IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

POWER MANAGEMENT STRATEGIES FOR A GRID CONNECTED PV-FC HYBRID SYSTEM(MICROGRID)

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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.

***Index Terms* - 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 [1], [2]. 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 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 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. RESEARCH METHODOLOGY

A. Structure of Grid-Connected Hybrid Power System.

The system consists of a PV-FC hybrid source with the main grid connecting to loads at the PCC as shown in Fig. 1. The photovoltaic, and the PEMFC, are modeled as nonlinear voltage sources. These sources are connected to dc–dc converters which are coupled at the dc side of a dc/ac inverter. The dc/dc connected to the PV array works as an MPPT controller. Many MPPT algorithms have been proposed in the literature, such as incremental conductance (INC), constant voltage (CV), and perturbation and observation (P&O). The P&O method has been widely used because of its simple feedback structure and fewer measured parameters. The P&O algorithm with power feedback control is shown in Fig. 2. As PV voltage and current are determined, the power is calculated. At the maximum power point, the derivative is equal to zero. The maximum power point can be achieved by changing the reference voltage by the amount of ΔVref.

B. PV Array Model

The mathematical model [3], [4] can be expressed as

$$I = I_{\text{ph}} - I_{\text{sat}} \left\{ \exp\left[\frac{q}{AKT}(V + IR_s) \right] - 1 \right\}.$$

Equation (1) shows that the output characteristic of a solar cell is nonlinear and vitally affected by solar radiation, temperature, and load condition.

Photocurrent I_{ph} is directly proportional to solar radiation G_a

$$I_{\text{ph}}(G_a) = I_{\text{sc}} \frac{G_a}{G_{\text{as}}}.$$

The short-circuit current of solar cell I_{sc} depends linearly oncell temperature

$$I_{\text{sc}}(T) = I_{scs}[1 + \Delta I_{\text{sc}}(T - T_s)].$$

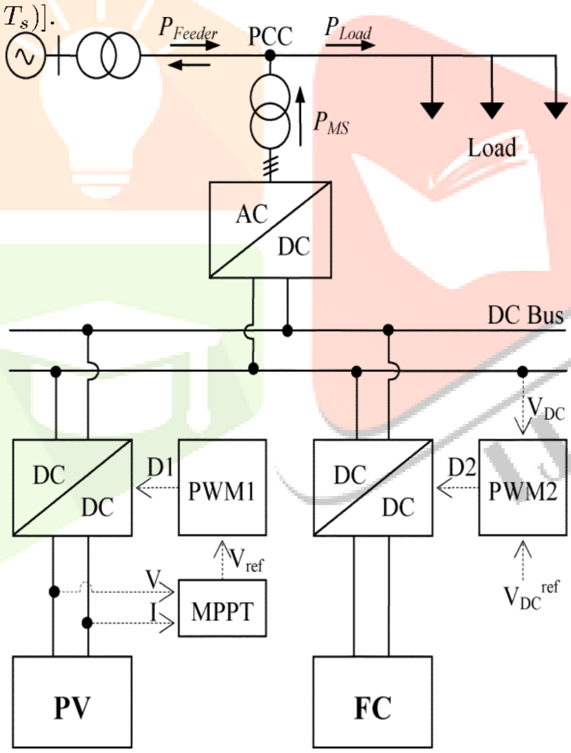


Fig. 1. Grid-connected PV-FC hybrid system.

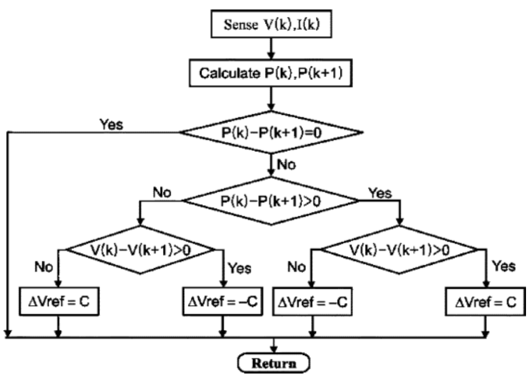


Fig. 2. P&O MPPT algorithm.

Thus, I_{ph} depends on solar irradiance and cell temperature

$$I_{\text{ph}}(G_a, T) = I_{scs}\frac{G_a}{G_{\text{as}}}[1 + \Delta I_{\text{sc}}(T - T_s)].$$

I_{sat} also depends on solar irradiation and cell temperature andcan be mathematically expressed as follows:

$$I_{\text{sat}}(G_a, T) = \frac{I_{\text{ph}}(G_a, T)}{e^{\left(\frac{V_{\text{oc}}(T)}{V_t(T)}\right)} - 1}.$$

C. PEMFC MODEL

The PEMFC steady-state feature of a PEMFC source is as-sessed by means of a polarization curve, which shows the non-linear relationship between the voltage and current density. ThePEMFC output voltage is as follows :

where E_{Nerst} is the "thermodynamic potential" of Nerst, whichrepresents the reversible (or open-circuit) voltage of the fuel cell. Activation voltage drop V_{act} is given in the Tafel equation as

$$V_{\text{act}} = T[a + bln(I)]$$

where a, b are the constant terms in the Tafel equation (in voltsper Kelvin)

The overall ohmic voltage drop V_{ohm} can be expressed as

$$V_{\text{ohm}} = IR_{\text{ohm}}.$$

The ohmic resistance R_{ohm} of PEMFC consists of the resistance of the polymer membrane and electrodes, and the resistances ofthe electrodes.

The concentration voltage drop V_{conc} is expressed as

$$V_{\text{conc}} = -\frac{RT}{zF}ln\left(1 - \frac{I}{I_{\text{limit}}}\right)$$

D. MPPT CONTROL

Many MPPT algorithms have been proposed in the literature,such as incremental conductance (INC), constant voltage (CV), and perturbation and observation (P&O). The two algorithms often used to achieve maximum power point tracking are the P&O and INC methods. The INC method offers good performance under rapidly changing atmospheric conditions. How-ever, four sensors are required to perform the computations.If the sensors require more conversion time, then the MPPT process will take longer to track the maximum power point. During tracking time, the PV output is less than its maximum power. This means that the longer the conversion time is, the larger amount of power loss will be. On the contrary, if the execution speed of the P&O method increases, then the systemloss will decrease. Moreover, this method only requires two sen-sors, which results in a reduction of hardware requirements andcost. Therefore, the P&O method is used to control the MPPT process.

In order to achieve maximum power, two different applied control methods that are often chosen are voltage-feedback con-trol and power-feedback control. Voltage-feedback control uses the solar-array terminal voltage to control and keep thearray operating near its maximum power point by regulating thearray's voltage and matching the voltage of the array to a desired voltage. The drawback of the voltage-feedback control is its neglect of the effect of irradiation and cell temperature. Therefore, the power-feedback control is used to achieve maximum power.The P&O MPPT algorithm with a power-feedback control.

The buck-boost converter consists of one switching device (GTO) that enables it to turn on and off depending on the applied gate signal . The gate signal for the GTO can be obtained by comparing the sawtooth waveform with the control voltage. The change of the reference voltage obtainedby MPPT algorithm becomes the input of the pulsewidth modulation (PWM). The PWM generates a gate signal to control the buck-boost converter and, thus, maximum power is trackedand delivered to the ac side via a dc/ac inverter.

III. RESULTS AND DISCUSSION

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

In order to verify the operating strategy, the load demand andPV output were time varied in terms of step. According to the load demand and the change of PV output, and the operating mode were determined by the proposed operating algorithm. Fig. 8 shows the simulation results of thesystem operating strategy. The changes of P_{PV} and P_{Load} areshown in Fig. 8(a) (line) and Fig. 8(b) (line), respectively.

Based on P_{PV} and the constraints of P_{FC} shown in Table I, the reference value of the hybrid source output $P_{\mathrm{MS}}^{\mathrm{ref}}$ is determined as dipicted in Fig. 8(a) (o line). From 0 s to 10 s, the PVoperates at standard test conditions to generate constant power and, thus, $P_{\mathrm{MS}}^{\mathrm{ref}}$ is constant. From 10 s to 20 s, P_{PV} changesstep by step and, thus, $P_{\mathrm{MS}}^{\mathrm{ref}}$ is defined as the algorithm shown in Fig. 4 or 5. The PEMFC ouput P_{FC}, as shown in Fig. 8(a)(line), changes according to the change of P_{PV} and P_{MS}. Fig. 8(c) shows the system operating mode. The UPC mode andFFC mode correspond to values 0 and 1, respectively.

The system works in FFC mode and, thus, $P_{\mathrm{Feeder}}^{\mathrm{max}}$ be- comes the feeder reference value. During FFC mode, the hybrid source output power changes with respect to the change of loaddemand, as in Fig. 8(b). On the contrary, in UPC mode, P_{MS} changes following $P_{\mathrm{MS}}^{\mathrm{ref}}$, as shown in Fig. 8(a).

It can be seen from Fig. 8 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 morestably.

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

It can be seen from Fig. 9(b) that during the UPC mode, thefeeder flow (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.

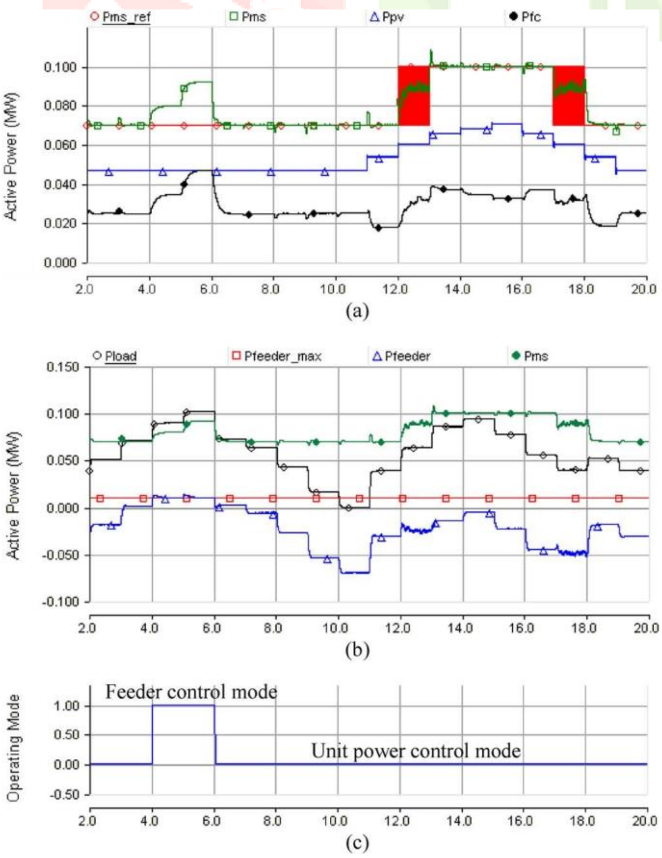
However, in a real-world situation, the microgrid should be a constant load from the utility viewpoint . In reality, the microgrid includes some DGs connected in parallel to the feeder. Therefore, in the UPC mode, the changes of load willbe compensated for by other FFC mode DGs and the power from the main grid will be controlled to remain constant.

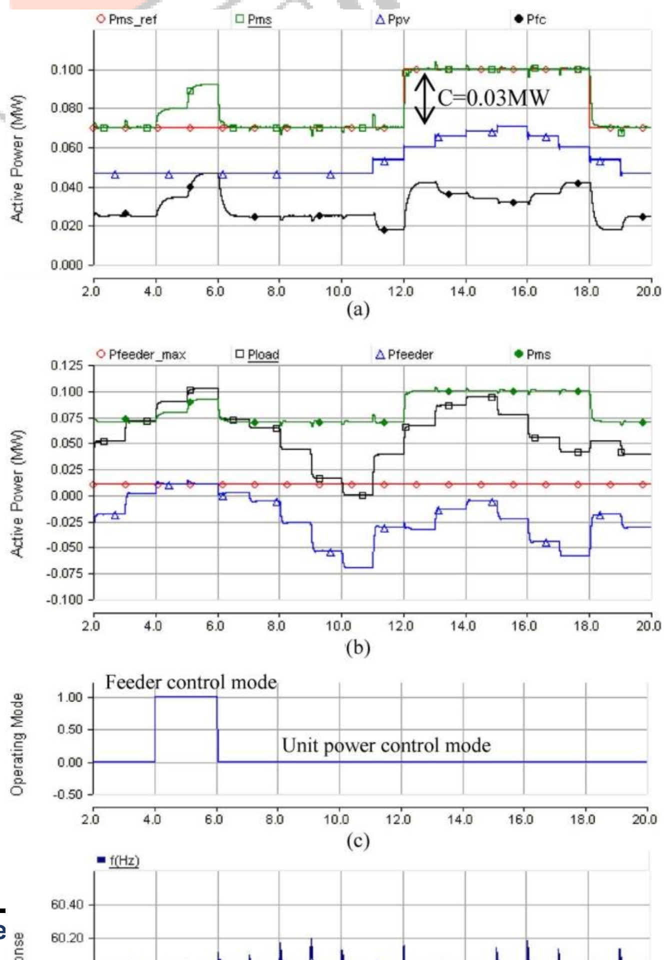
In the case in which there is only one hybrid source connected to the feeder, the hybrid source must work in the FFC mode to maintain the feeder flow at constant. Based on the proposed method, this can be accomplished by setting the maximum value of the feeder flow to a very low value and, thus, thehybrid 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 theproposed operating strategy is more applicable and meaningful to a real-world microgrid with multi DGs.

A. Improving Operation Performance by Using Hysteresis

The simulation results when hysteresis was included with the control scheme shown in Fig. 6. From 12 s to13 s and from 17 s to 18 s, the variations of $P_{\mathrm{MS}}^{\mathrm{ref}}$ [Fig. 9(a), oline], FC output [Fig. 9(a), line], and feeder flow [Fig. 9(b),line] are eliminated and, thus, the system works more stably compared to a case without hysteresis (Fig. 8). Fig. 9(d) showsthe frequency variations when load changes or when the hybridsource reference power 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.





IV. CONCLUSION

This paper has presented an available method to operate a hybrid grid-connected system. The hybrid system, composed ofa 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 thenumber of mode changes, to operate PV at the maximumpower point, and to operate the FC output in its high-efficiencyperformance band.

The main operating strategy, shown in Fig. 7, is to specify the control mode; the algorithm shown in Fig. 4 is to determine $P_{\mathrm{MS}}^{\mathrm{ref}}$ in the UPC mode. With the operating algorithm, PV always operates at maximum output power, PEMFC operates within the high-efficiency range, and feeder power flow isalways less than its maximum value. The change ofthe 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 de-mand is at the boundary of mode change, otherwise,the operating mode is either UPC mode or FFC mode. Besides,the variation of hybrid source reference power $P_{\mathrm{MS}}^{\mathrm{ref}}$ is eliminated by means of hysteresis. In addition, the number of modechanges is reduced. As a consequence, the system works morestably due to the minimization of mode changes and reference value variation.

In brief, the proposed operating algorithm is a simplified andflexible 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 perfor-mance 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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