ISSN: 2278-0181
Confcall - 2018 Conference Proceedings

Modulation Techniques for Solar Power Generation System with Seven Level Inverter

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***Abstract*: The work presented here is an attempt to study on various types of modulation strategy for new proposed solar power generation system. Solar power generation system is composed of DC-DC converter and a seven level inverter. This new seven level inverter is configured with capacitor selection circuit and full bridge power converter. The salient features of the proposed seven-level inverter are that only six power electronic switches are used, and only one power electronic switch is switched at high frequency at any time. The main aim of the project is to make comparative study on variety of Pulse width modulation strategy for newly proposed multilevel inverter used in solar power generation systems. The proposed system is simulated using MATLAB.**

Keywords: Solar power, seven level inverter, Multicarrier PWM strategy, Cascaded H-Bridge

I. INTRODUCTION

The ever increasing energy consumption, fossil fuels' soaring costs and exhaustible nature and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such system generates electricity by converting sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid –connected inverters. [1]The power conversion interface is important to grid connected solar power generation systems because it converts the dc power generated by a solar cell array into ac power and feeds this ac power into the utility grid. An inverter is necessary in the power conversion interface to convert the dc power to ac power. Since the output voltage of a solar cell array is low, a dc–dc power converter is used in a small-capacity solar power generation system to boost the output voltage, so it can match the dc bus voltage of the inverter. Output voltage of a solar cell array is low; a dc–dc power converter is used in a small-capacity solar power generation system to boost the output voltage, so it can match the dc bus voltage of the inverter. The power conversion efficiency of the power conversion interface is important to insure that there is no waste of the energy generated by the solar cell array. The active devices and passive devices in the inverter produce a power loss. The power losses due to active devices include both conduction losses and switching losses. Conduction loss results from the use of active devices, while the switching loss is proportional to the voltage and the current changes for each switching and switching frequency. A filter inductor is used to process the switching harmonics of an inverter, so the power loss is proportional to the amount of switching harmonics [2]. Multilevel inverters are promising; they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile. Cascaded H-Bridge (CHB) inverter has been gaining importance in market because it can achieve high range of voltage and power [3] and has important advantages such as high power quality that allows high motor performance; low total harmonic distortion (THD) that eliminates output filters. However, the CHB inverter has drawbacks such as the large number of active semiconductors, transformers and isolated dc supplies that must be balanced. Moreover as multilevel inverter, the CHB inverter reduces the power quality (number of levels) with voltage amplitude because they have the same voltage on each of the intermediate-circuit capacitors, and all the power semiconductors have to be capable to block the same voltage in their 'off' state [4]. Asymmetrical CHB (ACHB) inverter uses dc supplies with different voltages uses dc supplies with different voltage increasing power quality (number of levels) and it can maximize the number of levels if dc supply voltages are scaled in power of three.[5] Advantage of ACHB inverters are as follows: 1) only one dc source is instead of one isolated source per H-bridge ;2) automatic voltage balance among H-bridge because only one dc source is used; 3) Very low and constant THD at all operation ranges; and 4) simpler regenerative operation. [6].For the cascaded multilevel inverter variety of modulation strategy has been reported, with most popular being carrier –based and space vector modulation. Several multicarrier techniques have been developed to reduce the distortion in multilevel inverter, based on classical SPWM with triangular carriers. Multicarrier PWM methods can be categorized into two groups: Carrier Disposition method (CD), where the reference waveform is

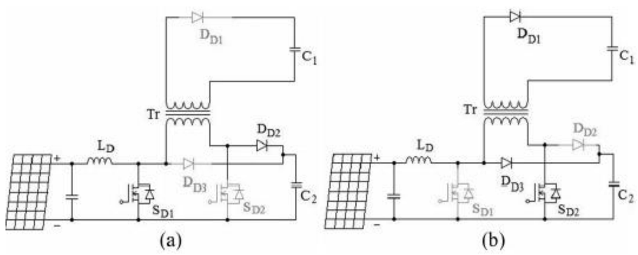

Fig. 1 Configuration of proposed solar power generation system

sampled through a number of carrier waveforms displaced by continuous increments of the reference waveform amplitude and Phase shift (PS) PWM method, where multiple carriers are phase shifted accordingly. This paper focuses on carrier disposition (CD) method as it gives least THD of 12% [7].A number of modulation strategies have been used in multilevel power conversion applications [8]. They can generally be classified into three categories [9-10]: multi-step, staircase or fundamental frequency switching, space vector PWM (SVPWM) and carrier-based PWM strategies. This paper focused on the carrier-based PWM technique which has been extended for use in asymmetric multi-level inverter topologies by using multiple carriers. Multi-carrier PWM methods for asymmetric multi-level can be categorized into three groups: Phase Disposition PWM (PD-PWM), Phase Opposition Disposition PWM (POD-PWM) and Alternate Phase Opposition Disposition PWM (APOD-PWM) methods. In this method, the reference waveform is sampled through a number of carrier waveforms displayed by contiguous of the reference waveform amplitude. This paper focuses on multicarrier pwm techniques as it gives least THD OF 14.4%

II. CIRCUIT CONFIGURATION

Figure.1 shows the configuration of the proposed solar power generation system. The proposed solar power generation system is composed of a solar cell array, a dc–dc power converter, and a new seven-level inverter. DC output obtained from solar array is low; DC-DC power converter is used to boost the output voltage so it can match the DC voltage of the inverter. Boost converter converts the output power of solar cell array into two independent voltage sources with multiple relationships which are supplied to seven level inverter. Seven level inverter is Configured using capacitor selection circuit and a full bridge power converter, connected in cascade. Power electronic switches of capacitor selection circuit converts two independent voltage source to three level dc voltage, which is fed to full bridge inverter where three levels is converted to seven level AC output that is synchronized to the utility voltage

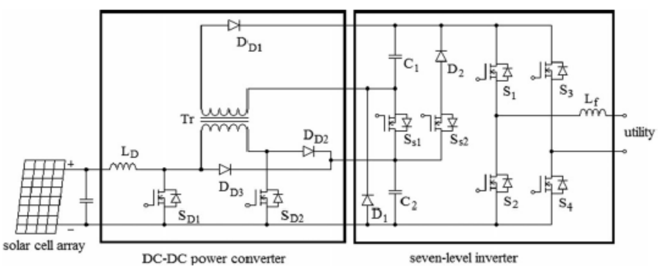

Fig. 2 Operation of dc-dc converter a)S_{D1} is on b)S_{D1} is off

III. DC–DC POWER CONVERTER

As seen in Fig. 1The DC–DC power converter incorporates a boost converter and a current-fed forward converter. The boost converter is composed of an inductor L_D, a power electronic switch S_{D1}, and a diode, D_{D3}. The boost converter charges capacitor C_2 of the seven-level inverter. The current-fed forward converter is composed of an inductor L_D , power electronic switches S_{D1} and S_{D2} , a transformer, and diodes D_{D1} and D_{D2} . The current-fed forward converter charges capacitor C_1 of the seven-level inverter. The inductor L_D and the power electronic switch S_{D1} of the current-fed forward converter are also used in the boost converter Fig 2(a) shows the operating circuit of the dc–dc power converter when S_{D1} is turned ON. The solar cell array supplies energy to the inductor L_D. When S_{D1} is turned OFF and S_{D2} is turned ON, it's operating circuit shown in Fig 2(b). Accordingly, capacitor C_1 is connected to capacitor C_2 in parallel through the transformer, so the energy of inductor L_D and the solar cell array charge capacitor C_2 through D_{D3} and charge capacitor C_1 through the transformer and D_{D1} during the off state of S_{D1}. Since capacitors C_1 and C_2 are charged in parallel by using the transformer, the voltage ratio of capacitors C_1 and C_2 is the same as the turn ratio (2:1) of the transformer. Therefore, the voltages of C_1 and C_2 have multiple relationships. It should be noted that the current of the magnetizing inductance of the transformer increases when S_{D2} is in the ON state. Conventionally, the forward converter needs a third demagnetizing winding in order to release the energy stored in the magnetizing inductance back to the power source. However, in the proposed dc–dc power converter, the energy stored in the magnetizing inductance is delivered to capacitor C_2 through D_{D2} and S_{D1} when S_{D2} is turned OFF. Since the energy stored in the magnetizing inductance is transferred forward to the output capacitor C_2 and not back to the dc source, the power efficiency is improved. In addition, the power circuit is simplified because the charging circuits for capacitors C_1 and C_2 are integrated. Capacitors C_1 and C_2 are charged in parallel by using the transformer, so their voltages automatically have multiple relationships. The control circuit is also simplified.

IV. SEVEN LEVEL INVERTER

The seven-level inverter is composed of a capacitor selection circuit and a full-bridge power converter, which are connected in cascade. The operation of seven level inverter can be divided into the positive half cycle and the negative half cycle of the utility. For ease of analysis, the power electronic switches and diodes are assumed to be ideal, while the voltages of both capacitors C_1 and C_2 in the capacitor selection circuit are constant and equal to $V_{dc}/3$ and $2V_{dc}/3$, respectively. Since the output current of the solar power generation system will be

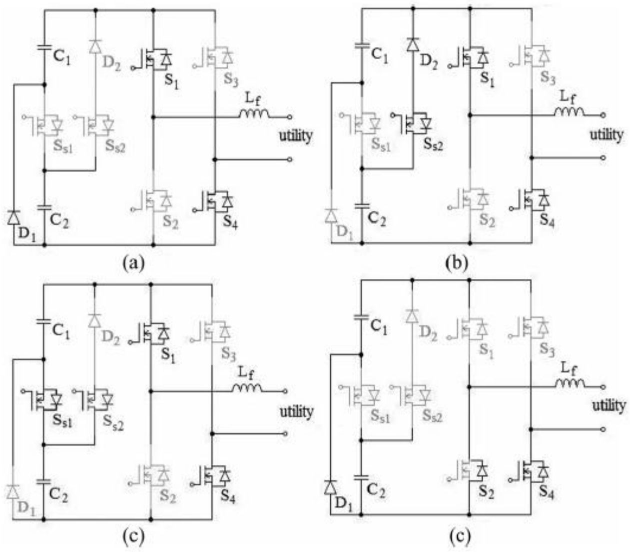

Fig. 3 Operation of seven level inverter in positive half cycle a) mode1 b) mode 2 c) mode 3 d)mode 4

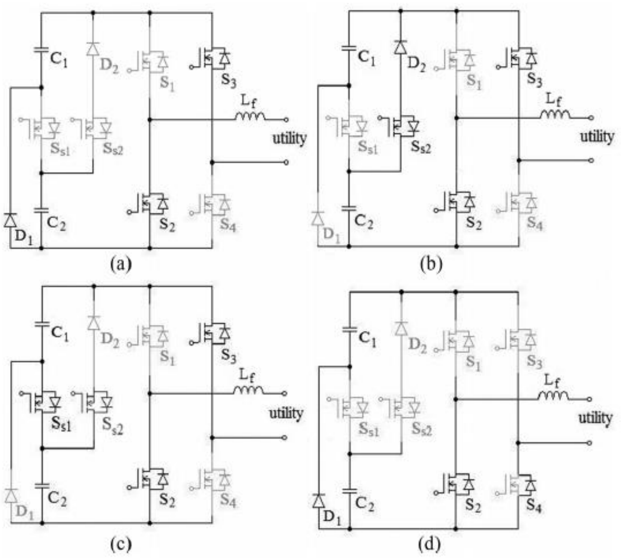

Fig. 4 Operation of seven level inverter in negative half cycle a) mode 5 b) mode 6 c) mode 7 d) mode 8

Controlled to be sinusoidal and in phase with the utility voltage, the output current of the seven-level inverter is also positive in the positive half cycle of the utility. The operation of the seven-level inverter in the positive half cycle of the utility can be further divided into four modes as shown in figure 3.

Mode 1: The operation of mode 1 is shown in Fig. 3(a) both S_{S1} and S_{S2} of the capacitor selection circuit are OFF, so C_1 is discharged through $D_1$and the output voltage of the capacitor selection circuit is $V_{dc}/3$. S_1 and S_4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is directly equal to the output voltage of the capacitor selection circuit, which means the output voltage of the seven level inverter is $V_{dc}/3$

MODE 2: The operation of mode 2, in the capacitor selection circuit, S_{S1} is OFF and S_{S2} is ON, so C_2 is discharged through S_{S2} and D_2 and the output voltage of the capacitor selection circuit is $2V_{dc}/3$. S_1 and S_4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is $2V_{dc}/3$.

MODE 3: The operation of mode 3, in the capacitor selection circuit, S_{S1} is ON. Since D_2 has a reverse bias when S_{S1} is ON, the state of S_{S2} cannot affect the current flow. Therefore, S_{S2} may be ON or OFF, to avoiding switching of S_{S2}. Both C_1 and C_2 are discharged in series and the output voltage of the capacitor selection circuit is V_{dc}. S_1 and S_4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is V_{dc}.

MODE 4: The operation of mode 4, Both S_{S1} and S_{S2} of the capacitor selection circuit are OFF. The output voltage of the capacitor selection circuit is $V_{dc}/3$. Only S_4 of the full-bridge power converter is ON. Since the output current of the seven-level inverter is positive and passes through the filter inductor, it forces the antiparallel diode of S_2 to be switched ON for continuous conduction of the filter inductor current. At this point, the output voltage of the seven level inverter is zero. Therefore, in the positive half cycle, the output voltage of the seven-level inverter has four levels: V_{dc}, $2V_{dc}/3$, $V_{dc}/3$, and 0. In the negative half cycle, the output current of the seven-level inverter is negative. The operation of the seven-level inverter can also be further divided into four modes. In comparison, the operation of the capacitor selection circuit in the negative half cycle is the same as that in the positive half cycle. The difference is that S_2 and S_3 of the full-bridge power converter are ON during modes 5, 6, and 7, and S_2 is also ON during mode 8 of the negative half cycle. Accordingly, the output voltage of the capacitor selection circuit is inverted by the full-bridge power converter, so the output voltage of the seven-level inverter also has four levels: $-V_{dc}$, $-2V_{dc}/3$, $-V_{dc}/3$, and 0. In summary, the output voltage of the seven-level inverter has the voltage levels: V_{dc}, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}/3$, $-2V_{dc}/3$, and $-V_d$

V. PROPOSED SYSTEM CONTROL SCHEME

Multicarrier pulse width modulation methods can be categorized into two groups. They are carrier disposition method [CD] and phase shifted [PS] pulse width modulation methods. Phase shifted pulse width modulation methods, where multiple carriers are phase shifted accordingly. In Carrier disposition method reference waveform is sampled through a number of carrier waveform displaced by continuous increments of the reference waveform amplitude. The carrier disposition method comprises phase

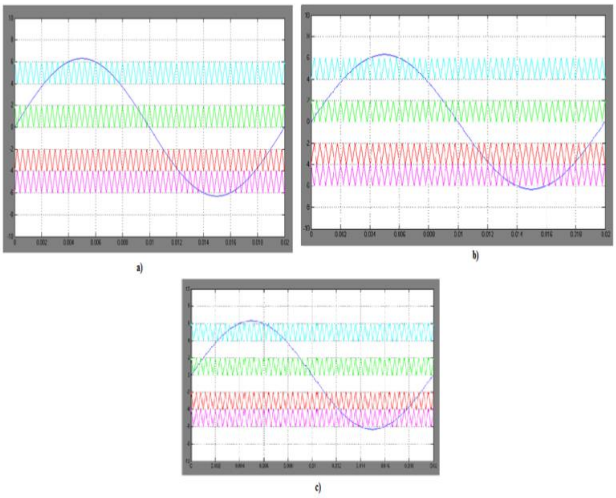

Fig 5. Modulation and carrier frequency waveform: a) POD PWM b) APOD PWM c) PD PWM

opposition disposition method, phase disposition method and Alternative phase opposition disposition method. This paper focuses on the carrier pulse width modulation method as it gives a low Total Harmonic Distortion (THD)

A. Phase Disposition Method (POD)

As shown in Fig. 5(a) With POD method the carrier waveform above zero reference values are in phase. The carrier waveforms below are also in phase but 180^0 degree phase shifted from those above zero. Compared to PD method, this method has better results from viewpoint of harmonic performance in lower modulation indices. There is no harmonics at carrier frequency and its multiples and dispersion of harmonics occurs around them. The POD method yields quarter wave symmetry for even modulation index and odd symmetry for odd modulation index

B. Alternating Phase Disposition Method (APOD)

As seen in Fig. 5(b) in this technique carrier waveform is phase displaced from each other by 180^0 alternatively. The major difference between POD and APOD are large amount of third order harmonic which is not important because of their cancellation yields better THD for line voltage comparing the POD method. The most significant harmonics are on side bands centered on the carrier frequency. Again this method yields quarter wave symmetry for even modulation index and odd symmetry for odd modulation index.

C. Phase Disposition Method (PD)

In this strategy, carriers are in phase and with same magnitudes, the difference between the carrier is that they displaced by a set DC offset. It achieves its superior performance by placing harmonic energy into carrier harmonic in each phase voltage and relaying upon cancellation of this harmonics in line to line voltage. It has two types of modulation; they are continuous and discontinuous modulation. In continuous two level modulations for each H- Bridge is achieved by comparing a single reference against 180^0 degree phase shifted carriers. However, two level modulations is known to be harmonically inferior compared to three level modulation and hence it's not attractive solution. In discontinuous modulation it requires only one of two phase leg in each H bridge is pulse width modulated at any one time. For multilevel inverter operating under discontinuous modulation, the reference waveform must be spilt into two sections; with each cascaded inverter synthesizing a different section of main reference waveform. It is generally accepted that this method gives rise to lowest harmonic distortion in higher modulation indices when compared to other disposition method.

VI. SIMULATION RESULTS

The simulation of proposed system was done using MATLAB and results was discussed and output waveforms for the modulation index 0.8 are shown in fig. 5 and THD of APODPWM was found to be minimum of 14.43%

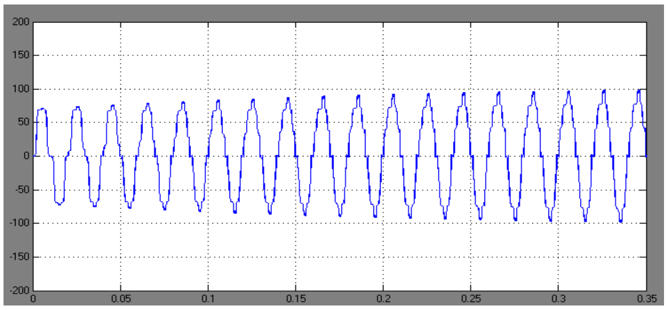

Fig. 6 output voltage of seven level inverter

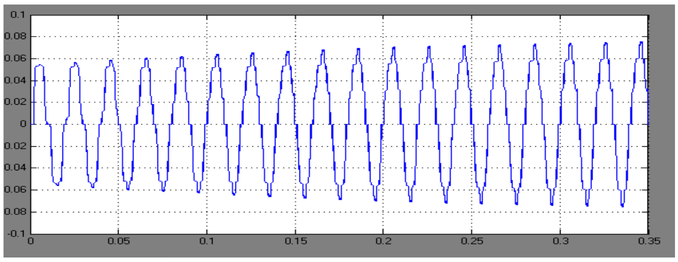

Fig. 7 Output current of seven level inverter

VII. CONCLUSION

This paper proposes comparative study of various multicarrier strategy for multilevel inverter used in solar power generating ystem, mainly with carrier disposition [CD] PWM method in which alternative phase opposition and disposition [APOD] is found to produce very low harmonics with THD 14.4 compared to other CD techniques. This paper also highlights the advantages of solar power generation system, composed of a dc–dc power converter and a seven level inverter. The seven-level inverter contains only six power electronic switches, which simplifies the circuit configuration. Furthermore, only one power electronic switch is switched at high frequency at any time to generate the seven-level output voltage. This reduces the switching power loss and improves the power efficiency. The voltages of the two dc capacitors in the proposed seven-level inverter are balanced automatically, so the control circuit is simplified.

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