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Modelling of Microcontroller Based Triple Reference-Single Carrier Grid Interactive Inverter for Microgrids

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Abstract— Single phase seven level inverter for grid connected photovoltaic system is proposed in this paper. PWM signals for switches are generated using three reference signals which are identical to each other and a single carrier signal. Seven level output is obtained from the proposed inverter. For grid synchronization, grid voltage is taken as the reference signal. The proposed system was verified through simulation model.

Index Terms—**Multilevel inverter, photovoltaic (PV) system, pulse width modulation (PWM), Grid interactive inverter.**

I. INTRODUCTION

The major concerns in the power sector are the day-by-day increase of power demand and the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand for renewable sources of energy has increased to meet the power demand along with conventional systems. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. Solar energy is abundantly available which made it possible to harvest and utilize properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending up on the location of a grid nearby. Thus it can provide power to the rural areas where the availability of grid is less. Grid interactive inverters are often used to convert direct current produced by many renewable energy sources, like solar panels and small wind turbines, into the alternating current and provide power to homes and businesses. A grid-tie inverter (GTI) or synchronous inverter is a special type of power inverter that converts direct current (DC) electricity into alternating current (AC) and feeds it into an existing electrical grid. Multilevel inverters have nearly sinusoidal output voltage and current with reduced harmonic distortions, reduced stressing of electronic components which decreases voltage drops, switching losses are less compared to that of conventional two-level inverters, filter size and effect of EMI are reduces all of which makes them cheap, light, and compact.

II. MODELING OF PHOTOVOLTAIC PANEL

The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output current of a solar cell is proportional to the light falling on the cell. PV cells are grouped in larger units called PV panels which are further interconnected in a parallel-series configuration to form PV arrays Equations used for modeling photovoltaic panel [6].

Terms used:

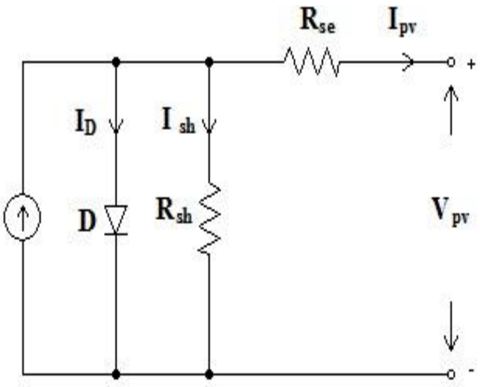

Fig.1. Equivalent circuit of SPV cell [6]

I_{ph} - photo generated current
I_D, V_D - Diode current and voltage
I_{PV}, V_{PV} - Solar cell current and voltage
G - Irradiance
T - Temperature
N - Diode ideality factor
K - Boltzmann's constant, $1.38*10^{\wedge-23}$
Q - Electron charge, $-1.6*10^{\wedge-19}$
R_{sh}, R_{se} - Shunt and series resistance

$I_{PV} = I_{ph}(G, T) - I_D - (V_D/R_{sh})$ ……………….(1)
$I_D = I_o (e^{(V_D/V_T)} - 1)$ ………………………… (2)
$V_T = NKT/q$ ……………………………… (3)
$V_D = V_{PV} + I_{PV} R_{se}$ ……………………… (4)

III. BOOST CONVERTER

A Boost converter is used to step up the output of solar panel to required level without the use of transformer. The main components of this converter are an inductor, a diode and a high frequency switch which are used in a co-ordinated manner and converter delivers power to the load, at a voltage higher than the input voltage magnitude. The duty cycle of the switch is controlled to change the output voltage magnitude. The efficiency of a solar cell is very low. Different methods are adopted to increase the efficiency. One such method is the Maximum Power Point Tracking (MPPT). This technique is used to obtain the maximum possible power from a varying source. The I-V curve of PV system is non-linear, so it is difficult to be used to power a certain load. Therefore a boost converter whose duty cycle is varied by using a mppt algorithm is used for this purpose.

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IV. MULTILEVEL INVERTER

A Single phase seven level inverter is used here as grid interactive inverter. It consists of a single-phase conventional H bridge inverter, two bidirectional auxiliary switches, and a capacitor voltage divider formed by C_1, C_2 and C_3. This modified H-bridge topology is significantly advantageous over other topologies, i.e., less number of power switches, power diodes, and less number of capacitors for inverters with same number of levels. Output of PV arrays is connected to the multilevel inverter circuit via dc-dc boost converter. Power generated by the inverter is delivered to the micro grid. If the solar energy is present load is met by the output from the inverter circuit otherwise, if solar energy is not there load gets power from the utility grid.

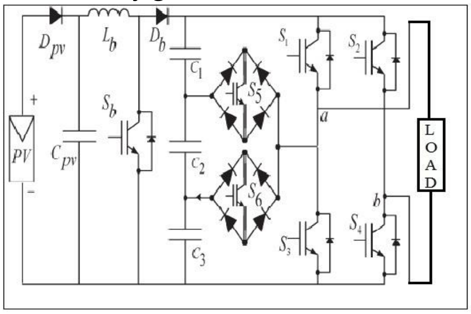

Fig.2. Seven level inverter for PV systems [1]

Proper switching of inverter switches can produce seven levels of output voltage from the dc input voltages. If V_{dc} is the equivalent dc input voltage, the seven output levels are V_{dc}, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}$, $-2V_{dc}/3$, and $-V_{dc}/3$. Inverter operation can be divided into seven switching states as shown in fig 3 (a)-(g). Required seven levels of output are generated as follow.

1) Maximum positive output (V_{dc}): Switches S_1 and S_4 ON, connecting the load positive terminal to V_{dc}, and load negative terminal to ground. All other controlled switches are OFF. Fig. 3(a) shows the current paths that are active at this stage.
2) Two-third positive output ($2V_{dc}/3$): The bidirectional switch S_5 and S_4 is ON. The voltage applied to the load terminals is $2V_{dc}/3$..All other controlled switches are OFF. Fig. 3(b) shows the current paths that are active at this stage.
3) One-third positive output ($V_{dc}/3$): The bidirectional switch S_6 and S_4 is ON; the voltage applied to the load terminals is $V_{dc}/3$. All other controlled switches are OFF. Fig. 3(c) shows the current paths that are active at this stage.
4) Zero output: This voltage level can be produced by two switching combinations either switches S_3 and S_4 are ON, or S_1 and S_2 are ON, and all other controlled switches are OFF; terminal ab is a short circuit. Fig. 3(d) shows the current paths that are active at this stage.
5) One-third negative output ($-V_{dc}/3$): The bidirectional switch S_5 and S_2 is ON. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}/3$. Fig. 3(e) shows the current path that is active at this stage.
6) Two-third negative output ($-2V_{dc}/3$): The bidirectional switch S_6 and S_2 is ON. All other controlled switches are OFF; the voltage applied to the load terminals $-2V_{dc}/3$. Fig. 3(f) shows the current paths that are active at this stage.
7) Maximum negative output ($-V_{dc}$): Switches S_2 and S_3 is ON. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}$. Fig. 3(g) shows the current paths that are active at this stage.

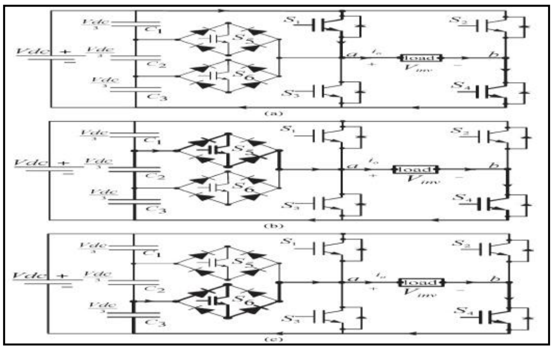

Fig.3. Switching Combination Required to Generate The Output Voltage [1]

The switching combinations that generates the seven output-voltage levels (0, $-V_{dc}$, $-2V_{dc}/3$, $-V_{dc}/3$, V_{dc}, $2V_{dc}/3$, $V_{dc}/3$) are shown in the table 1[1].

Table 1 :Switches On-Off condition for seven level output voltage

V_0	S_1	S_2	S_3	S_4	S_5	S_6
V_{dc}	On	Off	Off	On	Off	Off
$2V_{dc}/3$	Off	Off	Off	On	On	Off
$V_{dc}/3$	Off	Off	Off	On	Off	On
0	Off	Off	On	On	Off	Off
0*	On	On	Off	Off	Off	Off
-Vdc/3	Off	On	Off	Off	On	Off
-2Vdc/3	Off	On	Off	Off	Off	On
-Vdc	Off	On	On	Off	Off	Off

V. INVERTER CONTROL SCHEME

PWM modulation technique is used for controlling the inverter output**.** In other words switching signals for switches are generated by using PWM modulation technique. Here three sinusoidal reference signals (V_{ref1}, $V_{ref2}$and V_{ref3}) were compared with a triangular carrier signal ($V_{carrier}$).

Switching pattern for single phase seven level inverter is shown in fig 4. Switches *S*1, *S*3, *S*5, and*S*6 would be switching at the rate of the carrier signal frequency, whereas switches *S*2 and *S*4 would operate at a frequency that was equivalent to the fundamental frequency. the phase angle θ depends on modulation index *Ma*. Theoretically, for a single, reference signal and carrier signal, the modulation index is defined as,

Ma = Am/ Ac………… (5)

For a single-reference signal and a dual carrier signal, the modulation index Ma is defined as,

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Ma = Am/2Ac……….. (6)

Since the proposed seven-level PWM inverter utilizes three carrier signals, the modulation index is defined as,

Ma = Am/3Ac……….. (7)

Where Am, Ac are the magnitudes of reference and carrier signal respectively.

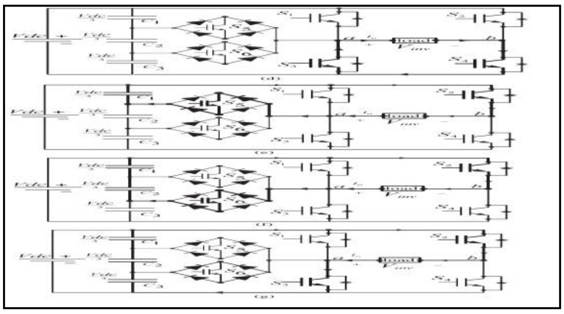

Fig.4. Switching Signals For Single Phase Seven Level Inverter [1]

VI. CONTROL SYSTEM

The output waveform of the inverter should be synchronized with the grid in terms of amplitude, frequency, and phase. For this purpose, the grid voltage is sampled and used to generate appropriate waveforms. Control system comprises a MPPT algorithm, dc bus voltage controller and reference signal generation. The main tasks of the control system are maximization of the energy transferred from the PV panels to the grid, and generation of a sinusoidal current with minimum harmonic distortion. Incremental conductance algorithm is utilized for maximum power tracking from PV panels. The incremental conductance algorithm was implemented in the dc–dc boost converter. The output of the MPPT is the function of duty-cycle. The dc-link voltage V_{dc}, controls the dc–ac seven level PWM inverter, the change in duty cycle changes the voltage at the output of the PV panels. To deliver energy from renewable sources to the grid, output frequency and phase of the PV inverter must be in synchronism with the grid; therefore, a synchronization method is needed. Since the frequency and phase of the PWM inverter is equal to the reference signal, grid voltage is taken as the reference itself. Therefore no additional methods are required for frequency and phase synchronization. The output from inverter must not exceed the grid voltage so transformer is employed at the output of inverter to obtain the required voltage level.

VI. SIMULATION MODEL AND RESULTS

The modeling of proposed PV inverter is done using Matlab/Simulink. Switching signals for inverter are generated by comparing three reference signal against single carrier signal. Switching signals for switches S_1-S_6 are shown in fig.5.

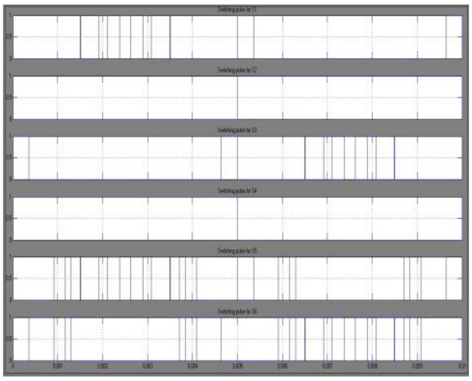

Fig.5.Switching signals for switches S_1-S_6

Simulation model for the seven level inverter is given in fig 6.

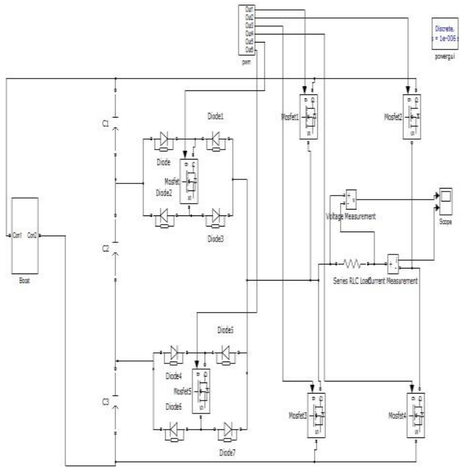

Fig.6.Simulation Model

Output voltage and current waveform

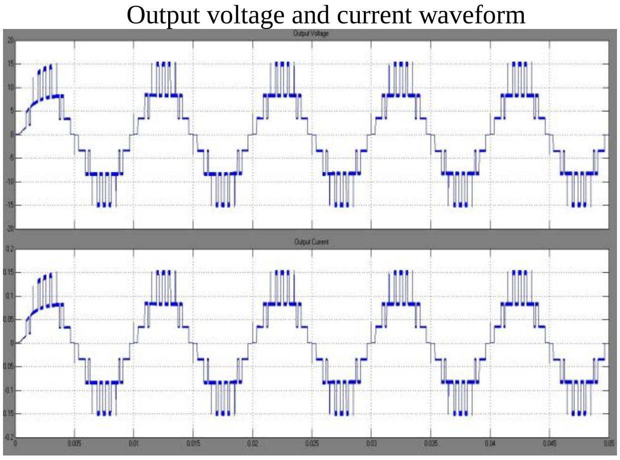

Fig 7. Output voltage and current waveform

VII. CONCLUSION

Model of grid interactive inverter for microgrid has been presented. The frequency, magnitude and phase of the inverter output are synchronized with grid voltage signal. Result shows that multilevel inverter offers improved output waveforms with lower THD. Results confirm that grid interactive inverters are capable of generating output AC voltage that is synchronized with the grid. Seven level Inverter with lower THD is an attractive solution for grid Interactive photovoltaic Inverters.

VIII. ACKNOWLEDGMENT

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