

MODELLING AND SIMULATION OF ENERGY FORECASTER FOR GRID CONNECTED & STANDALONE PV SYSTEMS

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ABSTRACT: Modeling and Simulation of a solar based energy generation system is a significant tool in predicting the performance of both grid-connected and standalone PV systems. There are multiple ways by which a PV system can be connected to the grid. However, the output of PV systems varies due to change of solar irradiation, ambient temperature, wind speed and other climatic conditions, that makes the real field prediction becomes complicated. Hence we need better tools to predict the real field performance of PV power stations. Herein, we developed a MATLAB/Simulink model that can accommodate all field parameters to make a better prediction. The PV array model has been implemented through an embedded MATLAB model. The maximum power point tracking algorithm is implemented to DC/DC converter to operate PV arrays at maximum power point. The incremental conductance algorithm is employed to control the boost converter. The inverter controlled by the boost converter is interfaced with the grid. Finally, system performance is analyzed under various conditions. The system validation is also carrying out using the real power plant data. Simulations performed with field conditions at various locations. The model is helpful for optimizing the power output of a PV system as well as achieving cost effectiveness by incorporating different PV system types.

KEYWORDS: PV on-grid, Standalone, Power prediction, MPPT, DC/DC Converter.

1 INTRODUCTION

Photovoltaic is the technology used to harvest the sun's energy and make it useable. One hour of solar energy that hits the surface of the planet is equivalent to an entire year of electric energy consumed by the world. The cost of energy is on the rise due to its growing demand and therefore photovoltaic system is a promising cheaper and cleaner alternative to conventional systems. The encumbrance factor is its high installation cost and low conversion efficiency. Therefore our aim is to increase the efficiency and power output of the system. It is also required that constant voltage is supplied to the load irrespective of the variation in solar irradiance and temperature. PV arrays consist of parallel and series combination of PV cells that are used to generate electrical power depending upon the incidence sunlight. Photovoltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV systems. Computer modeling is a powerful tool by which we can predict the performance of the PV panel under real field conditions and hence to optimize the power production.

2 MODELLING OF PV ARRAY

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has an equivalent circuit as shown below in Figure 1.

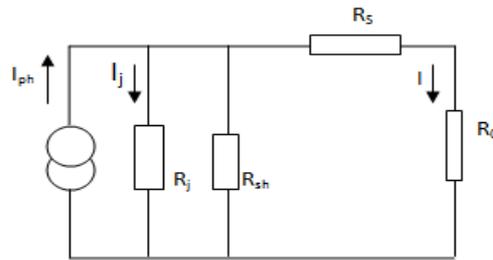


Fig. 1 Equivalent circuit of a PV cell

The current source I_{ph} represents the cell photo current; R_j is used to represent the non-linear impedance of the p-n junction; R_{sh} and R_s are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model used to simplify our PV array is represented by the equation [1]

$$I = n_p I_{ph} - n_p I_{rs} \left[e^{\left(\frac{q}{KTA} \frac{v}{n_s} - 1 \right)} \right]$$

where I is the PV array output current; V is the PV array output voltage; n_s is the number of cells in series and n_p is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current.

The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs} = I_{rr} \left[\frac{T}{T_r} \right]^3 \left[e^{\left(\frac{qEg}{KA} \frac{1}{T_s} - \frac{1}{T} \right)} \right]$$

Where T_r is the cell reference temperature, I_{rr} is the cell reverse saturation temperature at T_r and Eg is the band gap of the semiconductor used in the cell.

The temperature dependence of the energy gap of the semi-conductor is given by

$$EG = EG(0) - \frac{\alpha T^2}{T + \beta}$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph} = \left[I_{scr} + Ki(T - T_r) \frac{S}{100} \right]$$

where I_{scr} is the cell short-circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm^2 . The PV power can be calculated using equation as follows.

$$P = IV = n_p * I_{ph} * V \left[\left(\frac{q}{KTA} * \frac{v}{n_s} \right) - 1 \right]$$

3 BOOST CONVERTER

The maximum power point tracking is essentially a load matching problem. A DC to DC converter is required for changing the input resistance of the panel to match the load resistance by varying the duty cycle[2]. There are four topologies for the DC to DC regulators: boost converter, buck converter, buckboost converter, cúk converter. Since our project work deals with the boost converter, further discussions will be centred on this one.

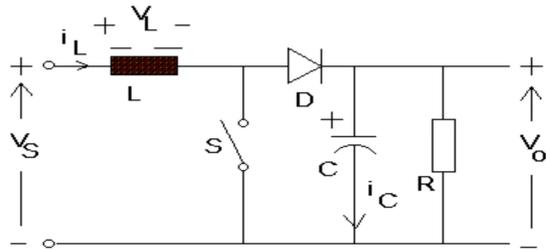


Fig. 2 Boost Converter Circuit Diagram

MODE 1 OPERATION OF BOOST CONVERTER

When the switch is closed the inductor is charged through the battery or from PV array and stocks the energy. In this mode, inductor current increases exponentially but for ease we assume that the charging and the discharging of the inductor are linear. The diode blocks the flow of current and so the load current remains constant which is being supplied due to the discharging of the capacitor.

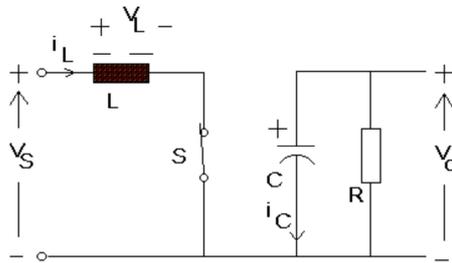


Fig. 3 Mode 1 Operation

MODE 2 OPERATION OF BOOST CONVERTER

In mode 2 the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation.

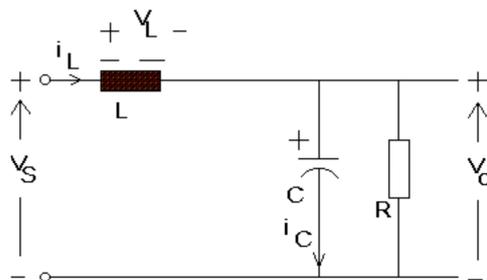


Fig. 4 Mode 2 Operation

Simulink Model – Boost converter

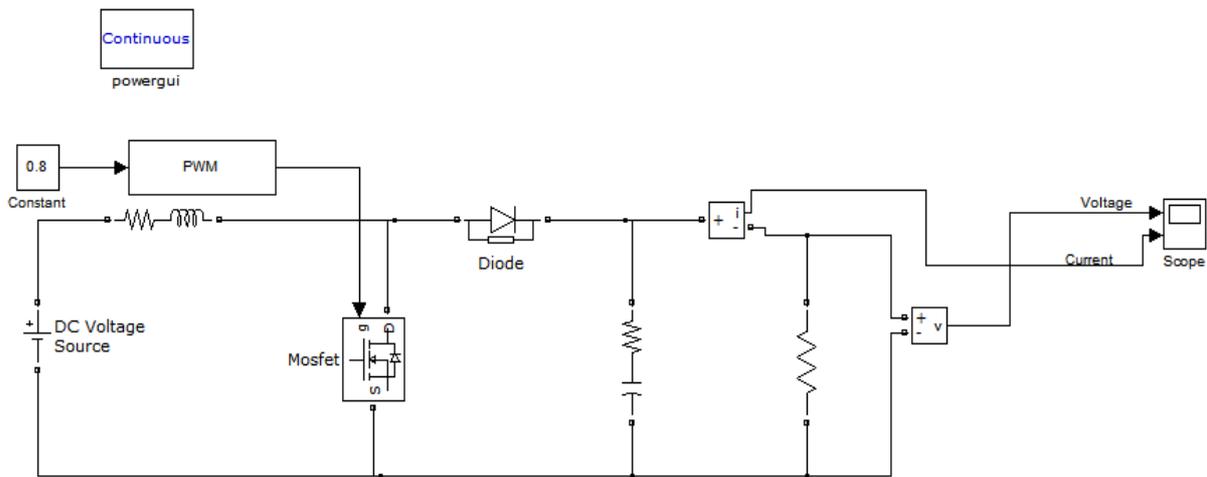


Fig. 5 Boost Converter

Voltage output from the inverter

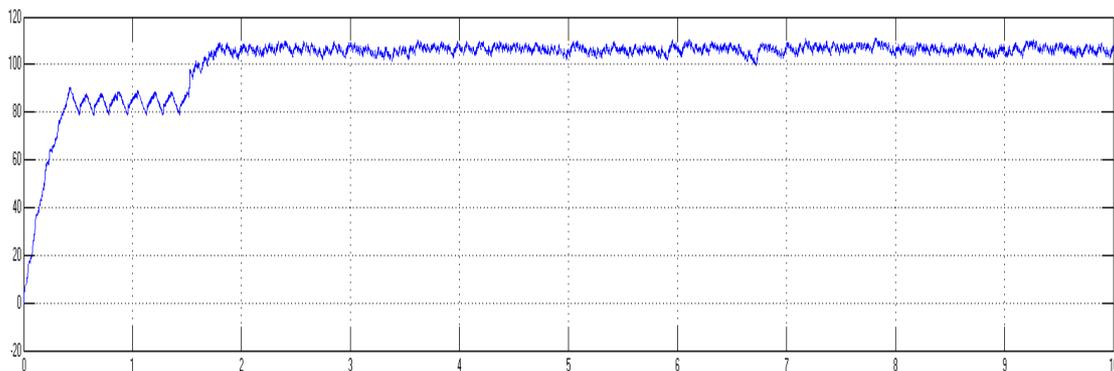


Fig. 6 Voltage output from the inverter

4 MPPT ALGORITHM

INCREMENTAL CONDUCTANCE METHOD

The Incremental Conductance (IC) algorithm is based on the observation that the following equation holds at the MPP $(dIPV/dVPV) + (IPV/VPV) = 0$ where IPV and VPV are the PV array current and voltage, respectively [3]. When the operating point in the P - V plane is to the right of the MPP, it is verified $(dIPV/dVPV) + (IPV/VPV) < 0$, whereas when it is to the left of the MPP this $(dIPV/dVPV) + (IPV/VPV) > 0$.

The MPP can thus be tracked by comparing the instantaneous conductance IPV/VPV to the incremental conductance $dIPV/dVPV$. Therefore, if the quantity $(dIPV/dVPV) + (IPV/VPV)$ is more than ϵ , its sign means a power production decrement and indicates the correct direction of perturbation leading to the MPP. Once MPP has been reached, the operation of PV array is maintained at this point and the perturbation stopped unless a change in $dIPV$ is noted. In this case, the algorithm decrements or increments the PV array voltage VPV to track a new MPP. The increment size determines how fast the MPP is tracked [4].

The IC method offers good performance under rapidly changing atmospheric conditions. The classic IC algo-rithm requires the measurement of the PV array voltage VPV and current IPV in order to determine the correct perturbation direction.

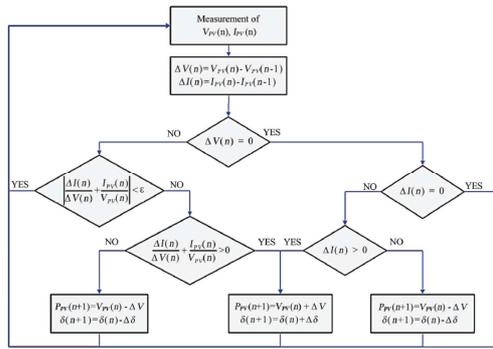


Fig. 7 Flow Chart of incremental conductance method

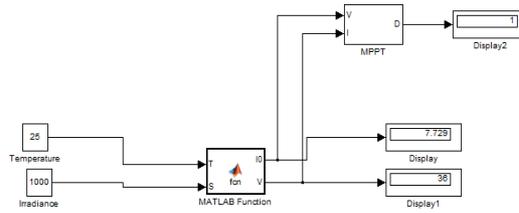


Fig. 7 Pulse generated from MPPT

5 GRID CONNECTED SYSTEM

GRID CONNECTED SYSTEM

The duty cycle from the MPPT is given to the converter circuit and this is given to the inverter. And an external pulse is given to the inverter. We are using a three phase load and a three phase source a V-I measurement will measure the voltage and the current. It will synchronize the power to the grid.

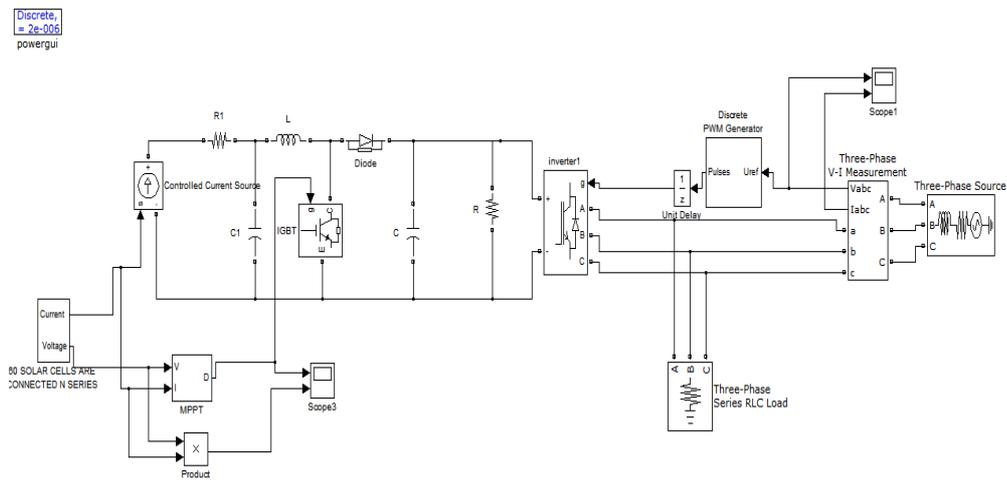


Fig. 8 Grid connected System

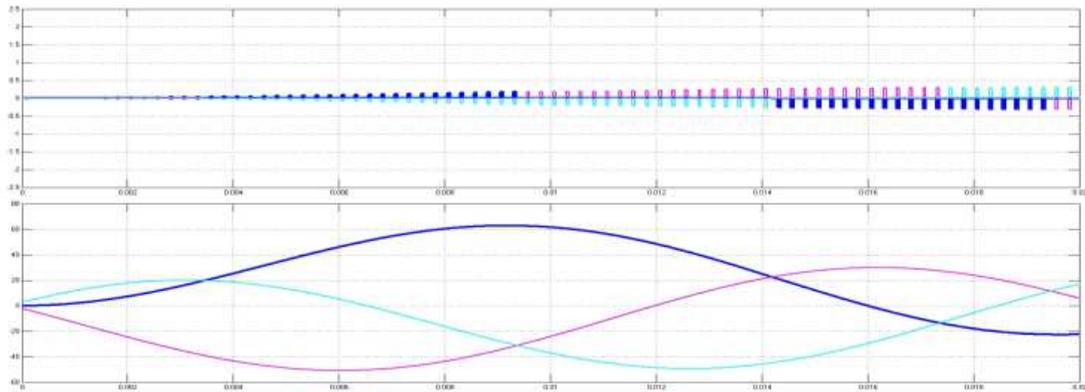


Fig. 9 Voltage and Current output of the grid

6 STANDALONE PV SYSTEM

Standalone PV system is a type of PV system that operates autonomously and supplies power to electrical loads independently of the electric utility. A stand alone photovoltaic (PV) system is an electrical system consisting of an array of one or more PV modules, conductors, electrical components, and one or more loads. But a small-scale PV system does not have to be attached to a roof top or building structures for domestic applications, they can be used for camper vans, RV's, boats, tents, camping and any other remote location [5].

Components of Standalone PV System:

Batteries: Batteries are an important element in any stand alone PV system but can be optional depending upon the design. Batteries are used to store the solar-produced electricity for night time or emergency use during the day. Depending upon the solar array configuration, battery banks can be of 12V, 24V or 48V and many hundreds of amperes in total.

Charge Controller: A charge controller regulates and controls the output from the solar array to prevent the batteries from being over charged (or over discharged) by dissipating the excess power into a load resistance. Charge controllers within a standalone PV system are optional but it is a good idea to have one for safety reasons.

Fuses and Switches: Fuses and isolation switches allow the PV system to be protected from accidental shorting of wires and allow power from the PV modules and system to be turned "off" when not requires saving energy and improving battery life.

Inverter: The inverter can be another optional unit in a standalone system. Inverters are used to convert the 12V, 24V or 48 Volts direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity and power of either 120 VAC or 240 VAC for use in the home to power AC mains appliances such as TV's, washing machines, freezers, etc.[6]

Wiring: The final component required in and PV solar system is the electrical wiring. The cables need to be correctly rated for the voltage and power requirements.

SIMULINK MODEL STANDALONE PV SYSTEM

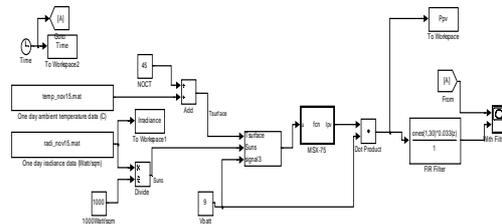


Fig. 10 Simulink model for generating estimated power for the panel

This simulink model has the following main parts:

1. Ambient Temperature data input block
2. Irradiance data input block
3. MSX-75 embedded MATLAB program
4. FIR Filter

MSX-75 is an embedded function. It includes an embedded program inside it which is being written using the information provided for the specification of the 75W panel. The following information is used in the program:

- Open-Circuit Voltage (Voc): 21.6
- Short-Circuit Current (Isc): 4.87
- Nominal Operating Cell Temperature (NOCT): 45+/-2⁰C
- Temperature Coefficient of Voc: -0.34%/⁰C
- Temperature Coefficient of Isc: 0.050%/⁰C
- Number of Cells, Ns: 36

EMBEDDED MATLAB PROGRAM

```
function Ipv = fcn(u)
% This block supports an embeddable subset of the MATLAB language.
% See the help menu for details.
TaC=u(1); Suns=u(2); Va=u(3); Ia=0;

if Va<0
    Va=0
end

k=1.38e-23;
q=1.60e-19;

A=1.2; Vg=1.12; Ns=36;

T1=273+25;
Voc_T1=21.6/Ns;
Isc_T1=4.87;

T2=273+75;
Voc_T2=17.93/Ns;
Isc_T2=4.99;

TaK=273+TaC;
TrK=273+25;
```

```

lph_T1=lsc_T1*Suns;
a=(lsc_T2-lsc_T1)/lsc_T1*1/(T2-T1);
%/a=(lsc_T2-lsc_T1)/(T2-T1);
lph=lph_T1*(1+a*(TaK-T1));

Vt_T1=k*T1/q;
lr_T1=lsc_T1/(exp(Voc_T1/(A*Vt_T1))-1);
lr_T2=lsc_T2/(exp(Voc_T2/(A*Vt_T1))-1);

b=Vg*q/(A*k);
lr=lr_T1*((TaK/T1)^(3/A))*exp(-b*(1/TaK-1/T1));

X2v=(lr_T1/(A*Vt_T1))*exp(Voc_T1/(A*Vt_T1));
dVdl_Voc=-1.15/Ns/2;
Rs=-dVdl_Voc-1/X2v;

Vt_Ta=A*k*TaK/q;

Vc=Va/Ns;
A1=lph-la-lr*(exp((Vc+la*Rs)/Vt_Ta)-1);
A2=-1-lr*(exp((Vc+la*Rs)/Vt_Ta)-1)*(Rs/Vt_Ta);
la=la-A1/A2;

%if (la<0)
% la=0.0001
%end

lph=la;

```

SIMULATION RESULT

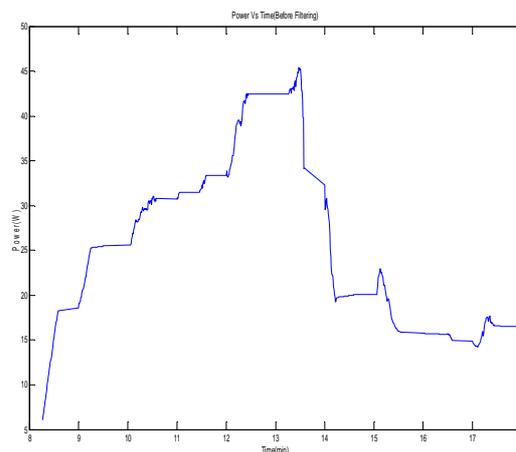


Fig. 11 Power Output before filtering

In order to achieve a smooth power graph output the power data is being filtered by using **Finite Impulse Response Filter (FIR Filter)**.

The Discrete FIR Filter block independently filters each channel of the input signal with the specified FIR filter[7]. The block can implement static filters with fixed coefficients, as well as time-varying filters with coefficients that change over

time. The coefficients of a static filter during simulation can be tuned also. This block filters each channel of the input signal independently over time, treating each element of the input as an individual channel. The output dimensions equal those of the input, except in single-input/multi-output mode.

This block has **Numerator Coefficient** parameter which specifies the vector of numerator coefficients of the filter's transfer function. For smoothening the power curve 30 samples have been taken for averaging.

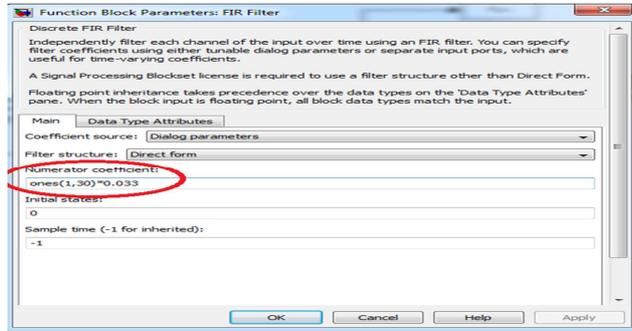


Fig. 12 Changing the numerical coefficient as per the requirement of the filtering.

Hence, the filtered output appears like following:

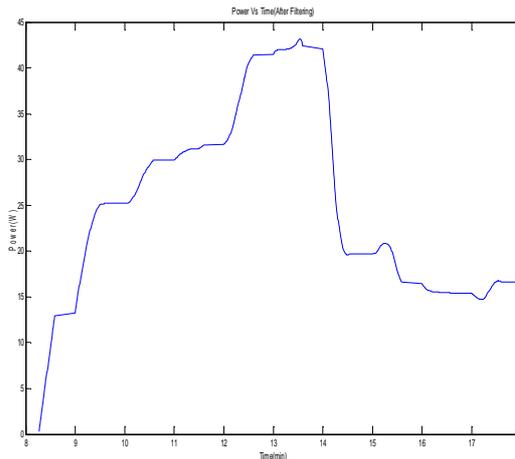


Fig. 13 Power Output after filtering

7 CONCLUSION

A PV electrical model is presented and demonstrated in MATLAB with various field data as the input and from it can predict the power at the particular location for any commercially available panel type from the field conditions such as solar insolation, temperature etc. The model has been validated with different filed data. This article is the first step to develop a complete solar photovoltaic power electronic conversion system simulation model. The performance of such model can be promoted by including various other parameters like wind, humidity and other climatic conditions.

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