IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Matlab/Simulink Based Modelling And SimulationOf Residential Grid Connected Solar Photovoltaic System

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Abstract: Solar energy maintains life on the earth and it is an infinite source of clean energy. Over fifty years, numerous studies have been performed on different design aspects andperformance characteristics of Photovoltaic (PV) cells with acommon goal of producing fully integrated PV modules to compete with the traditional energy sources. There is an increasing trend for the use of solar cells in industry and domestic appliances because solar energy is expected to playsignificant role in future smart grids as distributed renewable source. This reviews the generalized mathematical modelling and simulation of Solar Photovoltaic System. One-diode equivalent circuit is employed in order to investigate I-V, P-I and P-V characteristics of a 170W Mitsubishi solar module Perturb and Observe MPPT algorithm, Step up DC-DC transformer, PMDC motor and a Single phase grid tied inverter using MATLAB/Simulink.

Keywords- Boost Converter, Choppers, DC-AC Converter DC-DC Converter, Grid, Inverter, Maximum Power Point (MPP), Maximum Power Point Technique (MPPT), Perturb and Observe (P&O), Pulse Width Modulation (PWM), Solar Photo-voltaic System (PV), Photo-voltaic modelling, Standard Test Condition (STC), Step up DC Transformer, Matlab/Simulink R2013a.

Introduction :

Among the renewable energy resources, the energy due to the photovoltaic (PV) effect can be considered the most essential and prerequisite sustainable resource because of the ubiquity, abundance, and sustainability of solar radiant energy.

Regardless of the intermittency of sunlight, solar energy is widely available and is free. Recently, Photovoltaic system is recognized to be in the forefront in renewable electric power generation. It can generate direct current electricity without environmental impact and contamination when exposed tosolar radiation. Being a semiconductor device, the PV system is static, quiet, free of moving parts, and has little operation and maintenance costs. Application of Photovoltaic as electrical energy source shows increasing trend both in implementation on spread area over the world and in capacity of plant. This trend is triggered by many factors such as the increasing of fossil fuel cost and declination of productioncost per kW electric from Photovoltaic and also technology development that cause the Photovoltaic power conversion more efficient [1].

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of a PV module depend on the solar insolation, the cell temperature and the output voltage of the PV module. Owing to changes in the solar radiation energy and the cell operating temperature, the output power of a solar array is not constant at all times. Consequently, during the design process of PV array powered systems; a simulation must be performed for system analysis and parameter settings.

Therefore an efficient user friendly simulation model of the PV arrays is always needed. The PV array model proposed in this paper is a circuitry based model to be used with Simulink.

Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. Photovoltaic generation system can either be operated in isolated system or be connected to the grid to form integrated system, and with other electrical renewable energy source can form distributed renewable energy generation [9] asshown in figure 1.

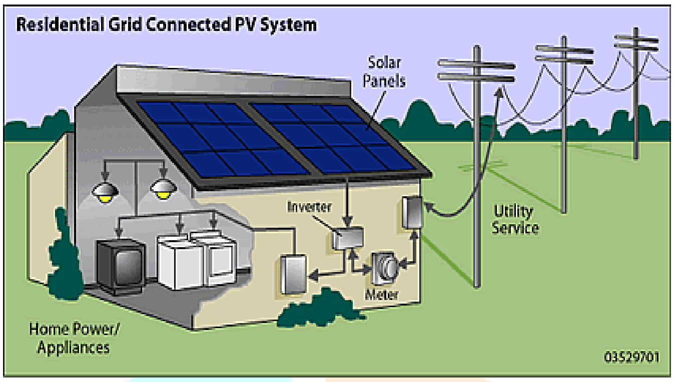


Figure 1. Residential Grid tied PV System

Other aspect concerning to application of photovoltaic as a part of distributed generation is the power quality resulted from their operation, especially for voltage unbalance and harmonics. Trend application of some single phase PV inverters and its PV array connected together to supply three phase system as alteration of high capacity centralized three phase PV inverter can be a factor that effect to unbalance grid voltage due to diversity of irradiance among array.

PV MODULE MATHEMATICAL MODELLING

Solar cell

A Solar cell (also called a Photo-Voltaic cell) is an electrical device that converts the electrical energy of light directly into electricity as in figure 2 and figure 3.

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type)silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P- N junction. When sunlight strikes the surface of a PV cell, thiselectrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load. Regardless of size, a typical silicon PV cell produces about 0.5-0.6 volt DC underopen circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 1.580*0.800 square metres will produce about 170W peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 67W [1].

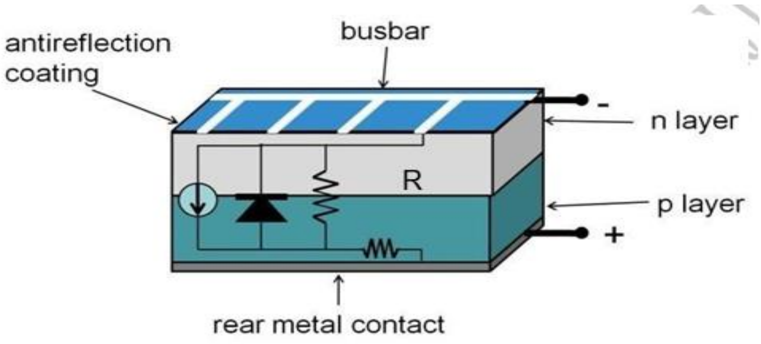


Figure 2. PV module configurations in a PV plant

Mathematical modelling of a solar cell:

The mathematical modelling describing the figure 2 andfigure 3 of a solar cell is given as:

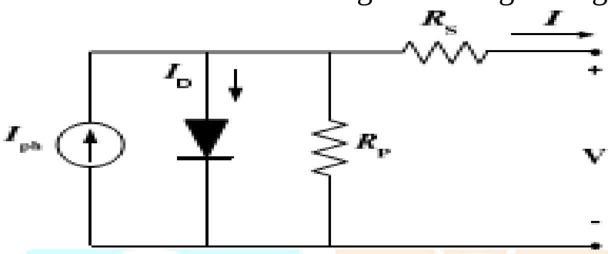


Figure 3. Equivalent circuit of a Solar cell

i. Light generated current

The short circuit current (Isc) is the current value that occurs when the voltage is zero (V=0). The Isc is equivalent to the photo generated current (Iph) unless the series resistance is high and there is a significant amount of leakage current flowing through the shunt resistance.

Open circuit voltage

The open circuit voltage (Voc) is a measure of the voltage across the PV module terminal when the leads are left open (I=0). It can be expressed as

$$V_{oc} = V_T \ln\left(\frac{I_{ph}}{I_{sat}} + 1\right)$$

i. Fill factor

The Fill factor (FF) is the ratio of maximum power output to the product of short circuit current (Isc) and open circuit voltage (Voc).

$$FF = \frac{P_{max}}{V_{oc} I_{sc}}$$

Efficiency

The efficiency of the solar module can be calculated from the equation

$$\eta = \frac{P_{max}}{SA}$$

Solar modules and Arrays:

Due to the low voltage of an individual solar cell (typically 0.5-0.6V), several cells are wired in series in the manufacture of a "laminate". The laminate is assembled into a protective weatherproof enclosure, thus making a photovoltaicmodule or solar panel.

Modules may then be strung together into a photovoltaic array.

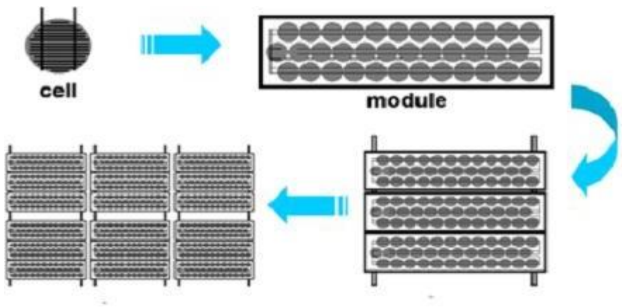


Figure 4. Photovoltaic cell, module, arrays and panels.

Characteristics of a PV cell

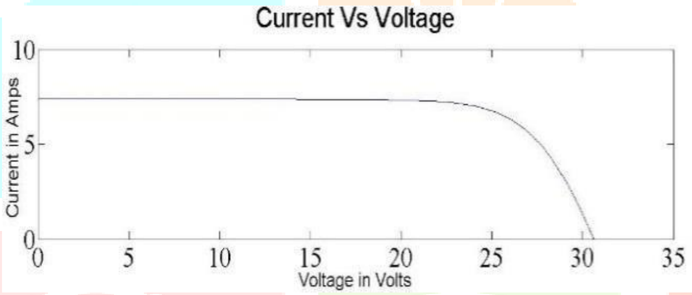
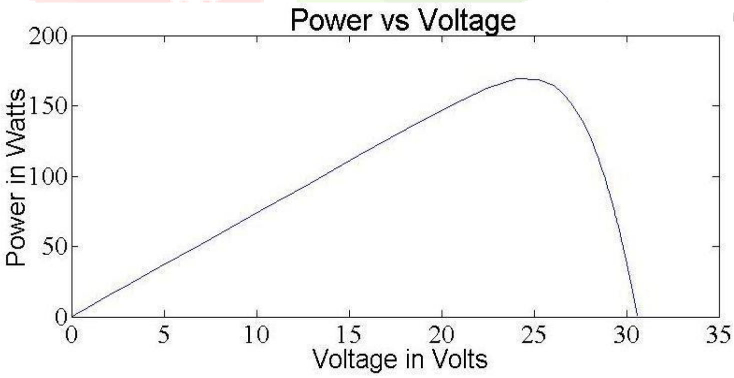


Figure 5. Current Vs Voltage curve at STC



Maximum Power point(MPP) and Perturb and Observe Algorithm

For PV converters the maximum power available is decided by the PV cell characteristics, but this value often mismatches the maximum power point (MPP) of the load. By implementing MPPT in a PV system, the MPP of the PV cell can be maintained (i.e. tracked) and hence the number andsize of the PV panels can be reduced or the energy yield canbe optimized. Due to moving Sun, which leads to change in irradiance Angle on the PV panels and the variation in amount of the Irradiation hitting the panels, the energy which the PV panels are able to absorb do not stay constant over time. When this happens, the I-V characteristics changes and the MPP will move. If the system was previously operating at the MPP, there will most probably a power loss with same operating point and new conditions.

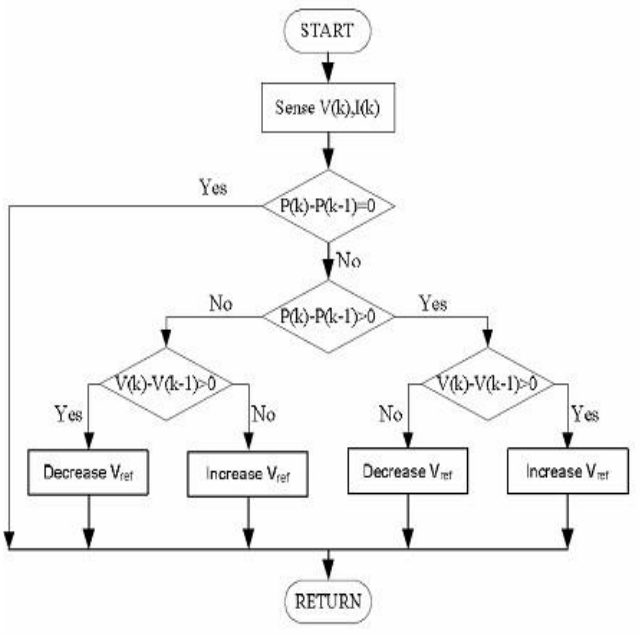


Figure 14. Perturb And Observe Algorithm

DC-DC Converter:

A DC-DC converter is a static device which converts or transfers the DC Power from one circuit to another from fixed voltage to variable and vice versa. In high power applications these are called Choppers circuits Switched mode power systems (SMPS).

A chopper is a high speed on/off semiconductor switch [5]. DC/DC converter also helps in regulating the PV outputvoltage to the required level. Buck, Boost and Buck-boostconverters are used for power conditioning purposes [11].

In Buck and Buck-boost, the source current is highlydiscontinuous due to the presence of high frequency mosfet switch on the source side. The source current will have more harmonic distortion. In order to filter out these harmonics, these three topologies require additional source filter where asin Boost converter input inductor will serve the purpose.

Boost converter

Boost Converter is a DC-DC converter for whichoutput voltage is greater than input voltage. When the MOSFET switch is ON, the current through the inductor increases and the inductor starts to store energy. When the MOSFET switch is closed, the energy stored in the

S.no	Parameter	Value
1.	Input Voltage(Vs)	75V
2.	Output Voltage(V0)	250V
3.	Switching frequency(Fsw)	2500Hz
4.	Inductor(L)	105mH
5.	Capacitor(C)	170µF

inductor starts dissipating. The current from the voltage sourceand the inductor flows through the fly back Diode D to theload. The Voltage across the load is greater than the input voltage and is dependent on the rate of change of the inductor current. Thus the average voltage across the load is greater than the input voltage and is determined with help of the duty cycle of the gate pulse to the MOSFET switch the boost converter used in this research work to step up the PV output voltage to a higher level suitable for the DC/AC inverter operation that connected to the utility grid

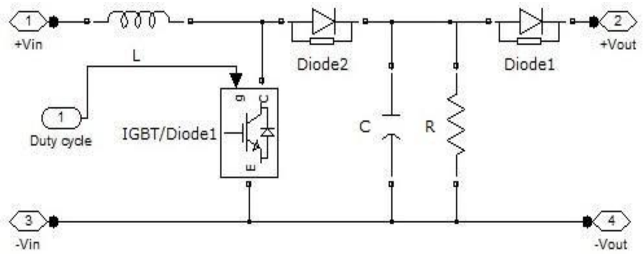


Figure Boost converter (step up)

Where

Vs is source voltage

Vo is the output voltage of the converterD is the duty cycle

Fsw=1/Tsw is switching frequency of the converterTon is on time period of the semiconductor switch Toff is off time period of the semiconductor switch

DC-DC Converter control in PV converter Systems

All electrical systems containing a converter stage with controllable switches often requires some sort of control. This control ensures that the required power available is transferredto the output according to the pre-set limitations.

$V_o = f(D)$

PERMANENT MAGNET DC (PMDC)MOTOR:

DC Motor

An Electric Motor is a Machine which consumes electrical energy into mechanical energy, and due to its straightforward operating characteristics and simple and stable control, it is still being used to some extent in speed-controlled applications. The speed of the motor is controlled bycontrolling the armature voltage, and the torque by the armature current, that is, the flux and the torque can easily be controlled separately. This is the main principle on which all). Network-connected thyristor bridges were mainly used in higher power range, typically in a variety of applications such as in printing and paper industry, passenger lifts, and any kinds of drives subjected to high transient loading, such as in rolling mills Chopper technology was mainly used in the lower power range, such as in machine tool applications.

Advantages of PMDC Motor:

Due to absence of the field current and field winding, permanent magnet machines exhibit high efficiency in operation, simple and robust structure in construction, some advantages in using permanent magnet excitation were decreased copper losses, higher power density, and a smaller torque ripple at low speeds. Using permanent magnet material in the magnetic circuit causes a low armature inductance and hence a low armature reaction. Extremely linear speed-torque characteristics of the motor, which result from the permanent magnet-provided constant field flux at all speeds, makes the control of the PMDC very straightforward; the speed of the motor is controlled by simply adjusting the armature DC voltage. PMDC machines were, however, limited to the lower power range due to the absence of the proper magnets until the1980s. Typical applications of PMDC were low-voltage battery powered applications, such as machine tools, automotive auxiliary drive applications, and solar poweredapplications. Above the 10 kW range, the separately excited DC motor was the only solution, as it provided high dynamic performance especially when fully compensated.

DC/AC CONVERTER:

In this paper single phase full bridge inverter is used. This is the DC-AC stage that converts DC power into AC power at desired output voltage and frequency. The power stage designed in this paper converts the 250V DC output voltage of the DC-DC converter to the grid voltage of 230V AC – 240V AC at 50 Hz frequency.

The single phase full bridge topology is shown in Figure 18 which consists of four switching devices, two of them on each leg. Single-phase converters are used where transformation between DC and AC Voltage is required; more precisely where converters transfer power back and forth between DC and AC [5]. Unfiltered output voltage is created by switching the full-bridge in an appropriate sequence.

The output voltage of the bridge, Vab can be either be +Vd, Vd or 0 voltage depending on how the switches are controlled [5].

The input voltage Vd at the DC link or bus link capacitor C isa fixed-magnitude voltage and the output voltage is Vab which can be controlled in both polarity and magnitude. The DC/AC inverter allows the PV to be connected to the grid [12]. Its main tasks are to generate an AC voltage that follows. the grid one with the same frequency as well as producing as low harmonics as possible [10]. It uses PWM scheme with a switching frequency in the range of 2-20 kHz. In PV generation system, PV inverter hold the role as interfacebetween photovoltaic module and ac power grid. In this function, PV inverter and associated generation systemequipment should have ability to maximize power extracting from the array, match DC voltage output from PV array produce sinusoidal ac voltage with minimum distortion onoutput side, and control the power flow.

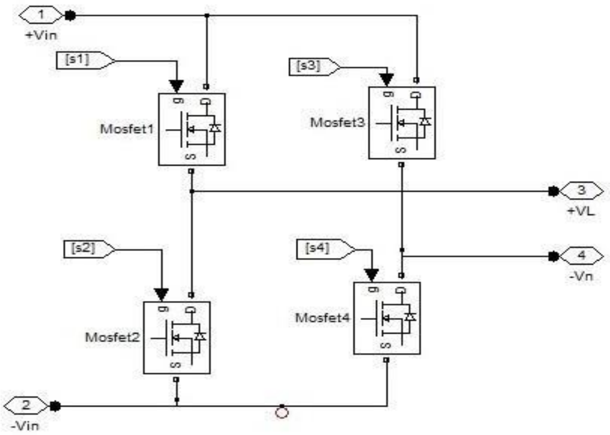


Figure 18. Single Phase full bridge Inverter

SIMULATION RESULTS:

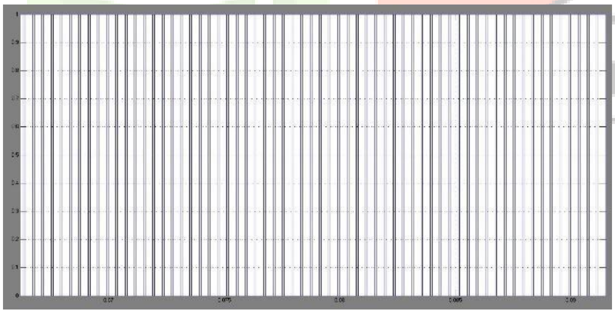
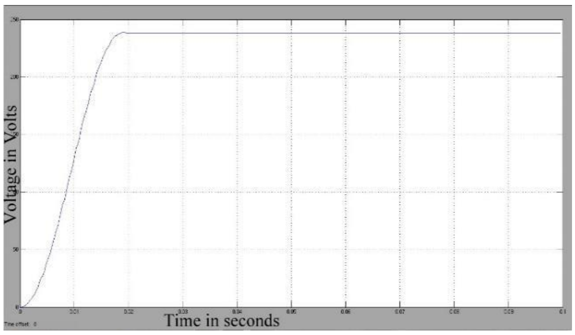
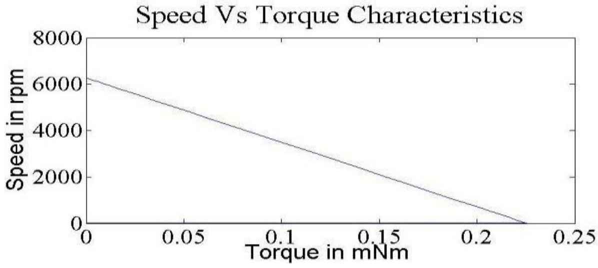


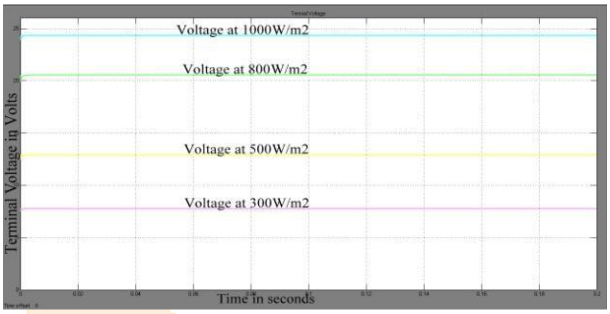
Figure Duty cycle from the MPPT algorithm



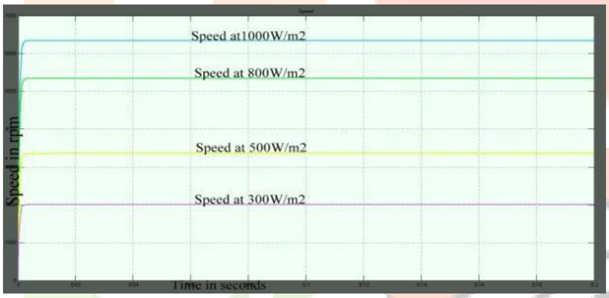
Output Voltage wave of boost converter



speed vs Torque at 1000Watts per square metres

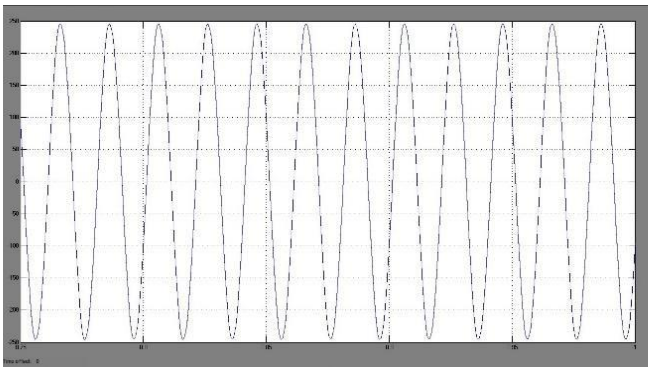


Terminal Voltage at different Irradiations



Speed at different Irradiations

Irradiation of the Sun in W/m^2	Speed of the motor in rpm	Terminal Voltage in volts	Armature Current in amps
1000	6343	24.35	$0.5468*10^{-3}$
800	5346	20.53	$0.5468*10^{-3}$
600	4029	15.49	$0.5468*10^{-3}$
400	2682	10.33	$0.5468*10^{-3}$
200	1333	5.164	$0.5468*10^{-3}$



Output voltage wave of Inverter

CONCLUSION:

In order to convert the solar energy efficiently, the maximum power point of the PV array should be tracked to ensure thePV array provide most power to both grid and the load. When solar irradiance or temperature fluctuates, PV generation will change as a result. The controller must act to maintain the DC bus voltage constant as possible and improve the stability of the whole system. A Solar Coupled PMDC motor model has been selected and proposed as the DC load in order to give an example of Standalone DC load feeding. Residential grid-connected photovoltaic power systems which have a capacity less than 10 kilowatts can meet the load of most consumers. They can feed excess power to the grid, which in this case acts as a battery for the system. Photovoltaic wattage may be less than average consumption,in which case the consumer will continue to purchase grid energy, but a lesser amount than previously. If photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand. In this case, the excess power can yield revenue by selling it to the grid shown in figure 1 and figure 19. Depending on their agreement with their local grid energy company, the consumer only needs to pay the cost of electricity consumed less the value of electricity generated. This will be a negative number if more electricity is generated than consumed. Additionally, in some cases, cash incentives are paid from the grid operator to the consumer.

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