Performance Optimisation and Power-Management in PV-FC Hybrid System

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Abstract— Integrating photovoltaic source with fuel cells, as a torage device replacing the conventional huge batteries or super storage capacitors, leads to a non-polluting reliable energy source and reduces the total maintenance costs. This work is based on a hybrid system where a combination of a Photovoltaic (PV) array and a Proton exchange membrane fuel cell (PEMFC) are connected. The major problem with PV array is that its output highly depends upon solar insolation and temperature hence even with maximum power point tracking technique it is still a unreliable and uncontrollable energy source. Whereas with the combination of PEMFC with solar PV array, the hybrid system output power can be made controllable. This work suggests the use of two operation modes namely, the unit-power control mode(UPCM) and the feeder-flow control mode (FFCM), that can be applied to the hybrid system. Hence the coordination of the PV array and the PEMFC in the hybrid system, as well as the determination of reference parameters are presented. A new strategy with a flexible operation mode which operates the PV array at maximum output power and the PEMFC in its high efficiency results in improving the performance of system operation, en-hancing system stability and decreasing the number of operating mode changes. The complete matlab simulation of this work is presented with easily interpretable waveforms and required results.

Index Terms—Distributed generation, fuel cell, hybrid system, microgrid, photovoltaic, power management.

I. INTRODUCTION

Small modular generation technologies interconnected to Low-Voltage (LV) distribution systems have the potential to form a new type of power system, the Micro-grid. Micro-scale Distributed Generators (DGs), or micro sources, are being considered increasingly to provide electricity for the expanding energy demands in the network. The concept of smart grid started with the notion of advanced metering infrastructure to improve demand-side management, energy efficiency, and a self-healing electrical grid to improve supply reliability and respond to natural disasters or malicious sabotage. Here, this paper discusses a hybrid photovoltaic and fuel cell generating system. The photovoltaic is used as primary energy source, while the fuel cell is used as secondary or back-up energy source. The control principle applied to track maximum power point of the photovoltaic system is without sensing the irradiance level and temperature.

The fuel cell is also controlled using a dc-dc converter to supply the deficit power when the primary energy sources cannot meet the load demandThe disadvantage of PV energy is that the PV output power de-pends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. This paper presents a hybrid solar PV and Proton Exchange Membrane (PEM) FC generating system [1],[2]. The PV is used as primary energy sources, while the FC is used as secondary or back-up energy source.

The FC is added to the system for the purpose of ensuring continuous load power flow. Each system is combined with its individual dc–dc boost converter to control each of the two sources independently.

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 co-ordinated to meet load demand. The hybrid source has two control modes: 1) unit-power control mode (UPCM) mode and feeder-flow control mode (FFCM) mode. In the UPCM, 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} must be determined. In the FFCM , 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} must be known. The proposed operating strategy is to coordinate the two control modes and determine the reference values of the UPCM and FFCM so that all constraints are satisfied. This operating strategy will minimize the number of operating mode changes, improves performance of the system and improves its stability.

II. STRUCTURE DESCRIPTION

A. Grid-Connected Hybrid Power System-Description

The system shown in fig. 1 consists of a PV-FC hybrid source with the main grid connecting to loads at the PCC. The photovoltaic and the PEMFC are modelled 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. As PV voltage and current are determined, the power is calculated. At the maximum power point, the derivative d_p/d_v is equal to zero. The maximum power point can be achieved by changing the reference voltage by the amount of ΔV_{ref} .

B. Solar Photovoltaic Model

The mathematical model can be expressed as

$$I = I_{ph} - I_{sat}\{\exp[q / AKT(V + IR_s)] - 1\} \quad (1)$$

Equation (1) shows that the output characteristic of a solar cell is which is not only nonlinear but also vitally affected by solar radiation, temperature, and load condition also on weather conditions. Photocurrent I_{ph} is directly proportional to solar radiation. Thus, depends on solar irradiance and cell temperature and also can be mathematically expressed for the sake of deriving suitable model for the simulation or even for real time applications.

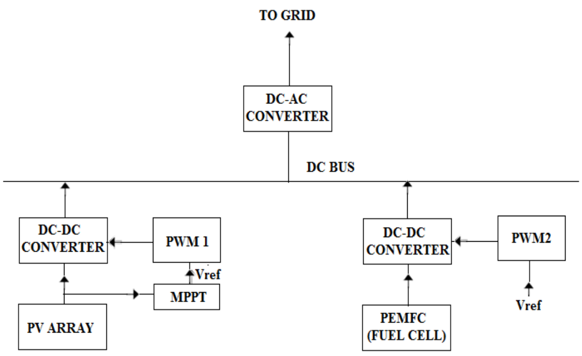

Fig. 1 Block diagram of the hybrid system connected to grid

C. Permeable Membrane Fuel Cell

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. The PEMFC output voltage is as follows [5]:

$$V_{out} = E_{Nerst} - V_{act} - V_{ohm} - V_{conc} \quad (2)$$

Where is the "thermodynamic potential" of Nerst, which represents the reversible (or open-circuit) voltage of the fuel cell Activation voltage drop V_{act} is given in the TAFEL equation as where ab are the constant terms in the TAFEL equation (in volts per Kelvin)

$$V_{act} = T[a + b\ln(I)] \quad (3)$$

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

$$V_{ohm} = IR_{ohm} \quad (4)$$

The ohmic resistance R_{Ohm} of PEMFC consists of the resistance of the polymer membrane and electrodes, and the resistances of the electrodes. The concentration voltage drop V_{conc} is expressed as

$$V_{conc} = -RT / zF \ln(1 - I / I_{limit}) \quad (5)$$

D. MPPT Control

The two algorithms often used to achieve maximum power point tracking are the P&O and INC methods[7].

In order to achieve maximum power, two different applied control methods that are often chosen are voltage-feedback control and power-feedback control [8], [9]. The P&O MPPT algorithm with a power-feedback control [9],[10]. As PV voltage and current are deter-mined, the power is calculated. At the maximum power point, the derivative (dP/dV) is equal to zero. The maximum power point can be achieved by changing the reference voltage by the amount of ΔV_{ref}.

The PWM generates a gate signal to control the buck-boost converter and, thus, maximum power is tracked and delivered to the ac side via a dc/ac inverter.

III. CONTROL STARTEGY

The control modes in the microgrid include unit power control model and feeder flow control mode. These two control modes were proposed by Lasserter [12].

In the UPCM mode, the distributed Generation sources regulate the voltage magnitude at the connection point . In this mode if a load increases anywhere in the microgrid, the extra power comes from the grid, since the hybrid source regulates to a constant power. In the FFCM mode, the DGs regulate the voltage magnitude at the connection point and the power that is flowing in the feeder at connection point P_{feed}. With this control mode, extra load demands are picked up by the DGs, which maintain a constant load from the utility viewpoint, 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 [13]–[16]. In this paper, a coordination of the UPCM mode and the FFCM mode was investigated to determine when each of the 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. OPERATING STRATEGY

As mentioned before, the purpose of the operating algorithm is to determine the control mode of the hybrid source and the reference value for each control mode so that the PV is able to work at maximum output power and the constraints $P_{FC}^{low}, P_{FC}^{up} and P_{F}^{max}$ are fulfilled. Once the constraints are known, the control mode of the hybrid source (UPC mode and FFC mode) depends on load variations and the PV output. The control mode is decided by the algorithm. In the UPC mode, the reference output power of the hybrid source depends on the PV output and the constraints of the FC output

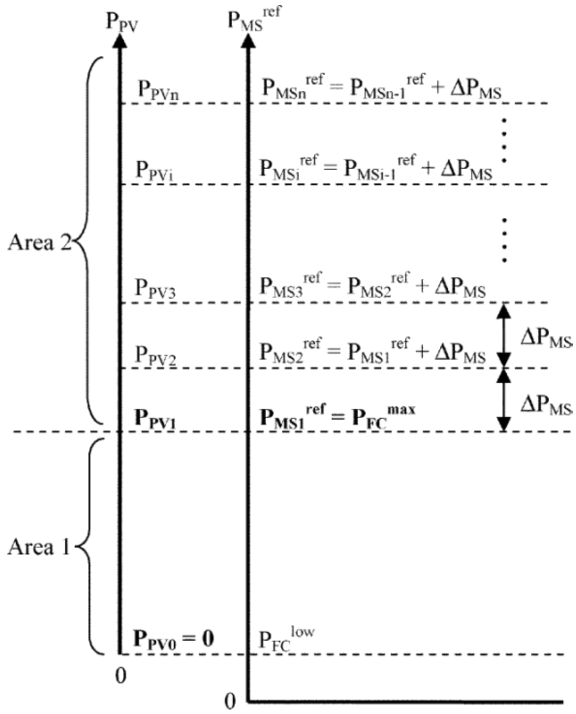

Fig 2. Operating strategy in UPCM

A. Operating Strategy for the Hybrid System in the UPCM

In this section, the algorithm presented as shown in fig 2 determines the hybrid source works in the UPC mode. This algorithm allows the PV to work at its maximum power point, and the FC to work within its high efficiency band. In the UPC mode, the hybrid source P_{MS}^{ref} regulates the output to the reference value. Then

$$P_{PV} + P_{FC} = P_{MS}^{ref} \quad (6)$$

Equation (6) shows that the variations of the PV output will be compensated for by the FC power and, thus, the total power will be regulated to the reference value.

However, the FC output must satisfy its constraints and, hence, P_{MS}^{ref} must set at an appropriate value. Fig.2 shows the operation strategy of the hybrid source in UPC mode to determine P_{MS}^{ref} . The algorithm includes two areas: Area 1 and Area 2. In Area 1, P_{PV} is less than P_{PV1} , and then the reference Power P_{MS1}^{ref} is set at P_{FC}^{up} where

$$P_{PV1} = P_{FC}^{up} - P_{FC}^{low}$$
$$P_{MS1}^{ref} = P_{FC}^{up} \quad (7),(8)$$

If PV output is zero, then P_{FC} deduces to be equal to P_{FC}^{up}. If the PV output increases to P_{PV1}, we obtain P_{FC} equal to P_{FC}^{low} . In other words, when the PV output varies from zero to P_{PV1}, the FC output will change from P_{FC}^{up} to P_{FC}^{low}. As a result, the constraints for the FC output always reach Area 1. It is noted that the reference power of the hybrid source during the UPC mode is fixed at a constant P_{FC}^{up} . Area 2 is for the case in which PV output power is greater than P_{PV1} . As examined earlier, when the PV output increases to P_{PV1}, the FC output will decrease to its lower limit P_{FC}^{low}. If PV output keeps increasing, the FC output will decrease below its limit P_{FC}^{low} .

In this case, to operate the PV at its maximum power point and the FC within its limit, the reference power must be increased. As depicted in Fig. 2 if PV output is larger than P_{PV1} , the reference power will be increased by the amount of ΔP_{MS} , and we obtain

$$P_{MS2}^{ref} = P_{MS1}^{ref} + \Delta P_{MS} \quad (9)$$

Similarly, if P_{PV} is greater than P_{PV2} , the FC output becomes less than its lower limit and the reference power will be thus increased by the amount of ΔP_{MS} . In other words, the reference power remains unchanged and equal to P_{MS2}^{ref} if is less than P_{PV2} and greater than P_{PV1} .Where,

$$P_{PV2} = P_{PV1} + \Delta P_{MS} \quad (10)$$

However, C should be small enough so that the frequency does not change over its limits 5%). In order to improve the performance of the algorithm, a hysteresis is included in the simulation model. The hysteresis is used to prevent oscillation of the setting value of the hybrid system reference power . At the boundary of change in , the reference value will be changed continuously due to the oscillations in PV maximum power tracking. To avoid the oscillations around the boundary, a hysteresis is included and its control scheme to control.

V. OVERALL OPERATING STRATEGY

In the aforementioned subsection, a method to determine in the UPCM mode is proposed. In this subsection, an operating strategy is presented to coordinate the two control modes.

The purpose of the algorithm is to decide when each control mode is applied and to determine the reference value of the feeder flow when the FFC mode is used. This operating strategy must enable the PV to work at its maximum power point, FC output, and feeder flow to satisfy their constraints. If the hybrid source works in the UPC mode, the hybrid output is regulated to a reference value and the variations in load are matched by feeder power. With the reference power proposed in Subsection A, the constraints of FC and PV are always satisfied. Therefore, only the constraint of feeder flow is considered.

On the other hand, when the hybrid works in the FFC mode, the feeder flow is controlled to a reference value and, thus, the hybrid source will compensate for the load variations. In this case, all constraints must be considered in the operating algorithm. Based on those analyses, the operating strategy of the system is proposed as demonstrated in Fig.2.7. The operation algorithm in Fig. 2.6 involves two areas (Area I and Area II) and the control mode depends on the load power. If load is in Area I, the UPC mode is selected. Otherwise, the FFC mode is applied with respect to Area II. In the UPC area, the hybrid source output.

If the load is lower than , the redundant power will be transmitted to the main grid. Otherwise, the main grid will send power to the load side to match load demand. When load increases, the feeder flow will increase correspondingly. If feeder flow increases to its maximum , then the feeder flow cannot meet load demand if the load keeps increasing.

In order to compensate for the load demand, the control mode must be changed to FFC with respect to Area II. Thus, the boundary between Area I and Area II is

$$P_{LOAD1} = P_{Feeder}^{\max} + P_{MS}^{ref} \quad (11)$$

When the mode changes to FFC, the feeder flow reference must be determined. In order for the system operation to be seamless, the feeder flow should be unchanged during control mode transition. Accordingly, when the feeder flow reference is set at, then we have

$$P_{Feeder}^{ref} = P_{Feeder}^{\max} \quad (12)$$

In the FFC area, the variation in load is matched by the hybrid source. In other words, the changes in load and PV output are compensated for by PEMFC power. If the FC output increases to its upper limit and the load is higher than the total generating power, then load shedding will occur. The limit that load shedding will be reached is

$$P_{Load2} = P_{FC}^{up} + P_{Feeder}^{\max} + P_{PV} \quad (13)$$

Equation shows that is minimal when PV output is at 0 kW. Then

$$P_{LOAD2}^{\min} = P_{FC}^{up} + P_{Feeder}^{\max} \quad (14)$$

Equation means that if load demand is less than , load shedding will never occur.

From the beginning, FC has always worked in the high efficiency band and FC output has been less than maximum load power. If the load is less than maximum load power, load shedding is ensured not to occur. However, in severe conditions, FC should mobilize its availability, to supply the load. Thus, the load can be higher and the largest load is

$$P_{LOAD}^{\max} = P_{FC}^{\max} + P_{Feeder}^{\max} \quad (15)$$

If FC power and load demand satisfy, load shedding will never occur. Accordingly, based on load forecast, the installed power of FC can be determined by following to avoid load shedding. Corresponding to the FC installed power, the width of Area II is calculated as follows

$$P_{Area-II} = P_{FC}^{\max} - P_{FC}^{up} \quad (16)$$

In order for the system to work more stably, the number of mode changes should be decreased. As seen in Fig. 2.6, the limit changing the mode from UPCM to FFCM is , which is calculated depending on $P_{Feeder}^{\max}$ and P_{MS}^{ref} . $P_{Feeder}^{\max}$ is a constant. Area 2 depends on P_{ms}^{ref}. Therefore, to decrease the number of mode changes, P_{ms}^{ref} changes must be reduced. Thus, must be increased. however ΔP_{MS} must satisfy condition and, thus, the minimized number of mode change is reached when ΔP_{MS} is maximized.

$$\Delta P_{MS}^{\max} = P_{FC}^{up} - P_{FC}^{low} \quad (17)$$

VI. SIMULATION AND RESULTS

A simulation was carried out by using the system model to verify the operating strategies. 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, the operating mode were determined by the proposed operating algorithm. Fig. 3 shows the simulation results of the system operating strategy.

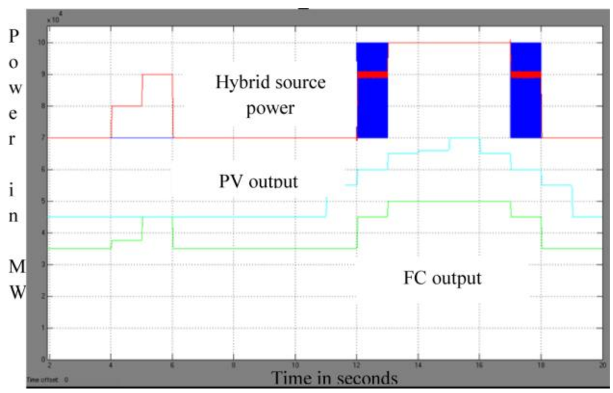

Figure 3 operating strategy of the hybrid source

From 0 s to 10 s, the PV operates at standard test conditions to generate constant power and thus hybrid system reference power is constant. From 10 s to 20 s, PV power changes step by step and, thus, is defined as the algorithm. The PEMFC ouput FC power as shown in Fig. 3, changes according to the change of PV power and hybrid system power Fig. 4 shows the system operating mode. The UPC mode and FFC mode correspond to values 0 and 1, respectively. It can be inferred from the figure 5.

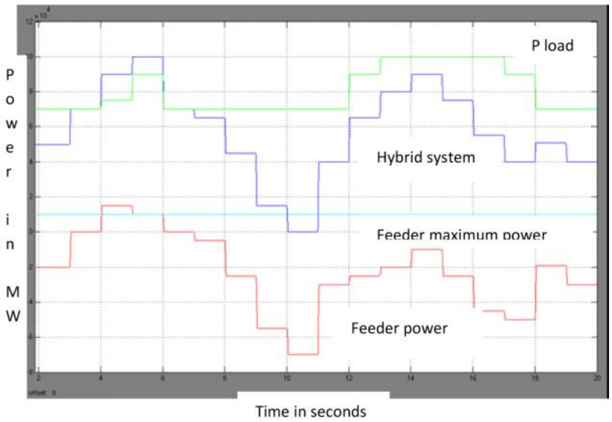

Figure 4 Operating strategy of the whole system

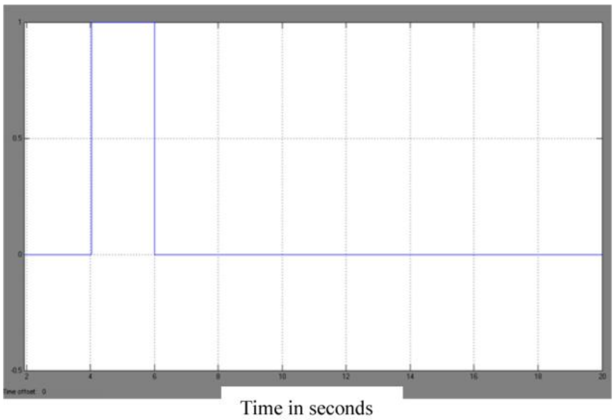

Figure .5 Change of operating mode

Fig. 6, 7, shows the simulation results when hysteresis was included with the proposed control scheme in fig 8 From 12 s to 13 s and from 17 s to 18 s, the variations of hybrid system power, FC output, and feeder flow are eliminated and, thus, the system works more stably compared to a case without hysteresis Fig. 9 shows the frequency variations when load changes or when the hybrid source reference power changes.

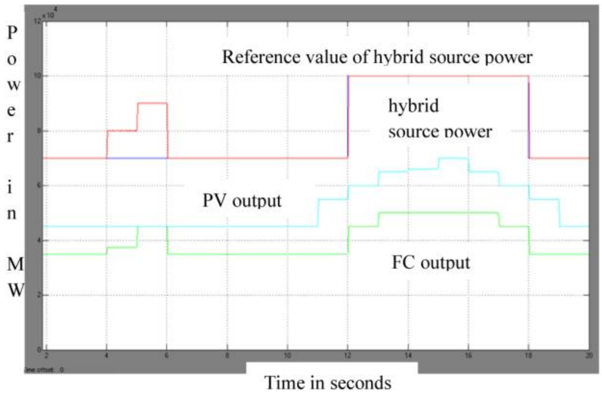

Figure 6 The operating strategy of the hybrid source with hysterisis

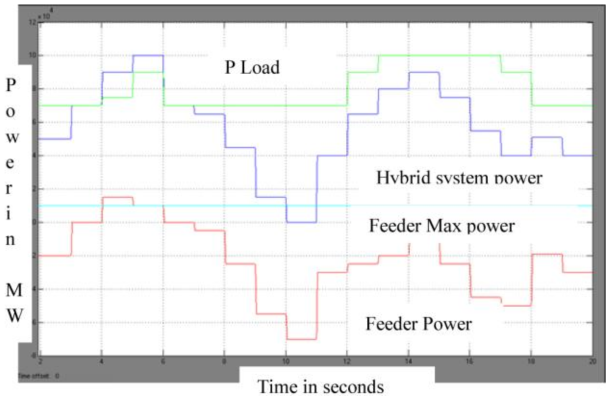

Figure 7 Operating strategy of the whole system with hysteresis

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.

VII. 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 UPCM mode and FFCM 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.

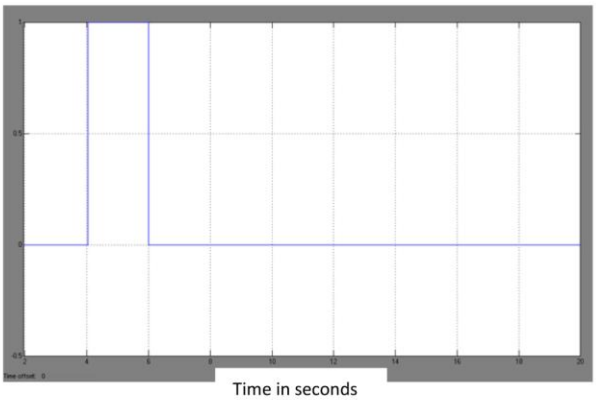

Figure 8 Change of operating modes with hysteresis

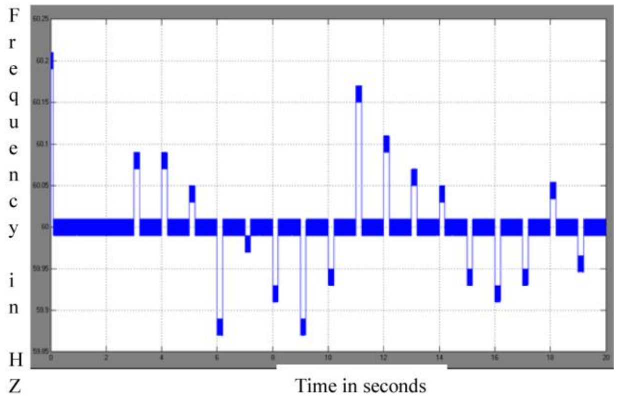

Figure 9 frequency response

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 UPCM 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} 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.

REFERENCES

[1] T. Bocklisch, W. Schufft, and S. Bocklisch, "Predictive and optimizing energy management of photovoltaic fuel cell hybrid systems with short-time energy storage," in Proc. 4th Eur. Conf. PV-Hybrid and Mini-Grid, 2008, pp. 8–15.

[2] J. Larmine and A. Dicks, Fuel Cell Systems Explained. New York: Wiley, 2003.

[3] W. Xiao, W. Dunford, and A. Capel, "A novel modeling method for photovoltaic cells," in Proc. IEEE 35th Annu. Power Electronics Spe-cialists Conf., Jun. 2004, vol. 3, pp. 1950–1956.

[4] D. Sera, R. Teodorescu, and P. Rodriguez, "PV panel model based on datasheet values," in Proc. IEEE Int. Symp. Industrial Electronics, Jun. 4–7, 2007, pp. 2392–2396.

[5] C. Wang, M. H. Nehrir, and S. R. Shaw, "Dynamic models and model validation for PEM fuel cells using electrical circuits," IEEE Trans. Energy Convers., vol. 20, no. 2, pp. 442–451, Jun. 2005.

[6] C. Hua and C. Shen, "Comparative study of peak power tracking tech-niques for solar storage system," in Proc. 13th Annu. Applied Power Electronics Conf. Expo., Feb. 1998, vol. 2, pp. 679–685.

[7] A. Hajizadeh and M. A. Golkar, "Power flow control of grid-connected fuel cell distributed generation systems," J. Elect. Eng. Technol., vol. 3, no. 2, pp. 143–151, 2008.

[8] C. Hua and J. R. Lin, "DSP-based controller application in battery storage of photovoltaic system," in Proc.22nd IEEE Int. Conf. Indus-trial Electronics, Control, and Instrumentation, Aug. 5–10, 1996, vol. 3, pp. 1750–1810.

[9] C. Hua, J. Lin, and C. Shen, "Implementation of a DSP-controlled pho-tovoltaic system with peak power tracking," IEEE Trans. Ind. Electron., vol. 45, no. 1, pp. 99–107, Feb. 1998.

[10] E. Koutroulism and K. Kaalitzakis, "Development of a microcon-troller-based, photovoltaic maximum power point tracking control system," IEEE Trans. Power Electron., vol. 16, no. 1, pp. 46–54, Jan. 2001.

[11] N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics, Converters, Applications and Design, 2nd ed. New York: Wiley, 2003.

[12] R. H. Lasseter, "Microgrids," in Proc. IEEE Power Eng. Soc. Winter Meeting, Jan. 2002, vol. 1, pp. 305–308.

[13] R. H. Lasseter and P. Piagi, "Control and design of microgrid compo-nents," Jan. 2006, PSERC final project reports.

[14] P. Piagi and R. H. Lasseter, "Autonomous control of microgrids," pre-sented at the Power IEEE Eng. Soc. General Meeting, Montreal, QC, Canada, 2006.

[15] F. Katiraei and M. R. Iravani, "Power management strategies for a mi-crogrid with multiple distributed generation units," IEEE Trans. Power Syst., vol. 21, no. 4, pp. 1821–1831, Nov. 2006.

[16] J. A. Peças Lopes, C. L. Moreira, and A. G. Madureira, "Defining con-trol strategies for microgrids islanded operation," IEEE Trans. Power Syst., vol. 21, no. 2, pp. 916–924, May

2006.

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