Design of integrated single stage photovoltaic solar inverter (stand-alone)

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Abstract. The extremely high demand for energy and increased demand for fossil fuels has led us to shift our concentration towards new and renewable sources of energy, which are seemingly unlimited sources. They are zero-carbon emitting, thus eco-friendly for the environment. Several issues have been addressed before regarding different topologies for standalone and grid connected inverters with and without microcontroller circuits. Some of them have addressed the introduction of multilevel inverter input using buck boost converters for improving the efficiencies of the output circuit. This paper enlightens the design of single stage photovoltaic inverter which is needed to run AC appliances as loads, which are mostly used as consumable purposes. The design implements MOSFETs as switching devices, which have considerably high switching frequency of 40 KHz, power diodes, inductors, capacitors, solar panel and a battery. The proposed inverter converts the DC output of the PV module into AC directly while maintaining the stability in the output voltage. PSIM software has been used for inverter design. The improved efficiency resulting in 75-90% is due to the minimized voltage drop over the inductor. High frequency operation of the MOSFET switch enables minimized switching losses.

1. Introduction
Environmental factors like drastic changes in climates and global warming are continually looking forward to the importance for the need of renewable resources of energy for production of electricity for the next generations. Solar Energy is the most sustainable and abundant resource among all of them. The power output from the photovoltaic system solely depends on radiation from the sun; temp. of the panel etc. To draw a constant DC output, normal photovoltaic power generating system uses at least two stages of power processing, where the pulsating DC gets converted into constant DC, followed by inversion through voltage source inverter or current source inverter [1]. VSI is mostly used as it doesn’t require large inductor in the output power circuit. The output may vary depending on the external conditions. The main drawback with solar energy is that it is intermittent, and depends on various factors like the geographical conditions and locations. Impedance source inverters (ZSI) have the capability of stepping up and stepping down of CSI and VSI respectively. Every step of power conversion leads to power loss; thereby decreasing the efficiency of the circuit. To draw maximum power output from the panel, extra potential difference and current sensors are needed. This leads to more complexities[2]. The switching losses can be reduced by implementing one power stage, chopping at high frequency.
The “boost”/“buck” state with high switching frequency only when the “boost” or “buck” is required to decrease the switching losses [3]. The over filtering is decreased by using LC filter circuit in the output. Lesser inductance in the power output loop will minimize loss in the power circuit which will ultimately improve the efficiency [4]. So decreasing the inductance is the most suitable way to get larger efficiency with minimum losses. The usage of LC filter will reduce the overall inductance in the output loop [5]. This design is likely to eliminate the excess of power conditioning circuit and is designed to provide output for variable input dc voltage.

2. Proposed inverter circuit
Flow chart of the full process is presented in Figure 1:

![Flow chart of the full process](image)

**Figure 1.** Full process through flow chart.

2.1. Methodology
The proposed inverter design is set to operate the following functions:
- Conversion of DC from the photovoltaic panel (P1, P2) into constant AC.
- Charging and discharging from the attached battery.
- Minimizing switching losses (as of other designs).

| Table 1. Simulation parameters. |
|-------------------------------|-----------------|--------|
| **Components**                | **Parameters**  | **Value** | **Unit** |
| Solar panels P1 and P2        | Voc             | 23.8    | V       |
|                               | Isc             | 15.7    | A       |
|                               | Vm              | 20.8    | V       |
|                               | Im              | 15.5    | A       |
| MOSFETs S1, S2, S3, S4, S5 and S6 | On resistance | 0.27    | Ω       |
|                               | Diode threshold voltage | 3.0 | V |
| Battery                       | Voltage         | 12.0    | V       |
| Gate pulse block              | Frequency       | 50.0    | Hz      |
| Power Diodes                  | Diode threshold voltage | 1.65 | V |
Passive components

| Component   | Value      |
|-------------|------------|
| Diode resistance | 0.4 Ω     |
| Inductances  |            |
| Lp          | 638.0 mH   |
| Ln          | 687.0 mH   |
| L           | 0.1 H      |
| Capacitance |            |
| C           | 1.0 mF     |
| Load        | 120.0 Ω    |
| Transformer |            |
| Np:Ns       | 100:320    |
| Simulation Control | Default |
Figure 3. Equivalent circuits when the output voltage is higher than the solar input voltage (a) during the positive period and (b) during the negative period.
During positive half cycle, for the operating segment TA is shown in Figure 5(a), the converter works like a pure Voltage Source Inverter with LCL filter connected at the output side. In this period, S1 works at high frequency, S3 is in ON position and rest of the switches are OFF.

During TA, as shown in Figure 5(a), the converter operates as a pure boost converter with LC.
filter connected at the output [6]. In this period S2 works at high frequency, switches S1 and S3 are in ON position, and the rest of the switches are in OFF position.

During the negative half, for the operation segment TC as shown in Figure 6(a), the converter operates as a pure Voltage Source Inverter with LCL filter connected at the output side. In this period, S4 works at high frequency, S6 is in ON position and rest of the switches are in OFF position. During time interval $T_D$ as shown in Figure 6(b) the converter runs as a pure boost converter with CL-filter connected at the output.

In this period, switch S5 works at high frequency, switch S4 and S6 are in ON position, and the other switches are in OFF position. The details of this operation have been explained in [7].

![Figure 6(a)](image)

**Figure 6(a)**

![Figure 6(b)](image)

**Figure 6(b)**

**Figure 6.** Equivalent circuits in negative period of the designed inverter (a) During $T_C$ and (b) During $T_D$. 
3. Results and discussion

Figure 7. Mode 2 Operation Segments.

Figure 8. Primary output voltage from inverter circuit.

Figure 9. Final output voltage after stepping up.
From the output graphs, the following inferences are made:

**Primary output voltage (Figure 8):**
- $V_{\text{peak-peak}} = 198.6$ V
- $V_{\text{rms}} = 71$ V
- Average value $|V1| = 63.56$ V

**Final output voltage (Figure 9):**
- $V_{\text{peak-peak}} = 635.1$ V
- $V_{\text{rms}} = 225.6$ V
- Average value $|V3| = 203.3$ V

**Final output current (Figure 10):**
- $I_{\text{peak-peak}} = 5.2514$ A
- $I_{\text{rms}} = 1.8764$ A
- Average value $|I| = 1.684$ A

Total Harmonic Distortion = 2-3 %.

The allowable limit for voltage harmonics in inverter design should be below 5% according to European Standards; and below 8% according to IEEE.

When we change the value of inductance $L$, the primary output waveform changes. It varies from distorted square wave to sine wave. This inductance has been chosen by “trial and error method”. The inductance value has been varied from 1μH to 0.1 H. For this high inductance value, there is a phase difference of almost 180°; i.e. they are almost completely out of phase.

The simulated inverter efficiency is found to be 86.37% with a load of 120 Ω.

Since the final output voltage from the transformer is 225 V, this is equivalent to the grid power we receive.
4. Conclusion
An innovative integrated photovoltaic inverter has been designed for standalone application. For this type of inverter, it puts together the characteristics of VSI as well as CSI during several working stages, when the input DC voltage is lesser than the magnitude of the output voltage. If the input is greater than the magnitude of output, it is a pure voltage source inverter. The charge controller is designed so as to operate under several operating conditions thereby giving a 50Hz constant output to the load elements. It uses one stage conversion of the power thereby reducing the losses. Since one active switch is maintained at output frequency, the switching losses are also most likely to be reduced. The LC filter plays an important role in providing shape of the output waveform. For this large value of L, the phase difference has been introduced.

5. References
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