Design and Implementation of Two-Stage 3-Level Inverter Grid-Connected for Photovoltaic Applications

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Abstract: In this study proposes a simple, cost effective and efficient system for solar photovoltaic applications. Solar energy is considered as fastest growing renewable energy source after wind energy for electricity generation. Solar energy is a free, clean abundant sun energy considered as inexhaustible source for electricity generation. Solar photovoltaic system is characterized with variable output power due to its operation dependency on solar irradiance and cell temperature. To maximize the energy generation potential of solar PV, research effort is focused on solar cell manufacturing technology to increase its generation efficiency and exploring advancement in power electronic devices for small and large scale deployment. In this study is a single-phase inverter with no transformer for solar PV application. A closed loop DC-DC boost converter that accepts wide input DC voltage assumed to be from 40-60V to produce constant 330V DC voltage is modelled in MATLAB/Simulink. An H-bridge 3-level inverter is used to convert the DC voltage to chopped AC voltage. Then filtered to give pure sinusoidal AC of 230 V RMS. The output voltage of the inverter should have a very low total harmonic distortion within <1% makes the system suitable for local AC load and grid connection.

Key words: Modeling, solar photovoltaic voltage controller, grid-tied inverter, Perturb and Observe (P and O), MPPT, single phase multilevel inverter, SPWM

INTRODUCTION

The prediction of a progressive power method is an accumulation of predictable along with renewable producing sources. The sun oriented is considered on the road to have the maximum possible of force utilization then just before control this force, possible must be located tapped beginning every job of the ground which is accepting sun-powered insolation. The previously mentioned concept has brought winds of change in the conventional recognition of production then load. The concept of the domestic customer organism a lead direct control transgressed in the direction of taking place a source because properly, for example, load, the informant being the Rooftop Solar Photovoltaic (RF-SPV) scheme. The spreading stage network mind a marine of drifters then annoyance an operative photovoltaic system ought to take place modelled that nourishes feature power in the direction of the network at the Peak of Common Combination (PCC) by means of the national customer. Production then sends out the purposes. In place of the above-mentioned cause, the job tries in the direction of type an SPV system designed to score the SPV largely comprises of the subsequent units the photovoltaic array, MMPT boost converter, the inverter, filter then the seclusion transformer. The MPPT holds the energy used for Maximum Power Point (MPP) by attractive criticism of voltage and current starting PV array (Dallago et al., 2015).

MATERIALS AND METHODS

Solar photovoltaic array: An ideal solar PV cell model involves an ideal current source in parallel with an ideal diode as shown in Fig. 1. A photovoltaic array is designed by linking many solar cells in series and parallel fashion. In PV module, series Resistance (Rs) is more predominant and shunt Resistance (Rsh) being quite large is assumed to be infinity. As solar insolation increases the open circuit Voltage (Voc) also increases and as temperature increases, the open circuit Voltage (Voc) decreases. The reason being for an increase in temperature, the band gap Energy (Eg) increases resulting in more energy required to traverse the band gap, resulting decrease in efficiency of the PV cell. The simulation work employs model of the panel (150 W) specification of the module are as follows.

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Fig. 1: The equivalent circuit of a PV cell

Fig. 2: a) Current-voltage characteristics and b) Power-voltage characteristics of the implemented PV array

- Short circuit current = \(I_{sc} = 9.17\, \text{A}\)
- Open circuit voltage = \(V_{oc} = 21.24\, \text{V}\)
- Number of strings in parallel = \(N_p = 1\)
- Number of series-connected modules per string = \(N_s = 2\)

The photovoltaic voltage-current characteristic is non-linear during natural operation the same as shown in Fig. 2. The power production intended for a certain radiance along with temperatures starting. The a maximum point increases through an increase inside the cell where output current starting the call the direct taking place, so, the V-I characteristics giving the maximum power are called the maximum power point designed for the particular Irradiance in addition to temperature. This maximum power point tracking algorithm (Dalliago et al., 2015) which gives the voltage by the side of which maximum power is given by the PV cell.

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Maximum power point tracking: The MPPT is a methodology taken after towards gathering the mainly created power on or after certain sources be partial to PV systems then storm turbine (Hua and Shen, 1998). During this investigation, this the calling was defended by a microcontroller-based DC towards the DC converter with the aim of optimizes the equivalent of the solar array (PV panels) as well as the load. Easily it is an algorithm encouraged by the principles of the voltage and current of the panel by the side of every one moment (Zhang et al., 2011).

The panel emerges next to daytime. This characteristically gives concerning a 15% increase in power during Winter in addition to up to a 35% increase during Summer. This is common in locales contain short time but inside the Middle East Region by the side of the majority time inside the year has a long day then using a sun tracker choice not create a real change inside the production of the panel (Wang and Lu, 2013; Bazyari et al., 2014). In place of our work we contain utilized the Perturb and Observe (P and O) method in addition called “Hill-Climbing” is the majority generally, utilized method designed for MPPT because of its plainness in addition to efficiency (Femia et al., 2005; Atallah et al., 2014). The P and O is used in this research for instance MPPT method. The flowchart of the P and O algorithm is shown in Fig. 3.

MPPT boost converter: Around are plentiful converter topologies obtainable in place of MPPT converter actualized the same as seen during the creative writing (Schaef and Stauth, 2014; Hua and Shen, 1998; Bazyari et al., 2014) designed for our research we include determined leading boost converter topology. The PV cell is a current source, consequently, the essentiality defamation inside maintenance a constant voltage summarizes crossways the load intended for maximum taking out of power intended for changing insolation levels in addition to temperature.

The input capacitor is required on the way to stabilize the input voltage appropriate towards the peak current obligation of switching power source. The input capacitor is chosen at this juncture is: \( \frac{C_i}{C_0} = 300 \mu F \). The choice of the inductor is of superior significance seeing that inductor lying on the enter boundary of the converter stores energy in addition to giving incessant input current waveform. Evaluated beginning the formula:

\[
L_{min} = \frac{V_{in}+(V_{out}-V_{in})}{\Delta I L \cdot f_s \cdot V_{out}}
\]  

\( L_{min} \) is the minimum value inductor necessary intended for boost process with no saturation of the central part of the
inductor. \( V_{in} = 40-60 \text{ V} \), input voltage beginning solar PV \( V_{cell} = 330 \text{ V} \), the output voltage of the MPPT boost converter, i.e., the voltage comparing to maximum power point. The \( f_s = 20 \text{ kHz} \), switching frequency of the MOSFET, \( S_{Load} \), shown in Fig. 4.

\[
\Delta I = (0.2 - 0.4) \times I_{out(max)} \times \frac{V_{in}}{V_n}
\]

where, the \( D \) – Duty cycle of the converter which is accepted towards being located, 25% with acknowledging to 40 V organism input and 330 V for the instance output of the MPPT converter. \( \Delta V_{out} = 3.3 \text{ V} \), voltage ripple is accepted \( C_{out(min)} = 120 \mu \text{F} \) is calculated from Eq. 3. We contain occupied \( C = 120 \mu \text{F} \) for our simulation purpose intended to improved voltage waveform.

**Grid Tied Inverter (GTI):** Grid-tied inverter theatres the significant position in the solar photovoltaic grid-tied power technique. The job of a GTI is double. Single creature of changing over DC power beginning SPV to AC power which is in the direction of being located given to network then the previous organism to realize, so as to in a shape that the photovoltaic panel otherwise array is spared as of response of network connected. Readily available are frequent topologies planned in creative writing (Atallah et al., 2014). Which utilizes a extensive breadth of semiconductor switches. Intended for our job we contain conceived a single phase H-Bridge inverter by means of IGBT existence our high-frequency switch as revealed in Fig. 5.
After the platform boosting, the DC power is connected to the inverter to modernize towards AC power. In that case, this favorably harmonic response is accepted through a filter which causes a damaging effect on the harmonics to obtain a suitable sinusoidal response. An awfully low Total Harmonics Distortion (THD) is achievable by appropriate determination of filter.

Designed for our modelling, we choose the Sinusoidal Pulse Width Modulation (SPWM) for instance, our gating technique to IGBT then an LCL filter configuration, causing the gating pulse to be constrained on a gate of IGBT of H-Bridge. The sacking arrangement is such that S1 and S4 Fig. 5 changes their switching situation consistently then the opposite switching situation is conventional by S2 and S3 simultaneously. Thereby generous an in close proximity sinusoidal ventured output which is filtered towards reducing THD, so as to can be established by the network standard (Zhang et al., 2011).

Circuit parameters for the simulation and hardware implementation;
List of parameters with specifications used for the design;
PV array:
• Model: solartech energy ASC 6P-36-150
• Short circuit current - Isc = 9.17
• Open circuit voltage = Voc = 21.24
• Number of cells per module = 36
• Number of strings in parallel = Np = 1
• Number of series-connected modules per string = Na = 2

MPPT converter:
• C1 = 120 μF
• L1 = 1 mH
• C2 = 120 μF*4

Inverter:
• Sinusoidal PWM switching frequency 20 kHz
• Inverter output voltage = 330 V (peak)
• 230 V (RMS), THD = 2.92%

T or LCL filter:
• L2 = 14mH
• C3 = 2μF
• L3 = 14mH

Power grid:
• VRGRID(RMS) = 230 V
• Grid frequency ~ 50 Hz

Filter modeling: Filters are utilized just before keeping in check the harmonic satisfied during the current waveform of a scheme like this progresses the source voltage waveform (Wu et al., 2014). In our occupation, we contain utilized streak filters as it reduces the harmonic satisfy during currently fashioned by the high-frequency switching process in PWM inverters, the line filters L and T-filter is principally utilized.

L-filter: L-filters are first order filters having a constriiction 20 dB/decade in excess of an extensive range of frequency. Intended for very high switching frequency PWM inverter it causes good quality attenuation.

T or LCL filter: The T-filter are comparatively improved than L-filter for construction of switching harmonics for PWM inverter In addition, other profit of using the T-filter creature:
• Current distortion is low down then the generation of reactive power
• Attenuation of -60 dB/decade designed for frequencies acceptably more than the resonant frequency

For a provide harmonic decrease, the lower switching frequency can take place utilized T-filter in addition forces the improvement of low THD stable at the low switching frequency than by a smaller amount storage space of energy. Hence, we chose T-filters designed for our occupation. In addition to our choice filter, the meaning is: With a THD = 4.31%. At the moment the AC power following taking into consideration the filter drop meets the acceptable network THD standards (Nguyen et al., 2014) which is fewer than 5% THD in addition to fulfils the voltage level regular of a creature more than network voltage with the intention of can take place encouraged to the power network.

RESULTS AND DISCUSSION

Simulation modul and simulation results: The projected system was actualized on MATLAB R2017a platform in addition to the results are discussed in this subdivision. The aggregate operational Simulink circuit diagram is made known in Fig. 6-8. The irradiance in addition to temperature were given in the direction of PV array utilizing single builder group of buildings in Simulink, the levels of irradiance in addition to signal builder building block in Simulink. In this simulation, the power network is arranged such, so as to the voltage of the network changes from 230-220 V (RMS), respectively, the location
Fig. 6: The simulation diagram single phase, h-bridge, 3-level inverter using MATLAB

Fig. 7: Pulse of the boost converter

Fig. 8: a) I-V characteristics of the MPPT control and b) P-V characteristics of the MPPT control
Fig. 9: Voltage of boost converter by using MPPT

Fig. 10: (a-d) Three-level Sinusoidal Pulse Width Modulation (SPWM) gate of the inverter

Fig. 11: Voltage and current* (100) profiles of inverter after the filter

from the network such as tapped by the PLL block changes towards generating closed-loop control signals designed for the inverter, an active exhibitions estimation has been surveyed on the designed controllers. The voltage profiles of the MPPT stage featuring in Fig. 9-11. Keeping up the imperative of the inverter output voltage
is more than the network voltage the output of the inverter after the filters crate 330 V (peak). The THD is 2.92% as the network voltage changes following filtering the sinusoidal summarize AC power are connected headed for the power network by means of an isolation transformer. The output voltage waveform starting inverter before the filter.

Different values of the output current fed to grid for different sunlight radiations and for 25°C temperature is shows in Fig. 12 and Table 1.

### Hardware implementation and experimental results

The design of the boost converter by using proteus: Figure 13 shows the boost converter design.

**Control circuit implementation:** Figure 14 shows the control schematic diagram of the H-bridge 3-level inverter.

**DC power supply:** Figure 15 shows the regulators connection circuits.

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**Table 1: Different simulation results with different sunlight radiation values for the single-phase H-bridge 3-level Inverter**

<table>
<thead>
<tr>
<th>S (W/\m^2)</th>
<th>P_o (W)</th>
<th>THD (%)</th>
<th>P.F</th>
<th>L, m sec (A)</th>
<th>P_r (W)</th>
<th>\eta (%)</th>
</tr>
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<tr>
<td>1000</td>
<td>250</td>
<td>2.912</td>
<td>0.999100</td>
<td>0.9454</td>
<td>217.442</td>
<td>86.9768</td>
</tr>
<tr>
<td>921</td>
<td>212</td>
<td>2.998</td>
<td>0.998900</td>
<td>0.9010</td>
<td>207.230</td>
<td>89.3250</td>
</tr>
<tr>
<td>810</td>
<td>217</td>
<td>3.082</td>
<td>0.998800</td>
<td>0.8629</td>
<td>198.260</td>
<td>91.3640</td>
</tr>
<tr>
<td>716</td>
<td>205</td>
<td>3.185</td>
<td>0.998500</td>
<td>0.8036</td>
<td>184.820</td>
<td>90.1600</td>
</tr>
<tr>
<td>652</td>
<td>183</td>
<td>3.269</td>
<td>0.998350</td>
<td>0.7230</td>
<td>166.290</td>
<td>90.0300</td>
</tr>
<tr>
<td>524</td>
<td>161.2</td>
<td>3.591</td>
<td>0.997800</td>
<td>0.6110</td>
<td>140.530</td>
<td>87.1770</td>
</tr>
<tr>
<td>406</td>
<td>146.1</td>
<td>4.128</td>
<td>0.993900</td>
<td>0.5412</td>
<td>124.476</td>
<td>85.2570</td>
</tr>
<tr>
<td>351</td>
<td>123</td>
<td>4.762</td>
<td>0.989980</td>
<td>0.4605</td>
<td>105.860</td>
<td>86.0160</td>
</tr>
<tr>
<td>242</td>
<td>97</td>
<td>5.315</td>
<td>0.986969</td>
<td>0.3561</td>
<td>81.9030</td>
<td>84.4360</td>
</tr>
<tr>
<td>103</td>
<td>48</td>
<td>5.972</td>
<td>0.985980</td>
<td>0.1698</td>
<td>39.1540</td>
<td>81.7740</td>
</tr>
</tbody>
</table>

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Fig. 12: a) Pin = 250 W, THD = 2.921; b) Pin = 150 W, THD = 4.08% and c) Pin = 50 W, THD = 6.344%
Fig. 13: Boost converter design

Fig. 14: Control schematic diagram of the H-bridge 3-level inverter

Fig. 15: Regulators connection circuits
Fig. 16: a-d) The characteristics between the voltage and current for the output PV

Fig. 17: Output voltage for the PV array
Fig. 18: The power circuit and MPPT control circuit

Fig. 19: a, b) The output for the boost converter

Fig. 20: The wave for the output boost converter

**PV array:** The voltage and current output for the PV array at when the sunlight radiation is 868 W/m² (Fig. 16-20).

**Boost converter:** The gate pulses sequence for the main switch for boost converter and shows the gate pulses for both S₁-S₄ switches for inverter is shown in Fig. 21-25 and Table 2. The experimental results for the current injected to the grid for different values of S and different values of input power with Temperature of T = 25°C other factors are also shown like the efficiency.
Fig. 21: The pulse for the switch power circuit

Fig. 22: The pulse for the switch $S_1-S_n$ for the inverter

Fig. 23: Voltage output profiles of the inverter
Fig. 24: Current output profiles of the inverter by using load 120 W

Fig. 25: System setup, power circuit and control circuits

<table>
<thead>
<tr>
<th>$S$ (W/m²)</th>
<th>$P_v$ (W)</th>
<th>THD (%)</th>
<th>$P_F$</th>
<th>$I_{m ax}$ (A)</th>
<th>$P_e$ (W)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>840</td>
<td>212</td>
<td>3.2820</td>
<td>0.992150</td>
<td>0.8890</td>
<td>204.470</td>
<td>88.133</td>
</tr>
<tr>
<td>723</td>
<td>212</td>
<td>3.1850</td>
<td>0.991500</td>
<td>0.7930</td>
<td>182.828</td>
<td>86.033</td>
</tr>
<tr>
<td>632</td>
<td>186</td>
<td>3.1210</td>
<td>0.997380</td>
<td>0.7530</td>
<td>172.290</td>
<td>90.030</td>
</tr>
<tr>
<td>535</td>
<td>165.2</td>
<td>3.6300</td>
<td>0.997600</td>
<td>0.6110</td>
<td>143.530</td>
<td>86.882</td>
</tr>
<tr>
<td>406</td>
<td>146.1</td>
<td>4.6860</td>
<td>0.991900</td>
<td>0.5508</td>
<td>124.176</td>
<td>85.852</td>
</tr>
<tr>
<td>312.6</td>
<td>126</td>
<td>4.8690</td>
<td>0.988900</td>
<td>0.4605</td>
<td>105.890</td>
<td>83.397</td>
</tr>
<tr>
<td>258</td>
<td>98.56</td>
<td>5.4020</td>
<td>0.988869</td>
<td>0.3761</td>
<td>83.8130</td>
<td>85.037</td>
</tr>
<tr>
<td>113</td>
<td>44.843</td>
<td>5.9812</td>
<td>0.975900</td>
<td>0.1598</td>
<td>36.1540</td>
<td>80.623</td>
</tr>
</tbody>
</table>

$(\eta)$ and THD. The results show good performance for the single-phase H-bridge 3-level inverter for injecting alternating current to the national grid with high efficiency and low total harmonic distortion is shown in Table 2.
CONCLUSION

Fasten indicating the MPP beginning the VI curves contain been tended to by a variety of algorithms, shown of which for the most part common are the Perturb and Observe (P and O) (Elgendy et al., 2012). Then the Incremental Conductance (INNCOND) (Kish et al., 2012) quite a lot of adjustments of these calculations contain been projected in current a long time which brightly calculates pace dimension, tracks MPP inside antenna less procedure, put in progressive cleverly fuzzy then neural method to exactly recognize the MPP (Sher et al., 2015; Kollimalla and Mishra, 2014).

REFERENCES


