Modelling and Analysis of Photo Voltaic Cell Fed Seven Level Multi-String Inverter

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Abstract — There is strong trend in the photovoltaic (PV) inverter technology to use transformer less topologies in order to acquire higher efficiencies. This paper presents a single-phase seven level grid connected PV inverter with two reference signals that were identical to each other with an offset that was equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. Multistring inverter based system gives better voltage regulation and efficiency compare to the multilevel inverters. Seven level multistring inverter consists of two auxiliary switches and diodes. The inverter produces output voltage in seven levels \(V_{dc} \), \(V_{dc}/3, 0, -V_{dc}/3, 2V_{dc}/3, -2V_{dc}/3, -V_{dc}\). The validity of the propose inverter is verified through simulation.

Keyword - Pulse Width modulation (PWM), Photo Voltaic (PV) Source, Maximum Power Point (MPP).

I. INTRODUCTION

PV inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the Inverter reduces its respective harmonic content and, hence, size of the filter used and the level of the Electromagnetic Interference (EMI) generated by switching operation of the inverter. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three level PWM Inverters. They offer improved output waveforms, smaller filter size and lower EMI, lower Total Harmonic Distortion (THD).

II. CIRCUIT DESCRIPTION OF THE PROPOSED SYSTEM

The proposed single-phase seven-level multi-string inverter circuit is shown in Fig 1. It consists of three strings of DC - DC step up converter connected to common dc bus, an auxiliary circuit, and conventional full-bridge inverter configuration. Input sources, PV strings are connected to the inverter via dc-dc boost converters. The dc–dc boost converters are used to track the Maximum power point (MPPT) independently and to step up inverter output voltage. The multi-string approach is adopted because each dc–dc converter can independently perform MPP tracking (MPPT) for its PV strings. This will compensate for mismatches in panels of like manufacture, which can be up to 2.5%. It further offers the advantage of allowing panels to be given different orientations and so open up new possibilities in architectural applications. Another advantage of multi-string configuration is that the mixing of different sources becomes possible, i.e., existing PV panel strings could be extended by adding new higher output panels without compromising the overall string reliability or performance [1]. Depending on the design, each converter module may be able to isolate its connected power source so that the wiring of series or parallel connection of these strings can be performed safely. The power-source converter connection is a safe low-voltage connection. The dc–dc boost converters are connected in parallel to avoid high dc-bus voltage, which will eventually increase the size of the capacitors and the inverter’s cost. Therefore, only three capacitors with equal capacitance rating are used as the dc bus, and the other dc–dc boost converters are connected to this dc bus, as shown in Fig.1. A filtering inductance \(L_f\) is used to filter the current injected into the grid. The injected current must be sinusoidal with low harmonic distortion. In order to generate sinusoidal current, a sinusoidal PWM is used because it is one of the most effective methods.

A sinusoidal PWM is obtained by comparing a high-frequency carrier signal with a low-frequency sinusoidal signal, which is the modulating or reference signal.

The carrier has a constant period; therefore, the switches have constant switching frequency. The switching instant is determined from the crossing of the carrier and the modulating signal.

The table 2.1 gives the switching operation of the Seven Level inverter. The voltage levels in the truth table are \(V_{dc}, V_{dc}/3, 2V_{dc}/3, 0, -V_{dc}/3, -2V_{dc}/3, -V_{dc}\). The switching operation of the above voltage levels for the switches will be on (1) and off (0) according to the input need to be given. In Pulse width modulation technique the input can be given as in...
the table 1. The on and off can be done according the output required.

### Table 1

<table>
<thead>
<tr>
<th>Voltage Levels</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vdc</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Vdc/3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2Vdc/3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-Vdc/3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-2Vdc/3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-Vdc</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2.1 Truth table for the 7-level multistring inverter

### III. PWM MODULATION

Modulation index $M_a$ for a seven-level PWM inverter is given as,

$$M_a = \frac{A_m}{2A_c}$$  \hspace{1cm} (1)

Where,

- $A_c$ is the peak-to-peak value of carrier
- $A_m$ is the peak value of voltage reference $V_{ref}$

As two reference signals are identical to each other, (1) can be expressed in terms of the amplitude of carrier signal $V_c$ by replacing $A_m$ with $V_{ref}$, and $A_m = V_{ref1} = V_{ref2} = V_{ref}$

then,

$$M = \frac{V_{ref}}{2V_c}$$  \hspace{1cm} (2)

If $M > 1$, higher harmonics in the phase waveform is obtained. Therefore, $M$ is maintained between zero and one. Here two reference signals $V_{ref1}$ and $V_{ref2}$ are compared with the carrier signal at a time. If $V_{ref}$ exceeds the peak amplitude of carrier signal $V_{carrier}$, then $V_{ref2}$ will be compared with the carrier signal until it reaches zero. At this point onward, $V_{ref1}$ takes over the comparison process until it exceeds $V_{carrier}$. This will lead to a switching pattern, as shown in Fig 2. Switches S4–S9 will be switching at the rate of the carrier signal frequency, while S7 and S8 will operate at a frequency that is equivalent to the fundamental frequency. Table 1 illustrates the level of $V_{inv}$ during S4–S9 switch on and off. Section 4 illustrating the Simulink model of the PV cell is given in the appendix.
IV. CHARACTERISTICS OF PV CELLS

A. Characteristics of PV cell at constant temperature

From the above characteristics (Fig.4, Fig.5, Fig.6, Fig.7) curves the power generation continuously varies along with two main factors, which are known as cell temperature and irradiance. In this work MPPT technique is used for finding the maximum output at various instant of time.

B. Characteristics of PV cell at constant irradiance

V. MAXIMUM POWER POINT TRACKING CONTROL (MPPT)

In order to operate the PV cells at the maximum power point, several techniques has been suggested in the literature. Some of them are,

(i) Look up table Method
(ii) Perturbation and Observation methods
(iii) Model based computation methods
(iv) Artificial intelligence techniques

Model based Computation methods are of two types they are,

a. Voltage based MPPT (VMPPT)
b. Current Based MPPT (CMPPPT)

In this work focus is made on Current Based MPPT (CMPPPT). The CMPPPT method simplifies the entire control structure of the power conditioning system and uses an inherent current source characteristic of solar cell arrays. Therefore it exhibits robust and fast response under rapidly changing environmental conditions.

A. Current Based Maximum Power Point Tracking Control

The main idea behind current based MPPT is that the current at the maximum point \( I_{mp} \) has a strong relationship with the short circuit current \( I_{sc} \). \( I_{sc} \) can either be measured on line under different operating conditions or can be computed from a validated model.

Fig.8 represents the current based control scheme which gives the linear relationship between short circuit current \( I_{sc} \) and current at maximum power \( I_{mp} \) using curve fitting.
VI. SIMULINK MODEL OF SEVEN LEVEL INVERTER

The feasibility of the proposed approach is verified using computer simulations. A model of the seven-level inverter is constructed in MATLAB-Simulink software. A new strategy with reduced number of switches is employed. Cascaded H bridge 7 level inverter requires 12 switches to get seven level output voltage and with the proposed topology requirement is reduced to 6 switches. The new topology has the advantage of its reduced number of switching devices (switches) compared to conventional cascaded H-bridge multilevel inverter, and can be extended to any number of levels. The simulink model of seven level multi-string inverter is represented in the Fig.9.

A. Simulation diagram of multistring inverter

Fig.9. Simulink model of Seven level multi-string inverter

The above simulink model in Fig.9 could recreate the characteristic curves shown in Fig.6 and Fig.7 of section V when correctly inserted into the program.

The life time of the PV panel depends on the environmental conditions at which the panel is installed. Aging effect is unavoidable but it can be minimized using anti-aging agents like ethylene vinyl acetate. This serve to improve the life time of PV panel to certain extent. The exact life time of the PV panel is unpredictable as it depends upon the field conditions and quality of manufacturing.

VII. RESULT AND DISCUSSION

A. Switching Pattern for the Single Phase seven-level inverter

Fig.10. Switching pattern for seven level inverter

Fig.10 represents the switching pattern for seven level inverter. Here two reference signals \( V_{\text{ref1}} \) and \( V_{\text{ref2}} \) will take turns to be compared with the carrier signal at a time. If \( V_{\text{ref}} \) exceeds the peak amplitude of carrier signal \( V_{\text{carrier}} \), then \( V_{\text{ref2}} \) will be compared with the carrier signal until it reaches zero. At this point onward, \( V_{\text{ref1}} \) takes over the comparison process until it exceeds \( V_{\text{carrier}} \). This will lead to a switching pattern, as shown in Fig.10. Switches S4–S9 will be switching at the rate of the carrier signal frequency, while S7 and S8 will operate at a frequency that is equivalent to the fundamental frequency.

Fig.11 Simulation results for seven level inverter output voltages

\[ M \leq 0.5 \]
VIII. CONCLUSION

This paper has presented a single-phase multistring seven-level inverter for PV application. A novel PWM control scheme with two reference signals and a carrier signal has been used to generate the PWM switching signals. The circuit topology, control algorithm, and operating principle of the proposed inverter have been analyzed in detail. The configuration is suitable for PV application as the PV strings operate independently and later expansion is possible.

IX. SCOPE FOR THE FUTURE WORK

The proposed model is simulated using MATLAB. The simulation results indicate the functioning of the proposed model. The future work is to implement the proposed model in hardware. The proposed model can be improved by increasing the level of the inverter output.

REFERENCES


APPENDIX

SIMULINK MODEL OF PV CELL

![Fig.3 Line diagram of PV cell](image)

\[ I = I_L - I_D \quad (3) \]

Where,

- \( I \) = Output Current in Amps
- \( I_L \) = Photo Generated Current in Amps
- \( I_D \) = Diode Current in amps

By Shockley equation, current diverted through diode is,
Where,

\[ I_o = \text{Reverse Saturation Current} \]
\[ n = \text{Diode Ideality Factor} \]
\[ k = \text{Boltzmann’s Constant} \]
\[ T = \text{Absolute Temperature} \]
\[ q = \text{Elementary Charge} \]

For silicon of 25\(^\circ\)C \( nkT/q = 0.0259 \) volts = \( \alpha \),

\[ I_D = I_o \left[ \exp \left( \frac{U + IR_s}{nkT/q} \right) - 1 \right] \] \( (4) \)

Substituting above equation in equation (3) we get,

\[ I = I_L - I_o \left[ \exp \left( \frac{U + IR_s}{\alpha} \right) - 1 \right] \] \( (5) \)

where \( \alpha = nkT/q \) is known as Thermal voltage timing completion factor.

Photo generated current \( I_L \) is calculated by

\[ I_L = \frac{\phi}{\phi_{ref}} \left[ I_{L,ref} + \mu_{I,SC} (T_c - T_{c,ref}) \right] \] \( (6) \)

where \( \phi = \text{Irradiance } (W/m^2) \)
\( \phi_{ref} = \text{Reference irradiance } (1000W/m^2) \)
\( I_{L,ref} = \text{Light current at reference condition} \)
\( T_c = \text{PV cell temperature} \)
\( T_{c,ref} = \text{Reference temperature} \)
\( \mu_{I,SC} = \text{Temperature coefficient of the short circuit current } (A/\degree C) \)

Saturation Current \( I_o \) is given by

\[ I_o = I_{o,ref} \left( \frac{T_{c,ref} + 273}{T_c + 273} \right)^{e_{gap}N_s/q} \exp \left( -\frac{T_{c,ref} + 273}{T_c + 273} \right) \] \( (7) \)

where,

\[ I_{o,ref} = \text{saturation current at the reference condition } (A) \]
\[ e_{gap} = \text{band gap of the material } (1.17eV \text{ for Si}) \]
\[ N_s = \text{number of cells in series of the PV module} \]
\[ q = \text{charge of the electron} \]
\( \alpha_{ref} = \text{value of } \alpha \text{ at the reference condition} \)

Thermal Model of Photovoltaic Cell is

\[ C_{pv} \frac{dT_c}{dt} = k_{in,pv} \phi - \frac{U \times 1}{A} - K_{loss} (T_c - T_a) \] \( (8) \)

where

\[ C_{pv} = \text{overall heat capacity of PV cell/Module} \]
\( k_{in,pv} = \text{transmittance absorption product of PV cells} \)
\( K_{loss} = \text{overall heat loss coefficient} \)
\( T_a = \text{ambient temperature} \)
\( A = \text{effective area of PV cell/Module} \)