Single Stage Grid-Tied PV Inverter for Renewable Energy System

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Abstract: *A single stage grid-tied photovoltaic (PV) inverter for residential application is presented. In this dissertation utilization of buck-boost converter for control of photovoltaic power using maximum power point tracking (MPPT) mechanism is presented. The MPPT is responsible for maintaining the maximum power from the photovoltaic and fed it to the load via buck-boost converter which step up or step down the voltage to the magnitude required by the grid. Here H-bridge inverter is used which is then connected to RL load and grid with LC filter for harmonic reduction and to get sinusoidal waveform required for grid.*

Keywords: MATLAB / Simulink, PV, MPPT, buck-boost, h-bridge inverter, grid

1. Introduction

One of the major concerns in the power sector is the day-to-day increasing power demand but the resources are not enough to meet the power demand using the conventional energy sources. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming. Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Another advantage of using solar energy is the portable operation whenever wherever necessary.

The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source. The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy [7].

2. Single Stage Grid Tied PV Inverter
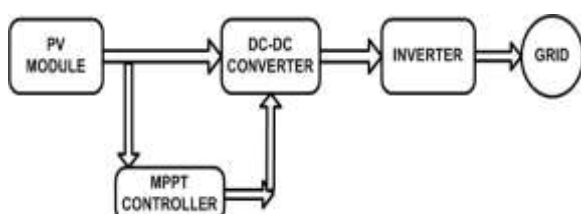
A. Proposed Scheme

Figure 1: Proposed scheme of grid tied PV inverter

Above figure represents proposed scheme of grid tied PV inverter. According to this input power is coming from photovoltaic system which is fed into DC-DC converter. MPPT is used to track maximum power from the PV system. Using MPPT, control scheme is used here which step up or step down the voltage and gives constant value of voltage. This DC voltage is going to single phase bridge inverter which converts DC to AC and finally system is connected to grid. According to above proposed scheme MATLAB simulation is done and models are given below.

3. Modeling of PV System

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. A single diode model of solar cell is given in figure below.
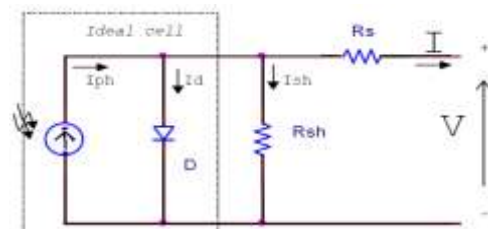

Figure 2: Single diode model of solar cell

From the above figure characteristic equations with their simulation model is given below

$$I = Iph - Id - Ish \qquad (1)$$

Where Iph = photo current

Id = diode current
Ish = current in shunt (parallel) branch
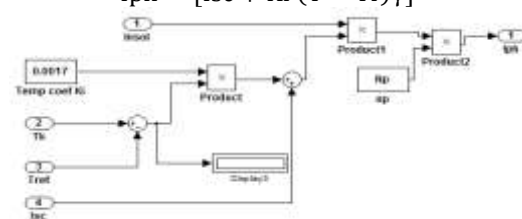
$$Iph = [Isc + Ki (T - Tr)\gamma] \qquad (2)$$

Figure 3: MATLAB model of photon current

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$$Id = Is \cdot (\exp^{\frac{V+Rs*I}{AKT}} - 1) \qquad (3)$$

and

$$Vt = \frac{KT}{q} \qquad (4)$$

On the other hand, the cell's saturation current varies with the cell temperature, which is described as

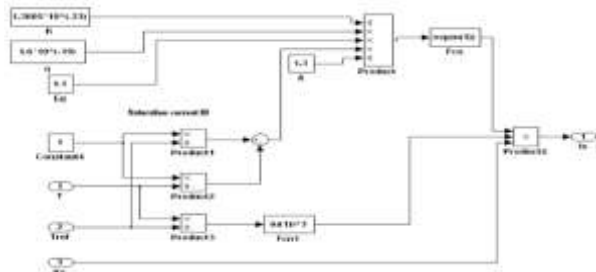$$Is(t) = Irs\left(\frac{T}{Tr}\right)^3 ex\left[\frac{qEg\left(\frac{1}{Tr}-\frac{1}{T}\right)}{KA}\right] \qquad (5)$$

Figure 4: MATLAB model of saturation current of diode

Where Isc = short circuit current
Ki = temperature coefficient of short circuit current
(here 0.0017 A/°C)
T = working temperature
Tr = reference temperature
γ = solar radiation W/m^2
Vt = terminal voltage
K = Boltzmann's constant having value 1.38*10^-1J/K
q = electron charge having value 1.6*10^-19 C
Eg = band gap energy of semiconductor which is approximately 1.2 eV
A = diode ideality factor whose value always lie between 1 to 5 (here 1.3)

The reverse saturation current at reference temperature can be approximately obtained as

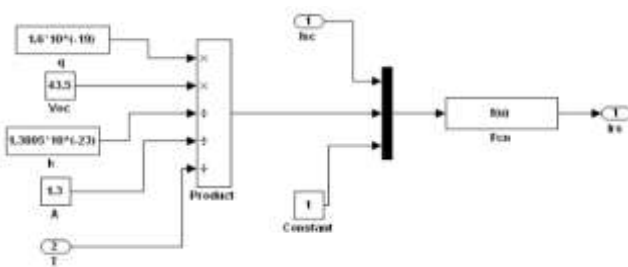$$Irs = \frac{Isc}{\left[\exp\left(\frac{q*Voc}{KTA}\right)-1\right]} \qquad (6)$$

Figure 5: MATLAB model of diode reverse saturation current

Where Irs = diode reverse saturation current
Voc = open circuit voltage
and current in shunt branch is given as

$$Ish = \frac{(V+I*Rs)}{Rsh} \qquad (7)$$

By putting equations from (2) to (7) in equation (1) we can get output current. Hence photovoltaic current Ipv is modeled as below
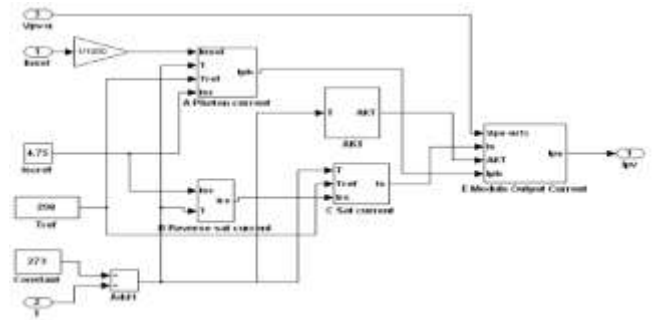

Figure 6: MATLAB model of PV module current

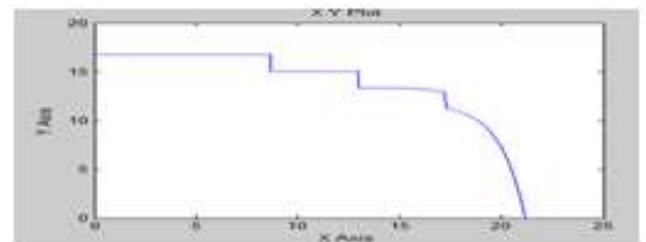1.   IV &PV Characteristic with varying irradiation obtained in MATLAB

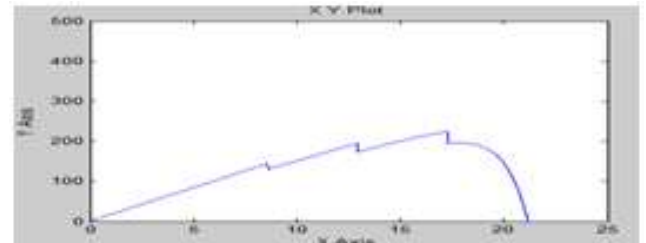**Figure 7:** IV characteristic with varrying irradiations

Figure 8: PV characteristic with varying irradiations

4.   Maximum Power Point Tracking

There are many different approaches to maximize the power from a PV system. There are various algorithms to track the maximum power point. Out of these methods P & O method is used here and explains below.

A.   Perturb & Observe (P & O) method

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power P is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If P is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed.
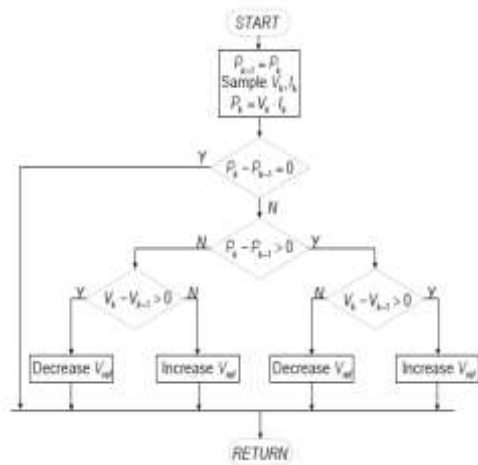
Figure 9: Flow chart of P& P algorithm

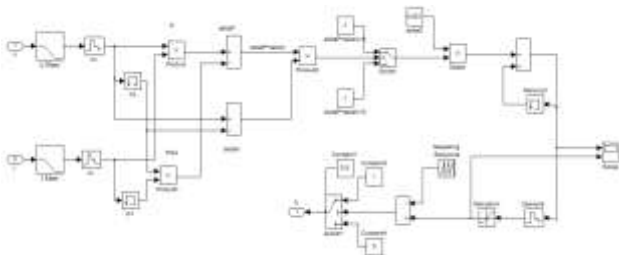Accordingly MPPT is modeled in simulation which is given below

Figure 10: MATLAB model of P & O method of MPPT

5. Buck-Boost Based PV Inverter Topology

A. Buck-Boost converter

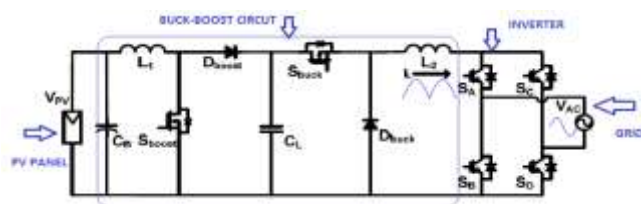A buck-boost type DC-DC converter is proposed with full bridge inverter which is given below.

Figure 11: Buck-Boost converter based inverter topology

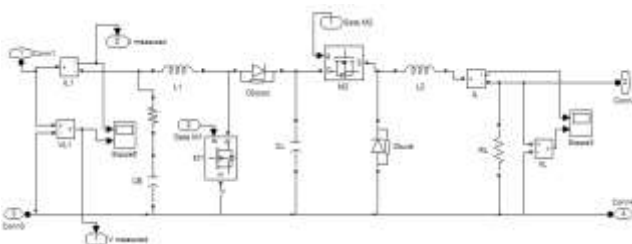Simulation model of above converter circuit is given below

Figure 12: MATLAB model of buck-boost converter

B. Single phase bridge inverter

An inverter is basically a device that converts electrical energy of DC form into that of AC. Here H-bridge inverter is used with LC filters. Simulink model of inverter is represented in figure below.
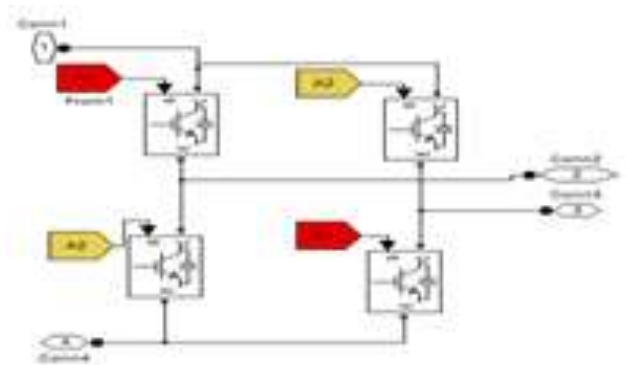

Figure 13: Single phase bridge inverter

1. SPWM technique

In this modulation technique, multiple numbers of output pulse per half cycle are used with pulses of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the center of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.
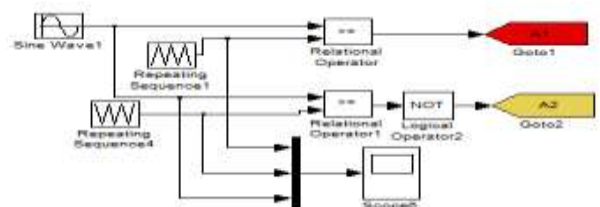
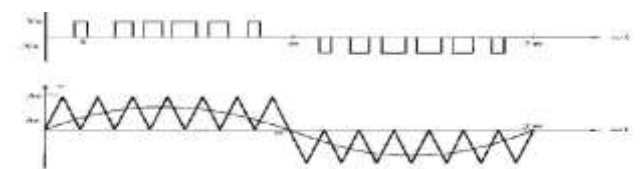

Figure 14: Simulation model of Gate pulse generator

Figure 15: Gate pulses for inverter circuit

6. Converter Control Circuit Using MPPT

A. Objective of this scheme

This is the main part of our system which control Buck-Boost output. PV output voltage is changing as per the environmental condition but we want a constant DC output voltage for grid. If PV panels voltage is greater than grid voltage it should buck i.e., step down the voltage or if PV panels voltage is lower than the grid voltage it should boost i.e., step up the voltage. To make this smooth transition between buck and boost mode this control scheme is developed which is given in figure 16.
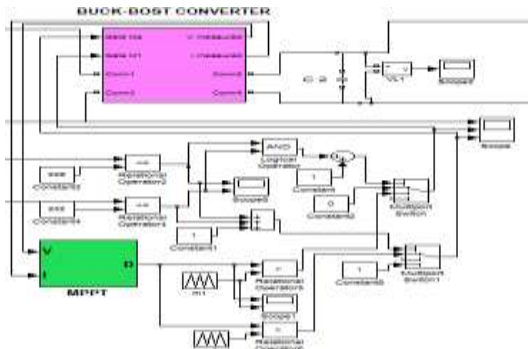
Figure 16: Buck-Boost control scheme

DC output voltage obtained in MATLAB is given below having peak magnitude 355V.

Figure 17: MATLAB model of DC-DC converter output voltage

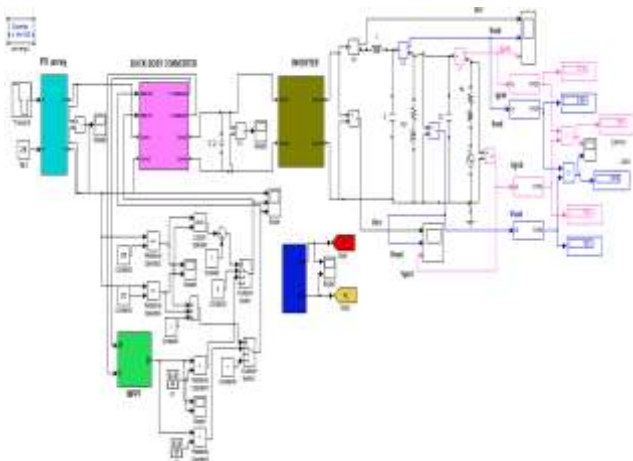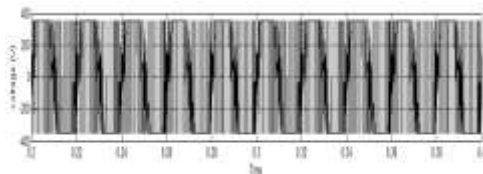# 7. MATLAB Model of Whole Circuit and Output Results

Figure 18: MATLAB model of whole system
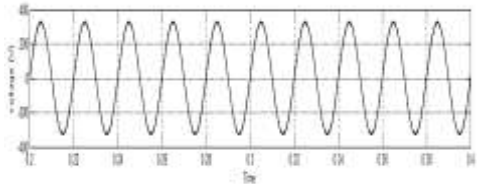
8. Simulation Results

A.   Output voltages
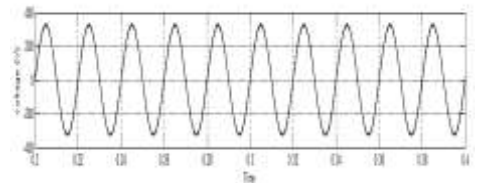
1.Inverter voltage

Peak magnitude = 355 V
THD = 98.42 %

To filter out these harmonics LC filter is used with inverter and then RL load is connected . Load voltage after using filter is given below

2.Load voltage

Peak amplitude of load output voltage = 325V
Rms value of load voltage =325/$\sqrt{2}$ = 230 V
THD = 0.39 %

3.Grid voltage

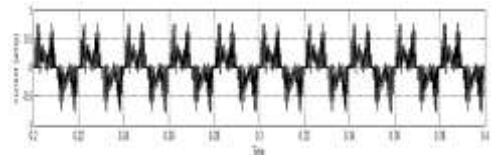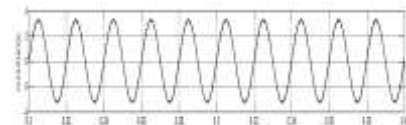Peak magnitude = 325V
Rms voltage = 230 V

B.   Output current
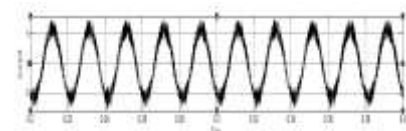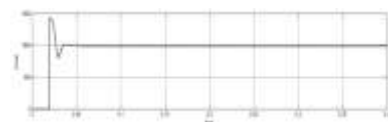
1.Inverter uotput current

2.Load current with filter
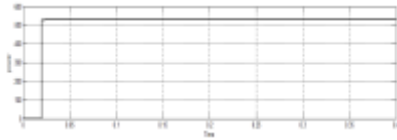

3.Grid current

Peak magnitude of grid current = 7amp

C Output power

1.Grid power

Power = Vrms * Irms = 983.6W

2.Load power

Power = Vrms * Irms = 529.3W

9. Conclusion

Modeling of PV module and MATLAB/SIMULINK model of Grid-Tied PV inverter is presented. P&O method of MPPT is modeled in MATLAB to track maximum power point of PV cell and check Dc-Dc output result.

A high efficiency boost-buck converter based single stage PV inverter is proposed. Control scheme is developed to make a smooth transition between buck and boost mode which gives constant output voltage with varying input voltage.

Inverter output current and voltage waveform having harmonics are reduced by using LC filter and total harmonic distortions calculated. Total system simulation is done and Results are presented

10. Future Scope

The Solar Photovoltaic technology has huge scope of development as per utilization of generated power is concern. We can still develop a better technology to extract the power under low irradiance conditions also as this is major setback for solar technology. Also these environmental constraints affect the overall efficiency of the system.

When the grid is abnormal, the PV inverter needs to be disconnected from the grid. A control scheme needs to be developed and further changes to make the inverter to operate between grid-tied mode and islanding mode. The development also needs in the field of materials used for construction of solar cell. These materials decide the efficiency and performance of the solar PV system.

Same system develop above can be run with three phase bridge inverter with certain modifications.

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