TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 13, No. 3, March 2015, pp. 418 ~ 424
DOI: 10.11591/telkomnika.v13i3.7061

Modeling and Simulation of Off-Grid Power Generation System Using Photovoltaic

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Abstract

Off-Grid is a part of the power distribution system which uses renewable energy based of power generation connected to the grid system. Power generation of multi energy is composed of renewable energy systems including photovoltaic, wind turbine, energy storage and local loads. Test bed of an Off-Grid system is the technique to ensure stable operation during faults and various network disturbances in grid and islanding connected mode. In this paper the Off-Grid using renewable energy consist of a 3 kW photovoltaic, with 30 pieces of 12V, DC/DC converter, charge controller for battery, single phase DC/AC inverter and various loads (resistor, capacitor, inductor) are develop. The AC buses 240V voltage include with isolation transformer to simulate the grid voltage level by Matlab/Simulink software.

Keywords: *boost, inverter, off-grid, photovoltaic, Matlab/Simulink*

1. Introduction

Nowadays, micro grid technology using renewable energy based on distributed power generation system combined with power electronic system will produce the concept of future network technologies. The integration of renewable energy sources and energy storage systems has been one of the new trends in power electronic technologies. The main advantages of Off-Grid development are providing good solution to supply power in case of an emergency and power outage during power interruption in the main grid. Off-Grids comprise low voltage distribution system with distributed energy resources, such as photovoltaic power system and wind turbines, together with storage device.

Currently, Photovoltaic generators are designed in order to generate a maximum power to the grid. Because of the stochastic nature of the PV power output, large developments of grid connected PV systems involve large fluctuations of the frequency, power and voltage in the grid. However, the disadvantage is that PV generation is intermittent, depending upon weather condition. Thus, the MPPT makes the PV system providing its maximum power and that energy storage element is necessary to help get stable and reliable power from PV system for both loads and utility grid, and thus improve both steady and dynamic behaviors of the whole generation system. Because of its low cost and high efficiency, the battery can be integrate into PV generation system which can more stable and reliable.

In this paper, Off-Grid testbed using renewable energy based power generation system which is composed of PV array, power electronic converters, filter, controllers, local loads and utility grid as shown in Figure 1. The paper discusses the detailed modelling of grid connected PV/Battery generation system. PV array is connected to the utility grid by a boost converter to optimize the PV output and DC/AC inverter to convert the DC output voltage of the solar modules into the AC system. Meanwhile, the battery is connected to the common DC bus via a charge controller to support a stable voltage from PV. The proposed model of the entire components and control system are all simulated under Matlab/Simulink software. All simulation results have verified the validity of the models and effectiveness of control method.

Received November 20, 2014; Revised January 1, 2015; Accepted January 25, 2015

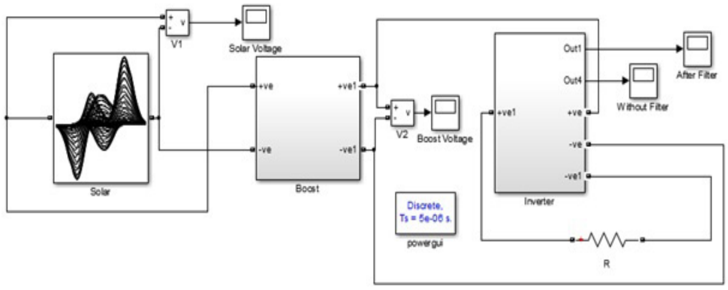

Figure 1. Configuration of the Off-Grid using PV based power generation

2. Off-Grid System Modeling
2.1. Photovoltaic (PV) Model

In this project the PV system is modeling based on the equivalent circuit model which has already state in theory section. The photocurrent generated when the sunlight hits the solar cell can be represented with a current source and the P-N transition area of the solar cell can be represented with a diode. The shunt and series resistances represent the losses due to the body of the semiconductor.

The electrical model of the PV system was simulated in Matlab/Simulink with an equivalent circuit model based on the PV model of Figure 2 and Figure 3. The circuit model is using one current source and two resistors R_{sh} and R_s. The value of the model current I_{pv} is calculated by the computational block that has V, I, and I_{pv} as inputs. All the input parameters were developed by using mathematical function that will supplying the information to the PV model circuit based on the mathematical calculation.

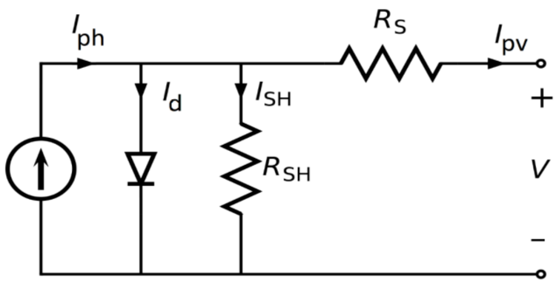

Figure 2. PV system model circuit with a controlled current source, equivalent resistors, and the equation of the model current

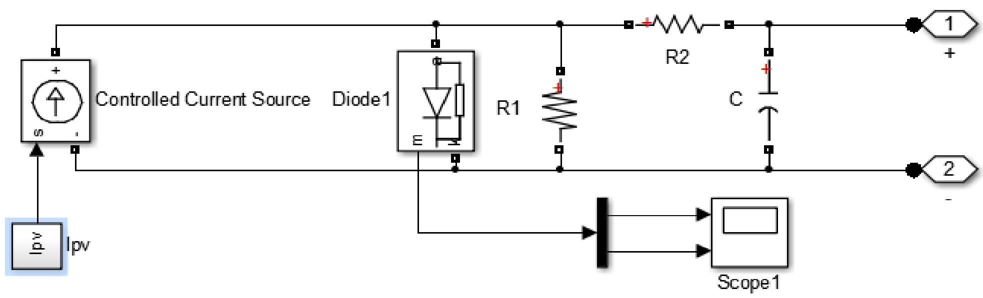

Figure 3. Equivalent model of PV system in Matlab Simulink with input and output port that connect to outside of subsystem

In order to create the input supply or model current, to the equivalent circuit of PV, firstly the saturation current of was developed. This is done by using the following equation of 1, 2 and also with the selected parameters. Then the mathematical model of I_o was developed in Matlab/Simulink as shown in Figure 4.

$$I_o = \left(\frac{I_{scref}}{\exp\left(q \frac{V_{ocref}}{AKT_{jref}} - 1 \right)} \left[\exp\left(\frac{-q \frac{E_g}{AK}}{\frac{1}{T_j} - \frac{1}{T_{jref}}} \right) \right] \left(\frac{T_j}{T_{jref}} \right)^{\frac{3}{\lambda}} \right) \quad (1)$$

$$I_{dd} = \exp\left(q \frac{(V_{PV} + R_S I)}{AKT_J} \right) \quad (2)$$

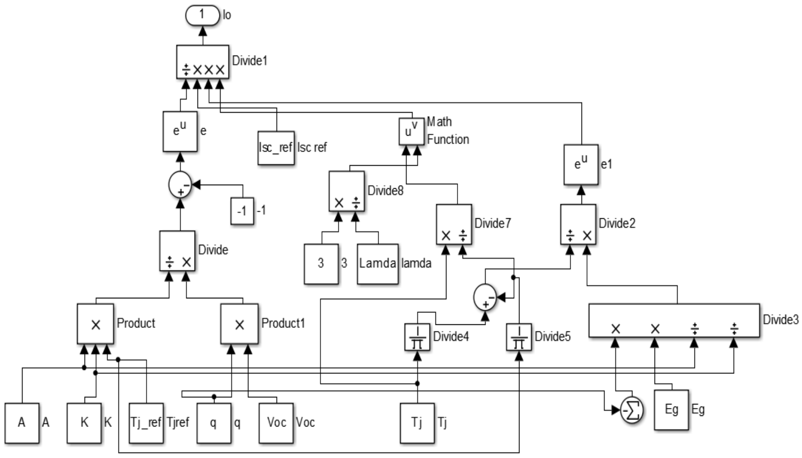

Figure 4. Mathematical model of I_o

Then the light generated current was developed by using Equation (3) with the selected parameters. Then the mathematical model of was developed in Matlab simulink as shown in Figure 5(a) and Figure 5(b).

$$I_{sc} = \frac{G}{Gref} I_{scref} \left[1 + \alpha_{sc} \left(T_j - T_{ref} \right) \right] \quad (3)$$

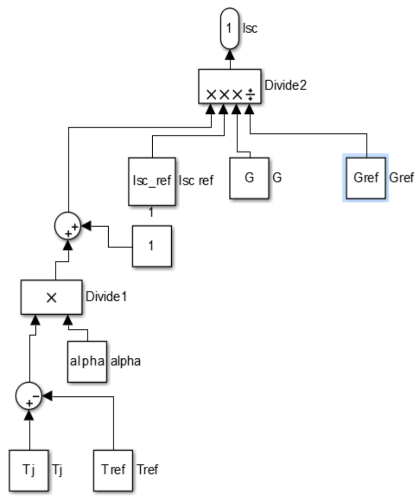

Figure 5(a). Mathematical model of Isc

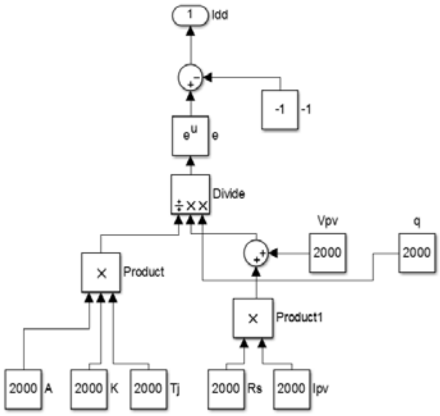

Figure 5(b). Mathematical model of Idd

Finally both parameters of and, also with the selected parameter were inserted in Equation (4) in order to obtain the input supply of I_{pv}. Then the mathematical model of was developed in Matlab/Simulink as shown in Figure 6.

$$I_{pv} = I_{sc} - I_o I_{dd} \tag{4}$$

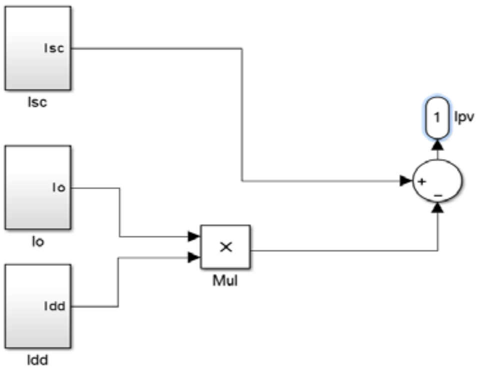

Figure 6. Mathematical model of I_{pv}

In this type of dc converter, the circuit modeling was firstly developed. The boost converter circuit is shown in Figure 7. Then the main parameter such as input and output voltage, inductance value, capacitance value, and resistor value also with the duty ratio were designed.

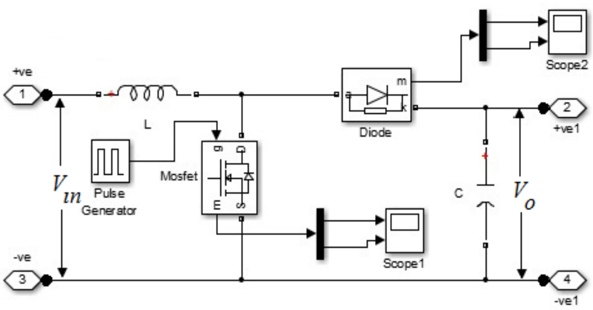

Figure 7. Boost converter topology

Duty ratio D, with desired output voltage V_o and voltage input V_{in}.

$$D = 1 - \frac{V_{in}}{V_o} \quad (5)$$

Inductance value, L:

$$L\min = \frac{D(1-D)^2 R}{2f} \quad (6)$$

2.2. Inverter Model

Figure 8 shows outputs from PV and battery connect to inverter, filter and grid system.

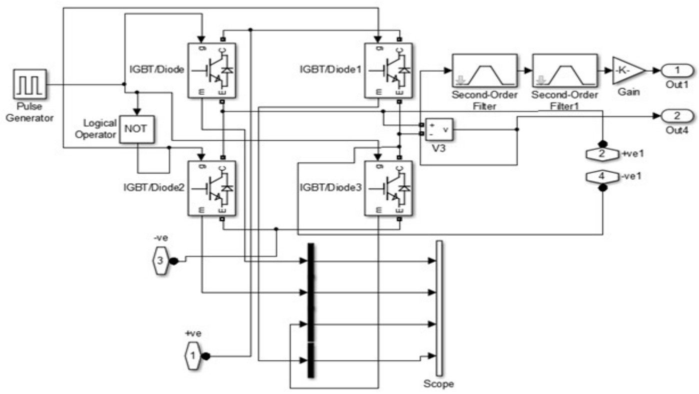

Figure 8. Inverter connects to filter

Single phase inverters are used the DC output voltage of the PV array into AC voltage to be connected to the electric utility grid. Configuration of the single phase full bridge voltage source inverter circuit is shown in Figure 9. It is composed of a DC voltage source (PV array) an input decoupling capacitor and four power switching blocks. C is used to filter the noise on the DC bus. After the inverter an LC harmonics filter is used to eliminate the high frequencies in the output inverter voltage. Each block of the switching blocks consists of a semiconductor switch (IGBT) and anti-parallel diode. To create proper gating signals for switches, pulse with modulation is used. The functions of PWM are the control output voltage amplitude and fundamental frequency.

3. Result and Discussion

Figure 9 shows the output voltage from PV as a 161V DC voltage.

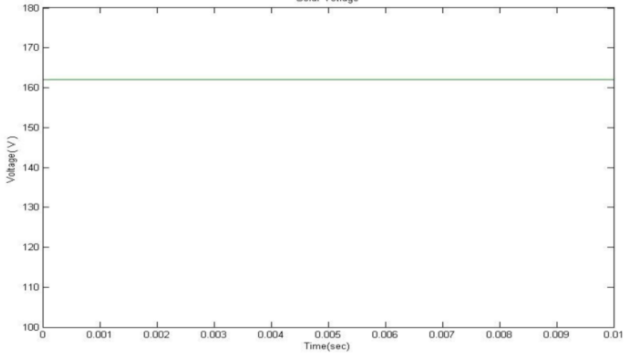

Figure 9. PV voltage

Figure 10 shows output voltage boost converter in DC volts. Here the voltage from PV 161V are fluctuated and boost converter are used to get pure DC voltage.

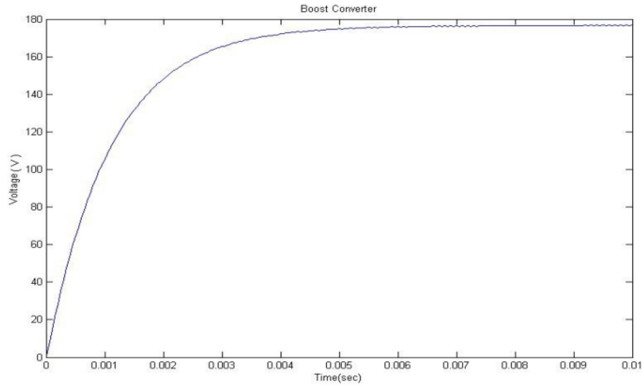

Figure 10. Output from DC-DC voltage

Figure 11 shows output voltage from inverter before filter in square curve. Here the voltage from DC converter 170V connected to inverter change to AC voltage.

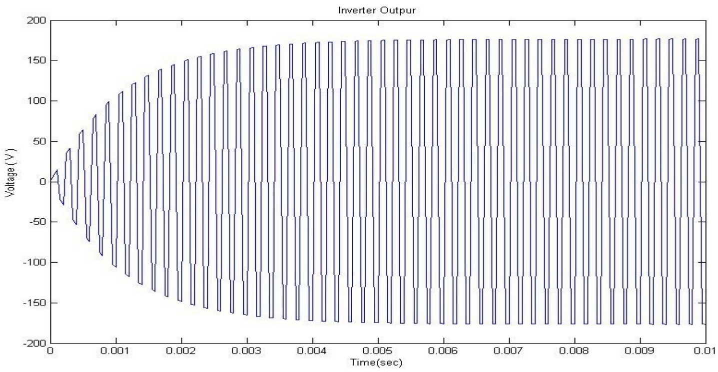

Figure 11. Outputs from inverter voltage before filters

Figure 12 shows output from inverter after filter in sine wave. The inverter works with a pulse width modulation technique. The output voltage of filter is shown as pure sine wave with almost no harmonic content.

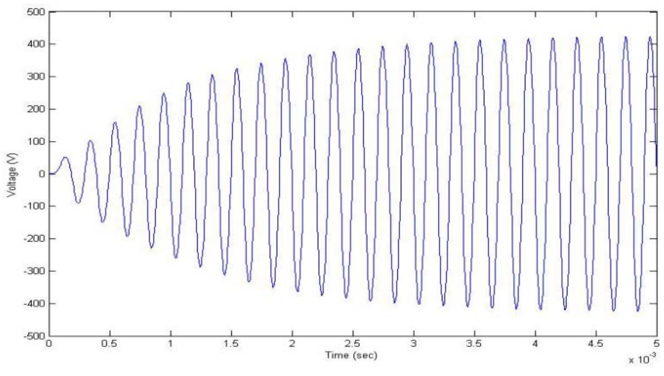

Figure 12. Outputs from inverter voltage after filters

4. Conclusion

In this paper the mathematical model of al system components was introduced in order to investigate the dynamic behavior of each system. Also the proposed control technique of the system was presented. This includes On/Off switch control of the system modes of operation and inverter control. The proposed system components implemented in Matlab/Simulink environment and interface with Sim Power System toolbox. The dynamic behavior of each subsystem is investigated showing the interaction between different components of grid connected PV system. Renewable energy based power generation as a photovoltaic (PV) with battery storage for Off-Grid system are simulated. Simulation is focus on the parameter of the each component to consider the outputs and effectiveness of inverter. Most of the results can be used for develop a small scale Off-Grid system for practical applications.

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