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A CONTROL METHOD FOR VOLTAGE OSCILLATION SUPPRESSION USING NEUTRAL-POINT-CLAMPEDINVERTER

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***Abstract*— The major problem in the electrical power quality is the harmonic content. There are several methods indicating the quantity of harmonic content and the most widely used measure is the Total Harmonic Distortion. If total capacitance of DC-link capacitor is smaller, the amplitude of oscillation is larger. In this paper, three-level neutral-point-clamped inverter system is analyzed by the small-signal modeling and the controlmethod reducing the oscillation of the neutral-point voltage isproposed. By the proposed method, the amplitude of the neutralpointvoltage oscillation is reduced. A nine level cascaded multilevel inverter power circuit is simulated in MATLAB simulink with sinusoidal PWM technique. The results are presented and analyzed.**

***Key words*— NPC, Oscillation Suppression, Modulation Index,THD,Discontinuous pulse width modulation (DPWM), Low frequency oscillation, Neutral-point voltage balancing,**

I. INTRODUCTION

The Pulse Width Modulated (PWM) inverters can control their output voltage and frequency simultaneously and also they can reduce the harmonic components in load currents. These features have made them suitable in many industrial applications such as variable speed drives, uninterruptible power supplies, and other power conversion systems. The popular single-phase inverters adopt the full bridge type using approximate sinusoidal modulation technique as the power circuits. The output voltage of them has three values: zero, positive and negative of supply DC voltage levels. Therefore, the harmonic components of their output voltage are determined by the carrier frequency and switching functions [1]. However, three-level NPC inverter has a problem with theneutral-point voltage fluctuation inherently.

The neutral-pointvoltage should be controlled for good performance of the invertersystem. To control the neutral-point voltage, the variouscontrol methods have been studied and introduced in manypaper[5-10]. One of drawbacks that the conventional controlmethods have is a low frequency oscillation of the neutralpointvoltage. Some modulation methods have been proposedfor improving this drawback. However, these methods haveanother drawback such as the complicated calculation processor the additional control loop.

To analyze the dynamic characteristic and control theperformance of the inverter system to the various variations,the accurate model of the system is essential [11]. However,the detailed analysis of three-phase grid-connected three-levelneutral-point-clamped (3P-GC-3L-NPC) inverter has not beendone completely. The switching model and the switchingfunction model predict the detailed transient response and thesystem behavior precisely [12], but these models are verycomplicated and need a long time to construct the models.Compared with switching model and switching functionmodel, the averaged small-signal model is the more simplifiedmodel due to approximation of the real switching model. Theappropriate compromise between the accuracy to analyze andthe complexity to construct model leads the widespread use ofthe averaged small-signal model. The averaged small-signalmodel is derived by averaging and perturbing and linearizingthe circuit equations of the system. The derived model is usedto design control system and to obtain the control-to-outputtransfer function and input-to-output transfer function.

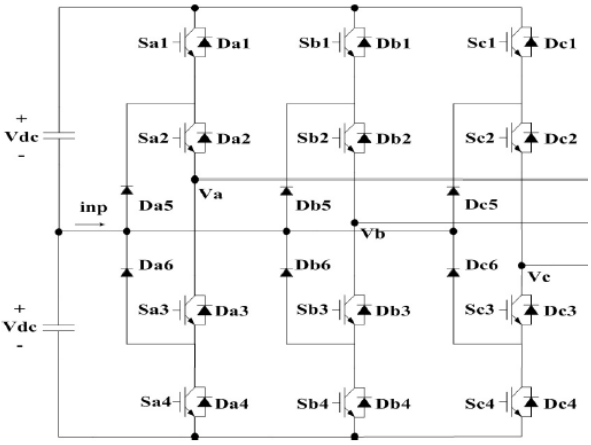

Figure. 1 Structure of three level inverter

3L-NPC inverter in Fig. 1 is a widely used topology ofmulti-level inverter. This NPC topology has inherent problemwhich is the neutral-point voltage caused by the neutral-pointcurrent that flows into or out from the neutral-point accordingto switching states . The unbalance and low frequency oscillationof the dc-link capacitor voltage cause the increase ofthe harmonic components and the destruction of the switchingdevices. Therefore, the analysis and the control of the neutralpointcurrent is very important issue. The maximum output phase voltage is given by $V_0 = V_1+V_2+V_3+V_4$.

Each unit generates a quasi-square waveform by phase shifting its position and negative phase-leg-switching timings. It should be noted that each switching device always conducts for 180° (or half-cycle), regardless of the pulse width of the quasi-square wave. This switching method makes all of the switching device current stresses equal. With enough levels and an appropriate switching algorithm, the multilevel inverter results in an output voltage that is near sinusoidal. The output voltage of the nine level cascaded multi-level inverter is shown in figure 2.

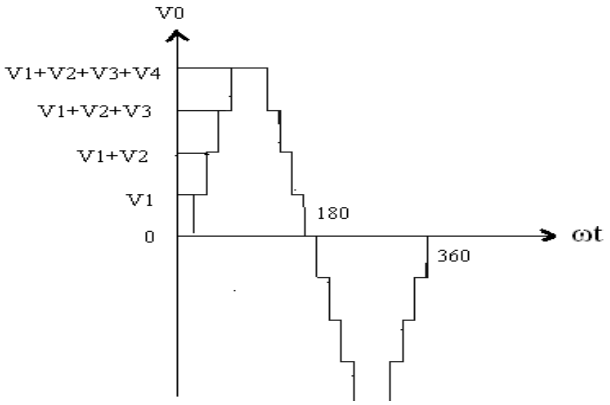

Figure .2 Output voltage of single phase cascaded nine level inverter

II. EXISTING METHOD

The conventional control method for two-level inverters isvery simple and easily implemented. However, there aresome drawbacks, such as high total harmonic distortion(THD) of the output waveforms, high voltage stress of theswitching devices, low system efficiency .This is especially true in middle and high voltage, or highpower conversions. Akira Nabae proposed a newneutral-point clamped (NPC) PWM inverter in 1980, which isthe basic three-level inverter [1]. Comparing with theconventional two-level inverter, the three-level inverter hasmany advantages, such as low voltage stress on switchingdevices, high equivalent switching frequency, reduced outputharmonics, etc.. Therefore, it is widely used in middleand high voltage, or high power applications [1], [4].

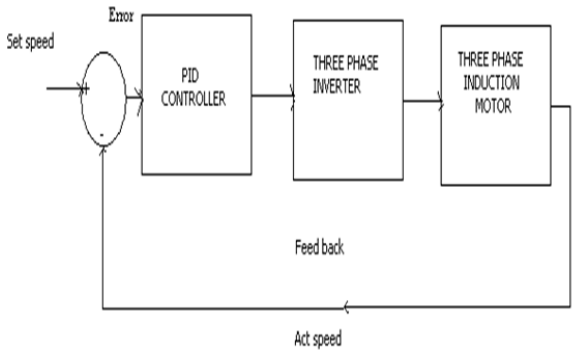

Figure.3.Block diagram of Existing Method

In order to generate phase voltage with three-levels andline voltage with five-levels, the NPC three-level invertercircuit needs two DC bus capacitors connected in seriesbetween the positive and negative poles of the DC bus.Ideally, the voltage on each capacitor is half the DC busvoltage. However, due to capacitance errors of the capacitors,different parameters of the switching devices, unbalancedthree-phase operation, and other factors, a DC busneutral-point voltage unbalancing problem appears, whichinfluences the output waveforms quality[2], [6]. In addition,this problem makes the output waveforms containing a lot oflow frequency harmonics. When the neutral-point voltageunbalancing problem becomes serious, it damages theswitching devices and affects the system operation [6]. Tosolve this problem, many methods have been proposed.The neutral-point voltage unbalancing problemcontains two parts: the dc deviation and the lowfrequency oscillation of the neutral-point voltage. The dcdeviation of the neutral-point voltage can be controlledby many solutions proposed in the literature.

For example,zero-sequence voltage injection methods have beenproposed in [2], [7], Ref. [3], [5] propose improved spacevector modulation (SVM) methods to reduce theneutral-point voltage unbalancing. In addition, theycorrectly select other vectors, which do not impact on theneutral-point voltage, to replace the small vectors.The low frequency oscillation of the neutral-point voltagecan lead to a lot of low frequency harmonics in the outputwaveforms, and the voltage stress of the switches is increased[4], [10]-[11]. When the dc deviation of the neutral-pointvoltage appears, the low frequency oscillation problem canalso exacerbate the neutral-point voltage unbalancing,especially in middle or high power applications.

However,the low-frequency oscillation problem of theneutral-point voltage is commonly ignored. a new modulation strategy using smallvectors to compensate for the effects of all of the vectors ineach carrier cycle is proposed to reduce the neutral-pointvoltage ripple. Ref. [4] proposes a double modulation wavesstrategy based on SPWM to enable the average neutral-pointcurrent to be zero. So the low frequency oscillation of theneutral-point voltage is eliminated. However, it has a muchhigher switching frequency when compared with theconventional SPWM control method.Based on the basic principle of discontinuous pulse widthmodulation (DPWM), this paper proposes a new DPWMcontrol method to suppress the low frequency oscillation ofthe neutral-point voltage. By distinguishing the odd and evencarrier cycles, and the prior and latter half carrier cycles, theproposed method controls the switches of a certain phase sothat there is no switching in each carrier cycle.

In addition, ineach carrier cycle, the operating time of the positive andnegative small vectors in pairs is equal. Therefore, theaverage value of the neutral-point current is zero in a carriercycle, and a neural-point voltage without low frequencyoscillation can be achieved. When compared with theconventional SPWM control, without adding complexhardware circuits or increasing the switching frequency, thenew DPWM control method proposed in this paper cansuppress the low frequency oscillation of the neutral-pointvoltage effectively under different load conditions. Thisdecreases the output waveforms harmonics and significantlyincreases the system efficiency. The proposed DPWM controlmethod is easy to achieve with digital implementation.Experiments have been realized by a NPC three-level inverter

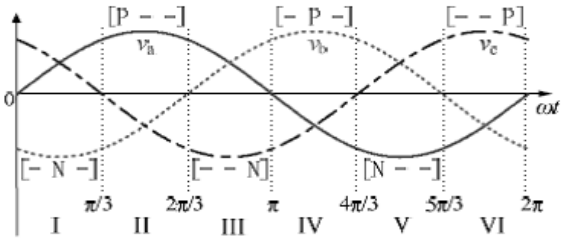

Fig. 2. The operating principle of 60 DPWM.

The regions are defined as follows:(0–π/3), II(π/3–2π/3), III(2π/3–π), IV(π–4π/3), V(4π/3–5π/3),and VI(5π/3–2π).In each region, the switches of one certain phase keep noswitching. So the corresponding output level is in the “P” or“N” state, the details are as follows:

(1) In regions I(0–π/3), III(2π/3–π), and V(4π/3–5π/3), forthe phase modulation wave with the lowest voltage value, the corresponding switches Sx3, Sx4 of this phase are kept in the

on-state, and the switches Sx1, Sx2 of this phase are kept in theoff-state. Therefore, the output phase leg is in the "N" state, (2) In regions II(π/3–2π/3), IV(π–4π/3), and VI(5π/3–2π),for the phase modulation wave with the highest voltage value,the corresponding switches Sx1, Sx2 of this phase are kept in the on-state, and the switches Sx3, Sx4 of this phase are kept inthe off-state. Therefore, the output phase leg is in the "P"state.

III. PROPOSED METHOD

The power electronic equipment such as inverter have switching devices and their operation produces current and voltage harmonics into the system from which they are working. These harmonics affect the operation of their equipments connected o the same system through the injection of harmonics. The even order harmonics are eliminated by using filters. The odd order harmonics can be eliminated by various techniques.The analysis of the harmonics and harmonic reduction by PWM techniques are described in this section.

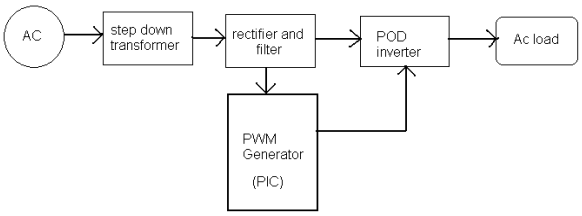

Figure.3.Block diagram of Proposed Method

The performance of each of these PWM control methods are based on the following parameters: a) Total harmonic distortion (THD) of the voltage and current at the output of the inverter, b) Switching losses within the inverter, c) Peak-to-peak ripple in the load current, and d) Maximum inverter output voltage for a given DC rail voltage. Thus the choice of a particular PWM technique depends upon the permissible harmonic content in the inverter output voltage. From above mentioned PWM control methods are applied in the proposed inverter since it has various advantages over other techniques. Sinusoidal PWM inverters provide an easy way to control amplitude, frequency and harmonics contents of the output voltage [6].The SPWM aims at generating a sinusoidal inverter output voltage without low-order harmonics. Sinusoidal pulse width modulation is one of the primitive techniques, which is used to suppress harmonics presented in the quasi-square wave. In the modulation techniques, there is an important parameter i.e., the ratio M = Ar/Ac known as modulation index, where Ar is reference signal amplitude and Ac is carrier signal amplitude.

The HESA is assumed to be the quarter-wave symmetric. Fourier series of the quarter-wave symmetric S H-bridge cell multilevel inverter output waveform is written as follows

$$V(wt) = \sum_{n=1}^{\infty} \frac{4V_{dc}}{n\pi} \left[\sum_{k=1}^{s} \cos(n\theta_k) \right] \sin(nwt) \quad (1)$$

Where the optimized switching angles, which must satisfy the following condition

$$\theta_1 < \theta_2 < \cdots < \theta_s < \pi/2 \quad (2)$$

The amplitude of all odd harmonic components including fundamental one, are given by

$$h(n) = \frac{4V_{dc}}{n\pi} \sum_{k=1}^{s} \cos(n\theta_k) \quad (3)$$

The switching angles of the waveform will be adjusted to get the lowest output voltage THD. If need to control the peak value of the output voltage to be V_1 and eliminate the third and fifth order harmonics, modulation index is given by

$$M = \frac{\pi V_1}{4V_{dc}} \quad (4)$$

The resulting harmonic equations are

$$\frac{4V_{dc}}{\pi} [\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) + \cos(\theta_4)] = V_1 \quad (5)$$

$$[\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) + \cos(5\theta_4)] = 0 \quad (6)$$

$$[\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) + \cos(7\theta_4)] = 0 \quad (7)$$

$$[\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) + \cos(\theta_4)] = M \quad (8)$$

To determine the switching angles for Selective Harmonic Eliminated PWM (SHEPWM) cascaded multilevel inverter. Such switching angles are defined by a set of nonlinear equations to be solved. In the case of two possible solutions for an angle θ*i*, the criteria for selecting one of them can be the Total Harmonic Distortion (THD). The best angle values are therefore the ones leading to the lowest THD.

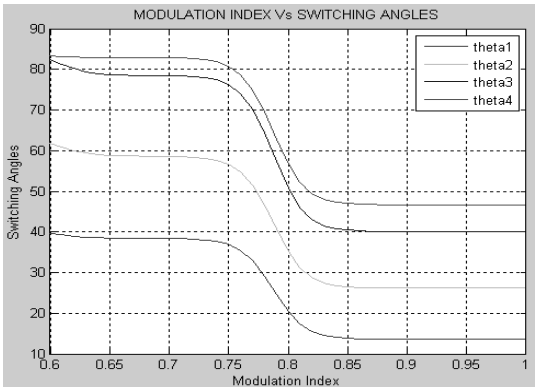

Fig. 3 Plot for Modulation index Vs corresponding Switching Angles

In the case of two possible solutions for an angle θ*i*, the criteria for selecting one of them can be the Total Harmonic Distortion (THD). The best angle values are therefore the ones leading to the lowest THD.The number of inputs and outputs depends from the considered process. In our application, the feed forward neural network has to map the underlying relationship between the modulation rate (i/p) and the switching angles (o/p) as shown in figure 3.The figure 4 shows that the relationship between modulation rate and its calculated THD for their corresponding switching angle. In view to confirm the validity of obtained results using the harmonics elimination technique with neural network, a test is carried out for M=0.8. The switching angles for test data are obtained from the neural network such as its output (switching angle). From that switching angles, the desired level of carrier signal levels are obtained. The triangular carrier signal is compared with sinusoidal reference which results the triggering pulses for various switches. These pulses are used to trigger the nine level cascaded multilevel inverter. The output voltage and current waveform and its harmonics spectrum are shown in figure 7,8. *Advantages:* Number of switching device low compared to previous system. Due to POD modulation the output accuracy of converter and system power factor of the converter are to be maintained within the permissible limit. Our proposed converter produces a better performance on electric traction drive.

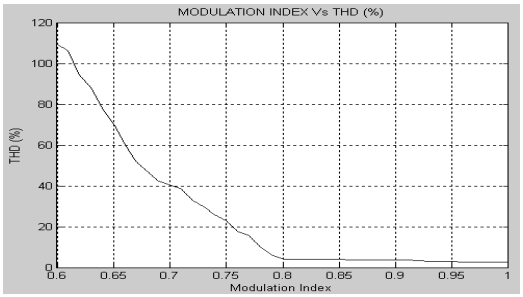

Fig. 4 Plot for Modulation index Vs THD in percentage

IV. SIMULATION RESULTS

The simulink model of the proposed nine level cascaded multilevel inverter systems for SPWM techniques with open loop, closed loop PI and neural implementation are described by following simulation diagrams.The simulation was done for a cascaded nine level inverter with sinusoidal pulse width modulation is described in following figures 7. The gating signals generated using sinusoidal PWM technique is given to the power circuit switches to obtain the output voltage. The Figure.5 shows the simulated output voltage and current

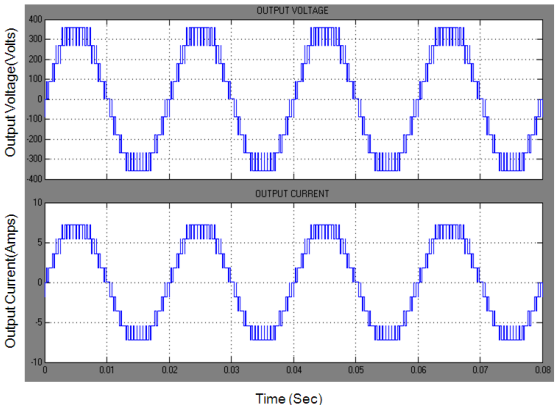

Fig. 5 Simulated output voltage and current waveform for sine PWM

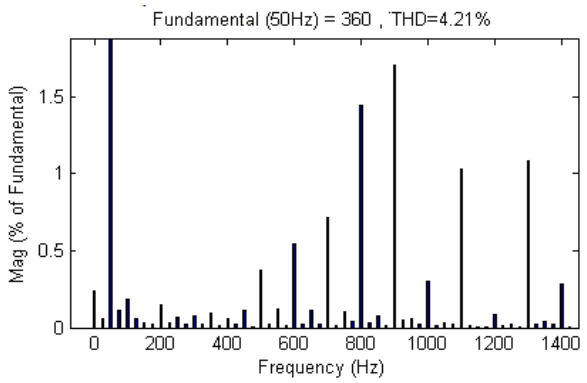

Fig. 6 Frequency spectrum of the output Voltage.

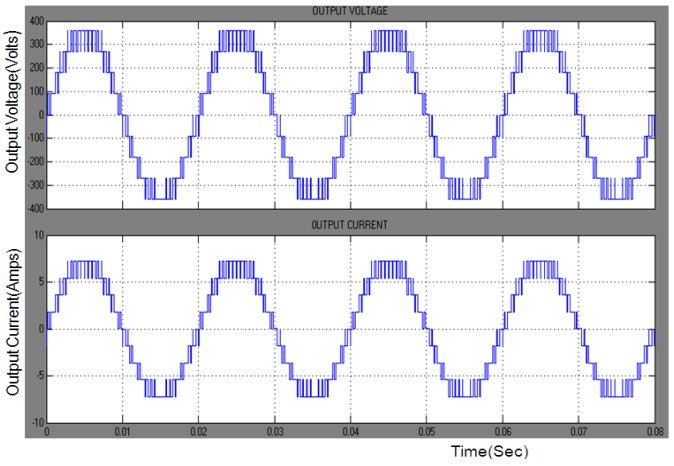

Fig. 7 Simulated output voltage and current waveform for sine PWM with Neural Network

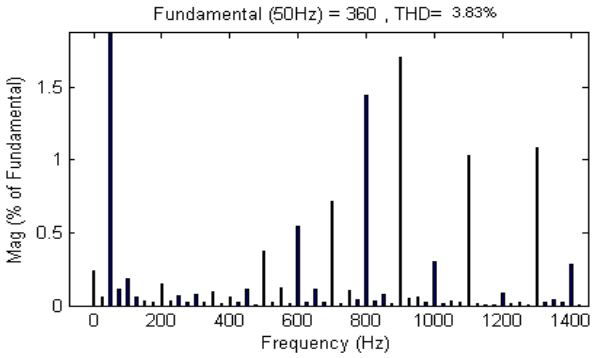

Fig. 8 Frequency Spectrum of the output voltage in Sine PWM with Neural Network

V. CONCLUSION

This paper has presented the three-level NPC inverter system and proposed the neutral-pointvoltage oscillation reduction method. The neutral-point current control by the small-signal modeling,the control-terms which are related to the neutral-point currentcontrol is set to zero for the reduction of the neutral-pointvoltage oscillation caused by the output phase current. The results show that the oscillation of theneutral-point voltage is reduced by the proposed method.

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