Modeling and simulation of 1kw single phase grid tied inverter for solar photovoltaic system

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Abstract: Solar energy is considered as fastest growing renewable energy source after wind energy for electricity generation. And it is considered environmentally friendly to effectively implements intelligent systems that feed household generated surplus power to distribution feeder network, modeling and simulation of the grid tied solar system is of high importance. The paper models the 1KW roof solar grid mooring system for the home connected to a 230-240 V single phase grid. The study proposes a converter topology with an efficient output voltage control system that synchronizes the phase, the frequency and voltage of the inverter with the network. The MPPT DC-DC converter, controlled by Perturb and Observe (P&O), generates the maximum power when it is detected that the mains voltage provides a control signal for the synchronous operation of the converter and the drive with the mains voltage. The developed model has been implemented and simulated using MATLAB/SIMULINK. Dynamic changes in the network voltage have been applied to evaluate the performance of the voltage controller and the DC-DC converter. The results show that the power output to the network depends not only on the level of power quality, but also on a rapid dynamic response to changes in voltage, phase and frequency, and the output of this system is low, simple, profitable and efficient. For photovoltaic solar applications.

Keywords: Modeling, Solar Photovoltaic Voltage Controller, Grid Tide Inverter, MPPT, Perturb and Observe (P&O), Single Phase Inverter, SPWM.

1. 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 controlling 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 load 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 modeled 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, MPPT 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 [1]. Fasten indicating the MPP beginning the VI curves contain been tended to by a variety of algorithms, shown of which the for the most part common are the perturb and observe (P&O) [2], then the incremental conductance (INNCOND) [3] 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 [4,5,6]

2. Solar Photovoltaic Array
An ideal Solar PV cell model involves an ideal current source in parallel with an ideal diode as shown in Figure 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 shunts 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 (260 w) specification of the module is as follows:
- Short circuit current = Isc = 8.93A
- Open circuit voltage = Voc = 37.76V
- Number of strings in parallel = Np = 2
- Number of series-connected modules per string = Ns = 2

The Photovoltaic voltage-current characteristic is non-linear during natural world the same as shown in figure 1, the power production intended for a certain radiance along with temperatures starting the cell increases to a maximum point through an increase inside output current starting the call the direct taking place 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 [1], which gives the voltage by the side of which maximum power is given by the PV cell.

![Figure 1. The equivalent circuit of a PV cell.](image-url)
2.1. 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 [6,8]. 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). The principles of the voltage and current of the panel by the side of every one moment. [9].

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[10,11] in place of our work we contain utilized the Perturb and observe (P&O) method in addition called “Hill-Climbing” is the majority generally utilized method designed for MPPT because of its plainness in addition to efficiency [12, 13]. The P&O is used in this work for instance MPPT method. The flowchart of the P&O algorithm is shown in Figure 2.

![Flowchart of P&O Algorithm](image-url)
2.2. **MPPT Boost Converter**

Around are plentiful converter topologies obtainable in place of MPPT converter actualized the same as seen during the creative writing [6, 7, 8, 11] designed for our work 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.

![Flowchart of the Perturb & observe algorithm.](image)

**Figure 2.** Flowchart of the Perturb & observe algorithm.

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: \( C_1 = 300 \mu F \).

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:

\[
L_{MIN} = \frac{V_{IN}}{I_{OUT(MAX)}}
\]

\( L_{MIN} \) is the minimum value inductor necessary intended for boost process with no saturation of the central part of the inductor. \( V_{IN} = 70 \) to 80 V, input voltage beginning solar PV, \( V_{OUT} = 330 \) V, the output voltage of the MPPT boost converter, i.e., the voltage comparing to maximum power point. \( f_s = 20 \) kHz, switching frequency of the MOSFET, M1 Figure 4.

\[
I_{OUT(MAX)} = 4.3 A, \text{ is the maximum Output current of this MPPT converter, } \Delta I_{L} = 2.86 A \text{ is the current ripple of the inductor } \text{ from equation (2)} \]

\( L_{MIN} = 1.23 \) mH.

This current ripple is not accepted previous is like this an approximation of 20% towards 40%.

\( I_{OUT(MAX)} = 4.3 A, \) is the maximum Output current of this MPPT converter, \( \Delta I_{L} = 2.86 A \) is the current ripple of the inductor \( \text{ from equation (2)} \) \( L_{MIN} = 1.23 \) mH.

Is assessed from eq (1) & (2) The inductor chosen intended for this converter is \( L_1 = 1.286 \) mH, the output capacitor is chosen towards minimizing the output ripple voltage is assessed by the formula: MOSFET, \( S_{Boost} \) Figure 4.

![Design Boost Converter & MPPT Control.](image)

**Figure 3.** Design Boost Converter & MPPT Control.
The D = duty cycle of the converter, which is accepted towards being located, 25% with acknowledging to 70 V organism input and 330 V for the instance output of the MPPT converter. $\Delta V_{\text{out}} = 3.3$ V, voltage ripple is accepted $C_{\text{OUT(MIN)}} = 140\mu\text{F}$, is calculated from eq. (3). We contain occupied $C_2 = 120\mu\text{F}$, for our simulation purpose intended for improved voltage waveform.

3. Grid Tied Inverter

Grid-tied inverter theatre 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 [13] which utilizes an 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 Figure 4.

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 modeling, 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 Figure 4 changes their switching situation consistently then the opposite switching situation is conventional by S2 &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 [9].

![Figure 4. Grid-tied inverter & Controller.](image)
Table 1. System design specifications

| Parameters                        | Symbol | Value | Unit  |
|----------------------------------|--------|-------|-------|
| Switching frequency              | \( f_s \) | 20    | kHz   |
| Grid voltage                     | \( V_{\text{grid}_{\text{rms}}} \) | 220   | V     |
| Inductance of converter          | \( L_c \) | 1.556 | mH    |
| Capacitance of converter         | \( C_c \) | 140   | \( \mu \)F |
| Input voltage                    | \( V_{\text{in}} \) | 70 ~ 80 | V     |
| Grid frequency                   | \( f_{\text{grid}} \) | 50    | Hz    |
| Total input capacitance          | \( C_{\text{DC}} \) | 10000 | \( \mu \)F |
| Output filter capacitance        | \( C_f \) | 3     | \( \mu \)F |
| Output filter inductance         | \( L_f \) | 2     | mH    |
| PI controller gain               | \( K_i \) | 56    | -     |
| PI controller gain               | \( K_p \) | 0.58  | -     |

Table 2. Specifications of the PV Panel for the system

| Parameters                        | Value | Unit  |
|----------------------------------|-------|-------|
| Maximum power \( (P_{\text{max}}) \) | 260   | W     |
| Maximum current \( (I_{\text{max}}) \) | 9.12  | A     |
| Maximum voltage \( (V_{\text{max}}) \) | 31    | V     |
| Short circuit current \( (I_{sc}) \) | 8.93  | A     |
| Open circuit voltage \( (V_{oc}) \) | 37.21 | V     |
| Shunt resistance \( (R_{sh}) \) | 161.321 | \( \Omega \) |
| Series resistance \( (R_s) \) | 0.15783 | \( \Omega \) |
| Temperature coefficient \( V_{oc} \) \( (K_v) \) | -0.3601 | \%/deg.C |
| Temperature coefficient \( I_{sc} \) \( (K_i) \) | 0.06  | \%/deg.C |
| Diode ideality factor \( (A) \) | 1.0101 | -     |
| Nominal Operation Cell Temperature  | 20°C ~ 85°C | C |

4. 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 [15]. 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-Filter & T-filter is principally utilized.

L-Filter: L-Filters are first order filters having a constriction 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-Filter or LCL Filter: The T-filter are comparatively improved than L-filter for constriction 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[14], which is fewer than 5% THD in addition to fulfills the voltage level regular of a creature more than network voltage with the intention of can take place encouraged to the power network.

5. Simulation Modul & 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 Figure 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 go to work, the power network is arranged such so as to the voltage of the network changes from 230 V (RMS) to 220 V (RMS), respectively the location from the network such as tapped by the PLL block changes towards generating closed-loop control signals designed for the inverter, am active exhibitions estimation has been surveyed on the designed controllers. The voltage profiles of the, MPPT stage featuring in Figure 6. Keeping up the imperative of the inverter output voltage is more than the network voltage the output of the inverter after the filters creature 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. Show in figure 5 (a) I-V Characteristics of different irradiances & constant Temperature 25°C (b) P-V Characteristics of different irradiances & constant Temperature 25°C
Show in figure 5 (c) I-V Characteristics of different Temperature & constant irradiances 1000 W/m² (d)
P-V Characteristics of different Temperature & constant irradiances 1000 W/m²
The designer of DC-DC converter is to simulate in the MATLAB Simulation for an effective result due to the high level. Figure 2 Circuit diagram to DC/DC by using the PV source of voltages and currents from the converter to a single-phase during converter. It is simulated to complete design requirements and test for power optimizer. The voltage between the Drain & Source for the switching the boost converter when operation being 550 volt and constant to 331 volt. The output dc voltage from the DC to DC converter, $V_{out} = 331$ V is under standard test conditions of irradiance 1000 W/m², and at a temperature of 25 °C shown in Figure 6.
The effect of the irradiance on the efficiency of the Boost converter for the Temperature be 25 °C shown in Table 3.

**Table 3. Effect of the irradiance on the Boost converter**

| irradiance W/m² | \( V_{PV} \) (Volt) | \( I_{PV} \) (Amp) | \( P_{PV} \) (Watt) | \( V_{Boost} \) (Volt) | \( I_{Boost} \) (Amp) | \( P_{Boost} \) (watt) | \( \eta_{Boost} \) % |
|-----------------|----------------------|---------------------|---------------------|----------------------|----------------------|----------------------|---------------------|
| 1000            | 74.5                 | 13.36               | 995.32              | 330.9                | 2.88                 | 955.64               | 96.418              |
| 800             | 67                   | 12.1                | 810.7               | 330.2                | 2.14                 | 706.865              | 87.192              |
| 600             | 55.7                 | 10.93               | 607.801             | 330                  | 1.584                | 522.9                | 85.89               |
| 400             | 36.6                 | 11.17               | 408.822             | 329.1                | 1.02                 | 337.02               | 82.437              |
| 200             | 22.6                 | 8.64                | 195.264             | 327.68               | 0.471                | 154.063              | 78.90               |

The effect of the Temperature on the efficiency of the Boost converter for the irradiance be 1000 W/m² shown in Table 4.

**Table 4. Effect of the Temperature on the Boost converter**

| Temperature | \( V_{PV} \) (volt) | \( I_{PV} \) (Amp) | \( P_{PV} \) (Watt) | \( V_{Boost} \) (Volt) | \( I_{Boost} \) (Amp) | \( P_{Boost} \) (watt) | \( \eta_{Boost} \) % |
|-------------|---------------------|---------------------|---------------------|----------------------|----------------------|----------------------|---------------------|
| 15          | 74.8                | 13                  | 997.12              | 330.9                | 2.97                 | 985.64               | 98.88               |
| 25          | 74.5                | 13.36               | 995.32              | 330                  | 2.88                 | 955.64               | 96.41               |
| 35          | 65.7                | 12.64               | 830.448             | 331.612              | 2.3246               | 770.91               | 92.83               |
| 40          | 53                  | 11.09               | 587.77              | 331.13               | 1.629                | 539.46               | 91.782              |
| 50          | 41                  | 8.31                | 340.71              | 330.081              | 0.8743               | 288.533              | 84.686              |
The SPWM Control for the inverter design shown in figure 4 four Switches are used in the power circuit at the single phase inverter. The first Switches, S1 & S4 is responsible for the positive part of the output signal and the second Switches, S2 & S3 is responsible for the negative & The Single-Phase, inverter. The Switches Pulses of inverter $S_1$, $S_2$, $S_3$, & $S_4$, for the IGBTs are shown in Figure 7.

![Figure 7. Sinusoidal pulse width modulation (SPWM) gate of the inverter.](image-url)
The simulation model single-phase grid connected consists of PV-panel, power circuits which include the inductance, capacitance and switches, control circuits and MPPT using P&O method and inverter with controller SPWM as shown in figure 8.

Figure 8. The Simulation Diagram Single Phase, Inverter Using MATLAB.

The simulation result for the output voltage fed to grid before filtering the state of the inverter is shown in Figure 9.

Figure 9. Inverter output Voltage before the filtering
The simulation result for the output current fed to grid after filtering, and which is almost in-phase with the grid voltage by power factor of $P.F = 0.9921$ and the output current has a low value of (THD), which is 2.904 % for 1000 W/m2 sunlight radiation and $25 \, ^\circ C$ is shown in figure 10.

![Figure 10. Voltage & Current*(10) Profiles of inverter after the filter.](image)

Different values of the output current fed to grid for different sunlight radiations and for $C$ temperature 
(a) $Pin = 995 \, W$, THD = 2.921 
(b) $Pin = 810 \, W$, THD = 4.08% 
(c) $Pin = 607 \, W$, THD = 5.344% are shows in Figure 11 below:

![Figure 11. Current Profiles for different Pin values.](image)
Figure 11. (a) Pin = 995 W, THD = 2.921 (b) Pin = 810 W, THD = 4.08\% (c) Pin = 607 W, THD = 5.344\%

Different simulation results with different sunlight radiation values for the single-phase Inverter are shown Table 5 below:
### Table 5. Different simulation results with different sunlight radiation values

| S (W/m²) | P_{in} (W) | THD% | P.F | I_{o_{rms}} (A) | P_{o} (W) | η % |
|----------|-------------|-------|-----|----------------|-----------|------|
| 1000     | 995.32      | 2.912 | 0.9991 | 2.938           | 955.64    | 96.418 |
| 921      | 891.2       | 2.998 | 0.9989 | 2.566           | 834.609   | 93.65  |
| 810      | 810.7       | 3.082 | 0.9986 | 2.277           | 740.68    | 91.364 |
| 716      | 780.25      | 3.185 | 0.9985 | 2.163           | 703.47    | 90.16  |
| 632      | 611.812     | 3.269 | 0.99836 | 1.6936          | 550.814   | 90.03  |
| 524      | 556.14      | 3.591 | 0.99780 | 1.4907          | 484.82    | 87.177 |
| 406      | 412.228     | 4.128 | 0.9939 | 1.0806          | 351.453   | 85.257 |
| 351      | 291.58      | 4.762 | 0.9898 | 0.7711          | 250.805   | 86.016 |
| 242      | 212.25      | 5.315 | 0.986869 | 0.5510         | 179.215   | 84.436 |
| 103      | 172.69      | 5.972 | 0.98598 | 0.4342         | 141.2155  | 81.774 |

### 6. Conclusion

The single-phase inverter with DC-DC boost converter for solar systems with a wide input voltage range is designed and modelled in the Matlab / Simulink environment. The result of the simulation shows that the DC-DC converter can adjust the input voltage of the PV variable power supply and maintain it at DC voltage regardless of the changes in the supply voltage. The inverter stage successfully converts the DC voltage into the highest AC voltage. From the values in Table (1.5), shows the performance of single-phase inverter in terms of inverter efficiency η, P.F, and THD when the inverter output power Po varies from 172.69 W to 955.32 W. The output voltage of the inverter is 230 V RMS AC with 5% low THD, which is suitable for the AC grid in the system and the network application.

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