A Proposed SVM for 3-level Transformer-less Dual Inverter Scheme for Grid Connected PV System

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Abstract

Objectives: This paper elucidates on proposed SVM for grid connected system using dual inverters to get improved output voltage and better current control with less switching loss and THD. Methods/Analysis: The system incorporates PV array, MPPT and boost converter which multiplies the output of the PV array. The split inductor used in this proposed system, which evades the treatment of the conventional transformer and the stepped output is converted into sinusoidal AC output and which gives better synchronization to ac applications. Split inductor reduces the shoot through problem, leakage current problem, reduces the defect in the scheme and reduces the expenditure of the scheme. The proposed SVM algorithm is used as PWM controller for this dual inverter. This proposed scheme is simulated using Matlab/Simulink and the experimental outcomes are verified using the dsPIC controller. Findings: The proposed system is used for the conversion of the alternating current waveform and it eliminates the total harmonic distortion. This scheme aspires at reducing switching losses and to switching control easier than conventional system. The proposed SVM controls the capacitor balancing problems avoided by dual inverter instead of using multilevel inverter. Application/Improvement: This method provides improved output voltage and better current control compare to SPWM and conventional controllers. And Total Harmonic Distortion of the system reduces less than that of IEEE standard.

Keywords: Boost Converter, Grid System, Multilevel Inverter (MLI), MPPT – P and O Method, Proposed SVM (Space Vector Modulation), PV Array, Split Inductor

1. Introduction

The source used is a PV array connected to MPPT. The PV array is a combination of many cells which operates on the principle of photoelectric effect. Since the output of PV array is not that efficient MPPT is employed to maximize the output power. The output received from the PV voltage is boosted by using dc/dc boost converter system. The output of the inverter is stepped and to obtain a sinusoidal waveform split inductors are used. The SVM control strategy is more efficient than other methods as it reduces the total ripple contents present in the system. It determines switching vector in complex space plane.

The proposed transformer-less coupled inductor based grid connected is very diminutive in size scheme, effective expenditure in nature; diminish grid current deformation and leakage current of the particular system. SVM Control methodology is used for the control IGBT power switches. It uses redundant switching state vectors, which gives enhanced control of the power switches and diminishes the harmonic distortion in the output waveform. The configuration of open end winding induction motor was employed and the PV connected grid system was used in. With the analysis regarding the advantages of these configurations used in the above references the proposed scheme is designed.

This paper deals with Proposed SVM for 3-level Transformer-less Dual Inverter for Grid connected PV system. Proposed system also employs transformer-less two level inverter which in turn reduces the cost of the system. The major benefits of the proposed system are that reduces the total harmonic distortion to a great
extent as compared with other schemes. Also reduces the losses caused by using a transformer and the leakage current which may lead to distortion\(^4\).

### 2. PV Array and MPPT

#### 2.1 PV Array

Electrical power grids and smart grids demands PV system in developed areas; it is situated near the area of consumption so as to reduce the generation and distribution cost. The utilization of the PV output which is dc converted to ac using an inverter the solar light, which incidents on the PV panels, can be used in several ways as it can be used as the battery to store dc power supply. This system is using grid-connected system which does not require any battery\(^6\). The PV array output will be minimum when the insulation is weak compared to conventional energy resources the PV power has greater advantages such as low cost. The output efficiency of the PV system can be optimized by a method called MPPT which is of two types PandO and Increment and decrement. If the solar array is directly connected to the load, demand is not satisfied which causes the increase in the range of the PV panels, enhance the cost of the scheme. The simulation of PV system will ensure operations satisfactory, protection settings and derive component ratings several simulations on PV systems are conducted based on V-I char and also based on weather conditions\(^9\). The power circuit of PV array shown in Figure 1.

\[
I = I_S - I_D
\]

Where \(I_s\) is the current for short circuit condition and \(I_d\) is the diode current. This diode current is further given by following equation using the transfer function expression using the PV array modeling.

\[
I_D = I_{sc} \left[ 1 - C_2 \exp \left( \frac{\Delta V}{C_2 V_{oc}} - 1 \right) \right] + \Delta I
\]

Where, \(C_1\) and \(C_2\) are temperature constants.

#### 2.2 MPPT

PV cells have nonlinear characteristics, and MPP is the operation point where maximum output power is obtained. With the changing weather conditions PV array output also continuously varies which is a problem. An MPPT control strategy is employed to compensate the problem aroused due to the changing weather conditions\(^11\). Usually P and O – MPPT algorithm is implemented for general applications due to simple to design and has more advantages.

The P and O algorithm extracts the maximum power based on the movement of the PV cell. When \((dv/dt)>0\) it shows the panel movement to its right side and When \((dv/dt)<0\) the panel movement to its left side of the system\(^12\). P and O algorithm provides better extracting of power from PV array compare to other conventional MPPT algorithms.

### 3. P and O MPPT Algorithm

MPPT is a device use to develop the competence of the solar panel scheme by maximizing the output power. MPPT maximizes the energy that is transferred from the PV array to the electrical system. It optimizes the match between PV array and the grid. The major occupation of MPPT is to regulate the PV panel’s output voltage such that panel supplies maximum power to the electrical system. A solar panel is capable of converting only 30-40%
of the solar energy into electricity. Thus by using a MPPT along with PV array helps it to produce better efficiency. The output of PV depends on sunrise and sunset and at MPP (mostly noon) is the most efficient point for output. The simplest and most used method to guarantee that the PV panel is operating at MPP is Perturb and Observe (P and O) algorithm. The perturb and observe methodology affirm that when a small increment perturbs the operating voltage of the PV panel. If the consequential modify value of $\Delta P$ is optimistic ($\Delta P > 0$), then it change to shift in the path of MPP and it keep on perturbing in the same direction. If $\Delta P$ is negative ($\Delta P < 0$), the perturbation abounding has to be distorted it leaves away from the direction of MPP. The P and O algorithm flow chat is shown in Figure 2.

Figure 2. P and O–MPPT algorithm.

Perturbation was made on the operating point of the PV panel; the voltage and current of the PV panel are obtained to calculate the power. The calculated power is compared with the previous power and $\Delta P$ is calculated. If the difference $\Delta P < 0$, then the perturbation is continued in the direction but when $\Delta P > 0$ then the direction is reversed. Grid-connected PV systems are designed to use the electric grid and no battery backup. The excess energy generated is directly supplied to the grid. When the irradiation alters swiftly, the MPP point as well shift on the right elevation of curvature.

4. Space Vector Modulation Technique

4.1 SVM

SVM is a control technique to generate gating pulses for power switches. There variations of SVM which result in variation of voltage vectors dissimilar superiority and computational necessities. Based on the various switching states the growth in the diminution of Total Harmonic Distortion (THD) shaped through the quick switching intrinsic to these methodologies. The reference signal $V_{ref}$ is illustrated with switching frequency ($f_s$) to implement the space vector modulation.

The reference signal may be produced from three divide phase references using the Alpha–Beta transformation also known as Parks Transformation. The reference vector is then amalgamated using a mixture of the two nearest switching vector; it contains both active and zero vectors. Various approaches used for choosing the order of the vectors and which zero vectors to use survive. The switching strategy selection scheme will influence the ripple content and the switching losses. Hexagon diagram for 3 level space vector modulations is shown in Figure 3.

Figure 3. Hexagon with 3-level space vector modulation.

4.2 Proposed SVM

This proposed theory is based on SVM on two sets of transformer-less dual level inverter which are connected to each other employing a grid system, and the source is fed from the PV array. The basic notion of the proposed theory is to reduce the total ripple distortion, reduce the cost of the system and increase the output voltage. The reference vector is obtained from the transformation of three phase voltages $V_a, V_b, V_c$ into two phase voltages $V_\alpha, V_\beta$ using parks transformation. The flow chart for control strategy of the proposed scheme shown in Figure 4.

The process after determining the $V_\alpha$ and $V_\beta$ is to find the clamping and the switching state of the two inverters respectively. The sub-hexagon determination is used to
determine the clamping state of the inverter and followed by this; the triangle determination is done inside the sub-hexagon as each sub-hexagon consist of four triangles which is determined by triangle algorithm using certain equations and calculations and these described in detail in coming chapter. The on time of inverter is calculated \( t_s \), which determines the switching state.

**Figure 4. Control strategy for proposed system.**

### 4.3 Triangle Algorithm

The fundamental scheme of SVPWM is to reimburse the necessary volt-seconds using distinct switching state vectors and their switching times. Traditionally, to establish the on times for a triangle of an \( n \)-level inverter, three instantaneous equations are solved. Nevertheless, traditional two level space vector structures can be used for switching time computation for a multilevel SVPWM.

Based on the sector identification, the height of the sector \( h = \frac{3}{2} \). On-time calculation for any of the six sectors \( S_i, i = 1, 2 \ldots 6 \) is same. Switching time computation is based on the position of the reference vector within a sector. Space vector modulation for 2 level inverter is shown in Figure 5.

\[
\begin{align*}
\vec{v}^* T_s &= \vec{v}_{a1} t_{a1} + \vec{v}_{b1} t_{b1} \\
\text{Time balance is given by} \\
T_s &= t_a + t_b + t_0 \\
\text{Resolving above along the } \alpha \beta 	ext{ axis, we obtain} \\
\vec{v}_{a0} T_s &= t_a + 0.5 t_b \\
\vec{v}_{b0} T_s &= h t_b \\
\text{Where, } h &= \sqrt{3} \cdot 2 \\
\end{align*}
\]

Solving the equations, we get the ON time for the three-level inverter. Identification of Triangle and Determination of Small Vector \( \vec{v} \). The tip of the \( P \) of the reference vector \( \vec{v}^* \) can be positioned in any of the triangles. Therefore, the intention here is to recognize the triangle in which the point \( P \) is located. The search of the triangle of the small vector (or point \( P \)) can be pointed down by using two integers’ \( k_1 \) and \( k_2 \). They are defined by the coordinates \( (\alpha, \beta) \) of point \( P \) as,

\[
\begin{align*}
k_1 &= \text{int} \left( \frac{v_{\alpha} + v_{\beta}}{\sqrt{3}} \right) \\
k_2 &= \text{int} \left( \frac{v_{\beta}}{\sqrt{3}} \right) \\
\end{align*}
\]

Triangle number \( \Delta j \) is calculated along with switching time calculation using the same idea, using \( k_1 \) and \( k_2 \). For a triangle, the triangle number \( \Delta j \) is obtained as,

\[
\Delta j = k_1^2 + 2k_2
\]

### 5. Simulation Output

The proposed system was simulated using Matlab R2013a. The simulation of the projected scheme has the switching frequency of 10 kHz. The routine of the scheme is experienced with various solar radiations from 400 W/m\(^2\) to 800 W/m\(^2\), and different temperatures (0- 40)\(^\circ\)C.

**Table 1. Simulation parameters**

| Simulation parameters | Values |
|-----------------------|--------|
| Grid voltage (Vg)     | 200V   |
| Grid and PLL frequency (f) | 50 HZ |
The limitation painstaking for the simulation are, coupled inductor $L = 4 \, \text{mH}$, resistance value $R = 2W$, capacitance value $C = 100 \, \text{mF}$. Table 1 shows the simulation parameters for the proposed system.

| Parameter                        | Value            |
|----------------------------------|------------------|
| Split inductor NPC (L)           | 4mH              |
| DC bus capacitance (C)           | 100 micro farad  |
| Inverter switching frequency ($f_s$) | 10kHZ          |
| Solar radiations ($S$)           | 400W/m^2 to 500W/m^2 |
| Temperature ($T$)                | 40 degree        |

Figure 6. Output power getting from PV array.

Figure 7. Pulses of MPPT algorithm.

Figure 8. Switching pulses for leg A.

Figure 9. 3-level output voltage of the dual inverter.

The input power generated from PV array is 700 W, which is shown in Figure 6. And maximum power is followed from the PV array using MPPT –P and O algorithm; the MPPT output pulses are shown in Figure 7. The switching pulses for dual inverter leg a shown in the Figure 8. In this proposed system 3-level, output voltage of the dual inverter is 210 V, which is shown in Figure 9. The split inductor is added to the output of the dual inverter to synchronize with the grid connected system, which is shown in Figure 10.

Figure 10. Line to line voltage of dual inverter with split inductor.

Figure 11. Current control for SI based dual inverter.

(a) (b)  

Figure 12. THD analysis (a) output voltage (b) current control.

Figure 13. Reducing the capacitor balancing problem using proposed SVM.
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ler, which depicts that the level of current control is better in the projected scheme as compared to the conventional SPWM. In Figure 12 (a) and Figure 12 (b) express the THD analysis for output voltage and output current control of proposed system respectively. Capacitor balancing problem reduced the using proposed SVM is shown in Figure 13.

6. Experimental Results

To authenticate the various simulation results of the projected scheme, the experimental setup for 3-levelSI based dual inverter was premeditated and experienced. This system with input source of 220 V ac is rehabilitated to 210 V dc using a conventional bridge rectifier circuit and fed to split inductor based dual inverter. The multilevel stepped output of 200 V is acquired at the inverter side which is exposed in Figure 14.

Figure 14. 3 level output voltage of dual inverter using proposed SVM.

Figure 15. Output current for SI based dual inverter using proposed SVM.

With the help of coupled inductors a sinusoidal output of 195 V is acquired which is fed to the 0.2 KW single phase induction motor system, which is revealed in Figure 15. IRF/840 MOSFET power switches were used for the construction of inverter legs. The output waveforms and graphs are attained using Digital Storage Oscilloscope. The proposed SVM is executed using DSPIC30F microcontroller based fed with 6V dc voltage and the investigational setup is shown in Figure 16.

Figure 16. Experimental setup.

7. Conclusion

The proposed scheme presents the implementation of 3 level voltages with split inductor based dual inverter using proposed SVM controller. Using MPPT control finest available power is obtained from the PV array. SVPWM is more advantageous and efficient as compared to the conventional SPWM because the Total Harmonic Distortion (THD) of the projected scheme is lesser than conventional scheme. The proposed SVM is obtainable in the easy manner, which diminishes the capacitor balancing problem and common mode voltage reduction and affords precise estimation for switching on time result and switching vector position. Precise fortitude of split inductor arrangement is critical to inverter with grid harmonization. The output voltage of SVPWM is 21% more than that of the SPWM. The modulation index is higher SVPWM than SPWM.

- THD analysis for the proposed system, 3.54% for output voltage and 4.63% for output current control.
- In future, the 3dimensional SVM will be added to achieve full elimination of common mode voltage.

8. References

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