THE MODULAR MULTILEVEL CONVERTER FOR ADVANCED GRID BALANCING SYSTEMS

DR.P.RAM KISHORE KUMAR REDDY¹, DR.P.LAKSHMI SUPRIYA², CH.VINAY KUMAR³, G.ARUN KUMAR⁴

¹Professor, Department of EEE, Mahatma Gandhi Institute of Technology
²Assistant Professor, Department Of EEE, Mahatma Gandhi Institute of Technology, email
³Assistant Professor, Department Of EEE, Mahatma Gandhi Institute of Technology, email
⁴Assistant Professor, Department Of EEE, Mahatma Gandhi Institute of Technology, email

ABSTRACT

One of the most interesting topologies for clean energy applications is the modular multilevel converter (MMC). The MMC has appealing characteristics such as flexible realisation, scalability, and transformer less running, making it a suitable converter for PV systems in particular. Maintaining controlled voltage through each sub module is critical for MMC to work properly (SMs). For three-phase multi-string PV systems based on MMC, this article presents an adaptive balancing solution based on Space Vector Pulse Width Modulation (SVPWM). The suggested approach, in combination with the control technique, uses just one SVPWM, which not only reduces measurement time but also balances the SM capacitor voltage, allows each PV string to provide its own MPPT, and reduces circulating voltage. As a result, the PV system's performance improves. The suggested approach is tested using Matlab/Simulink simulations under various operating conditions.

Keywords: MMC; Space vector PWM, PV system; voltage balance; circulating current.

I. INTRODUCTION

Renewable sources, especially solar photovoltaic (PV) systems, have attracted interest in recent years due to the feasibility of producing energy with less reliance on fossil fuels. PV panels may provide energy that is both renewable and dependable. PV modules have since been considerably less expensive. There are two types of power converter configurations for PV to grid integration: centralised topology and multi-string topology [1]. The unified topology is the most straightforward method of connecting PV to the grid. For a large portion of the PV farm, only one converter is needed. The energy yield is diminished where there is partial shade or a module mismatch. This is attributed to the fact that a significant majority of PV plants use centralised maximum power point monitoring (MPPT). Independent MPPT, on the other side, may be used in multi-string topologies to maximise energy yields. Due to the DC-DC converter in each line, however, using a multi-string topology increases the PV System's complexity and expense. Until recently, this drawback was tolerated owing to the higher energy generation of this topology; each of these topologies used three step two-level inverters, limiting the voltage and power capacity of the PV device. The development of induction motors for PV systems is undergoing extensive study.

Multilevel converters can have output waveforms with less harmonic distortion, prevent series semiconductor connections, and reduce electrostatic discharge, in addition to having high power and high voltage capabilities (EMI). Flying capacitor converters (FCC), Neutral-point-clamped (NPC) converters, Cascaded H-bridge (CHB) converters [2, 3], and compact multilevel converters are the most specific multilevel converter topologies (MMC)

In comparison to other induction motors, the MMC has a few additional appealing features, such as modular realisation, scalability, and transformer less service, which makes it a perfect converter for PV systems[4-6]. However, for MMC to function properly, a balanced voltage over each sub module (SM) is needed, as well as a reduction in the inner current flow [7- 15].
This paper suggests a balancing solution for three-phase multi-string PV systems focused on MMC using space vector PWM (SVPWM). Unlike other methods, this one uses just one SVPWM for the upper arm to produce the switching vectors for the MMC. Finding the complement of the upper arm switching vectors yields the lower arm switching vectors. The usage of a single SVPWM not only simplifies the measurement, but it also helps to reduce the circulating current in the MMC, lowering the PV system's power loss. Furthermore, the suggested balancing system, in combination with the control technique, is capable of stabilizing the SM capacitor voltages under partial shading conditions and realizing individual MPPT for each string.

The following is the format of this paper: The structure and basic function of the multi-string PV method based on MMC are briefly described in Section II. The suggested juggling approach is explained in Section III. The control strategy for the grid-connected MMC as seen in Section IV. In section V, the suggested approach is validated by simulation. At last, Section VI contains the closing remarks.

II. CASCADED MODULAR TRANSFORMER

Figure 1 depicts the topology of a 3 multistring PV structure centred on MMC. The MMC will generate sinusoidal output voltages with low voltage rating systems, eliminating the need to link them in sequence. A 3-phase MMC's power circuit is made up of similar elements called sub modules (SMs) linked in order, as seen in Fig. 1. The upper and lower arms of each step of m-level MMC are separated. The amount of SMs in each arm is $N = m \times 1$.

![Fig.1 Functional Block Diagram of Voltage Balancing System](image)

As seen in Fig. 1, each SM is made up of PV strings, a DC-DC converter, and an MMC half-bridge with a DC capacitor. The PV string is built by connecting PV modules are connected in series to achieve the required voltage, then parallelizing to meet the power requirement. The circuits are used to insert or override the SMs into the arm connection, while the DC capacitor acts as a voltage source.

III. VOLTAGE BALANCING OF MMC

This segment focuses on demonstrating how to balance the voltage of the SM capacitors. For proper MMC service, the voltage balancing device in Fig. 1 contains of an SVPWM and a voltage balancing tool. The switching vectors and duty cycles are produced using the SVPWM. The amount of SMs that should be switched on in the upper arm in each step is determined by each switching vector. The amount of SMs that should be switched ON in the lower arm, on the other side, may be calculated using the supplement of the upper arm's switching vectors without the use of another SVPWM. The assumption that the total number of SMs that should be ON at any given moment equals $N$ gives rise to this simple concept. The voltage balance block receives these switching vectors. The voltage balancing method's main goal is to decide which SM should be installed into the arm based on the capacitor voltage, the amount of SMs to be turned on, and the arm current's path.
Fig.2 shows the space vectors of a 5-level MMC \( m = 5 \). A simple implementational algorithm is followed. First, the Center of the sub-hexagon (C) that has the tip of the reference vector \( OT = (v_a, b, v_c) \) is found and is utilized for mapping the OT to the innermost sub-hexagon with centroid at origin (O) by \( OT' = OT - OC \). The switching states \((S_{aj}, S_{bj}, S_{cj})\) associated with vectors of the innermost sub-hexagon \( (v_{i1}, v_{i2}, v_{i3}, v_{i4})\), their sequences and dwell times can be found as in a conventional two-level inverter which simplifies the dwell time calculation. By adding the switching state associated with C to \((S_{aj}, S_{bj}, S_{cj})\), \( j \in \{1, 2, 3, 4\} \), the switching states \((S_{ajup}, S_{bjup}, S_{cjup})\) associated with the switching vectors of the upper arm \((v_{1up}, v_{2up}, v_{3up}, v_{4up})\) are obtained. This is depicted as reverse mapping in Fig.1. The switching states \((S_{ajlo}, S_{bjlo}, S_{cjlo})\) associated with the lower arm switching vectors \((v_{1lo}, v_{2lo}, v_{3lo}, v_{4lo})\) are given by:

\[
\begin{align*}
S_{ajlo} & = N - S_{aj} \\
S_{bjlo} & = N - S_{bj} \\
S_{cjlo} & = N - S_{cj}
\end{align*}
\]  

(1)

**Stage I: Generation of index number**

Where \( y \in (up, o) \), represents the arm \( h \in \{1, 2, 3 \ldots N\} \), \( v_{nyh} \) is the normalized capacitor voltage of the \( h^{th} \) SM, \( v_{cyh} \) is the actual capacitor voltage of the \( h^{th} \) SM, and \( v_0 \) is the nominal capacitor voltage \( V_o = V_dc/N \). The \( v_{nyh} \) voltage of each SM is compared with that of other SMs and the outputs of these comparisons are added together to generate the index \((I_{kyh})\) of this particular SM as illustrated in Fig. 3. The value of \( I_{kyh} \) varies from 0 to \( m-2 \). \( I_{kyh} \) is used by the second stage directly without any modification, since the direction of the arm current \((i_{yx}, y \in \{up, lo\}, x \in \{a, b, \})\) is incorporated within the comparison logic by using XNOR logic as shown in Fig. 3.

![Fig.3 Capacitor voltage balancing method](image)

**Stage II: Generation of SM Switch status**

This stage requires the switching vectors \((v_{1up}, v_{2up}, v_{3up}, v_{4up})\) and \((v_{1lo}, v_{2lo}, v_{3lo}, v_{4lo})\) that were obtained from the SVPWM. The states \((S_{aup}, S_{bup}, S_{c_{up}})\) and \((S_{a_{lo}}, S_{b_{lo}}, S_{c_{lo}})\) represent the number of the SMs that should be turned ON in each phase. The element \( v_{yj}(x), y \in \{up, lo\} \) is used to generate the reference index number \((I_y)\) as follows:

\[
I = N - v_{yj}(Sx)
\]

(3)
Where $S_x$ represents the switching state of each phase ($x \in \{a, b, c\}$) associated with the switching vector $v_y$. The switching device status ($B_{yhj}$) of the $h^{th}$ SM is determined as in (4).

$$B_{yhj} = \begin{cases} 1 & I_{K_{yh}} \geq I_{yf} \\ 0 & I_{K_{yh}} < I_{yf} \end{cases}$$

So when $B_{yhj} = 1$ the switching device 1 of the $h^{th}$ SM is ON, else OFF.

**IV. CONTROL STRATEGY**

The control strategy of the multi-string PV system based on MMC involves two decoupled control stages: the MPPT control of each SM and the vector control for the grid tied MMC.

**A. MPPT**

The amount of energy derived from a PV depends on the temperature, irradiation, and shading circumstances. The MPPT is needed in order to optimise the power production. The classical Perturb and Examine algorithm is implemented on each SMs boost DC-DC converter in this article. Since the MPPT specification is not the subject of this article, further detail can be found in [16].

**B. Vector control**

The vector control system is realized in the form of a cascaded structure as shown in Fig.4 and involves the transformation of the grid side quantities from a-b-c stationary reference frame to the d-q synchronous reference frame and vice versa.

![Fig.4 Vector control of grid connected MMC](image)

In Fig.4 the outer control loop provides the set points to the inner current control loop. Depending on the application and the control objective, the outer control loop can include the direct voltage controller, active power controller, reactive power controller and AC voltage controller. In this paper, the control objective is direct voltage ($V_d$) control and reactive power ($Q$) control. The reference value for the d-axis current component $i_q^*$ is provided from the $V_d$ controller, while the reference value for the q-axis current component current $i_d^*$ is provided from the Q controller. In vector control the phase locked loop PLL is used for synchronization which is required to transform the grid side quantities from a-b-c stationary reference frame to the d-q synchronous reference frame and vice versa. The reference voltage ($v_a, v_b, v_c$) obtained from the current controller are given to the voltage balancing system in order to generate the gate pulses for the MMC.

**V. SIMULATION RESULTS**

For the purpose of verifying the proposed method, a detailed simulation model of the 5 level MMC based multi-string PV system is developed in SIMPOWER/MATLAB. Each arm of MMC consists of 4 SMs, so a total of 24 SMs are utilized in the three-phase system. Each SM is made up of PV strings, DC-DC converter and the MMC half-bridge with DC capacitor as shown in Fig.1. The MMC and the PV string parameters are given in TABLE.1.
In order to investigate the performance of the proposed method the simulation was carried out for two cases: Homogenous irradiation and Inhomogeneous irradiation.

A. Homogenous Irradiation

In this case, the irradiation of PV strings of each SM is set at 1000 W/m². According to Table (I) the Maximum power of Each SM $P_{Sm}=13.98$KW as a result the total power of the Converter is equal to $p_{max}=3*N*P_{Sm}=3*8*13.98K=335.5200$KW. Fig 5 indicates that the converter is capable of injecting the Maximum power to the grid. The simulation results, demonstrate that the balancing algorithm is able to balance SMs capacitors as shown Fig.6.a In additions the DC controller is cable of controlling the average voltage of the SMs as shown in Fig.6.b. It can also be observed from Fig. 7 that the use of one- SVPWM gives lower circulating current compared to the use of two- SVPWM.

B. Inhomogeneous Irradiation

In order to investigate the performance of the proposed method in balancing the capacitor voltages of SM under partial shading conditions, and the possibility to realize the independent MPPT for each SM the simulation was carried out under different irradiation. Initially, the irradiation of PV strings in each SM is set at 1000 W/m². At $t=0.5s$ the PV strings of SM4 and SM5 in each phase are shaded and subjected to irradiation of 400 W/m². In this case the maximum power of the converter is calculated as $p_{max} = 3 * (N - 2) * P_{Sm} + 3 * 2 * 5509 = 284 Kw$ this agrees with the simulation result as shown in Fig.8.b. From Fig 8The maximum power of SM4 and SM5 is 5509 while the maximum power of SM1 13.9K.

This Indicate the capability of the proposed method in achieving Independent MPPT. It can also be observed from Fig.9 that the balancing method is capable of balancing the SMs capacitors under different irradiation conditions.

<table>
<thead>
<tr>
<th>Arm inductance</th>
<th>$L0=1.59mH$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submodule capacitance</td>
<td>$C=26000\mu F$</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$f_{sw}=5KHz$</td>
</tr>
<tr>
<td>Rated power</td>
<td>335.6KW</td>
</tr>
<tr>
<td>Transformer ratio</td>
<td>$3kV(\Delta)/25kV(Y)$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irradiance(W/M²)</th>
<th>Open Voltage ($V_{oc}$)</th>
<th>Short current $I_s(A)$</th>
<th>Maximum Voltage $V_{mpp}(V)$</th>
<th>Maximum power $P_{max}(W)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>515</td>
<td>37.6</td>
<td>430</td>
<td>13.98k</td>
</tr>
<tr>
<td>400</td>
<td>494</td>
<td>15.1</td>
<td>421</td>
<td>5509</td>
</tr>
</tbody>
</table>
Fig.5 Homogeneous irradiation a) generated power by MMC. b) Generated power by one SM

Fig.6 Homogeneous irradiation a) lower arm SM voltages. b) Total voltages of SMs

Fig.7 MMC circulating current
VI. CONCLUSION

This paper describes a new MMC-based SM capacitor voltage balancing process for three-phase multi-string PV systems. Each SM is connected to PV strings and a DC-DC boost converter in this topology. The calculation results reveal that the improved approach will balance the capacitor voltages of SM under inhomogeneous irradiation conditions and achieve individual MPPT for each SM. Furthermore, the usage of one SVPWM has helped to reduce the circulation voltage, which would continue to reduce the PV service's power loss.

REFERENCES:


Fig. 8 Inhomogeneous irradiation a) generated power by MMC. b) generated power by SM1 & SM4

Fig. 9 Inhomogeneous irradiation a) lower arm SM voltages. b) Total voltages of SMs

www.turkjphysiotherrehabil.org