SIMSCAPE BASED MODELING AND SIMULATION OF A PV GENERATOR IN MICROGRID SCENARIO

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ABSTRACT

This paper presents detailed modeling and design of a PV generator, capable of working in grid connected and islanded modes, using Simscape, Matlab software considering practical on-site condition such as constant and variable load condition including natural uncertainty due to varying irradiance situation etc. The steps of modeling of a sample PV generator is described in detail which will be useful to study the performance of a solar energy based system prior on-site installation. The PV generator system is studied under fixed load, variable load and varying irradiance conditions. The feasibility of the model is also tested as one of the distributed energy resources of an inverter based microgrid catering an ac load as a sample study of industrial application of an inverter based microgrid under grid connected and islanded mode of operation. The simulation results are found satisfactory proving feasibility of the proposed model of PV generator at the stage of research and development in the emerging power scenario of microgrid.

INTRODUCTION

The performance based investigation of a photovoltaic (PV) generator needs detail knowledge of several characteristic under different operating states or condition [1]. To investigate the feasible operation of a proposed PV system or study the performance of an existing PV system, several photovoltaic simulation softwares are available worldwide for simulation, modeling and analysis of PV systems which are now very popular in the power system community dealing with implementation of distributed energy resources in the microgrid scenario [2]. The performance of a PV system is highly dependent on the climatic condition such as varying solar irradiance and ambient temperature [3] etc. Proper simulation can verify the notable performance variation due to inhomogeneous irradiance [4]. So operation of a microgrid system would be affected while a PV generator faces such natural uncertainty which should be addressed properly. In future, scarcity of fossil fuels and their environmental impact could be minimised by effective successful implementation of microgrid technology which will face challenges like integration of dispersed type renewable energy resources (RER). Among several types of RERs, solar PV based microgrid could play significant role in electricity production in remote areas [5]. To save the R&D cost of microgrid installation, software simulation of proposed system is well accepted today [2]. As reported in [6], the growing number of installed PV plants is making the simulation of their performance on the power generation gradually becoming more appropriate and an accurate and simple model of a plant is desirable for performance analysis. Motivation of the present work is gained from [7]. The prime objective is modeling of a PV generator system using Simscape, Matlab software which may be very useful as a sample study showing the approach of simulation of a real proposed PV system considering effect of varying irradiance and load at fixed ambient temperature. The effect of variation of ambient temperature could be taken into consideration on the proposed PV system but it is beyond the scope of this paper. As reported in [8], the power produced by the PV panels and the same stored in the battery could be consumed by a dc load locally; whereas a part of this paper presents brief result of simulation of the PV generator model in conjunction with an inverter supplying ac power to a resistive load.

The following sections present description of PV system, simulation of PV generator with uniform and random irradiation, simulation of PV generator catering resistive load through an inverter in microgrid scenario and conclusion.

DESCRIPTION OF PV SYSTEM

Simscape offers a MATLAB-based, object-oriented, physical modeling language for use in the Simulink environment. It is a software extension for MathWorks Simulink and provides tools for modeling systems spanning mechanical, electrical, hydraulic, and other physical domains as physical networks. From these different physical domains one can create models of his own custom components. Simscape provides a set of block libraries and special simulation features especially for modeling physical systems that consists of real physical components.

Table-I: Specification of a Solar Cell

Open circuit voltage, V_{oc} of solar cell	0.6V
Short circuit current, I_{sc} of solar cell	5A
Quality factor, N	1.5
Maximum Irradiance used for measurement	1000W/m^2
Series resistance, R_s	0 ohm
Measurement temperature	25˚C
Energy gap, E_g	1.11eV
Temperature exponent for series resistance	0
Temperature exponent for saturation current	3
First order temperature coefficient for solar induced current	0K^{-1}

It is accessible as a library within the Simulink environment. We have used Simscape tool of Matlab to develop the model of the solar generator. In this work the system components are 800 solar cells, a battery bank, relay and a 5amp load etc. The specifications of the solar cells are shown in Table I.

Solar Sub-module

In the Simscape model of the sub module, 20 solar cells are connected in series and all of them are subjected to the same irradiation input. This is shown in the Fig. 1. The voltage and current rating of each of these sub modules has been shown below:

Open circuit voltage of each sub module= (Open circuit voltage of each solar cell)*(Total no of solar cells connected in series) = (0.6*20) Volts = 12 Volts. The Short circuit current of the sub module, I_{sc} = 5 Ampere

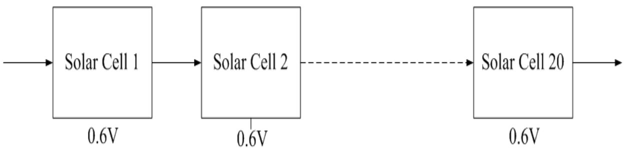

Fig. 1. Schematic diagram of a solar sub-module

Solar Module

Two solar sub modules are connected in parallel to develop one solar module. Schematic diagram of one module is shown in Fig. 2. The voltage and current rating of each of these solar modules has been shown below: Open circuit voltage, V_{oc} of module: 12 V, Short circuit current I_{sc} of the module: I_{sc}= (Short circuit current of each solar sub module)* (No. of solar sub modules connected in parallel) = (5*2)A = 10 A.

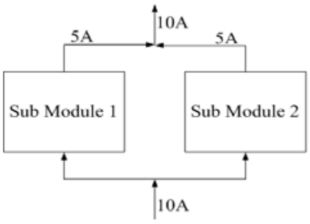

Fig. 2. Schematic diagram of a solar module

Solar Array

20 solar modules have been connected in series to build up the solar array as shown in Fig. 3. The voltage and current specifications of the solar array thus obtained has been shown below:

Open circuit voltage, V_{oc} of solar array= (Open circuit voltage of each solar module)*(Total no of solar modules connected in series)= (12*20) Volts = 240 Volts

Short circuit current, I_{sc} of the solar module = 10 A

Uniform and Random Irradiation

The Uniform Random Number block generates uniformly distributed random numbers over a specified interval. This block is available in Simulink tool of Matlab (Simulink > Sources). This block is used to vary the irradiation input to the solar cell in a random fashion. The maximum and minimum values of intervals are specified as 1000 and 0 to indicate maximum and minimum level of irradiance respectively.

PV System Simulation with Fixed Load and Variable Irradiance Condition

The Fig. 3 shows the simulated model of the PV system designed with the help of the different tools available in the Simscape, Matlab software. This is a PV system supplying a constant dc load of 10 A at 240 Volts both under zero and 1000 W/m^2. Under completely dark condition the load is fed from the battery bank and the solar unit remains isolated from the load. During the daylight the battery is cut off from the

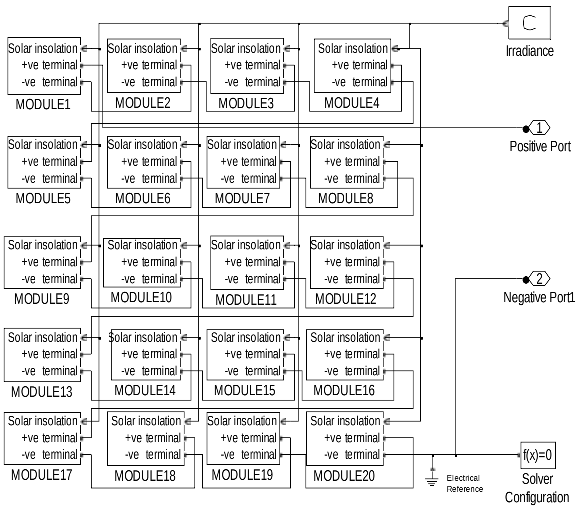

Fig. 3.: Schematic diagram of PV generator model

Load; the solar unit then supplies both the load current and the charging current of the battery. Thus the battery gets charged during the daylight and the load current remains constant irrespective of the irradiation throughout the day. The simulation results are shown below in Fig. 4.

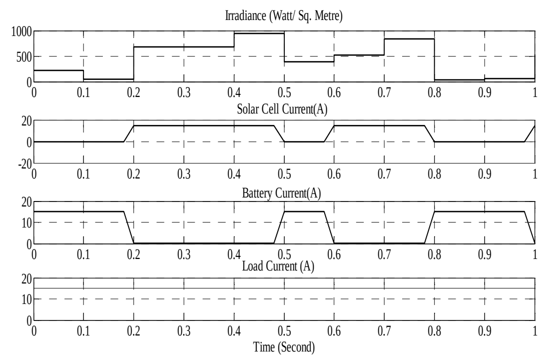

Fig. 4. Simulation result under fixed load and variable irradiance condition of PV generator

Here the irradiation has been varied in a random manner and the load has been kept constant. In the regions where the irradiation is above the threshold value (500 W/m^2), the solar cell supplies both the load current (10 Amp) and the charging current of the battery bank. The battery bank is disconnected from the load by the relay and is connected to the PV unit. Therefore in this region the battery current approaches zero as it gets charged to its nominal voltage, 240 V and the load current remains constant at 10 Amp.
In the region where the irradiation is below the threshold value (500), the solar cell is disconnected from both the load and the battery bank and the load gets connected to the battery bank. Therefore the solar cell current decreases to zero and the battery supplies the load current, 10 Amp. So, the load current remains constant at 10 A. During this time interval the battery gets discharged and its voltage level falls below 240 V. Therefore the load current remains constant at its rated value 10 A irrespective of the irradiation value.

PV System Simulation with Variable Load and Fixed Irradiance Condition

Effect of variation of load is also studied in the behavior of a PV unit under variable load condition, but the irradiation has been kept constant at 1000 W/m^2. For simplicity, the load is considered as a resistance varying over a specified range. Here the resistance has been varied with the help of the ramp function block available in Simulink, Matlab. The ramp function block has been connected to the variable resistor block, available in Simscape, to vary the resistance from zero to onwards. In this study only the PV array is simulated and the battery bank has been omitted from the designed system. The variation of current (produced by the PV cell) and that of the load voltage with respect to time (for variable resistance connected across PV unit) has been shown in Fig. 5. The open circuit voltage obtained is 240V and the short circuit current is 10Amp. The load resistance has been varied from zero to onwards up to the open circuited state.

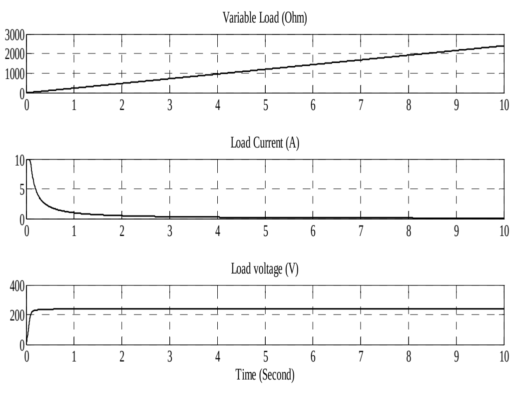

Fig. 5. Result obtained from simulation of PV system under variable load and fixed irradiance condition

PV System Simulation as a DER of a Sample Microgrid

In this section, performance of the PV generator as a distributed energy resource (DER) of a microgrid is studied. The schematic diagram of a PV generator based microgrid catering dc and ac loads are shown in Fig. 6. The modeled PV generator is one of the few DERs present in this system. The output of the PV generator (open circuit voltage: 240V, short circuit current: 10A) is connected to a 240V battery bank which is charged by the PV generator when solar irradiance is high. On the other hand the battery bank supplies the dc load in low irradiance or dark condition. Simultaneously a resistive ac load (100 ohm) which is catered by ac power received from output of the inverter connected with the PV generator and battery unit. Since detailed study of microgrid is beyond the scope of this paper and it is focussed mainly to the application of Simscape for modeling of PV generator in microgrid scenario; brief result is shown in the Fig. 7 for implementation of this model supplying ac power to a 100 ohm resistive load as a component of microgrid system. This study shows the possibility of simulation of microgrid for inductive loads as a token of industrial application of microgrid.
The result as presented in Fig. 7 shows the rms values of ac voltage across the resistive load and rms value of ac current drawn by the load in two states. Total simulation time is 1 sec. First 0.5 sec of total simulation time the load is catered by single phase grid and the inverter simultaneously. Magnitude of the voltage and current found satisfactory in this period. In the rest part of the simulation time, the ac grid is disconnected from the microgrid and profiles of load voltage and current found gradually drooping in nature. This is due to supply of electric power from the inverter which in turn supplied with dc power from the battery bank alone as the grid is disconnected from the microgrid.

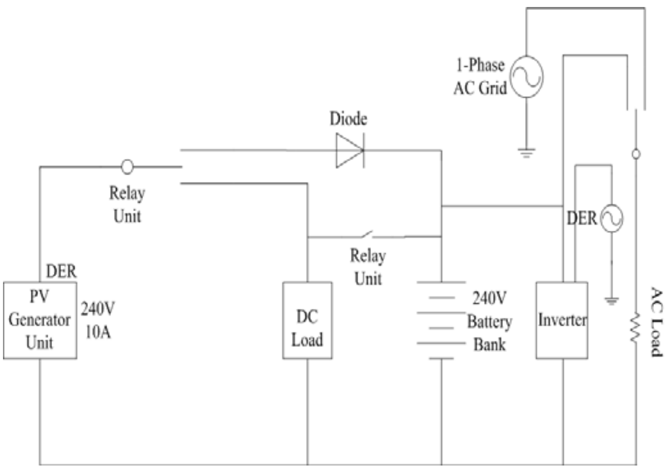

Fig. 6. Schematic diagram of a PV generator based microgrid catering dc and ac loads

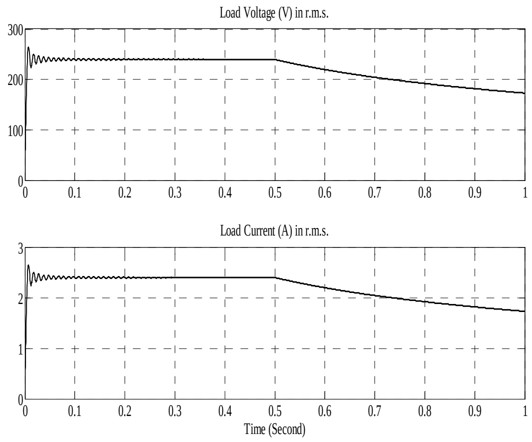

Fig. 7. Result obtained from simulation of PV system catering a resistive ac load through inverter

CONCLUSION

This paper shows an effective approach of physical system modeling using Simscape. It is to be noted that total 800 numbers of PV cells have been connected in series parallel mode which may be used to simulate any existing or proposed PV generator plant for investigation of their performance. In this work, the ambient temperature is considered as 25˚C. Effect of temperature variation is not shown since it is beyond the scope of this paper. The modeling of PV generator is mainly focused towards performance investigation finally in microgrid scenario considering natural uncertainty like random variation of irradiance between a range of $500W/m^2$ and $1000W/m^2$. In some cases even fixed irradiance is considered ($1000\ W/m^2$) while system is studied to observe the effect of variation of resistance of dc load. This range of irradiance is a sample case. It could be considered as per climatic condition and geographical location of a region in real life. This kind of approach in PV system simulation can considerably reduce research and development cost and time both, if the results are analyzed prior to on-site installation of a proposed real system and preventive measures are taken to enhance system performance.

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