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Power-Management Strategies for a Grid-Connected PV-FC Hybrid System

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Abstract: This paper presents a method to operate a grid connected hybrid system. The hybrid system composed of a Photovoltaic (PV) array and a Proton exchange membrane fuel cell (PEMFC) is considered. The PV array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when variations in irradiation and temperature occur, which make it become an uncontrollable source. In coordination with PEMFC, the hybrid system output power becomes controllable. Two operation modes, the unit-power control (UPC) mode and the feeder-flow control (FFC) mode, can be applied to the hybrid system. The coordination of two control modes, the coordination of the PV array and the PEMFC in the hybrid system, and the determination of reference parameters are presented. The proposed operating strategy with a flexible operation mode change always operates the PV array at maximum output power and the PEMFC in its high efficiency performance band, thus improving the performance of system operation, enhancing system stability, and decreasing the number of operating mode changes.

Keywords: Distributed Generation, Fuel Cell, Hybrid System, Microgrid, Photovoltaic, Power Management.

I. INTRODUCTION

Renewable energy is currently widely used. One of these resources is solar energy. The photovoltaic (PV) array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when there are variations in irradiation and temperature. The disadvantage of PV energy is that the PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. In order to overcome these inherent drawbacks, alternative sources, such as PEMFC, should be installed in the hybrid system. By changing the FC output power, the hybrid source output becomes controllable. However, PEMFC, in its turn, works only at a high efficiency within a specific power range ($P^{low}_{FC} \div P^{up}_{FC}$) [2], [3]. The hybrid system can either be connected to the main grid or work autonomously with respect to the grid-connected mode or islanded mode, respectively.

In the grid-connected mode, the hybrid source is connected to the main grid at the point of common coupling (PCC) to deliver power to the load. When load demand changes, the power supplied by the main grid and hybrid system must be properly changed. The power delivered from the main grid and PV array as well as PEMFC must be coordinated to meet load demand. The hybrid source has two control modes: 1) unit-power control (UPC) mode and feeder-flow control (FFC) mode. In the UPC mode, variations of load demand are compensated by the main grid because the hybrid source output is regulated to reference power. Therefore, the reference value of the hybrid source output P^{ref}_{MS} must be determined. In the FFC mode, the feeder flow is regulated to a constant, the extra load demand is picked up by the hybrid source, and, hence, the feeder reference power P^{ref}_{feeder} must be known. The proposed operating strategy is to coordinate the two control modes and determine the reference values of the UPC mode and FFC mode so that all constraints are satisfied. This operating strategy will minimize the number of operating mode changes, improve performance of the system operation, and enhance system stability.

II. DISTRIBUTED GENERATION

Distributed Generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy generates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal, gas powered) nuclear or hydropower plants. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. Most plants are built this way due to a number of economic, health & safety, logistical. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water

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flow. Most power plants are often considered to be too far away for their waste heat to be used for heating buildings.

Distributed generation is another approach. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed. Typical distributed power sources in a Feed-in Tariff (FIT) scheme have low maintenance, low pollution and high efficiencies. In the past, these traits required dedicated operating engineers and large complex plants to reduce pollution. However, modern embedded systems can provide these traits with automated operation and renewable, such as sunlight, wind and geothermal. This reduces the size of power plant that can show a profit. Recently interest in Distributed Energy Systems (DES) is increasing, particularly onsite generation. This interest is because larger power plants are economically unfeasible in many regions due to increasing system and fuel costs, and more strict environmental regulations.

In addition, recent technological advances in small generators, Power Electronics, and energy storage devices have provided a new opportunity for distributed energy resources at the distribution level, and especially, the incentive laws to utilize renewable energies has also encouraged a more decentralized approach to power delivery. There are many generation sources for DES: conventional technologies (diesel or natural gas engines), emerging technologies (micro turbines or fuel cells or energy storage devices), and renewable technologies (small wind turbine s or solar/photovoltaic’s or small hydro turbines). These DES are used for applications to a standalone, a standby, a grid-interconnected, a cogeneration, peak shavings, etc. and have many advantages such as environmental-friendly and modular electric generation, increased reliability, high power quality, uninterruptible service, cost savings, on-site generation, expandability, etc. So many utility companies are trying to construct small distribution stations combined with several DES available at the regions, instead of large power plants.

Basically, these technologies are based on notably advanced Power Electronics because all DES require Power Converters, interconnection techniques, and electronic control units. That is, all power generated by DES is generated as DC Power, and then all the power fed to the DC distribution bus is again converted into an AC power with fixed magnitude and frequency by control units using Digital Signal Processor (DSP). So improved power electronic technologies that permit grid interconnection of asynchronous generation sources are definitely required to support distributed generation resources. The research works in the recent papers about DES focus on being utilized directly to a standalone AC system or fed back to the utility mains. That is, when in normal operation or main failures, DES directly supply loads with power (standalone mode or standby mode), while, when DES have surplus power or need more power, this system operates in parallel mode to the mains. Therefore, in order to permit to connect more generators on the network in good conditions, a good technique about interconnection with the grid and voltage regulations should overcome the problems due to parallel operation of Power Converter for applications to DES.

III. HYBRID SYSTEM CONTROL STUDY

Hybrid power systems combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either. Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and / or economics. Hybrid systems can be designed to maximize the use of renewable, resulting in a system with lower emissions than traditional fossil-fueled technologies. Hybrid systems can be designed to achieve desired attributes at the lowest acceptable cost, which is the key to market acceptance. Now a day‘s most popular renewable energy resources are solar, wind and fuel cells. The photovoltaic (PV) array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when there are variations in irradiation and temperature. The disadvantage of PV energy is that the PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night.

In order to overcome these inherent drawbacks, alternative sources, such as PEMFC and wind mill, should be installed in the hybrid system. By changing the FC output power and wind mill output power, the hybrid source output becomes controllable. The hybrid system can either be connected to the main grid or work autonomously with respect to the grid-connected mode or islanded mode, respectively. In the grid-connected mode, the hybrid source is connected to the main grid at the point of common coupling (PCC) to deliver power to the load. When load demand changes, the power supplied by the main grid and hybrid system must be properly changed. The control modes in the micro grid include unit power control, feeder flow control, and mixed control mode. The two control modes were first proposed by Lasserter. In the UPC mode, the DGs (the hybrid source in this system) regulate the voltage magnitude at the connection point and the power that source is injecting. In this mode if a load increases anywhere in the micro grid, the extra power comes from the grid, since the hybrid source regulates to a constant power.

In the FFC mode, the DGs regulate the voltage magnitude at the connection point and the power that is flowing in the feeder at connection point $P_{Freeder}$. With this control mode, extra load demands are picked up by the DGs, which maintain a constant load from the utility view point. In the mixed control mode, the same DG could control either its output power or the feeder flow power. In other words, the mixed control mode is a coordination of the UPC mode and the FFC mode. Both of these concepts were considered. In this paper, a coordination of the UPC mode and the FFC two control modes was applied and to determine a reference value for each mode. Moreover, in the hybrid system, the PV and PEMFC sources have their constraints. Therefore, the reference power must be set at an appropriate value so that the constraints of these sources are satisfied. The proposed operation strategy presented in the next section is also based on the minimization of mode change. This proposed operating strategy will be able to improve performance of the system's operation and enhance system stability.

IV. SIMULATION RESULT AND DISCUSSION

A. Simulation Results in the Case without Hysteresis

A simulation was carried out by using the system model to verify the operating strategies. The system parameters are shown in Table I.

TABLE I: System Parameters

Parameter	Value	Unit
P_{FC}^{low}	0.01	MW
P_{FC}^{up}	0.07	MW
P_{Feeder}^{max}	0.01	MW
ΔP_{MS}	0.03	MW

In order to verify the operating strategy, the load demand and PV output were time varied in terms of step. According to the load demand and the change of PV output, P_{FC}, P^{ref}_{MS}, P^{ref}_{Feeder} and the operating mode were determined by the proposed operating algorithm. Fig. 1 shows the simulation results of the system operating strategy. The changes of P_{PV} and P_{Load} are shown in Fig. 1(a) (Δ line) and Fig. 1(b) (0, line), respectively. Based on P_{PV} and the constraints of P_{FC} shown in Table I, the reference value of the hybrid source output P^{ref}_{MS} is determined as dipicted in Fig. 1(a) (o line). From 0 s to 10 s, the PV operates at standard test conditions to generate constant power and, thus, P^{ref}_{MS} is constant. From 10 s to 20 s, P_{PV} changes step by step and, thus, P^{ref}_{MS} is defined as the algorithm. The PEMFC ouput , as shown in Fig. 1(a) (● line), changes according to the change of P_{PV} and P_{MS}. Fig. 1(c) shows the system operating mode.

The UPC mode and FFC mode correspond to values 0 and 1, respectively. From 4 s to 6 s, the system works in FFC mode and, thus, P^{max}_{Feeder} becomes the feeder reference value. During FFC mode, the hybrid source output power changes with respect to the change of load demand, as in Fig. 1(b). On the contrary, in UPC mode, P_{MS} changes following P^{ref}_{MS}, as shown in Fig. 1(a). It can be seen from Fig. 1 that the system only works in FFC mode when the load is heavy. The UPC mode is the major operating mode of the system and, hence, the system works more stably. It can also be seen from Fig. 1(a) that at 12 s and 17 s, P^{ref}_{MS} changes continuously. This is caused by variations of in P_{PV} the MPPT process. As a result, P_{MS} and P_{FC} oscillate and are unstable. In order to overcome these drawbacks, a hysteresis was used to control the change of P^{ref}_{MS}, as in the simulation results of the system, including the hysteresis, are depicted in Fig. 2.

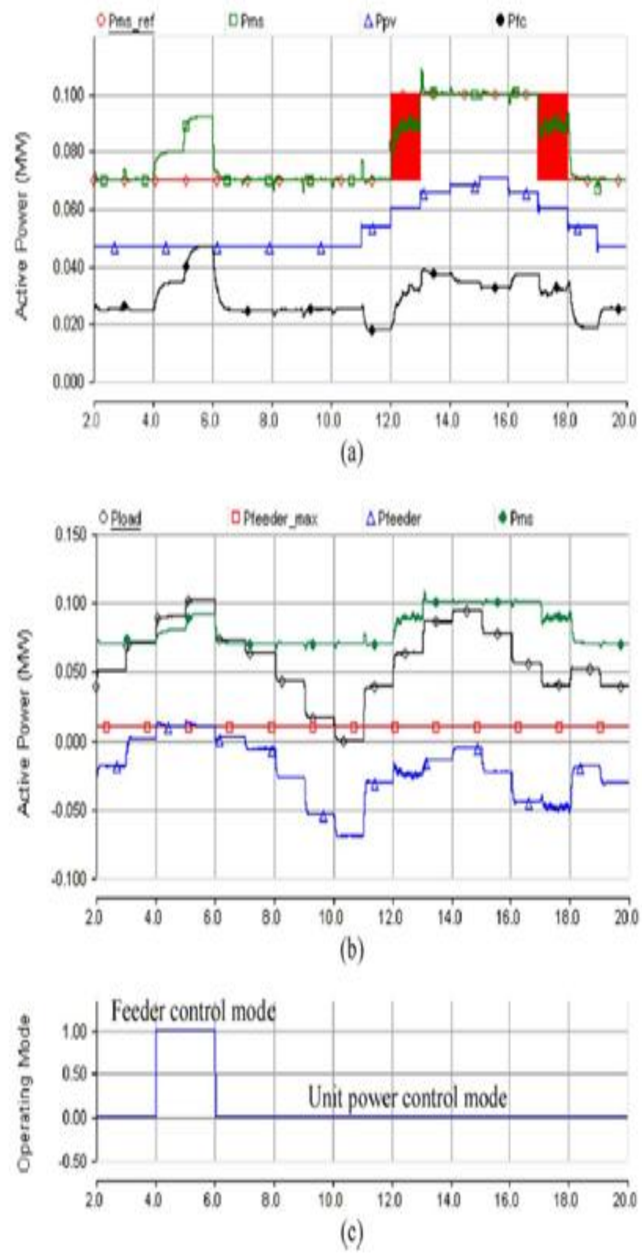

Fig.1. Simulation result without hysteresis. (a) Operating strategy of the hybrid source. (b) Operating strategy of the whole system. (c) Change of operating modes.

B. Improving Operation Performance by Using Hysteresis

Fig.2 shows the simulation results when hysteresis was included with the control scheme. From 12 s to 13 s and from 17 s to 18 s, the variations of P^{ref}_{MS} [Fig. 2(a), o line], FC output [Fig. 2(a), ●line], and feeder flow [Fig. 2(b), Δ line] are eliminated and, thus, the system works more stably compared to a case without hysteresis (Fig. 1). Fig. 2(d) shows the frequency variations when load changes or when the hybrid source reference power P^{ref}_{MS} changes (at 12 s and 18 s). The parameter C was chosen at 0.03 MW and, thus, the frequency variations did not reach over its limit (±5 % * 60 = ± 0.3 Hz).

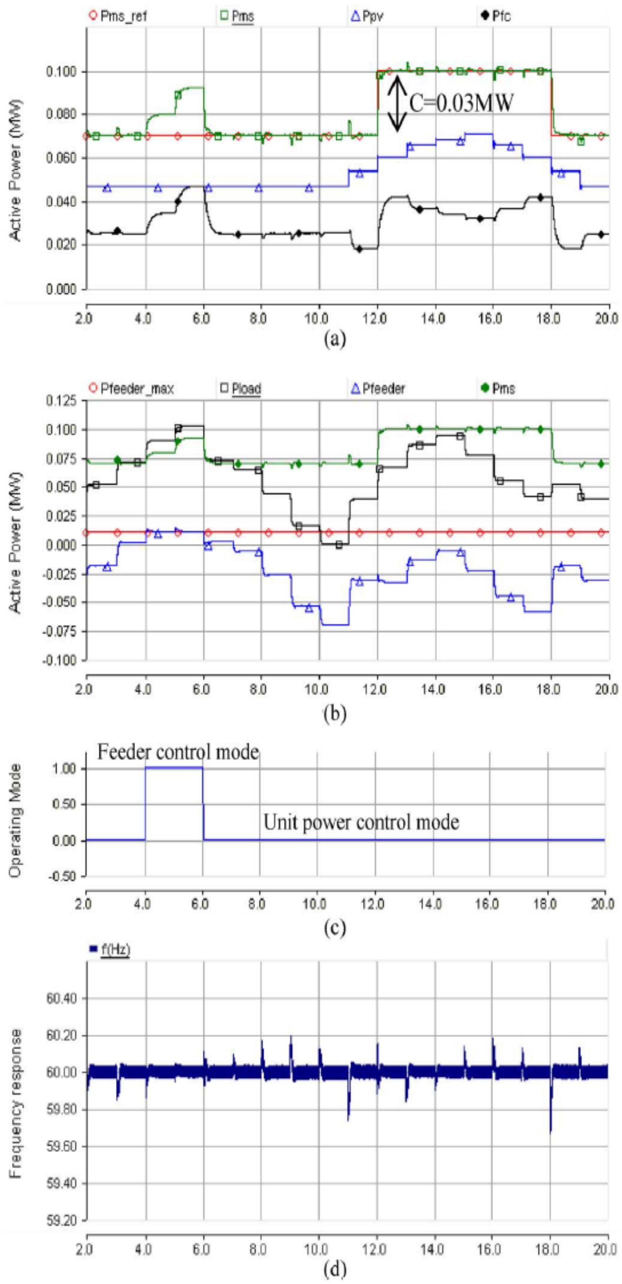

Fig. 2. Improving operation performance by using hysteresis: (a) The operating strategy of the hybrid source; (b) Operating strategy of the whole system. (c) Change of operating modes. (d) Frequency variations occur in the system.

C. Discussion

It can be seen from Fig. 2(b) that during the UPC mode, the feeder flow (Δ line) changes due to the change of load (□ line) and hybrid source output (● line). This is because in the UPC mode, the feeder flow must change to match the load demand. However, in a real-world situation, the microgrid should be a constant load from the utility viewpoint. In reality, the microgrid includes some DGs connected in parallel to the feeder. Therefore, in the UPC mode, the changes of load will be compensated for by other FFC mode DGs and the power from the main grid will be controlled to remain constant. In the case in which there is only one hybrid source connected to the feeder, the hybrid source must work in the FFC mode to maintain the feeder flow at constant. Based on the proposed method, this can be accomplished by setting the maximum value of the feeder flow (P^{max}_{Feeder}) to a very low value and, thus, the hybrid source is forced to work in the FFC mode. Accordingly, the FC output power must be high enough to meet the load demand when load is heavy and/or at night without solar power. From the aforementioned discussions, it can be said that the proposed operating strategy is more applicable and meaningful to a real-world microgrid with multi DGs.

V. CONCLUSION

This paper has presented an available method to operate a hybrid grid-connected system. The hybrid system, composed of a PV array and PEMFC, was considered. The operating strategy of the system is based on the UPC mode and FFC mode. The purposes of the proposed operating strategy presented in this paper are to determine the control mode, to minimize the number of mode changes, to operate PV at the maximum power point, and to operate the FC output in its high-efficiency performance band. The main operating strategy, is to specify the control mode; the algorithm is to determine P^{ref}_{MS} in the UPC mode. With the operating algorithm, PV always operates at maximum output power, PEMFC operates within the high-efficiency range ($P^{low}_{FC} \div P^{up}_{FC}$), and feeder power flow is always less than its maximum value (P^{max}_{Feeder}). The change of the operating mode depends on the current load demand, the PV output, and the constraints of PEMFC and feeder power. With the proposed operating algorithm, the system works flexibly, exploiting maximum solar energy; PEMFC works within a high-efficiency band and, hence, improves the performance of the system's operation. The system can maximize the generated power when load is heavy and minimizes the load shedding area. When load is light, the UPC mode is selected and, thus, the hybrid source works more stably.

The changes in operating mode only occur when the load demand is at the boundary of mode change (P_{Load1}); otherwise, the operating mode is either UPC mode or FFC mode. Besides, the variation of hybrid source reference power P^{ref}_{MS} is eliminated by means of hysteresis. In addition, the number of mode changes is reduced. As a consequence, the system works more stably due to the minimization of mode changes and reference value variation. In brief, the proposed operating algorithm is a simplified and flexible method to operate a hybrid source in a grid-connected microgrid. It can improve the performance of the system's operation; the system works more stably while maximizing the PV output power. For further research, the operating algorithm, taking the operation of the battery into account to enhance operation performance of the system, will be considered. Moreover, the application of the operating algorithm to a microgrid with multiple feeders and DGs will also be studied in detail.

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