MPPT WITH A NOVEL MODULAR CASCADED H-BRIDGE MULTILEVEL PV INVERTER FOR GRID-CONNECTED APPLICATIONS USING FUZZY

B. SOMESH KUMAR  
M.Tech (E.P.S)  
Gnyana Saraswati College Of Engineering & Technology.  
Affiliated to JNTUH, Hyderabad.

ABSTRACT- A modular cascaded H-bridge multilevel photovoltaic (PV) inverter is proposed for single- or three-phase grid-connected applications. The PV systems efficiency and flexibility can be improved by using the modular cascaded H bridge inverter. To extract maximum power from the PV system a MPPT control is applied to both single- and three-phase multilevel inverters, which allows separate control for each dc-link voltage. PV mismatches may introduce unbalanced supplied power, leading to unbalanced grid current For three-phase grid-connected applications. To compensate this problem a modulation control is used. By using nine H-bridge modules (three modules per phase) An simulated three-phase seven-level cascaded H-bridge inverter has been built. Here we are using the fuzzy logic controller compared to other controller, because of its high accuracy performance. Each H-bridge module is connected to a 185-W solar panel. Simulation results are shown using MATLAB/SIMULINK.

Index Terms—Cascaded multilevel inverter, distributed maximum power point (MPP) tracking (MPPT), modular, modulation compensation, photovoltaic (PV).

I. INTRODUCTION

Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years [1], and the growth is mostly in grid-connected applications. Because of the decreasing resources like fossil fuels and conventional energy resources and pollution problems. Therefore market demand for PV systems is gets increasing. [2]–[7]. The configurations of PV systems are shown in Fig. 1. Cascaded inverters consist of several converters connected in series; thus, the high power and/or high voltage from the combination of the multiple modules would favor this topology in medium and large grid-connected PV systems. configurations of the PV system of Five inverter: 1) central inverters families; 2) string inverters; 3) multistring inverters; 4) ac-module inverters; and 5) cascaded inverters. There are two types of cascaded inverters. Fig. 1(e) shows a cascaded dc/dc converter connection of PV modules. Each PV module has its own dc/dc converter, and the modules with their associated converters are still connected in series to create a high dc voltage, which is provided to a simplified dc/ac inverter.

Fig. 1. Configurations of PV systems. (a) Central inverter. (b) String inverter. (c) Multi string inverter. (d) AC-module inverter. (e) Cascaded dc/dc converter. (f) Cascaded dc/ac inverter.

This approach combines aspects of string inverters and ac-module inverters and offers the benefits of individual module maximum point (MPP) tracking (MPPT), however it’s less costly and more efficient than ac-module inverters. However, there are 2 power conversion stages in this configuration. Another cascaded inverter is shown in Fig. 1(f), where every PV panel is connected to its own dc/ac inverter, and those inverters are then placed serial to achieve a high-voltage level. This cascaded inverter would
maintain the advantages of "one converter per panel," such as higher utilization per PV module, capability of blending completely different sources, and redundancy of the system. Additionally, this dc/ac cascaded inverter removes the necessity for the per-string dc bus and therefore the central dc/ac inverter, that additional improves the potency. The distributed MPPT control scheme can be applied to both single and three-phase systems. In addition, for the presented three-phase grid-connected PV system, if each PV module is operated at its own MPP. The modular cascaded H-bridge multilevel inverter, which needs associate isolated dc supply for every H-bridge, is one dc/ac cascaded electrical converter topology. The separate dc links within the structure inverter build independent voltage management possible.

As a result, individual MPPT management in every PV module will be achieved, and therefore the energy harvested from PV panels will be maximized. Meanwhile, the modularity and low price of Multi level converters would position them as a first-rate candidate for the next generation of efficient, robust, and reliable grid connected solar energy electronics. A standard cascaded H-bridge structure inverter topology for single- or three-phase grid-connected PV systems is presented in this paper. The panel mismatch issues are addressed to show the necessity of individual MPPT control, and a control scheme with distributed MPPT control is then proposed. A three-phase modular cascaded multilevel inverter prototype has been built. Each H-bridge is connected to a 185-W solar panel. The modular design will increase the flexibility of the system and reduce the cost as well. To show the necessity of individual MPPT control, a five-level two-H-bridge single-phase inverter is simulated in MATLAB/SIMULINK.

II. SYSTEM DESCRIPTION

Each phase consists of n H-bridge converters connected in series, and therefore the dc link of every H-bridge is fed by a PV panel or a short string of PV panels. Modular cascaded H-bridge multilevel inverters for single and three-phase grid-connected PV systems are shown in Fig. 2. The cascaded structure inverter is connected to the grid through L filters, that are used to reduce the switching harmonics within the current. By completely different combinations of the four switches in every H-bridge module, 3 output voltage levels is generated: −vdc, 0, or +vdc.

Fig. 2. Topology of the modular cascaded H-bridge multilevel inverter for grid-connected PV systems.

A cascaded structure inverter with n input sources can offer 2n + 1 levels to synthesize the ac output waveform. This (2n + 1)-level voltage waveform allows the reduction of harmonics within the synthesized current, reducing the dimensions of the required output filters. Structure inverters even have other advantages such as reduced voltage stresses on the semiconductor switches and having higher efficiency when compared to alternative converter topologies.

III. PANEL MISMATCHES

Due to the unequal received irradiance, different temperatures, and aging of the PV panels, the MPP of each PV module may be different. PV mismatch is an important issue in the PV system. The efficiency of the overall system will get decreased if the PV controlling is not done separately.

Every H-bridge has its own 185-W PV panel connected as an isolated dc source.

Fig. 3. Power extracted from two PV panels

The PV panel is modeled in keeping with the specification of the commercial PV panel from a robust energy CHSM-5612M. take into account an in operation condition that every panel includes a different irradiation from the sun; panel one has irradiance $S = 1000$ W/m², and panel two has $S = 600$ W/m². If only panel one is tracked and its
MPPT controller determines the typical voltage of the 2 panels, the power extracted from panel one would be 133 W, and the power from panel two would be seventy W, as can be seen in Fig. 3.

Without individual MPPT control, the total power harvested from the PV system is 203 W. However, Fig. 4 shows the MPPs of the PV panels under the different irradiance.

![Fig. 4. P–V characteristic under the different irradiance](image)

The maximum output power values will be 185 and 108.5 W when the S values are 1000 and 600 W/m², respectively, which means that the total power harvested from the PV system would be 293.5 W if individual MPPT can be achieved. This higher value is about 1.45 times of the one before. Thus, individual MPPT control in each PV module is required to increase the efficiency of the PV system. In a three-phase grid-connected PV system, a PV mismatch may cause more problems. Aside from decreasing the overall efficiency, this could even introduce unbalanced power supplied to the three-phase grid-connected system. If there are PV mismatches between phases, the input power of each phase would be different. Since the grid voltage is balanced, this difference in input power will cause unbalanced current to the grid, which is not allowed by grid standards. For example, to unbalance the current per phase more than 10% is not allowed for some utilities, where the percentage imbalance is calculated by taking the maximum deviation from the average current and dividing it by the average current.

To solve the PV mismatch issue, a control scheme with individual MPPT control and modulation compensation is proposed.

**IV. CONTROL SCHEME**

A. Distributed MPPT Control

To increase the efficiency and to eliminate the mismatching effect this control scheme is proposed. The separate dc links in the cascaded H-bridge multilevel inverter make independent voltage control possible. To realize individual MPPT control in each PV module, the control scheme proposed in [19] is updated for this application. The distributed MPPT control of the three-phase cascaded H-bridge inverter is shown in Fig. 5.

![Fig. 5. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.](image)
the modulation index for the first H-bridge can be obtained by subtraction. The control schemes in phases b and c are almost the same. The only difference is that all dc-link voltages are regulated through fuzzy controllers, and n modulation index proportions are obtained for each phase.

A phase-shifted sinusoidal pulse width modulation switching scheme is then applied to control the switching devices of each H-bridge. It can be seen that there is one H-bridge module out of N modules whose modulation index is obtained by subtraction. For single-phase systems, \( N = n \), and for three-phase systems, \( N = 3n \), where \( n \) is the number of H-bridge modules per phase. The reason is that \( N \) voltage loops are necessary to manage different voltage levels on \( N \) H-bridges, and one is the total voltage loop, which gives the current reference. So, only \( N - 1 \) modulation indices can be determined by the last \( N - 1 \) voltage loops, and one modulation index has to be obtained by subtraction. Many MPPT methods have been developed and implemented \([23], [24]\). The incremental conductance method has been used in this paper. It lends itself well to digital control, which can easily keep track of previous values of voltage and current and make all decisions.

### B. Modulation Compensation

As mentioned earlier, a PV mismatch may cause more problems to a three-phase modular cascaded H-bridge multilevel PV inverter. With the individual MPPT control in each H-bridge module, the input solar power of each phase would be different, which introduces unbalanced current to the grid. To solve the issue, a zero sequence modulation index can be generated as

\[
d_j = \frac{1}{2} \left[ \min(r_a, d_a, r_b, d_b, r_c, d_c) + \max(r_a, d_a, r_b, d_b, r_c, d_c) \right]
\]

where \( d_j \) is the modulation index of phase \( j \) (\( j = a, b, c \)) and is determined by the current loop controller. The modulation index of each phase is updated by

\[
d_j' = d_j - d_0
\]

Only simple calculations are needed in the scheme, which will not increase the complexity of the control system. An example is presented to show the modulation compensation scheme more clearly. Assume that the input power of each phase is unequal

\[
P_{in_a} = 0.8 \quad P_{in_b} = 1 \quad P_{in_c} = 1
\]

By injecting a zero sequence modulation index at \( t = 1 \) s, the balanced modulation index will be updated, as shown in Fig. 7.

![Modulation indices before and after modulation compensation.](image)

Fig. 7. Modulation indices before and after modulation compensation.

It can be seen that, with the compensation, the updated modulation index is unbalanced proportional to the power, which means that the output voltage \((v_j N)\) of the three-phase inverter is unbalanced, but this produces the desired balanced grid current.
V. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani’s, ‘min’ operator. v. Defuzzification using the height method.

### TABLE I: Fuzzy Rules

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<tr>
<th>Change in error</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
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<tbody>
<tr>
<td>NB</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
<td>PS</td>
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<td>NS</td>
<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
</tr>
</tbody>
</table>

**Fuzzification:** Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

\[ E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \]

(5)

\[ CE(k) = E(k) - E(k-1) \]

(6)

**Inference Method:** Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table I shows rule base of the FLC.

**Defuzzification:** As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height” method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output. The set of FC rules are derived from

\[ u = [\alpha E + (1-\alpha)*C] \]

(7)

Where \( \alpha \) is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

V. SIMULATION RESULTS

A three-phase seven-level cascaded H-bridge inverter is simulated and tested. Each H-bridge has its own 185-W PV panel (Astronergy CHSM-5612M) connected as an independent source. The inverter is connected to the grid through a transformer, and the phase voltage of the secondary side is 60 Vrms. The system parameters are shown in Table II.
TABLE II
SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-link capacitor</td>
<td>3600 μF</td>
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<tr>
<td>Connection inductor $L$</td>
<td>2.5 mH</td>
</tr>
<tr>
<td>Grid resistor $R$</td>
<td>0.1 ohm</td>
</tr>
<tr>
<td>Grid rated phase voltage</td>
<td>60 Vrms</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>1.5 kHz</td>
</tr>
</tbody>
</table>

A. Simulation Results

To verify the proposed control scheme, the three-phase grid connected PV inverter is simulated in two different conditions. First, all PV panels are operated under the same irradiance $S = 1000 \text{W/m}^2$ and temperature $T = 25 \, ^\circ\text{C}$. At $t = 0.8$ s, the solar irradiance on the first and second panels of phase $a$ decreases to $600 \text{W/m}^2$, and that for the other panels stays the same. The dc-link voltages of phase $a$ are shown in Fig. 8. At the beginning, all PV panels are operated at an MPP voltage of 36.4 V. As the irradiance changes, the first and second dc
VI. CONCLUSION

A modular cascaded H-bridge multilevel photovoltaic (PV) inverter is proposed for single- or three-phase grid-connected applications. Here by using MPPT and modular cascaded H bridge inverter we extracted the maximum power and overall efficiency is increased respectively. For the three-phase grid-connected PV system, and the three-phase grid current is balanced even with the unbalanced supplied solar power. PV mismatches may induce the unbalances in the power supply resulting in unbalanced injected grid current. A modulation compensation scheme, is suggested to balance the grid currents which will not increase the complexity and power loss of the system. Here we are using the fuzzy controller compared to other controllers. With the proposed control scheme, each PV module can be operated at its own MPP to maximize the solar energy extraction.

REFERENCES


B. SOMESH KUMAR
Completed B.Tech. in Electrical & Electronics Engineering in 2014 from GNAYANA SARASWATI COLLEGE OF ENGG & TECH., DHARMARAM(B), NIZAMABAD Affiliated to JNTUH, Hyderabad and pursuing M.Tech in Electrical Power system in 2015 from GNAYANA SARASWATI COLLEGE OF ENGINEERING & TECHNOLOGY Affiliated to JNTUH, Hyderabad, Telangana.
E-mail id: someshbdn209@gmail.com