# Investigating the Effect of Sinusoidal Pulse Width Modulation and Vector Space Pulse Width Modulation in Three-Phase Inverters on Common Mode Voltage

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***Abstract*— Voltage source control methods include the switching method of sinusoidal pulse width modulation and pulse width modulation of vector space. These methods are based on a fixed pattern when on and off inverter switches until generate a waveform of fixed voltage in output. In this paper, by performing simulations using MATLAB software, methods sinusoidal pulse width modulation and vector space pulse width modulation in three-phase inverters in terms of common mode voltage generation are compared with each other and finally, the best method of the target selected. Because, the simulation results of the paper, which is done under different status, compare and conclude with each other. A similar test system for use in all status be defined. Such system is including a ohmic–inductive load with connecting the stars that by a capacitance is connected to ground.**

***Index Terms*— Sinusoidal pulse width modulation, vector space pulse width modulation, common mode voltage.**

## I. Introduction

Renewable energy sources ,particularly resources that are the source of photovoltaic have had a lot of advancement have had in recent years that is mainly because of increase in temperature and privileges are given to governments for this type of technology is. Power processing of renewable energy sources done by power converters which the issues of efficiency and cost as key factors, along with them. In particular status, grid –connected PV inverters, most topologies of power converter are used the transformer which works in a low or high frequency and This isolation creates galvanic between the photovoltaic panel and the power grid. Low-frequency transformers are large, heavy and expensive and they are entered additional losses into the system. Isolating transformer size with using two –level topology which in that transformer works in high frequency, can be reduced to a large extent. This method reduces efficiency, because at least two power converter of the type cascaded is required. As a result, a large number inverter with transformer less topology have been proposed in recent years which Leading to generate power processing systems, is more compact, cheaper and more efficient. In addition, when using of the inverters without transformer, some measurement techniques of isolation reactance and remnant flow should be used. It makes the inverters without transformers even safer than transformers with transformer. Given the size of power inverters connected to the network, changing pattern has been observed in recent year. Large central inverters with power above 100 kw by power inverters in small size which supplied much energy by a string or a small group of strings can provide, have been replaced. Following this method, tracking point of maximum power of panels groups of large photovoltaic can be improved, because they can be placed under very different levels of solar radiation. In this context, using of single –phase inverters up to 5 kw is paramount importance. For the reasons mentioned a significant number of single –power topology to implement single and three phase transformer less inverters connect to grid, have been proposed. In this type of converters, there is not galvanic isolation between photovoltaic panels and network. So that problems can arise that require special attention such as common mode voltages and leakage currents across the photovoltaic panels, which this is due to this fact that there is a non –negligible parasitic capacitance between photovoltaic cells and isolation ground and under specific operating conditions (for example moisture, dirt and mode installed) can reach very high values. Normally values of this capacitance between 50 to 150 for silicon crystalline cells and for film cells reach up to values 1uf/kw_p. Common mode current leakage increases The harmonic of zinc in the system, Reduces the connection quality of network current and directing rupture and electromagnetic radiation interference is caused and lead to problems in personal safety. In solar cells that are connected to the network via the transformer, electrical isolation of transformer windings and high frequency of common –mode voltage and current are not anywhere to flow and therefore

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does not produced virtually certain common mode current. Therefore, type of inverter arrangement and switching style has not so much effect on this problem. But in transformer less arrangement should be discover away to prevent the transmission of leakage current produced by common mode voltage to network. In figure(a) common mode current and parasitic capacitance and in figure (b) photovoltaic system model is shown.

If the number of levels must be high enough, can switch also bridges in the fundamental frequency by square wave modulation. Therefore, the strength of electromagnetic interactions between power and electronic of system are decreased. At the same time output voltage of inverter will be close to sinusoidal waveform there won't be need for large filtering and common mode voltage also will not create. Naturally for the low frequencies, using of square wave modulation will create distortion in voltage and current. So using of sinusoidal pulse width modulation with different modulation index for different levels has been suggested

## II. METHODS

### A. *The system under study*

Because the simulation results of this paper which is done under different status, compare and conclude with each other a similar test system for use in all status be defined. Such system is including a ohmic–inductive load with connecting the stars that by a capacitance is connected to ground. In fact, modeling of a three phase motor inductive-ohmic load is R=250 ohms and L=5Mh. This modeling is because that in MATLAB /SIMULATION software that in this paper is used to perform simulations, three phase induction motor model with neutral point is not available. The capacitance defined, too, modeling of capacitance between the neutral point of coil is connecting with the motor shaft. Motor grid with capacity 5hp and standard supply voltage of AC power (380 volt (v) and 50 Hertz (HZ)) is intended. The DC link voltage equal to 400 v is selected. This voltage in the multilevel inverters splits between different bridge.

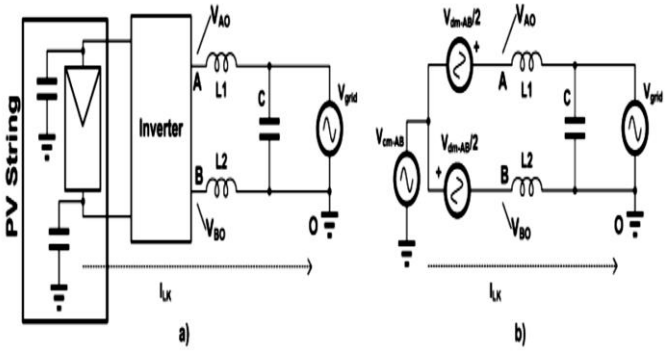


Fig. 1. Figure (a) is common mode current and parasitic capacitance and figure (b) is photovoltaic system model

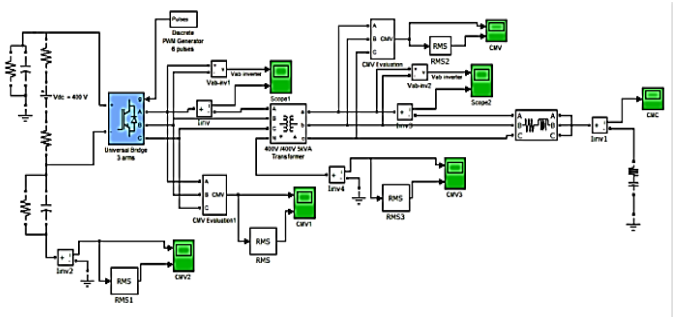

Fig. 2. Outline of the simulated system under study.

Voltage source control methods include the switching method of sinusoidal pulse width modulation and pulse width modulation of vector space. These methods are based on a fixed pattern when on and off inverter switches until generate a waveform of fixed voltage in output. In this way of viewing the output, the inverter will act like a voltage source. These methods used, especially in the inverters control that the output as isolate from the grid feeds one distinctive load. Also in parallel inverters to the grid, when the goal is just to inject active or reactive power, such methods can be used easily.

## III. SIMULATION RESULT AND ITS ANALYSIS

### A. *Switching technique of sinusoidal pulse width modulation*

This method is based on the predetermined pattern on and off circuit switches frequency of carrier wave in the method, to determine harmonics order minimum of output voltage, at least ten times the fundamental frequency is selected. The main reason for this choice is the ease of filtering out the output harmonics.

Also raising too frequency of carrier wave, the number of switching in the power circuit raises. This causes problems such as noise and etc. will be. The main component domain of produced voltage, in the unipolar modulation according to the dc-link voltage and modulation index is equal to formula (1):

$$(V_1)_{Peack} = mV_{dc} \qquad (1)$$

In the first with simulating transformer less, are checked operation of this modulation method. Then the effect of transformers is checked on common–mode voltage and current. Frequency of carrier wave also in this mode equal to 1 KHZ is selected. Figure 3 shows line–line voltage waveform that is produced in this way. In addition to waveform, harmonic spectrum is also shown. It is clear that produced voltage up to 1 KHZ frequency almost has not outstanding harmonic. It is worth nothing since there is not the neutral point in output, phase voltage to neutral is obtained using the following equation.

$$(V_1)_m = mV_{dc}/2 \qquad (2)$$

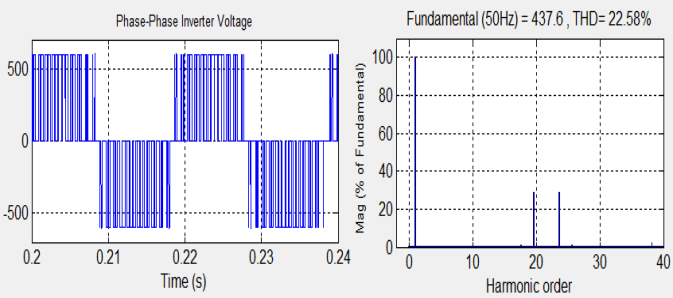


Fig. 3. Production line voltage of inverter by sinusoidal modulation method

Figure 3 also shows produced common mode voltage in this way. In this figure also effective amount of common mode voltage is shown. As seen in figure the common mode voltage is produced that effective amount is equal to 180 volts.

Figure 4 also shows output current of transformer with high level harmonics that it requires to filtering. Leakage current of solar cells (current passing through the leakage capacitive impedance between the sun cell and ground) and three phase ground current is connected to ground are shown in figures 5 and 6.

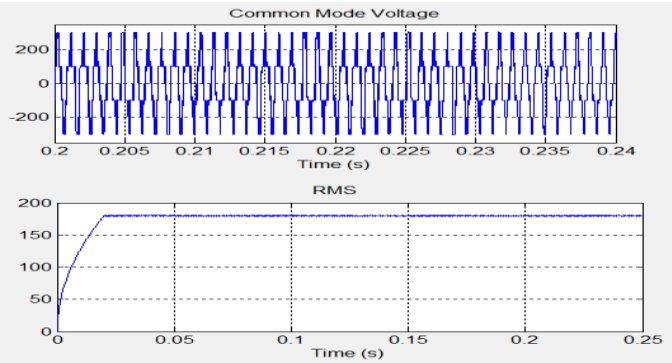


Fig. 4. Common mode voltage in three phase six key inverter with sinusoidal modulation

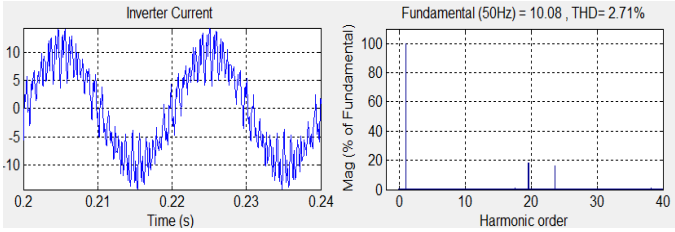


Fig. 5. Output current of inverter in sinusoidal pulse width modulation

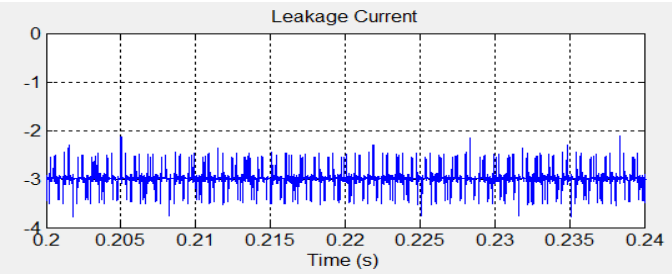


Fig. 6. Leakage current of source

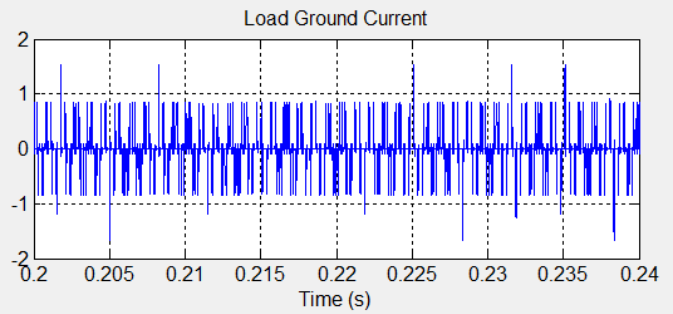


Fig. 7. Ground current of three phase load

To investigate the effect of transformer on common mode voltage, a transformer with connecting YND be put on the way of load figures 7 and 8 show voltage and current of transformer secondary that their s harmonic spectrum is clearly improved. Using of transformer with triangle secondary connecting that causes there is not full path to ground current. For this reason, common mode voltage and leakage current of system and ground current of load reach about zero.

But in the primary side of the transformer due to the use of the star connection that connected to the ground path of the leakage current exists. Figure 9 shows ground wire current of transformer.

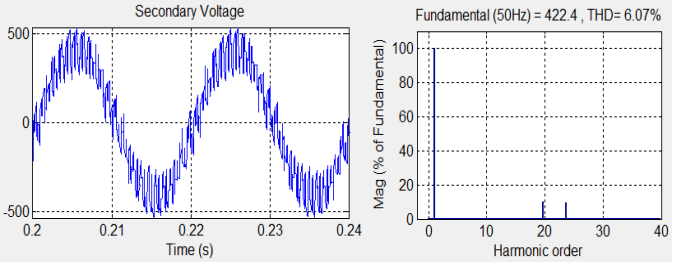


Fig. 8. The voltage produced by 6 key-three phase inverter in secondary of transformer

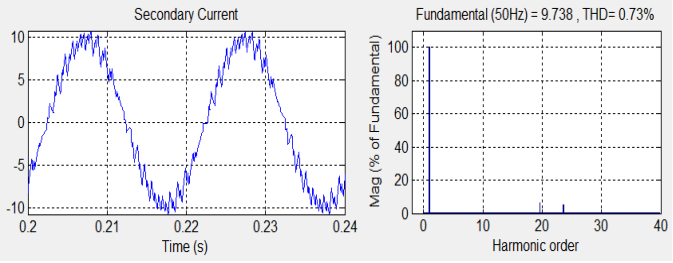


Fig. 9. Secondary current of transformer

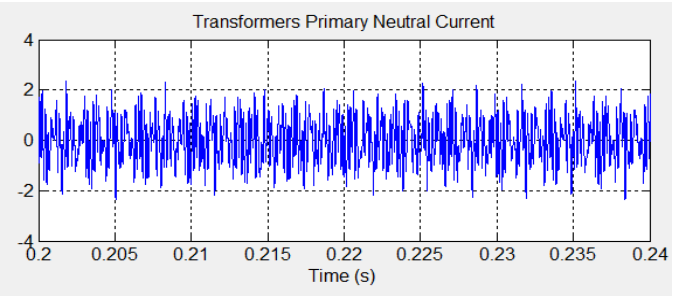


Fig. 10. Ground wire current of star connection in the primary of transformer

## IV. THE SWITCHING METHOD OF VECTOR SPACE PULSE WIDTH MODULATION (SPWM)

This method shows quality similar to SPWM method on the output side, but the number of keying in this method compare to SPWM is slightly down. Given that frequency of the first dominant harmonic in output voltage will depend on sampling frequency. In here, the sampling frequency is selected equal to $20\ f_0$. Until results, with PWM results be comparable. Figure 10 shows waveform case of line to line voltages generated to this method by a three-phase 6 key inverter that it's harmonic spectrum also is placed in the figure. As voltage harmonic spectrum of voltage shows, there isn't output voltage any harmonic up to degree 38 harmonic in output voltage. This is way generated current of inverter as figure 11 b shows has harmonic spectrum very acceptable. Note here isn't used of the specific filtering in the inverter output.

Common mode voltage created by this modulation, leakage current of power supply and ground current of three phase load, respectively are shown in figures 12-14. Each three of these waveforms are represents the relative improvement of results in compared with the sinusoidal modulation method.

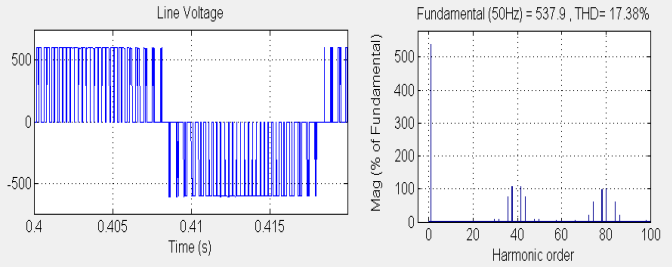


Fig. 11. Line voltage generated in method of vector space modulation

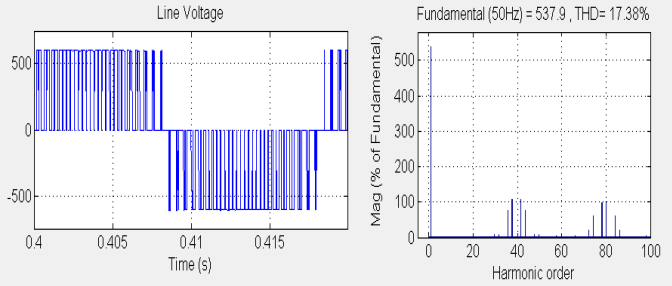


Fig. 12. Current generated by the inverter in vector space modulation

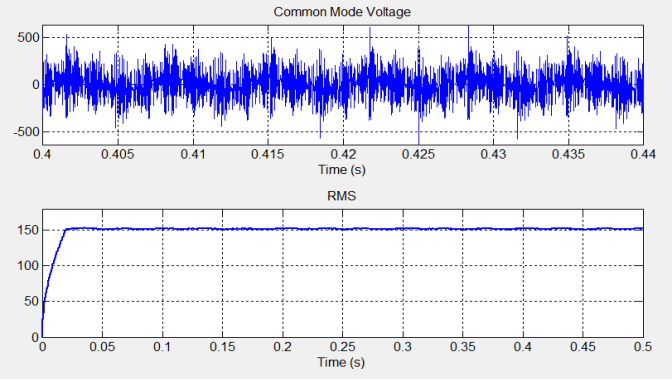


Fig. 13. Generated common mode voltage in inverter 6 key with vector space modulation

TABLE I
COMPARISON OF SIMULATIONS RESULTS

| | Switching frequency | Low-order harmonics | THD voltage depending percent | Effective voltage of common mode |
|---|---|---|---|---|
| SPWM three level | high | have not | 23 | 185 |
| SVPWM three level | relatively high | have not | 17.4 | 152 |

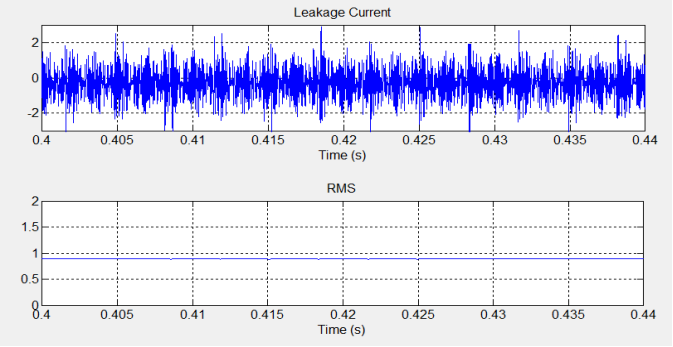


Fig. 14. Leakage current of power supply in vector space modulation

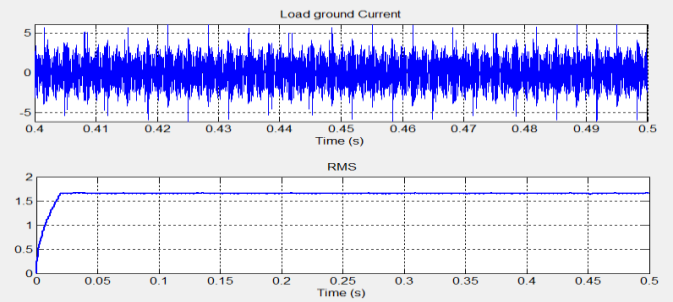


Fig. 15. Ground current of three phase load

## V. CONCLUSION

In this paper have tried some conventional methods in the switching of six keys–three phase inverters and three level inverters in terms of generating common mode voltage to be compared with each other. For clear and tangible results has been helping of computer simulations for this purpose. The results show that vector space pulse width modulation method can lead to a reduction in the number of inverter switching, which this in turn is an advantage. But calculations to determine the keys state vector, in three level inverters is shortly complicated. That's why this method optimization to decrease common mode voltage is difficult. This method especially in three level inverters can be decreased harmonic distortion even in transformer less inverters at very acceptable levels. Sinusoidal pulse width modulation method is simpler and more intuitive than vector space method that its action in inverters, three level unipolar and bipolar is not need complex calculations That's why its optimized to decreased common mode voltage is possible. Improving harmonic distortion in this modulation method, generally occur with increasing frequency of carrier wave. This act on behalf of excess switching in circuit to follow.

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