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Research paper

Development of Smart Monitoring and Control System for Standalone Microgrids with PV Generation based on Everyday Power Consumption

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Abstract

In this paper, we propose a development of smart monitoring and control (SMC) system for Microgrids (MGs) with photovoltaic (PV) generation based on everyday power consumption. Since their introduction, microgrid systems have attracted both the utility and public interest as they represented autonomous structures for generating, delivering, and distributing clean and sustainable electric energy to loads and/or utility grids. A microgrid system is generally defined as an independent combination of generating units, storage units, and loads, and can be interconnected to a utility grid as a single entity. We develop SMC for a microgrid with PV generation based on the everyday power consumption, so the microgrid can be operated within specification and prevented from the battery over-discharging. As a result, the battery lifetime also keeps longer.

Keywords: *Microgrid; Photovoltaic Generation; SMC; Battery Lifetime*

1. Introduction

Photovoltaic (PV) penetration levels in the power grid have significantly increased during the last years. However, issues such as cloud-induced intermittency in PV generation forces equipment on the electrical grid to cycle excessively, preventing PV generation from being considered as a reliable or dispatchable source of power, particularly by utilities.

At the same time, the concept of the microgrid (MG) is gaining traction. Microgrids are standalone electrical grids or portions of a larger utility grid that can operate in a self-sustaining islanded mode. Examples of microgrids include a college campus or military base. For a microgrid with renewable generation such as PV, it is necessary to make it dispatchable by coordinating it with the energy storage units (ESU) and local fossil-fuel generation [1]. They typically include local generation, ESU, and controllable loads with coordinated control [2].

Also a microgrid is attracting considerable attention as a solution to energy deficiency, especially, in remote areas. A MG is defined as a group of interconnected loads and multiple distributed generators that are usually integrated via voltage source convertors and is able to operate in both grid-connected or island-mode.

In many countries of the world, it is usually difficult to extend the power grid to remote areas due to a variety of reasons including economic factors and reliability issues. As a result, many communities use independent diesel generators of firewood for daily energy needs. Because of cost of the fuel and its transportation, the capacity of power supplies on those remote areas are very limited and has a negative impact on the economic development of those regions [3]. However, many remote areas are normally rich in renewable energy that could be a key factor to solve the power supply problems when used adequately. Over the past years, different concepts of microgrid have been proposed by academicians and industry professionals in order to solve the power supply problems in remote areas [4]-[9]. The MG system is generally based on renewable energy sources such as wind, solar, and hydro, but these type of energies are usually stochastic and intermittent [10]. So, it is essential to make effective use of renewable energy sources while keeping a table,

reliable, and economic operation of MG. Much research has been made to pursue the optimization of MG system.
By the way, due to substantial generation and demand fluctuations in standalone green microgrids, energy management strategies are becoming essential for the power sharing and voltage regulation purposes. Methods for controlling an ESU can be broadly classified into deterministic scheduling, stochastic scheduling, rule-based control, feedback control, and feedforward control [11]-[15], with deterministic scheduling most commonly employed.
In this paper, the smart monitoring and control system for microgrid with PV generation is developed. Existing technology only displays the voltage and current and provides a warning or power control in accordance with the low voltage (over-discharge) of the battery. However, it does not show the amount of power consumption, so it is also difficult to investigate the cause of short lifetime of the battery which is used in that microgrid. To resolve this problem, we use deterministic scheduling and set a capacity of energy consumption per day (period setting also available). In case of power over-consumption, the system blocks the electricity or warns to the user and by doing this, we can make the microgrid operate within the planned specifications, which means there is no over-discharge to make the battery lifetime shorten or no abrupt stop of the electricity without any notice. Furthermore, by setting the period one day, everyday energy consumption will be reset and this results in everyday same power consumption.

2. SMC for Microgrids

Microgrids have two types, which are standalone or grid-connected.
Stand Alone System
A stand-alone system is a system that supplies electricity by solar power generation to areas where no electricity is supplied, such as remote islands. This microgrid consists of power generation modules (solar cell), ESU (battery), and DC/AC converter (inverter). Solar power modules generate electricity, and ESU stores electricity for use in the middle of the night or in bad weather, and the inverter converts direct current to an available alternating current.
The stand-alone system has the advantage of being able to use the electricity stored in the battery in the late night or the bad weather, but the battery is the cause of environmental destruction, the efficiency decreases due to charging and discharging, and the replacement cost due to short battery life is a disadvantage.
Grid-Connected System
The grid connection system is a system that uses both the electricity obtained from power generation modules and the electricity supplied by the utility. If you can't get solar photovoltaic generation in the late night or bad weather, you can get electricity from the existing power system, and if the electricity from solar power is left, you can send it to electric power company.
PV generation is an eco-friendly power generation system that uses sunlight, which is a clean and unlimited energy source. There is no emission of harmful substances or generation of pollution in the process of power generation. PV is robust and durable, not only has a long service life but also easy maintenance and also it is possible to reduce the electricity rate noticeably in the electricity bill of the residential use in Korea which progressive rate is applied.
Compared to other new and renewable energy facilities, installation time is shorter, so you can respond quickly to demand growth. It can be applied not only to houses, but also to various fields and products that are close to real life such as street lamps, cars, mobile phones. But of course, there is not good aspects in PV generation. It is a disadvantage that the amount of power generation depends on the amount of solar radiation in each region, the initial cost of installation is high, and the wide installation area is required due to low energy density.
This system has battery for energy storage, solarcell for PV generation, inverter for AC output and embedded system (MICOM) which monitors electric power and control output. In Fig. 1, there is the real prototype. The battery is Lithium-Ion type and nominal output voltage is 25V and the charging amount is 54AH. The inverter send AC output to the user for daily electric use and can provide 1KW. The solar cell is for PV generation and is designed for proper voltage generation which is enough to charge the battery and it provides charging current to the battery. The main part of our prototype is system monitoring and control module. it connects all modules and it executes electric power monitoring and control the output.

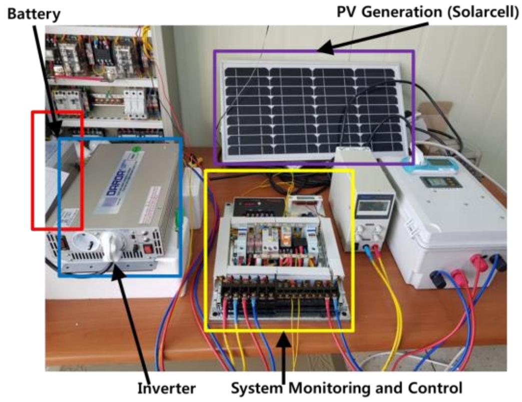

Fig. 1. Prototype.

System monitoring and control module consists of many functions as shown in Fig. 2. Charging controller get the solar cell electric current and provides it to the battery. Fuse is inserted for stopping the sudden large current flowing and the circuit breaker is the main switch which can stop all the system manually. For electric power monitoring, there is sensors and for electric power control, power control module (relay) is applied. Terminal block connects all the system properly.

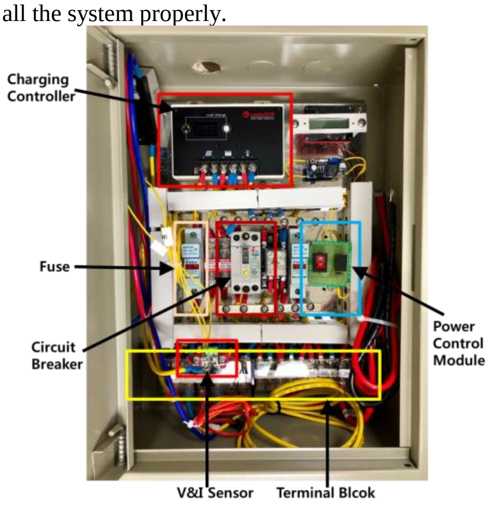

Fig. 2. Prototype.

3. System Monitoring and Control

For smart monitoring and control (SMC), the algorithm is designed as shown in Fig. 3. Everyday this algorithm starts and everyday it resets. The system charges the Li-Ion battery and when it starts, the everyday power consumption and period time (usually one day, i.e., 24 hours) can be set up. After setup, the electricity output starts until reaching the setup power consumption. So this process prevents from over discharging of the battery and also blocks more power consumption than the predetermined value.

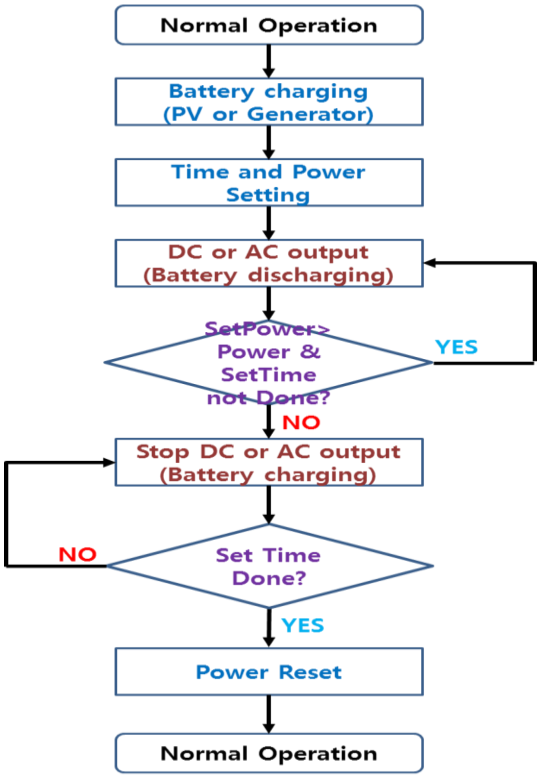

Fig. 3. SMC algorithm.

After reaching the pre-assigned power, the system stops the electric power output and waits for the used time 24 hours, which means next day. And the system resets and starts again. Of course, although the user does not reach the pre-assigned electric power, if the used time becomes 24 hours, than the system resets and starts again.

When monitoring electric power, we detect the voltage and electric current. In section 3.1, we talks about the voltage monitoring and in section 3.2, the electric current monitoring is described.

A. Voltage Monitoring

The embedded system detects analog value as a voltage, such as 5V range, which means that usually the minimum is 0V and the maximum value is 5V and the result is expressed as 1024 levels as a digital value. The applied voltage sensor uses voltage division law by two resistors 30KΩ, 7.5KΩ and by calculating, the measurable voltage range can be founded 0~25V(Vcc). As a result, the output of voltage sensor (0~1023, measured between (s) and (-) terminals) means 0~25V.

When monitoring, the electric power of the monitoring system also should be considered. It can be calculated as shown in (1), which assumes the maximum voltage 25V.

$$P_m = \frac{V^2}{R} = \frac{25^2}{37.5K} = 0.0167 \text{ [w]} \tag{1}$$

Usual unit system is Kwh for everyday electric power and if we convert the value into this unit system, the computed value is 0.0000167. It's very small enough to disregard for electric power consumption.

B. Current Monitoring

There are three ways to measure electric current, which are shunt resistor, transformer, and hall effect.

1) Shunt Resistor

It has inherent resistance and it outputs its own voltage proportional to the flowing current. It should be made of material so that the characteristic resistance does not change even when the maximum current flows. Most brass ends are connected with nichrome. If you measure big current, it becomes bulky and expensive. The decisive disadvantage is that it can't be isolated in a circuit.

2) Current Transformer

It makes use of magnetic induction phenomenon. It is the same principle as a transformer. The hook itself acts as an iron core, and the wire inside the hook corresponds to the primary winding (one-turn winding). Invisible, but inside the hook is a very thin coil wound with a secondary winding. Then, the current flowing in the primary winding is induced in the secondary winding, and the current is generated at the same ratio. This is to measure. However, the magnetic induction phenomenon must be possible only in the alternating current.

3) Hall Sensor

Another method is to use a Hall sensor. Hall sensors are devices whose voltage varies with the intensity of a magnetic field. By inserting a conductor into the magnetic field generated in a direction perpendicular to the current which flows through the conductor, a voltage-hole effect is generated in a direction perpendicular to the electric current. It can measure both direct current and alternating current.

4. Power Monitoring and Control

C. Power Monitoring

Power monitoring use the sensed V and I value. Basically electric power is computed as (2).

$$P_{kw} = \frac{V \cdot I}{1000} \text{ [kw]} \tag{2}$$

But usually we use the unit system [kwh] and it can be calculated as (3)

$$P_{kwh} = \frac{V \cdot I}{1000} t_s \text{ [kwh]} \tag{3}$$

where $t_s = \frac{\Delta t}{3600}$ [hr] and Δt is the time interval for monitoring, so the time interval is big, the measured electric power is just approximation and the time interval is small, the measured electric power becomes more accurate.

D. Power Control

As mentioned in the chapter 2, everyday power consumption and period is pre-assigned and the power control algorithm follows Fig. 4. In SMC embedded system, we use kwh unit system, so if we set the power consumption Pkwh=10, then it means 10 [kwh] every day. For power control, relay device is used and the relay control signal is generated by the SMC by comparing the used electric power with the pre-assigned value.

5. Test and Validation

For algorithm test, we used the 185wh Li Po battery, 500W inverter, sensor module and an embedded system for smart monitoring and control as shown in Fig. 4.

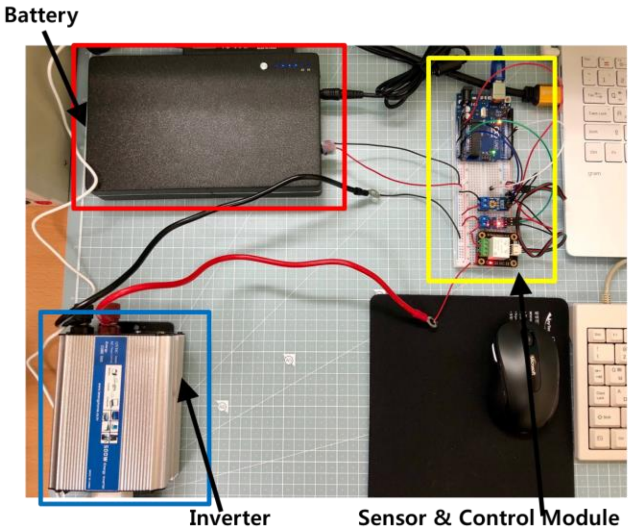

Fig. 4. SMC algorithm test system.

Sensor and control module consists of voltage sensor (25V), electric current sensor (30A), and a relay module for power control.

E. Voltage(V) Sensor

For verifying the sensor accuracy, voltage sensor is tested at first. By using DC power supply and multimeter, we measure the accurate voltage value and compare with the sensed value and the graph in Fig. 5 show the result Vm-Vs, which means the difference between accurate voltage and sensed voltage.

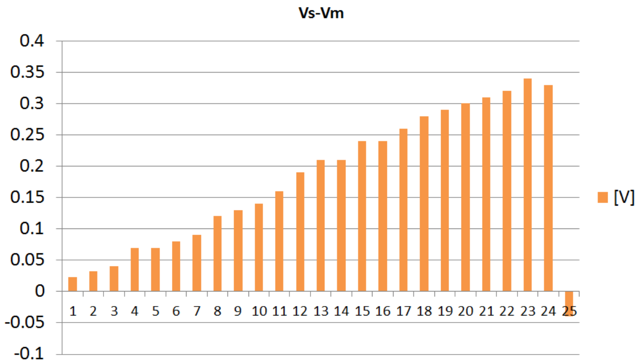

Fig. 5. Vm-Vs.

From the graph, the maximum difference is 0.34 and it's 1.36% of the maximum voltage 25V. Although it's not big and for fine sensing, the voltage sensor can be tuned by piece wise linearizing at the embedded controller programming.

F. Current(I) Sensor

For current sensor, we use the product specifications and a graph of output voltage and current based on product is shown in Fig. 10. At 0A which does not flow anything, 2.5V is output. It seems that the minimum / maximum are measured between 0.5 / 4.5V.

For showing everyday power consumption control, we used Pwh=0.1 [wh] for not long time experiment. It's very small and for the reference, usually in korea, the family daily electric usage is 10 [kwh]. The monitoring and control result is Fig. 6 and before reaching the pre-assigned power consumption (red alternated long and short dash line), every second shows the used electric power and after reaching the value, the power becomes zero because the power control shuts down the output.

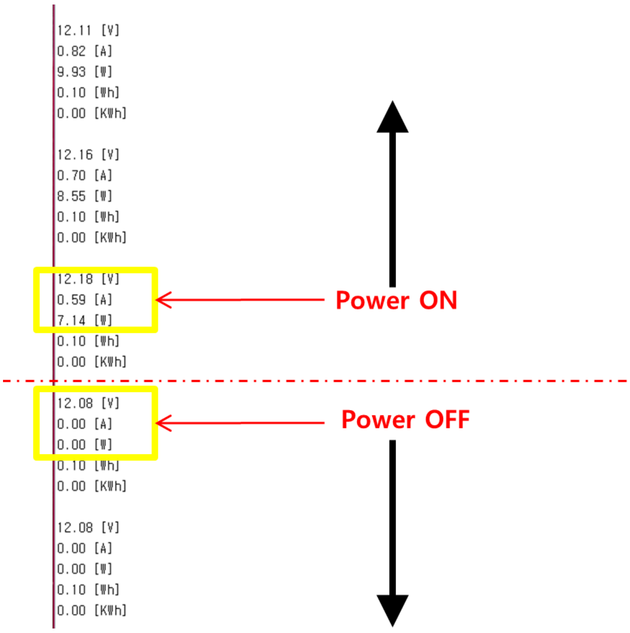

Fig. 6. Power monitoring and control.(Serial Communication)

6. Conclusion

This paper proposes the smart monitoring and control system development for micrograids with PV generation. This research object is to control everyday power consumption and to manage the battery effectively for better lifetime. By setting the amount of electricity used at home, it is possible to manage the amount of electricity used every day smartly and also to prevent over discharge of the battery. To do this, it monitors the amount of power and implements the function of resetting the amount of power used every day. The performance of the algorithm is verified using a test module and the same performance is achieved when the prototype is transplanted. In addition, by managing the charging and discharging of the battery, the battery life can be prolonged. As a following research, by monitoring the battery voltage every day, it is possible to efficiently manage the performance of the power system and improves the convenience of user's battery replacement by warning the battery replacement time in advance. The developed system will be the base for developing next algorithm.

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