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Modeling of Micro-Grid System Components using MATLAB/Simulink

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Abstract: Micro-grid system is presently considered a reliable solution for the expected deficiency in the power required from future power systems. Renewable power sources such as wind, solar and hydro offer high potential of benign power for future micro-grid systems. Micro-Grid (MG) is basically a Low Voltage (LV) or Medium Voltage (MV) distribution network which consists of a number of called Distributed Generators (DG's); micro-sources such as photovoltaic array, fuel cell, wind turbine etc. energy storage systems and loads; operating as a single controllable system, that could be operated in both grid-connected and islanded mode. The capacity of the DG's is sufficient to support all; or most, of the load connected to the micro-grid. This study presents a micro-grid system based on wind and solar power sources and addresses issues related to operation, control and stability of the system. Using MATLAB/ Simulink, the system is modeled and simulated to identify the relevant technical issues involved in the operation of a micro-grid system based on renewable power generation units.

INTRODUCTION

The increasing need for energy generated with clean technologies has driven researchers to develop distributed power generation systems using renewable energy sources (Ackermann and Knyazkin, 2002). On the other hand, the integration of a large number of distributed generations into distribution networks is restricted due to the limitation of the networks capacity and unidirectional power flow behavior (Blaabjerg *et al*., 2006; Katiraei *et al*., 2013). Such barriers have motivated the search for to an alternative conceptual solution to enhance the distributed generation integration into the distribution networks.

"Micro-grid" approach was proposed as a means of integrating more distributed generations into the distribution networks (Lasseter, 2001). Distributed Generation (DG) in micro-grid operation provides multi benefits to the utility operators, DG owners and consumers in terms of reliable power supply, reduction in transmission system expansion and enhancement of renewable power penetration.

Lasseter (2001) proposed the first micro-grid architecture that was called Clean Energy Resources Teams (CERTS) (Lasseter, 2001). CERTS micro-grid generally assumes converter-interfaced distributed generation units based on both renewable and non-renewable power sources. A micro-grid system was also proposed by Barnes *et al*. (2005) under the umbrella of "Micro-grids" European project. Future power network is expected to a focus on a micro-grid system based on renewable power generation units. The characteristics of a micro-grid system depend on the type and size of the micro-generation units as well as the site and the availability of the primary energy resources on the site, especially, renewable power sources.

Advancement in Distributed Generations (DGs) and micro-grids is accompanied by the development of various essential power conditioning interfaces and their associated control to connect multiple micro sources to the micro-grid and tie the micro-grids to the traditional network (Barnes *et al*., 2007). Micro-grid operation becomes highly flexible with such interconnection and can be operated freely in the grid connected or islanded mode of operation. The islanded mode of operation with more balancing requirements of supply-demand may be started when the main grid disconnected due to any fault. All the above mentioned literature presented single renewable source micro-grids. The current work presents the simulation of a micro grid model that includes two renewable energy sources; Photovoltaic (PV) and a Wind Turbine (WT) in addition two operational modes of operation (island and Grid connected) are investigated.

MATERIALS AND METHODS

Modeling MG components: As mentioned above the components of the identified system are modeled using MATLAB/Simulink Software tool.

PV module: A generalized PV model is built using MATLAB/Simulink to illustrate and verify the nonlinear I-V and P-V output characteristics of PV module.

The behavior of Photovoltaic (PV) cells can be modeled with an equivalent circuit that includes a photo current source, a single diode junction and a series resistance and a shunt resistance (Soto, 2012). The Simulink model of PV module is shown in Fig. 1.

WT module: Wind turbine is composed of a rotor, a generator, three-blades and a drive train. In case of high wind speed, the generator output power is controlled by adjusting the pitch angle. Power is transmitted to the grid through power electronic interface, the. A wind turbine extracts kinetic energy from the wind blowing through the blades. The power developed by a wind turbine is given by Slootweg *et al*. (2001). The simulink model of a wind turbine equation is shown in Fig. 2.

Energy storage modules: The electricity demand fluctuates depending on the time of the day and the time of a year. Since, the traditional power grid is not able to store up electricity, the mismatch between supply and demand is more likely observed. As the concept of micro-grid is becoming more pervasive, a mixed power system makes the best use of the different types of local generation. Some forms of generations have large response time and others have little flexibility in operation. In addition, some forms of generations can start up very quickly to provide more or less energy depending on the real-time load demand pattern. Provided these reasons clearly, the energy storage is beneficial in managing such a system. A desired form of energy storage is expected to provide the required power into the power system and store up sufficient energy at low electricity consumption. Two types of short-term storage are studied and modeled: Storage batteries and super-capacitor.

Battery bank: There are several approaches to model a battery. A commonly used battery model is the thevenin equivalent circuit (Tremblay *et al*., 2007). In this case

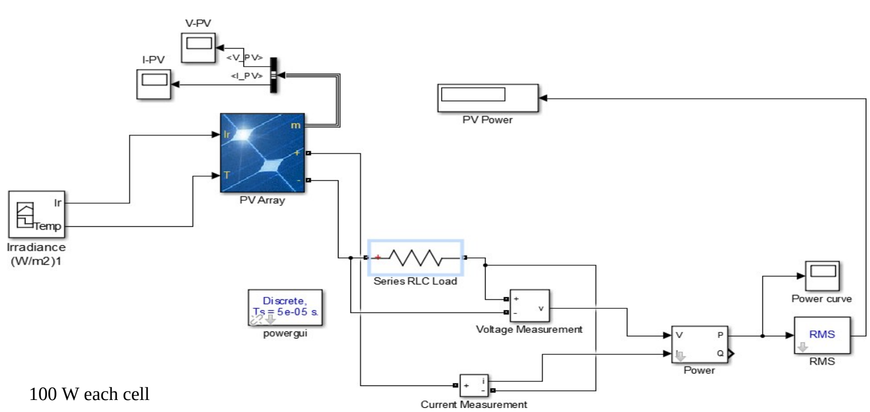

Fig. 1: MATLAB/Simulink model of the PV array

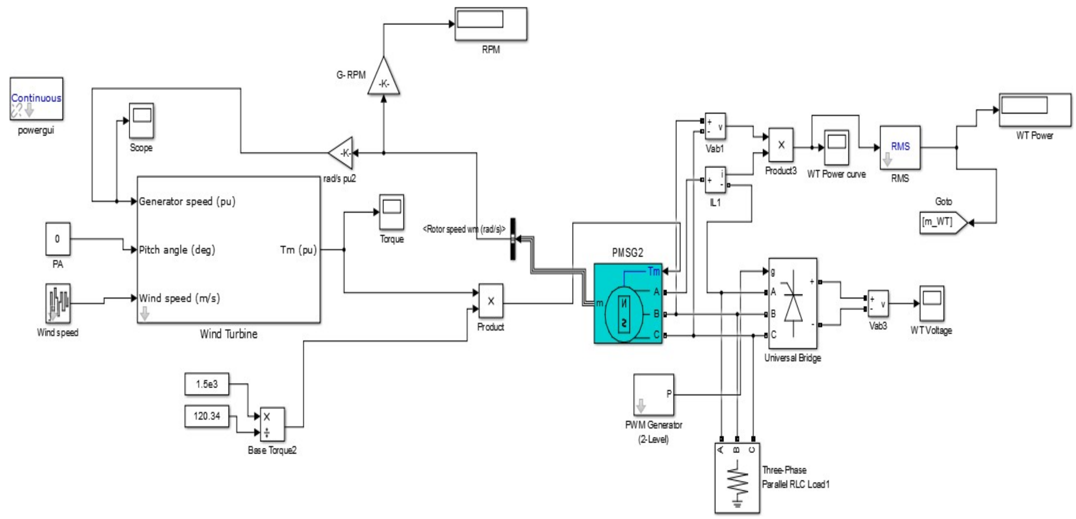

Fig. 2: MATLAB/Simulink model of the wind turbine block

Simulink implements set of predetermined charge behavior for four types of battery: lead-acid, lithium-ion, Nickel-Cadmium and Nickel-Metal-Hydride. Figure 3 illustrates a detailed modeling of charge and discharge battery in MATLAB/Simulink.

Super-capacitor: The super-capacitor, also known as ultra-capacitor is the electrochemical capacitor that has higher energy density than common capacitors on the order of thousands of times. The equivalent circuit used for conventional capacitors can also be applied to super-capacitors.

If the simulation time is much larger than the self-discharge time, the equivalent parallel resistance might be neglected as well. The actual capacity C varies with quantities as current, voltage and temperature. Equations of RL&RC circuits are shown in this study. Figure 4 illustrates modeling of super-capacitor block.

Diesel generator model: Diesel engines; both Spark Ignition, (SI) and Compression Ignition (CI), were first among distribution generator technologies. The Diesel Engine model gives a description of the fuel consumption rate as a function of speed and mechanical power at the output of the engine and is usually modeled by a simple first order model relating the fuel consumption to the engine echanical power. The power output of the engine and the generator varies according to load in order to meet the demand.

The governor can be defined as a mechanical or electromechanical device for automatically controlling the speed of an engine by relating the intake of the fuel, (Stavrakakis and Kariniotak, 1995). The task of the governor is to adjust the fuel flow and then regulate the input of the engine and generator, hence, provides the required power to meet the change in the load. Several types of governors exist such as mechanical, electronic, microprocessor based and others. Figure 5 illustrates the diesel engine model in MATLAB/Simulink.

Inverter controller model: Inverter or power inverter is a device that converts the DC sources to AC sources. Power inverters produce one of three different types of wave output:

- Square Wave
- Modified square wave (Modified sine wave)
- Pure sine wave (True sine wave)

The three different wave signals represent three different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices. Modified square wave (modified sine wave) inverters deliver power that is consistent and efficient enough to run most devices fine while sensitive equipment requires a sine wave (Cao *et al*., 2013). Figure 6 shows Model of Inverter block MATLAB/Simulink.

Load and utility grid models: The utility grid is modeled as a three phase's ideal voltage source with infinite power rate. This simplified model is only used for analyzing the dynamic behavior of the proposed systems. A utility grid model is shown in Fig. 7 while Fig. 8 describes three phase load model. The models of three dynamic load and three phase fixed load with constant impedances are available in the standard Sim-power systems library. The active power and reactive power can be controlled via. the external control signals. It is especially, useful when the demand response or demand side management is taken into account.

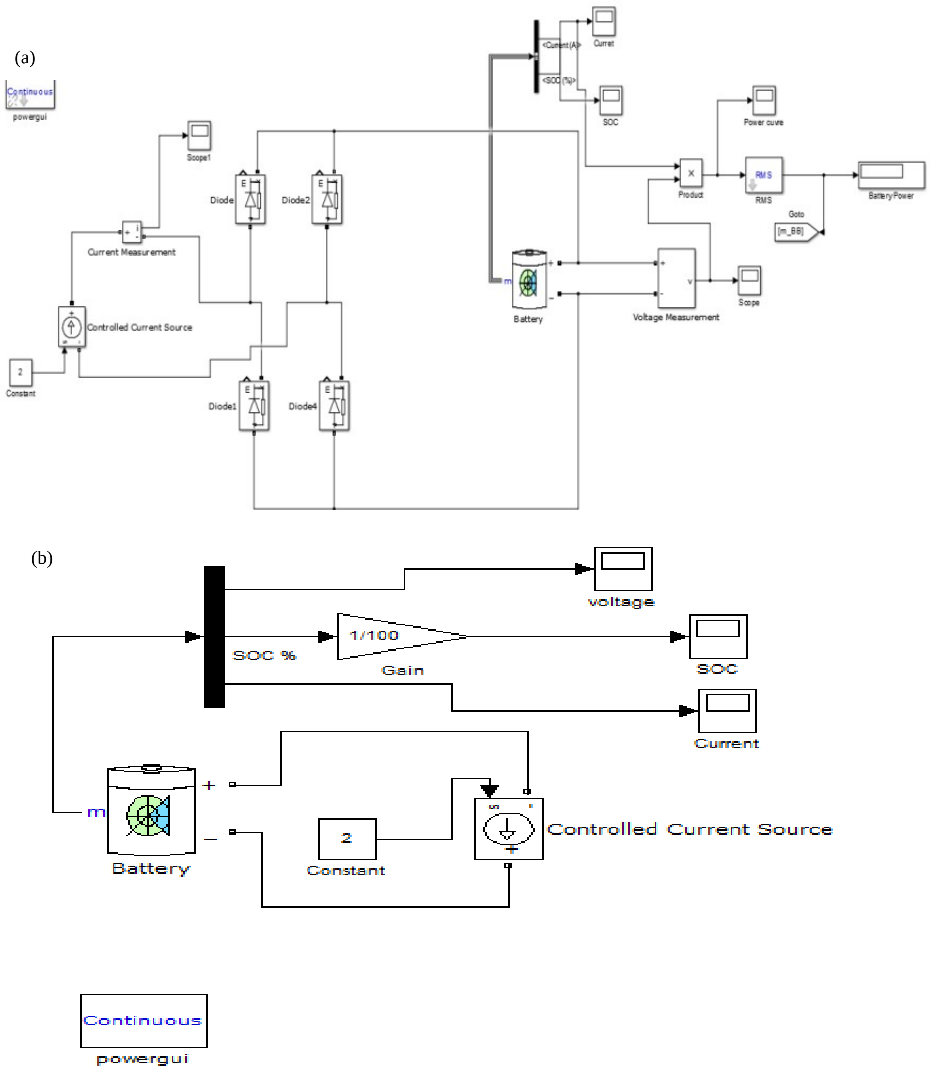

Fig. 3(a, b): Charge and discharge battery modeling in MATLAB/Simulink (a) Charge model and (b) Discharge model

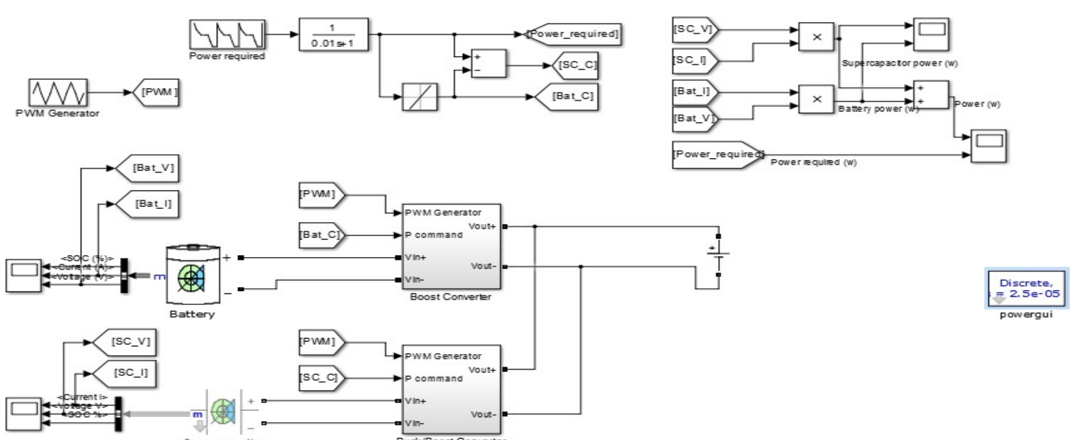

Fig. 4: Super-capacitor block model in MATLAB/Simulink

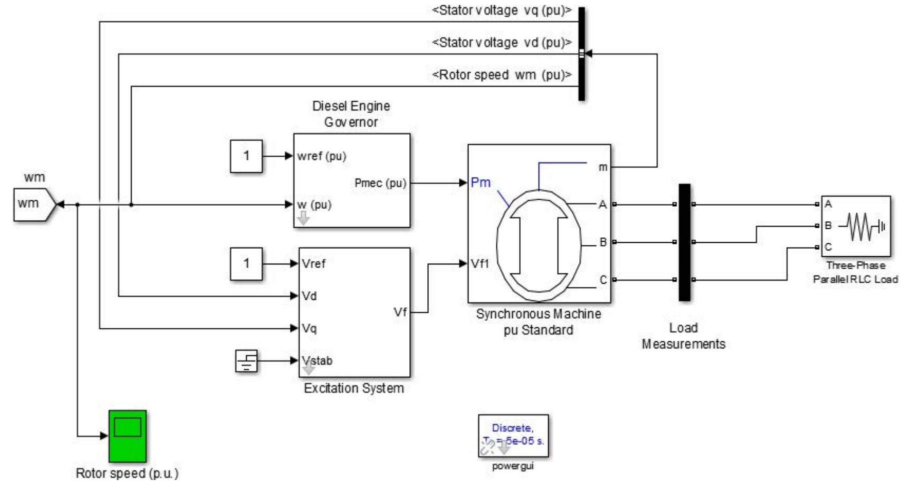

Fig. 5: Model of diesel generator in MATLAB/Simulink

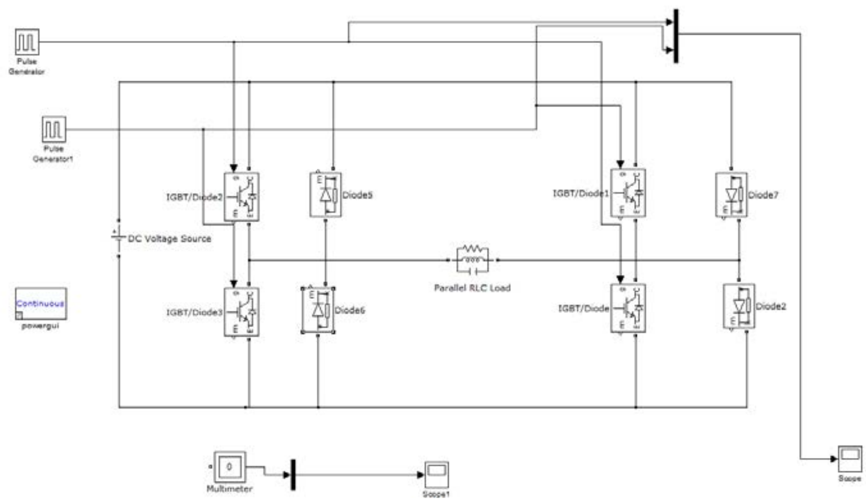

Fig. 6: Inverter block model in MATLAB/Simulink

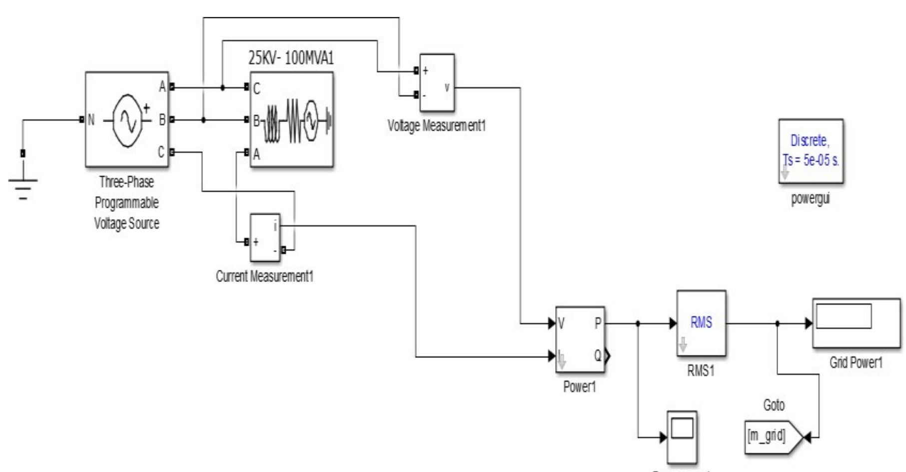

Fig. 7: Utility grid model in MATLAB/Simulink

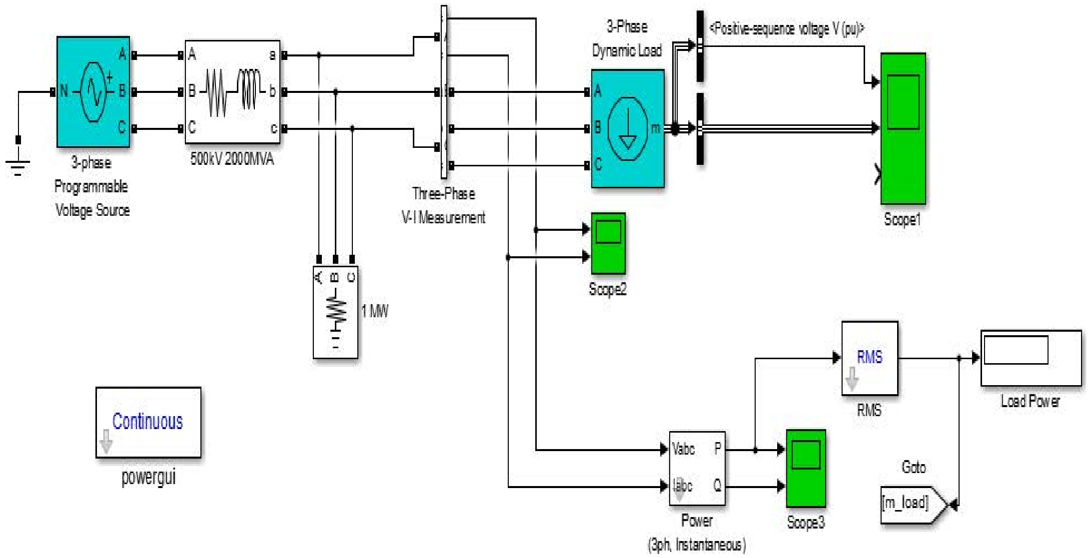

Fig. 8: Three phase load model in MATLAB/Simulink

RESULTS AND DISCUSSION

Results of components simulation: Figure 9a represents the I-V &P-V characteristics obtained from the PV array, while Fig. 9-b illustrates power curve from WT. Charge output curves from battery bank are presented in Fig. 9c while Fig. 9d shows output curve in discharge battery. Output curves from diesel generator are described in Fig. 9e while Fig. 9f presents inverter output curves.

Micro-grid control switch unit: In order to operate the micro-grid in grid-connected mode or off-grid mode, a simple control logic circuit is designed in MATLAB/ Simulink in Fig. 10. In the on grid system when power output from renewable greater than load power, excess power exported to grid sell block and when renewable output less than load power, grid purchase block used. In the off-grid system when power output from renewable greater than load power, batteries operate and excess energy stored in it’s and when renewable output less than load power, diesel generator used to cover this shortage.

Complete simulink model of a micro-grid system: After implementing all these models in MATLAB/ Simulink, the models are combined together to form a micro-grid system (off/on grid) as shown in Fig. 11a, b.

The below illustrated micro-grid is small scale which is divided into three important parts: Renewable energy sources, load and grid. Two renewable energy sources are included; PV array and a simplified model of a wind turbine. The load is the energy required for two small industries: Fodder production and hydrogel. Simulating the system using simulink tool, the following power measurements are observed on display as explained in the following section.

Simulation results: The results of simulation of the performance of the above modeled micro-grid are shown in Fig. 12. The figure is divided into ten illustrations that represent different outputs. The first six figures show (a-f) PV and WT characteristic and power curves. The rest four parts of Fig. 12 exhibit the power flow from renewable to either grid or load.

Figure 12g, h demonstrates the energy flow from RES to the grid and from grid to load, respectively. The vertical axis represents the fuzzy membership function as shown in Fig. 12k, while the horizontal axis represents the difference between the generated RE and the load (RE-L), at any time.

In Fig. 12-i the three columns that represent; from left to right, the difference (RE-L) output, power flow from grid to load and the power from renewable to grid. In case that the difference is positive, so, the energy flows directly to the grid while negative value means that the power is flowing from grid to load. At the top left it could be seen that the power is about 40 kW. As for Fig. 12-k, it could be seen that the difference is less than zero, hence, the load is supplied from the grid. The red vertical line represents the fuzzy logic control position.

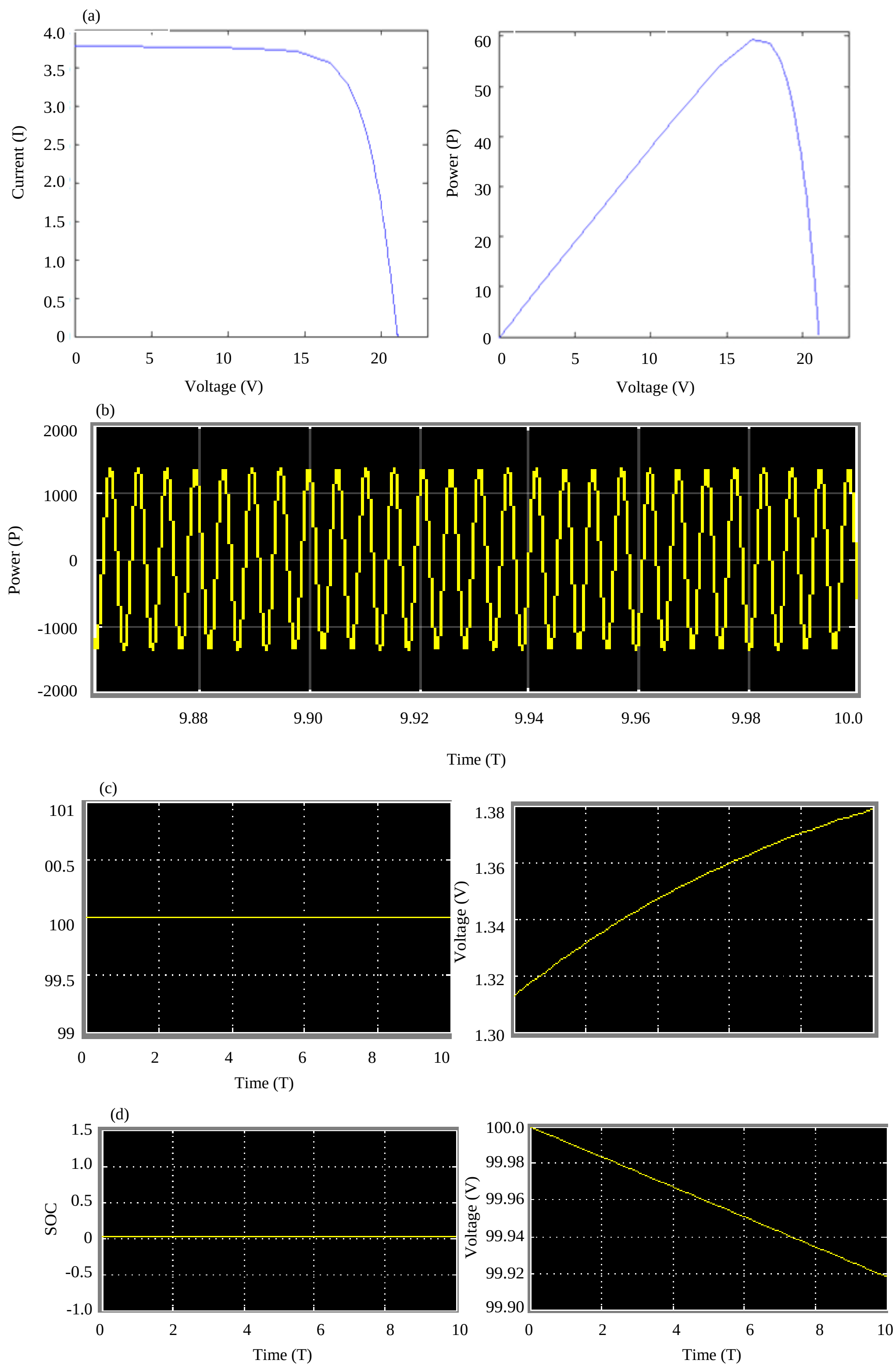

Fig. 9: Continue

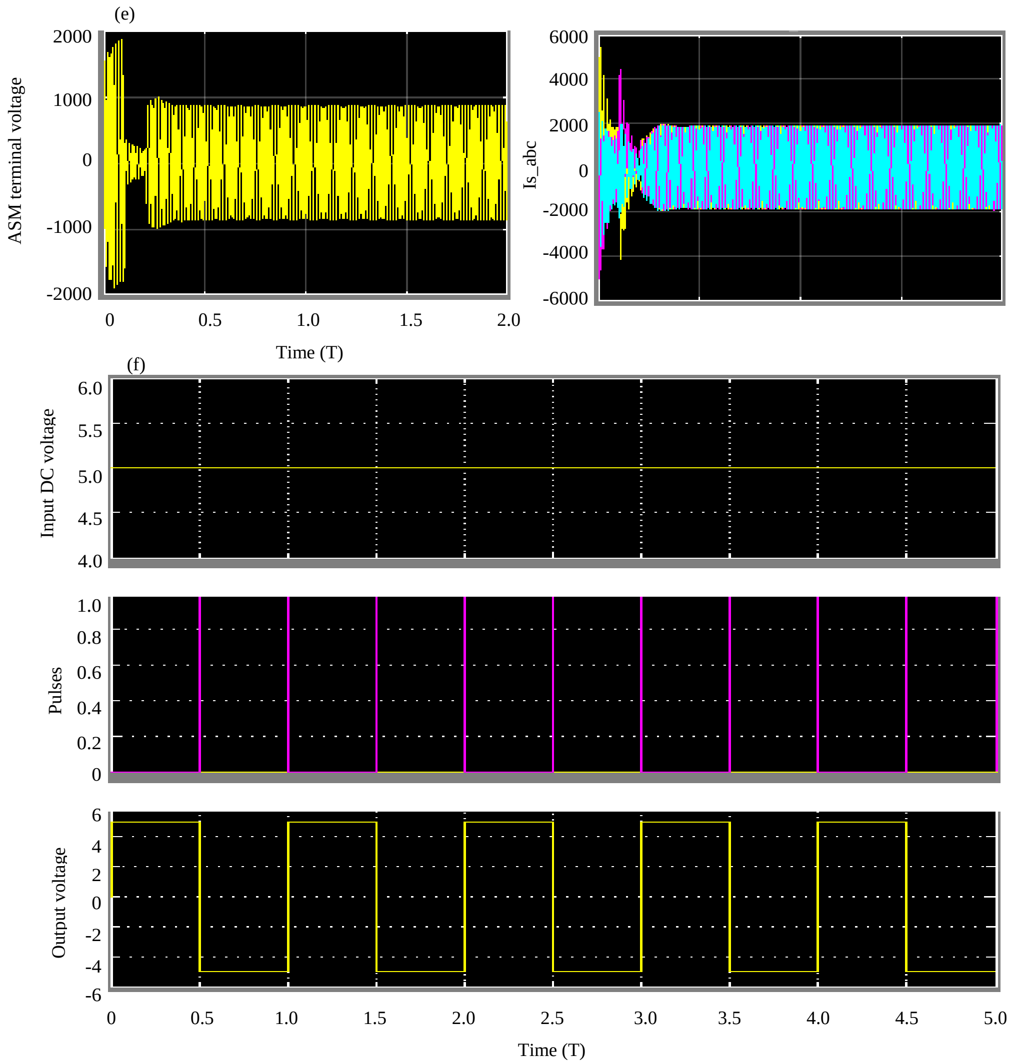

Fig. 9(a-f): (a) Simulation results of I-V and P-V curves of PV array output, (b) Simulation results of WT power curve, (c) Simulation results of SOC and V curves in charge battery (d) Simulation results of SOC and V curves in discharge battery, (e) Simulation results of I and V curves from diesel generator and (f) Simulation results of I and V curves from inverter output

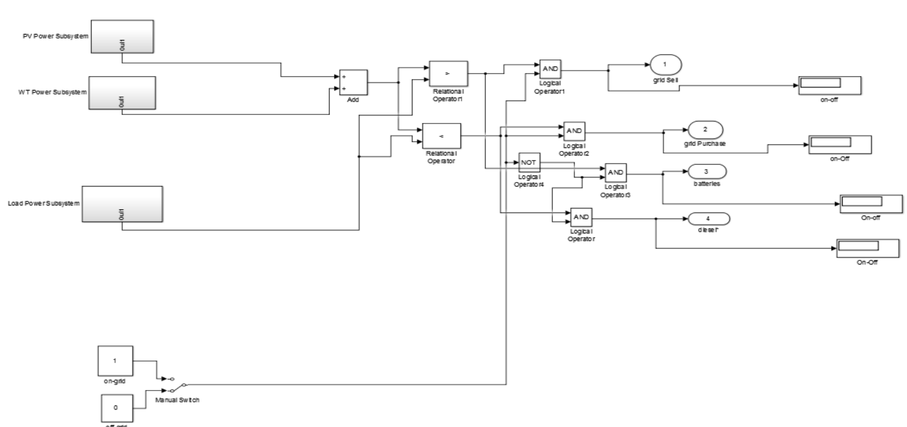

Fig. 10: Micro-grid control model in MATLAB/Simulink (On/O ff-grid mode)

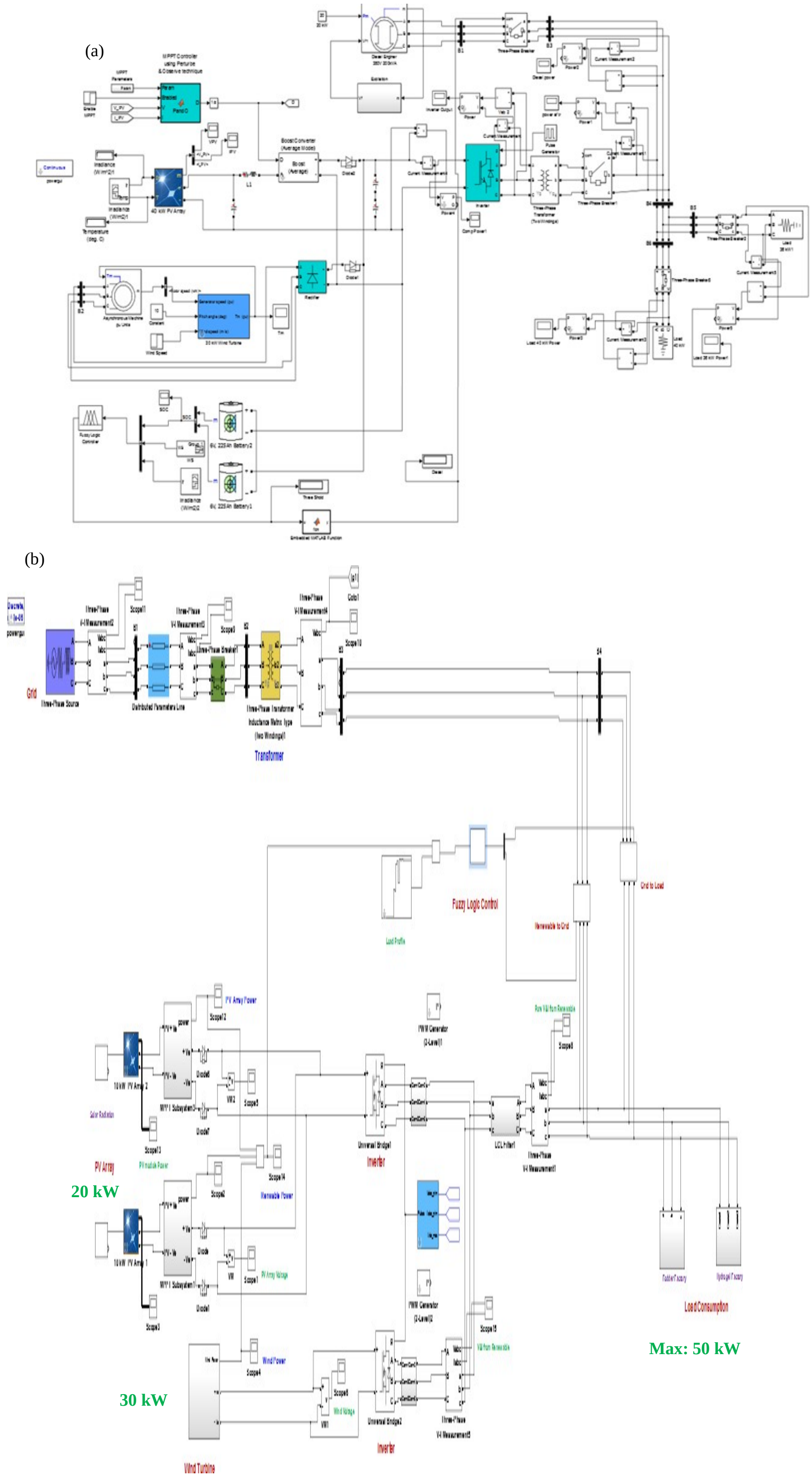

Fig. 11(a, b): Complete MATLAB/Simulink model of a micro-grid system (off grid) and (b) Complete MATLAB/Simulink model of a micro-grid system (on grid)

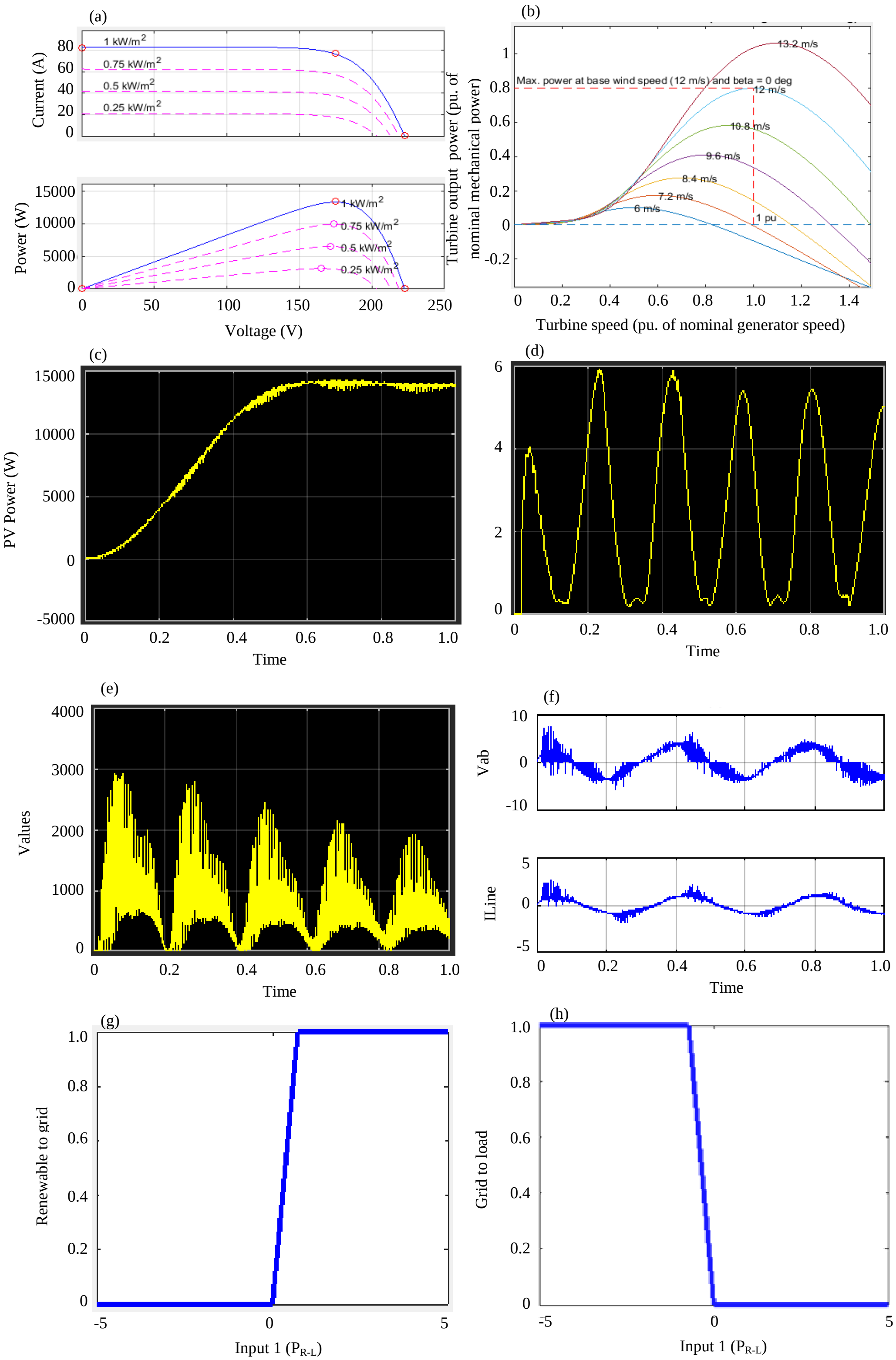

Fig. 12: Continue

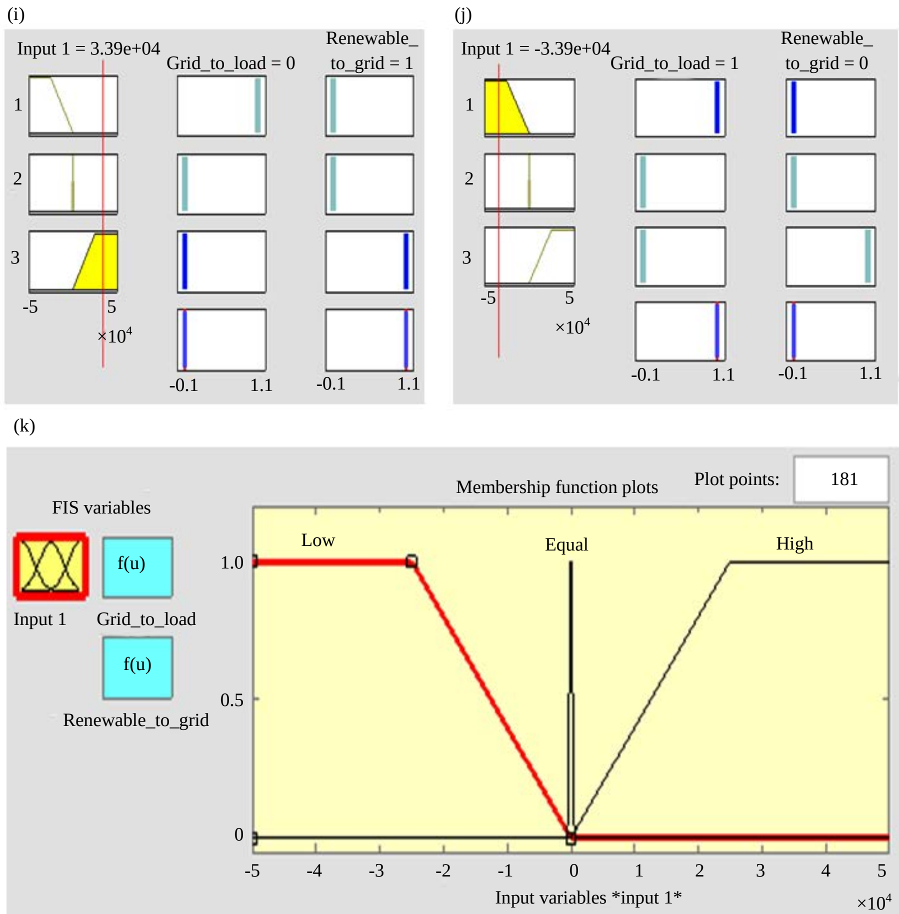

Fig. 12(a-k): (a) Simulation results of I-V & P-V curves of PV array output, (b) Simulation results WT characteristics, (c) Simulation results of PV power curve, (d) Simulation results of WT power curve, (e) Simulation results of PV array voltage, (f) Simulation results of WT current and voltage, (g) Renewable-to-grid curve, (h) Grid-to-load curve, (i) System fuzzy membership function, (j) Ruler viewer $0<P_{R\text{-}l}$ £5×10^4 and (k) Ruler viewer $0>P_{R\text{-}l}$ ³-5×104; $P_{R\text{-}l}$ is the difference power between renewable sources and the load

CONCLUSION

A Micro-Grid (MG) system that is based on renewable power generation units is presented in this paper. The proposed system has been designed to operate in two operational modes; islanded and grid connected. The system performance is investigated using a simulation based on MATLAB/Simulink software package.

A control coordinator and monitoring system is also included to monitor micro-grid system state and decide the necessary control action for an operational mode. The system design took into consideration cost reduction through using a single 3-phase inverter instead of three one-phase inverters. Moreover, transformer has been eliminated to supply power to its local loads. It is intended that this work will be the base for the developing more sophisticated micro-grid designes.

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