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Real-Time simulation microgrid model for *Solar Photovoltaic*

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Abstract

This paper is covering the works for Real-Time simulation of a DC micro grid system in Solar PV. Conventionally, centralized generation stations are widely implemented in the electricity generation. With the growing awareness of environment issues, the impacts of connecting distributed generations to micro grid are evaluated. Under this circumstance, the main purpose of this paper is to develop a functional Real-Time simulation micro grid model, and also its corresponding control strategies to stabilize the voltage output produced from different types of Distributed Generators and Battery Storage System. The micro grid model is developed using Simulink, meanwhile, three case studies concerning normal operation, PV sudden drop have been conducted. The outcomes from Simulink have confirmed its ability to handle fault occurrence to one distributed generator without influencing other generators and the grid connected.

Keywords: *Distributed Generation, Micro-grid, Real-Time Simulation, Photovoltaic Generation, and DC/DC Converter.*

1. Introduction

Human beings started using energy from nature from centuries ago. For the early stage of electricity generation industry, fossil fuel and coal are most-commonly used sources. These sources however, brought huge pollutions to the environment by exhausting toxic gas to air and releasing contaminated Water to surroundings. The pollutions increase massively with the huge demanding of energy in human Social activities in recent decades, bringing us the urge and necessity of renewable energy exploitation on to the stage. Under this circumstance, the world-wide efforts have been made to reduce the pollutions. For example, plenty of renewable energy generating plants have been involved in supporting electrical. By generating electricity in smaller amounts closer to end-users, we can dramatically increase energy efficiency, reduce carbon pollution, improve grid resiliency, and curtail the need for new transmission investments. Distributed generation (also called on-site generation or decentralized generation) is a term describing the generation of electricity for use on-site, rather than transmitting energy over the electric grid from a large, centralized facility (such as a coal-fired power plant).

As economic development outpaces the expansion of electricity supply in some areas of the country, and with other regions facing constraints on the ability to deliver power where and when it is needed, it is important to encourage local options for electricity transmission. Distributed energy resources (DER) refers to often smaller generation units that are located on the consumer's side of the meter.

Examples of distributed energy resources that can be installed include:

- Roof top solar photovoltaic units
- Wind generating units
- Battery storage
- Batteries in electric vehicles used to export power back to the grid
- Combined heat and power units, or tri-generation units that also utilize waste heat to provide cooling
- Biomass generators, which are fueled with waste gas or industrial and agricultural by-products.
- Open and closed cycle gas turbines
- Reciprocating engines (diesel, oil)
- Hydro and mini-hydro schemes
- Fuel cells.

1.1 Solar Photovoltaic

Photovoltaics (often shortened as PV) gets its name from the process of converting light (photons) to electricity

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(voltage), which is called the photovoltaic effect. This phenomenon was first exploited in 1954 by scientists at Bell Laboratories who created a working solar cell made from silicon that generated an electric current when exposed to sunlight. Solar cells were soon being used to power space satellites and smaller items such as calculators and watches. Today, electricity from solar cells has become cost competitive in many regions and photovoltaic systems are being deployed at large scales to help power the electric grid. Solar photovoltaic has become the two fastest renewable sources. In 2022, 212.5 TWh electricity was produced from solar power, comprised 12.0% of the total renewable energy production.

1.2 Silicon Solar Cells

The vast majority of today's solar cells are made from silicon and offer both reasonable prices and good efficiency (the rate at which the solar cell converts sunlight into electricity). These cells are usually assembled into larger modules that can be installed on the roofs of residential or commercial buildings or deployed on ground-mounted racks to create huge, utility-scale systems.

1.3 Thin-Film Solar Cells

Another commonly used photovoltaic technology is known as thin-film solar cells because they are made from very thin layers of semiconductor material, such as cadmium telluride or copper indium gallium dieseline. The thickness of these cell layers is only a few micrometers—that is, several millionths of a meter.

Thin-film solar cells can be flexible and lightweight, making them ideal for portable applications—such as in a soldier's backpack—or for use in other products like windows that generate electricity from the sun. Some types of thin-film solar cells also benefit from manufacturing techniques that require less energy and are easier to scale-up than the manufacturing techniques required by silicon solar cells.

1.4 III-V Solar Cells

A third type of photovoltaic technology is named after the elements that compose them. III-V solar cells are mainly constructed from elements in Group III—e.g., gallium and indium—and Group V—e.g., arsenic and antimony—of the periodic table. These solar cells are generally much more expensive to manufacture than other technologies. But they convert sunlight into electricity at much higher efficiencies. Because of this, these solar cells are often used on satellites, unmanned aerial vehicles, and other applications that require a high ratio of power-to-weight.

2.Micro-grid

The growth of DG, especially the renewable energy sources is considerable. It is predicted that the consumption and generation of renewable energy will increase by 30% from 2015 to 2040. As the integration of different types of distributed generations, huge challenges have been brought to the micro grids. Micro grid is generally expected to solve the problem of determining and reducing the power constraints of the irregularity of distributed generations and local loadings within the system [3]. Micro grid (MG) systems are usually comprised by different renewable energy sources, like solar energy or wind energy, local loadings, and energy storage devices. For the grid-connected micro grids, point of common coupling is also included, as shown in Fig.1.0

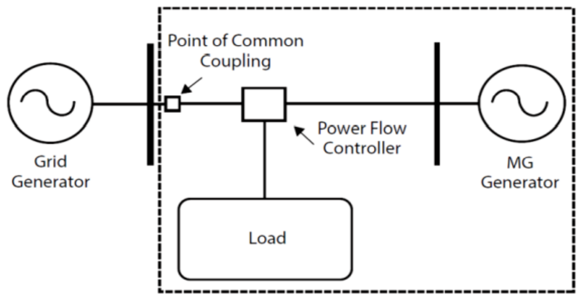

Figure 1: Generic Structure of Grid-connected Micro grid

2. Real-Time Simulation

To accommodate the rapid development of renewable energy sources, the stability and reliability of the grid has encountered severe challenges. It will take risks on testing the micro grid or distributed generations on active power grid. Therefore, the simulations of micro grid operation are significant for minimizing the unexpected or unpredictable scenarios. In the past, computers have already been able to simulate and analyze operation of electrical devices in the Simulink environment with detailed outcomes produced [5]. The computing performance of offline simulations is still not sufficient for complicated system at dynamic order. Apart from that, offline simulations have limitations on micro grid studies, including communications and protections The Real-Time platform that will be discussed more detailed in this project is OPAL-RT real-time simulator environment. OPAL-RT is one of the fastest and most reliable platforms which is widely accepted by the industry. It is able to test different types and levels of micro grid system and also be implemented with Hardware-in-the-Loop (HIL) simulation, which can be connected with actual controllers or protective relays. PV solar panel is basically a surface with PN junctions, which is based on photovoltaic effect. It works by having sunlight shines on the photovoltaic cell and absorbing photons with enough energy. Electrons from P-type and N-type silicon are excited from covalent bond to generate electron hole pairs the minority of electrons and holes close to interface layer are recombined, then the rest are separated by the electric field of the space charge. Electrons will flow to positively charge N region, while holes will be shifting to the P region, which creates potential difference between two regions.

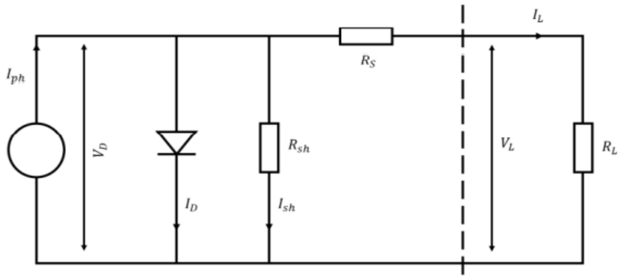

Figure 2: Equivalent circuit for photovoltaic cell

The equivalent circuit diagram for a photovoltaic cell is plotted in Fig.2.0, consisting of constant current source, diodes and resistors. The internal current generated from photovoltaic Iph can be formulated as below:

$$Iph = [Isc + KT\,(T - Tr\,)]\,S\,/1000$$

Where, Isc is the nominal short-circuit current level of photovoltaic cell;
K_T is the temperature index of Isc;
S is the irradiance level, $W/m2$;
T is the temperature around cell;
T_r is the nominal operation temperature of cell;
According to Kirchhoff's current law, it is significant to get the current flowing through diode to obtain the value of I_L. Then I_D is formulated as below

3. Modelling of Micro grid System

The requirements for this project are designing a typical low-voltage DC micro grid, and the structure of the micro grid is illustrated in Fig.3.0

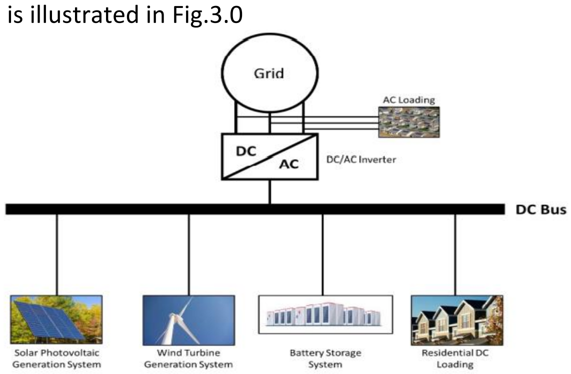

Figure 3: Line diagram of designed DC micro grid designed in the project

A micro grid system has been developed using MATLAB Simulink Power System function, in this case, a typical low voltage DC micro grid is presented in Fig.4

4.Simulation parameter and result discussion

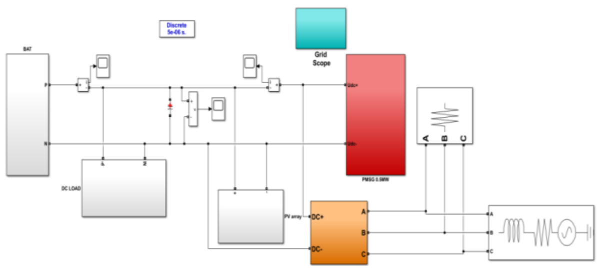

Figure 4: Simulink Micro grid Model designed in the project

The model is consisting of two main sections, DC side and AC side. The DC side is the main structure of the micro grid, while the AC side is the grid connecting section. In this model, the grid is modelled as a three-phase AC source. Within the DC micro grid, distributed generations, battery storage system and DC loadings are connected to demonstrate the full image of micro grid operation.

The photovoltaic generations convert solar energy into electricity for industry productions or residential demanding. For a better comprehensive of the impacts on photovoltaic arrays caused by irradiance levels and environment temperature, the solar cell model is developed. The key parameters of PV module used in the simulation have been listed in the Table.1

Table.1 Key parameters for Solar Photovoltaic modelling

Temperature	Parameters	Value
Temperature 30^0 C Irradiance Level=1000 W/m2	Open circuit voltage	560 V
	Short Circuit Current	1.30×10^3 A
	Maximum Operation Voltage	490.0 V
	Maximum Operation Current	950.0 A
	Maximum Power	4.70×10^5 W

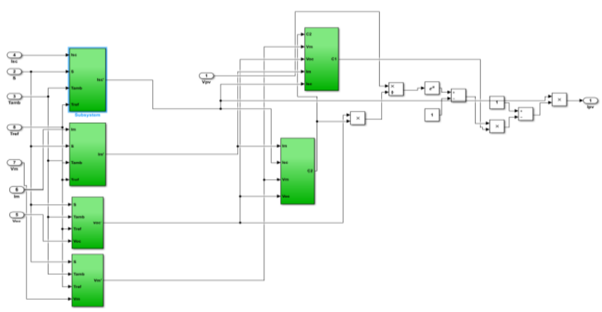

Figure 5: Detailed solar array modelling in the Simulink

Voc, open-circuit voltage, is the maximum voltage that a photovoltaic could output under certain temperature and irradiance level. Isc, short circuit current, is the maximum current level that can be generated under certain temperature and irradiance conditions. Im, maximum operational current, is the current level while the PV module is operating at maximum power condition (Pm). Vm, is the corresponding voltage level when PV module is at Pm. Incremental Conductance Algorithm is used for maximizing and tracking the photovoltaic generation system, hence, the full package of photovoltaic generation system is designed,

In this case study, a fault signal was input into the solar generation system, for the purpose of observing the reaction of the system handling this issue. In the Simulink solar module, a step-down signal has been introduced to the irradiance input, which steps from 1000 W/m2 to 0 W/m2 at T=2 (s). The output from solar suddenly drops from regular output level of 5 × 105 W to 0 W.

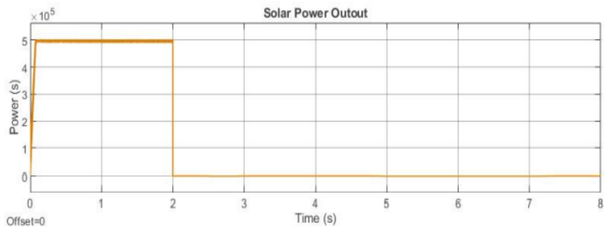

Figure 6: Solar Power output in PV sudden drop case when fault happens at T=2 s

It is clear that after PV gets disconnected from the system, the oscillation of bus voltage has become much lower, because of the MPPT's disturbance of voltage output across the solar generation system. The voltage was hovering around the maximum power point. Therefore, when PV gets disconnected, the MPPT was disabled, and there will be no severe oscillations for the value of voltage. As for the battery, since the total connected generation capacity has decreased, the rate of charge for battery has also been declined. Fig.7 shows the battery status before and after the PV disconnection.

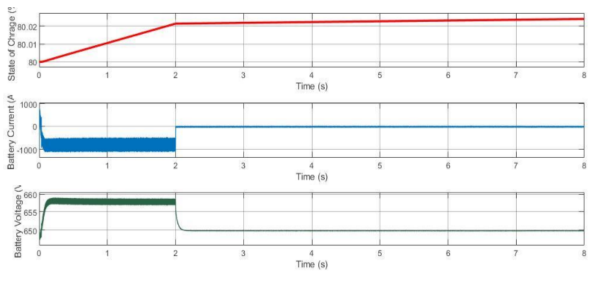

Figure 7: Battery Status before and after PV disconnection (State-of-Charge, Battery Current, and Battery Voltage)

Conclusion

The model is working as expected under fault occurrence. It is clear that the micro grid system designed can handle sudden drop of wind generation or PV generation. In the PV sudden drop case study, the bus voltage of micro-grid encountered with a drop, and re-climbed back to normal voltage level within 1200 ms, the drop lasts only 17 ms. In both fault handling cases, the battery storage system was not fully involved in the regulation of voltage level, which means the designed micro-grid system can handle larger capacity loss of generation within the system. In addition to its advantages, the limitation of the model is obvious. The delay of voltage climbing in PV sudden drop case is over 1 s, which can be further decreased by implementing faster reacting control method. Because of the limited project time, the outcomes discussed in this thesis are offline Simulink simulation results, thus, the ability of responding faults in Real-Time simulation has not been proved

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