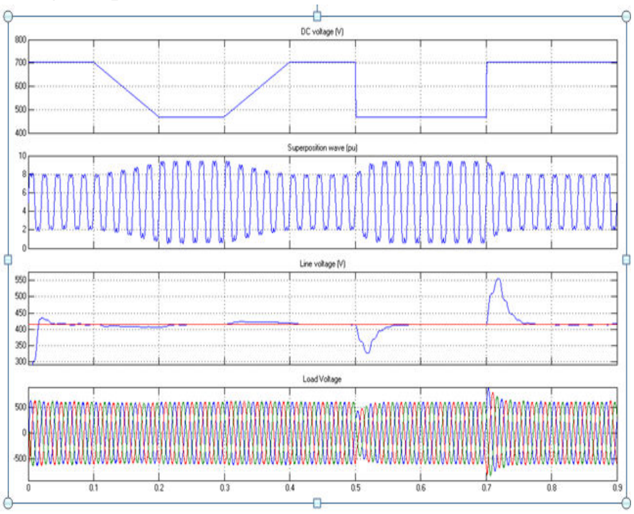

Figure-15.Simulation results of 5level inverter connected to resistive load ***Using with ANN controller*** with input DC voltage fluctuation of 20% .

Fig(a) DC voltage fluctuation of 20%. Fig(b) the superposition signal wave (pu).fig(c) Inverter output line voltage response

From Figure-14. We can observe that simulation results has been anlysed without using ANN control performance of inveter,in fig14(a) input DC voltage has been fluctuated 20% value,from fig14(c)andfig(d) shows the output line voltage and peak voltages are also follows to input voltage. From fg14(b) can observed that there is no superposition wave improvement,because of without using any controllers

From Figure-15, can obsrved that input DC voltage is fluctuating from 0sec to 0.9sec, the voltage has been fluctuated step change in Vdc. From fig(b) the superposition wave has been improving acordingly input voltage fluctuations,In fig(c),(d) the inverter out put line voltage(Vrms) and peak voltages response as shows that inverter output line voltages are stabilized with ANN control implimenting, even thought input voltage fluctuating cases. In this case to train the ANN controller with new feed forward neural network with two inputs and one output.

Table-1.

S.no	Various Controllers with Loads	Input DC voltage fluctuation	5level Inverter output line voltage (THD)	Stabilization of inverter output Voltage in (sec)
1	PI-Resistive load	14% (669.05-504.73)V	3.90%	0.2sec
2	PI-Induction motor	14% (669.05-504.73)V	5.32%	
3	ANN-Resistive load	20% (469.51-704.26)V	1.03%	0.05sec
4	ANN-Induction motor	20% (469.51-704.26)V	1.24%	

The maximum controllability and absorption of the input DC voltage fluctuation using PI and ANN controller with SPWM method shown in table.1.

Table-2. Load Parameters.

Resistive	6kw
Induction Motor	5.4HP, 50Hz

CONCLUSIONS

In this paper detailed analysis has been examined the control of superposition ratio of odd harmonic wave and improvement on voltage utilization factor. The varies type input DC voltage fluctuations are applied to the multilevel inverters like 1) Step change in Vdc 2) Sudden step change in Vdc, the 5level and 7level diode clamped inverters connected to static and dynamic loads are applied and tested with PI and ANN controllers, concluded that.

i) The control and absorption of the fluctuations of input DC voltage is effectively up to 14% with SPWM using PI control method and have significant harmonics distortion.

ii) The fast response of the controllability and absorption of the fluctuation of the input DC voltage is Using Artificial Neural Network Controller (ANN) with SPWM, maximum controllability and absorption of the fluctuation of the DC voltage is 20% using SPWM. And has been consisting less settling time compare to PI control method. i.e Settling time to reach the rated voltage is 0.05sec. and And using 7level inverter there is no significant harmonic reduction in output line voltages comparatively so that 5level inverter are suitable one for real time implementation.

In the future, we intend to focus on further more controllability and absorption of input DC voltages fluctuations.

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