Modelling and Simulation of Solar Plant and Storage System Based Microgrid

Rupesh kumar[1], Matta Mani Sankar[2], R. P. Gupta[3]
[1]PG Scholar, Dept. of Electrical Engineering, B.I.T. Sindri, Dhanbad, India
[23] Assistant Professor, Dept. of Electrical Engineering, B.I.T. Sindri, Dhanbad, India

Abstract- This paper presents the modelling of micro-grid with Photovoltaic system and Storage device to provide power as required. The whole system tracks the Maximum Power Point (MPP) from PV array using "incremental conductance + integral regulator" technique, with the help of DC-DC boost converter output voltage of PV array boost up and this voltage converted to AC by using voltage source converter (VSC). As required the AC voltage raised with the help of three phase transformer. The performance of the micro-grid has analyzed for both cases i.e. in island mode as well as grid-tied mode operation. All simulation works are carried out in MATLAB/SIMULINK environment.

Keywords- Boost Converter, Micro-grid System, Photovoltaic System, Storage System (Battery)

I. INTRODUCTION

To implement the renewable energy based-electricity generation, micro-grid system has been adopted. Micro-grid system integrates several types of renewable energy sources, such as solar system (PV array), wind turbine, fuel cell [1, 3, 8, 10]. In this paper, the concentration is limited to the solar energy resources, solar plants and storage system. The contribution of this paper is as follows, characteristics of solar cell, I-V characteristics of the PV module, incremental conductance method is applied to track the maximum power of a PV system, by applying boost converter the output voltage increases, Battery is used as storage device which is connected through bidirectional converter to DC BUS, voltage source converter (VSC) is used to convert DC voltage to AC voltage. The 100-kW PV array uses 330 Sun Power modules (SPR-315E-WHT-D). The array consists of 64 strings of 5 series-connected modules connected in parallel (64*5*315.072 W= 100.8 kW**),** PV array delivering a maximum of 100 kW at 1000 W/m^2 sun irradiance. The simulation and analysis are described for certain parameters in the case of islanded mode of micro-grid operation and grid-tied mode operation where solar plants are used as one of the sources of renewable energy based power generation.

II. CONFIGURATION OF MICROGRID SYSTEM

Fig. 1 represents schematic block diagram of whole system i.e. 100-kW PV array connected to a 25-kV grid via a DC-DC boost converter, a Lithium-ion Battery, a three-phase two-level VSC, 10-kvar capacitor bank filtering harmonics produced by VSC, 100-kVA 260V/25kV three-phase coupling transformer, Utility grid (25-kV distribution feeder + 120 kV equivalent transmission system) and load.

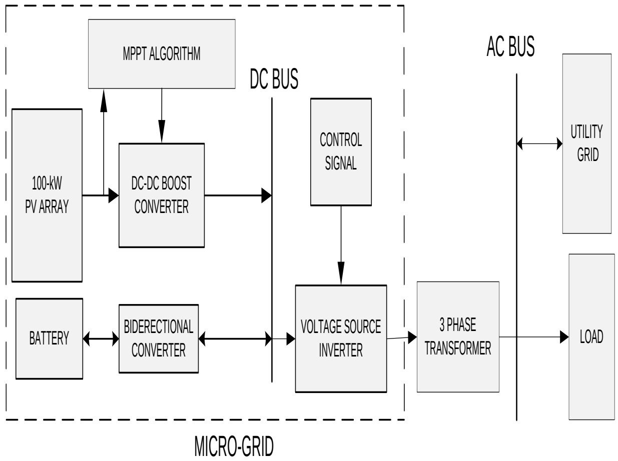

Fig.1: Block diagram of whole system

A. MICROGRID

PV system is connected to the DC bus via a DC-DC boost converter with maximum power point tracker to draw the maximum power from the PV system for a given temperature and irradiation. Battery is chosen to consider the long and short term energy storage device connected with a buck boost converter, which is connected to the DC bus. As the converter is bidirectional it can charge and discharge based on the direction of power flow. The control scheme is implemented for voltage source inverter (VSI) to convert DC voltage to AC voltage and 3-phase transformer is used to increase voltage from low level to required level. This micro-grid system supply active and reactive power to grid and load.

B. PHOTOVOLTAIC SYSTEM

Solar cell converts sunlight directly to dc power also generates electricity from the sun. PV panel works under the phenomenon of photoelectric effect [2]. When solar cells are exposed to sunlight, it converts solar energy into electrical energy. Here the PV array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel (here 64 used), each string consisting of modules connected in series (here 5 used). The PV array block is a five parameter model using a current source I_L(light generated current), diode, series resistance R_S and shunt resistance R_{Sh} to represent the irradiance and temperature dependent I-V characteristics of the modules which is shown in figure 2 and figure 3 respectively.

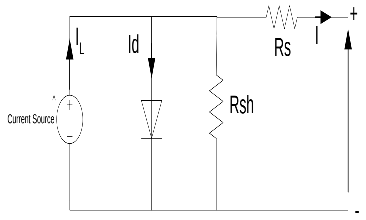

Fig.2: Circuit diagram of single module of PV array

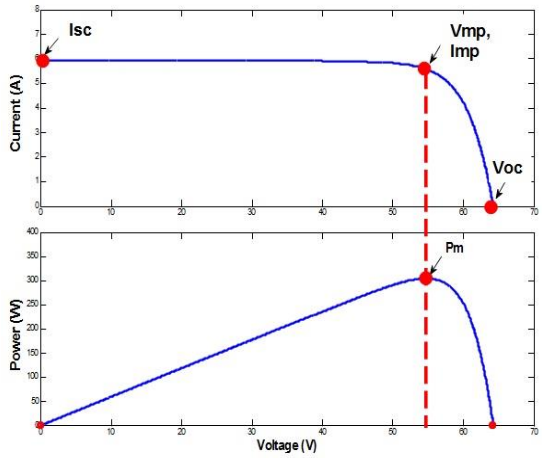

Fig.3: Graph between Current and Power with respect to Voltage

From figure 2 the diode current (I_d) and terminal voltage (V_T) will be found as:-

$$I_d = I_o[\exp(\frac{V_d}{V_T} - 1)] \quad (1)$$

$$V_T = \frac{kT}{q} * nI * N_{cell} \quad (2)$$

Where,

I_d = diode current (A)

k = Boltzmann constant = 1.3806e-23 J/K

V_d = diode voltage (V)

q = electron charge = 1.6022e-19 C

I_o = diode saturation current (A)

T = cell temperature

nI = diode ideality factor, a number close to zero

N_{cell} = number of cells connected in series in a module.

C. DC-DC BOOST CONVERTER

Choppers are DC-DC converters for generating one level DC source voltage to a fixed voltage source. The DC-DC converter consists of capacitor, inductor, switches and diode as shown in figure 4. All of these devices in ideal condition do not consume power. The switch is typically an IGBT transistor which is a semiconductor device. The input-output relationship for continuous conduction mode of DC-DC boost converter is given by

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \quad (3)$$

Where,

D=Duty cycle

V_{in}=Input voltage

V_o=Output voltage

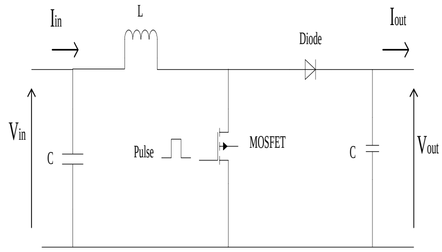

Fig.4: Circuit diagram of DC-DC Boost converter

D. BATTERY

A lithium-ion battery is reliable and has high power performance, symmetrical charge and discharge capability, wider operational temperature capabilities, longer cycle life, and higher safety aspects so this is used as Storage device [1, 4]. Battery is connected through bidirectional converter to DC BUS so it charges when Solar power generated is greater than power demand and discharges vice-versa [9, 11].

III. MPPT TECHNIQUES

There are various methods developed and implemented by researchers for maximum power point tracking (MPPT).The voltage at which PV array gives maximum output power is known as maximum power point (MPP). The MPPT algorithms that include in this kind are perturbed and observe (P&O), incremental conductance (IC), feedback voltage and current, fuzzy logic control and neural network methods. MPPT plays a very important role in photovoltaic (PV) power system because they maximize the power output from a PV system for a given set of conditions and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. As said there are many methods available but the most widely used technique is the incremental conductance method described in the following section.

A. The incremental conductance algorithm

Incremental conductance method is based on variation in power. Current and output voltage of PN panel is used to calculate the conductance and incremental conductance. The ratio of the derivative of power and derivative of the voltage is shown in [5, 6]

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad (4)$$

The maximum power point (MPP) will be found when:

$$\frac{dP}{dV}=0 \Rightarrow I+V\frac{dI}{dV}=0 \Rightarrow -\frac{I}{V}=\frac{dI}{dV} \quad (5)$$

Where: I/V is instant conductance and dI/dV is the incremental conductance (instantaneous change of conductance). The comparison of these two amounts indicates which side of the MPP point currently operates the PV panel.

From the analysis of the derivatives shown in the following relationship can be determined whether the PV panel operates at the MPP or away from this point, as shown in figure 5.

$$\frac{dI}{dV}=0 \; for V < V_{mpp} \quad (6)$$

$$\frac{dI}{dV}=0 \; for V = V_{mpp} \quad (7)$$

$$\frac{dI}{dV}=0 \; for V > V_{mpp} \quad (8)$$

Incremental conductance method is simple, easy to implement and has a very high efficiency tracking. In the case or ideal condition, it is able to determine whether the current operating point is MPP or not, but the measurements, the operating point could however moves around MPP. The solar industry continues to expand several solutions to simultaneously perform MPPT and control this efficient conversion of DC/DC power, especially by passing architectures more sophisticated, offering tuning per solar module.

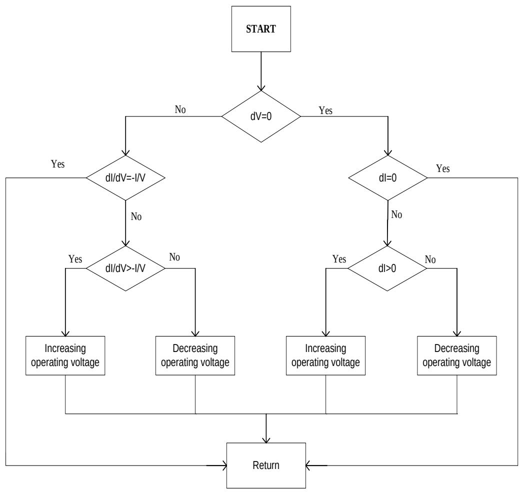

Fig.5: Flowchart of the incremental conductance algorithm

IV. SIMULINK MODELS

Using the following relationships (9)-(13) it is determined the variation of measured parameters of PV panel such as voltage and current. Then it is determined variation in the ratio of power derivative to voltage derivative and error variation [5-7]. With the help of above equations the SIMULINK model of Incremental conductance with MPPT technique is shown in figure 6.

$$E(k)=\frac{\Delta I}{\Delta V}+\frac{I}{V}=\frac{\Delta P}{\Delta V}=\frac{\Delta P}{\Delta I} \quad (9)$$

$$dE(k)=E(\mathrm{k})-\mathrm{E}(\mathrm{k}-1) \quad (10)$$

$$\Delta I = I(k)-I(k-1) \quad (11)$$

$$\Delta V = V(k)-V(k-1) \quad (12)$$

$$\Delta P = P(k)-P(k-1) \quad (13)$$

The model which is shown in figure 7 contains the following basic components:

1. Photovoltaic Panel
2. Signal builder block for irradiation and temperature
3. DC-DC boost converter
4. Incremental conductance MPPT algorithm
5. Load connected to terminal

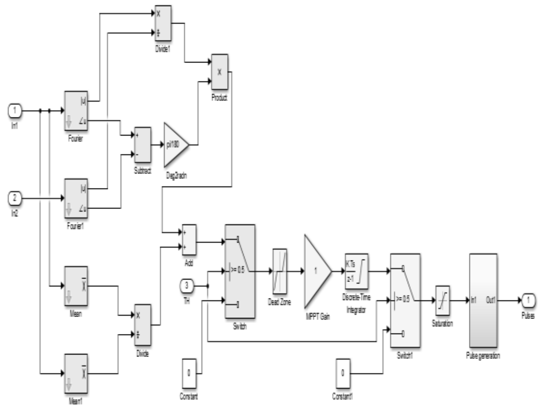

Fig.6: Simulink model of Incremental conductance algorithm

A 100kW PV array is connected to a 25kV grid via a DC-DC boost converter, Battery, a three-phase two-level voltage source converter (VSC), 10-kVAR capacitor bank for filtering harmonics produced by VSC, 100-kVA 260V/25kV three phase coupling transformer and Utility Grid (25-kV distribution feeder + 120kV equivalent transmission system) as shown in figure 7.

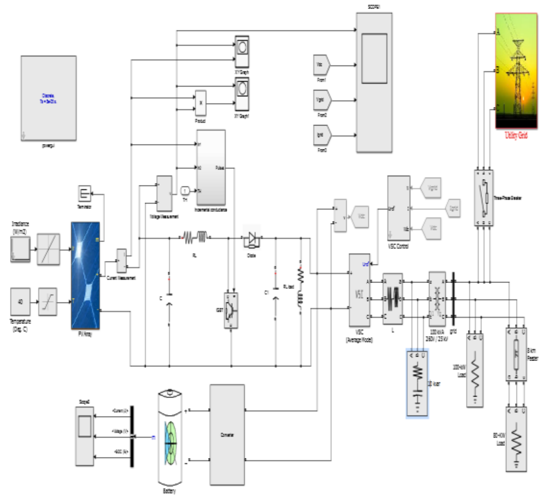

Fig.7: Simulink model of whole system

V. RESULTS AND DISCUSSION

Modeling of whole system tracks the maximum power from PV array using "Incremental conductance" technique, also it optimized the duty cycle (pulses) for Boost Converter. With the help of DC-DC boost converter voltage increases from 300V DC (PV voltage at maximum power) to 500V DC. Battery charges when Solar power generated is greater than power demand and discharges vice-versa. Battery cannot reach greater than 100 % SOC as the converter is bidirectional it can charge and discharge based on the direction of power flow. VSC converts 500V DC link voltage to 260V AC, after that 3-Phase Coupling Transformer rises 260V AC to 25kV AC approximately with and without utility grid as shown in figure 8 and figure 9 respectively.

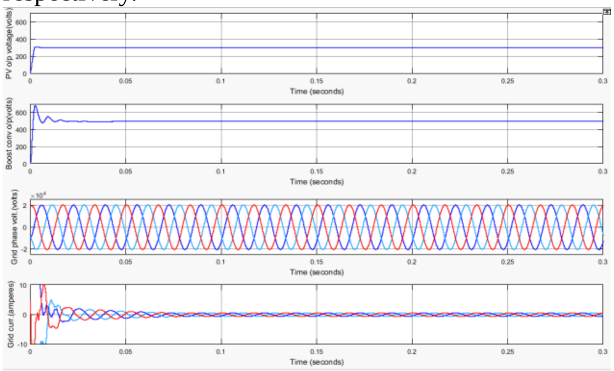

Fig.8: Output of various parameter with utility grid.

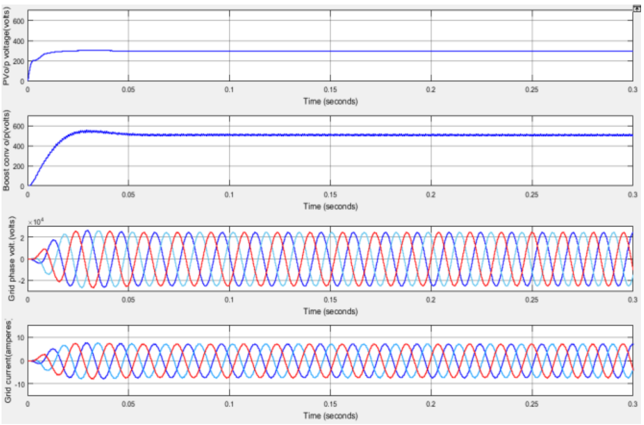

Fig.9: Output of various parameter without utility grid.

Figure 8 and figure 9 show the output voltage of PV array, output voltage of Boost Converter, Phase to Phase grid voltage and grid current with and without utility grid. This results shows that by using storage device, micro-grid system is capable of delivering smooth power while giving variable irradiance and temperature.

VI. CONCLUSIONS

This paper has been associated with the performance of micro-grid system with the Solar Plant and storage unit for the different aspects and cases of islanded mode and grid-tied mode operation have been analyzed for the different parameters. A battery energy storage system is integrated and a control algorithm is proposed in order to minimize the negative transient effects due to PV panel shading. It is clear from the results by using storage device the micro-grid system is capable of delivering smooth power to utility grid or load (island mode).

VII. REFERENCES

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