Multilevel Inverter with Minimum Switches in A PV System Under Partial Shading Conditions

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Abstract— The paper presents the idea to implement a 5 level multilevel inverter with a smaller number of switches for photovoltaic based applications under partial shading conditions. This proposed topology reduces the switching losses due to reduced number of switches. It consists of a full-bridge inverter, an auxiliary circuit (comprises of one switching element and four diodes) and two capacitors as a voltage divider. For the cascaded H Bridge 5 level inverter requires 8 switches to get five level output voltage but the proposed topology requires only 5 switches. Photovoltaic modules have relatively low conversion efficiency. This paper, proposes an improvised Maximum Power Point Tracking of PhotoVoltaic system using a Modified Particle Swarm Optimization methodology. This method helps us to track the Maximum Power under partial shading condition. The advantage of this method is fast tracking speed, simple algorithm and reduced steady state oscillations, once the Maximum Power Point is located. The proposed system is modeled and simulated using MATLAB/Simulink software program.

Keywords—Multilevel inverter, Maximum Power Point Tracking (MPPT), Single-ended primary-inductor (SEPIC), A Modified particle swarm optimization (PSO), Partial shading condition

I. INTRODUCTION

Recently, for increasing the use in practice and fast developing of high power devices and related control techniques, multilevel inverters have become more attractive to researches and industrial companies. Multilevel inverter is defined as level and it refers to the various voltage values in a cycle. The basic inverter produces three voltage levels 0, +V dc and −V dc. The three level output voltage contains the harmonic content reduced compared to the two level value of output voltage. The voltage levels are risen, the harmonic content in the output voltage reduces and the easily sine wave output wave form produces from multilevel inverters. As the number of levels goes high, the output waveform synthesized has more steps, which, in turn produces a staircase type wave which approaches the desired waveform. As the number of levels increases, the voltage that can be spanned by connecting devices in series also increases.

A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels tends to infinity, the output THD tends to zero.

II. LITERATURE REVIEW

It has been suggested in [1] a multi string five-level inverter with novel PWM control scheme for PV application. The proposed topology which introduces the multilevel inverter with reduced number of switches. The concept is so advantageous because of reducing number of switches and thereby reducing switching losses.

It has been suggested in [2] a transistor-clamped h-bridge based cascaded multilevel inverter with new method of capacitor voltage balancing. The proposed inverter is found potential not only for medium-voltage drive application but also other applications demanding higher output quality.

It has been suggested in [4] the modeling and controller design of the PV charger system implemented with the single-ended primary inductance converter (SEPIC). In modern age different portable electronic equipment have benefited from a power converter is able to achieve high efficiency with a wide input and output voltage ranges will be low. But conventional converters can’t maintain a wide operation range with high efficiency. These characteristics can be obtained in a single ended primary inductor converter (SEPIC). So SEPIC converter is used. The SEPIC converter is used in the proposed system.

In [7], it describes about the multilevel inverter topologies for stand-alone PV systems. Multilevel inverter promises a lot of advantages over conventional inverter especially for high power applications. Some of the merits are that the output waveform were improved since multilevel inverter produced nearly sinusoidal output voltage waveforms, hence the total harmonic distortion is also low. The switching losses also become low.

When partial shading occurs in a small surface inside a cell group bypass diodes may not be able to protect the shaded cells. So, these solar cells are thus made to operate with increased current, meaning that they will heat up. Then the lifetime of solar panel will be reduced.
In normal condition only one global peak is present in P-V curve. But in partial shading condition multiple peaks are present. It affects the output power of PV [8].

Maximum Power Point tracking (MPPT) that allows a PV array to deliver the maximum amount of power under varying under environmental condition. The point that gathers the power called the Maximum Power Point (MPP).

Over the years, various MPPT methods are proposed. For example, Perturb and Observe (P&O), Incremental and Conductance (I&C), Hill climbing (HC), Neural Network (NN) and Fuzzy Logic Controller (FLC). These methods are not suitable for partial shading condition. P&O, I&C and HC are very likely to lose its direction while tracking the true MPP. FLC and NN are effective with the nonlinear characteristics of the I-V curves, but they require more operations [9].

In order to get maximum power under partial shading condition, Particle Swarm Optimization (PSO) method is used.

III. PROPOSED METHOD

The proposed system consists of PV, SEPIC, 5 level multilevel inverter with reduced number of switches and MPPT controller. Fig.1 demonstrates the block diagram of proposed system.

A. Photovoltaic Modeling

A modeling PV module among various modeling methods of the PV module, the two-diode model, as depicted in fig.2. The output current of the module can be described

\[ I = I_{PV} - I_{d1} - I_{d2} - \left( \frac{V + IR_s}{R_p} \right) \]

Where,

\[ I_{d1} = I_{o1} \left[ \exp \left( \frac{V + IR_s}{a_1 V_T} \right) - 1 \right] \]

and

\[ I_{d2} = I_{o2} \left[ \exp \left( \frac{V + IR_s}{a_2 V_T} \right) - 1 \right] \]

Fig.2 Two diode model of PV cell

Where

- \( I_{PV} \) is the current generated by the incidence of light
- \( I_{o1} \) and \( I_{o2} \) are reverse saturation of diode 1 and diode 2, respectively. The \( I_{o2} \) term is introduced to compensate for the recombination loss in depletion region
- \( V_{T1} \) and \( V_{T2} \) (both equal to \( N_S k T/q \)) are thermal voltages
- \( N_S \) cells connected in series
- \( N_P \) cells connected in parallel
- \( q \) is the electron charge (1.60217646 x 10^-19 C)
- \( k \) is the Boltzmann constant (1.3806503 x 10^-23 J/K)
- \( T \) is the temperature of p-n junction in Kelvin
- Variables \( a_1 \) and \( a_2 \) represent the diode constants, respectively
- \( R_s \) is a series resistance
- \( R_p \) is a parallel resistance
B. Modeling Of The PV Array

A large PV power generation system, the modules are configured in a series-parallel structure (i.e., \( N_{SS} \times N_{PP} \) modules), as depicted fig.3.

\[
I = N_{PP} \{ I_{PV} - I_{0}(1 + 2) \} - (V + I_{PV} R_{s} \Gamma / R_{p} \Gamma) \tag{4}
\]

Where

\[
I_{p} = \exp \left( \frac{V + I_{PV} R_{s} \Gamma}{V_{T} N_{SS}} \right) + \exp \left( \frac{V + I_{PV} R_{s} \Gamma}{(p - 1) V_{T} N_{SS}} \right) \tag{5}
\]

and\( \Gamma = \frac{N_{SS}}{N_{PP}} \tag{6} \)

Fig.3 Series parallel combination of PV array

\[ I_{PV}N_{pp} \]

C. PV Array Under Partial Shading Condition

Normally, numbers of PV modules are connected in series or parallel to form a PV array and the power of the PV array is the combination of the power derived from each PV module. In fig.4, there are two series connected PV modules and one of the PV modules is found to be partially shaded. The shaded module can hence a power consumer and dissipates heat [9].

If the operating current of the PV array that consists of these two series connected PV modules is at \( I_{s} \), then the shaded PV module is forced to operate at the reverse biased region. Thereby, it works as a load instead of a power source. In long term conditions, the shaded PV module will be damaged due to the localized power dissipation. Hence, the bypass diodes as shown in fig.4 are added to protect the PV modules from self-heating during partial shading.

Under uniform isolation, the bypass diodes are reverse biased and have nil effect. When the PV module is being shaded, the bypass diode across the PV module is forward biased and the current passes through the diode instead of the PV module. However, there lies a demerit in using the bypass diodes where there will be multiple peaks that appear in the \( P-V \) curve during partial shading conditions [9].

C. A Modified Particle Swarm Optimization Algorithm

In case of slow variation in the solar isolation, a proper initialization of the duty cycles in PSO is very crucial. In this case a change in duty cycle from the previous one should be small to track the MPP [1].

Thus, due to initialization, when the change in the duty cycle is large, the particles will have to search a large area of the \( P-V \) curve. However, MPP will still be tracked at the expense of large fluctuations in the operating point. Consequently, certain amount of energy will be wasted during the exploration process. However, the large change in the duty cycles does not allow for the duty cycles to follow the new MPP very accurately [1].

On the other hand, a large change in the operating point can also occur due to a large change in isolation, for example, during the partial shading condition. In this case, if the change in the duty cycle is small, the convergence toward the MPP could be slow [1]. This could be more critical for the case of partial shading. As duty cycles are not allowed to explore a larger area of the \( P-V \) curve, the final MPP could settle at a local instead of global peak.

PSO is a stochastic, population-based EA search method. The PSO algorithm consists of a swarm of components (called particles), where each particle represents an individual solution. Particles follow an easy path, emulate the success of neighboring particles and its own achieved successes [2]. The position of a particle is, therefore, made convinced by the best particle in a neighbourhood \( P_{best} \) as well as the best solution found by all the particles in the entire population \( G_{best} \). The particle position \( X_{i}^{k} \) is adjusted using,

\[
X_{i}^{k+1} = X_{i}^{k} + \varphi_{i}^{k+1} \tag{7}
\]
Where the velocity component $\Phi_i$ represents the step size. The velocity is calculated by

$$
\varphi_i^{k+1} = w \varphi_i^k + c_1 r_1 (P_{besti} - x_i^k) + c_2 r_2 (G_{best} - x_i^k)
$$

(8)

Where $w$ is the inertia weight, $c_1$ and $c_2$ are the acceleration coefficients, $r_1, r_2 \in U(0, 1)$, $P_{besti}$ is the personal best position of particle $i$, and $G_{best}$ is the best position of the particles in the entire population.

$$
d_i^{k+1} = d_i^k + \varphi_i^{k+1}
$$

(9)

However, for the case of PSO, resulting perturbation in the present duty cycle depends on $P_{besti}$ and $G_{best}$. If the present duty cycle is far from these two duty cycles, the final variation in the duty cycle will also be large, and it can be in the opposite way too. Hence, PSO can be taken as an adaptive form of HC. In the latter, the perturbation in the duty cycle is always fixed but in PSO it varies according to the position of the particles. With proper choice of control parameters, a suitable MPPT controller using PSO can be easily designed.

To describe the implementation of the PSO algorithm in tracking the MPP using the direct control technique, first a solution vector of duty cycles with $N_P$ particles is determined.

$$
X_i^k = d_1 = [d_1, d_2, ....... d_j]
$$

$j = 1, 2, 3, ......., N_P$

(10)

The objective function is defined as,

$$
P(d_i^k) > P(d_i^{k-1})
$$

(11)
IV. SEPIC CONVERTER

Single Ended Primary Inductor Converter (SEPIC) is a DC to DC converter and is capable of operating in either step up or step down mode and widely used in battery operated equipment by varying duty cycle of gate signal of MOSFET. We can step up or step down voltage [3].

The advantage of this converter is it provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. It act as both like a buck and boost converter. It also has minimal active components, a simple controller that provides low noise operation [3].

When switch $Q_1$ is turned on, current $I_{L1}$ increases and the current $I_{L2}$ increases in the negative direction. The energy to increase the current $I_{L1}$ comes from the input source. Since $Q_1$ is a short while closed, and the instantaneous voltage $V_{CS}$ is approximately $V_{IN}$, the voltage $V_{L2}$ is approximately $-V_{IN}$. Therefore, the capacitor $C_S$ supplies the energy to increase the magnitude of the current in $I_{L2}$ and thus increase the energy stored in $L_2$.

When switch $Q_1$ is turned off, the current $I_{CS}$ becomes the same as the current $I_{L1}$, as the inductors will not allow instantaneous changes in current. Current $I_{L2}$ will continue in the negative direction, in fact it never reverse direction.

### TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$</td>
<td>47e-6 H</td>
</tr>
<tr>
<td>$L_2$</td>
<td>1e-6 H</td>
</tr>
<tr>
<td>$C_{IN}$</td>
<td>2000e-6 F</td>
</tr>
<tr>
<td>$C_{OUT}$</td>
<td>2000e-6 F</td>
</tr>
<tr>
<td>$C_S$</td>
<td>1e-6 F</td>
</tr>
<tr>
<td>Type of switch used</td>
<td>IGBT</td>
</tr>
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</table>
V. PROPOSED TOPOLOGY

For 5-level inverter, the topology is presented in Fig.7. This topology consists of a full-bridge inverter, an auxiliary circuit (comprises of one switching element and four diodes) and two capacitors as voltage divider.

A new strategy with reduced number of switches is employed. For cascaded H Bridge 5 level inverter requires 8 switches to get five level output voltage but the proposed topology requires 5 switches only. One H-bridge inverter produces three voltage levels they are 0, +Vdc and −Vdc. The five-level output voltage are producing from two full H-bridge inverters connected in cascaded form. They are 0, +2Vs, +Vs, −2Vs and −Vs [6].

Fig.7 Topology of 5-level multilevel inverter

Table 2
The Switches On-Off Condition For 5-Level Multilevel Inverter

<table>
<thead>
<tr>
<th>Output Voltage</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Vdc</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>+Vdc/2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>−Vdc</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>−Vdc/2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: “1” for ON, “0” for OFF

VI. SIMULATION RESULTS

Modelling and simulation of proposed system has been carried out in MATLAB- SIMULINK.

Fig.8. Simulation circuit of proposed system

Fig.9. Output voltage of proposed topology

VII. CONCLUSION

In this paper, presented a single-phase multistring five-level inverter for PV implementation. The topology is useful for PV application because of low conversion efficiency. It only requires less number of switches rather than other multilevel inverter topologies. This proposed topology reduces both switching losses and cost. Here proposes a Modified Particle Swarm Optimization (PSO) with the capability of direct duty cycle is used to track the MPP of a PV system under partial shading condition. It gives the best result under partial shading condition.

REFERENCES


