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Power Management Stategies of a Grid Connected Hybrid System in UPC and FFC Modes

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Abstract: *This paper proposes a method to operate a grid connected hybrid system which comprises photo voltaic (PV) array and proton exchange membrane fuel cell (PEMFC). To deliver highest power to load continuously PV array uses maximum power point tracking (MPPT) technique when there are variations in irradiation and temperature, and makes it as an uncontrollable source. The output power of hybrid system becomes controllable with the coordination of PEMFC. The coordination of the two operating modes unit-power control (UPC) mode and the feeder-flow control (FFC) mode are applied to the hybrid system and determination of reference parameters are presented. The proposed operating strategy operates the PV array at maximum output power and the PEMFC with high efficiency performance band to enhance the performance of the system operation, system stability and decreasing the number of operating mode changes.*

Index Terms: *Photovoltaic, fuel cell, hybrid system, distributed generation, micro-grid, and power management.*

NOMENCLATURE

PV	Photovoltaic.
FC	Fuel cell (PEMFC).
P_{PV}	Photovoltaic output power.
P_{FC}	PEMFC output power.
P_{MPP}	PV maximum output power.
P_{FC}^{low}	FC lower limit of high efficiency band
P_{FC}^{UP}	FC upper limit of high efficiency band
P_{FC}^{max}	FC maximum output power.
P_{Feeder}	Feeder power flow
P_{Feeder}^{ref}	Feeder reference power
P_{Feeder}^{max}	Feeder maximum power
P_{MS}^{ref}	Hybrid source reference power
P_{Load}	Load demand

I. INTRODUCTION

Renewable energy is currently widely used; one of the renewable energies is solar energy. Maximum power point tracking (MPPT) technique is normally used by photo voltaic (PV) array which continuously deliver the highest power to the load when there are variations in irradiations and temperature.

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The drawback of PV energy is that the PV output power relies on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, solar energy cannot be generated during the night time. In order to overcome these inherent drawbacks, alternative source such as PEMFC should be installed in the hybrid system. By changing the FC output power, the output of hybrid source becomes controllable. However, PEMFC in its turn works only at higher efficiency within a specific power range ($P_{FC}^{LOW} \div P_{FC}^{UP}$).

The hybrid system can either connected to the main grid or work autonomously with respect to the grid-connected mode or islanding 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 the load demand. The hybrid source has two control modes 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 the reference power. Therefore, the reference value of the hybrid source output P_{MS}^{ref} must be determined. In the FFC mode, the feeder flow is regulated to a constant, the extra load demand is compensated by the hybrid source, and hence the feeder reference power P_{feeder}^{ref} 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. SYSTEM DESCRIPTION

A. Structure of Grid-Connected Hybrid System

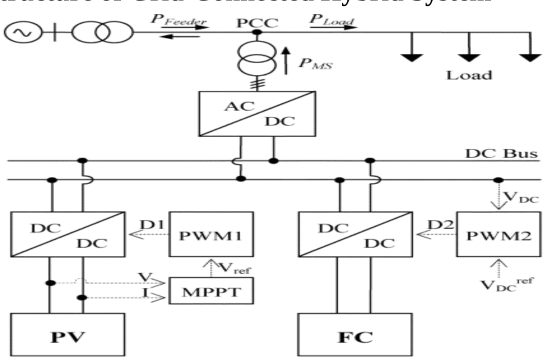

Fig.1 Grid Connected PV-FC Hybrid System

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The system comprises PV-FC hybrid source with the main grid connecting to the loads at the PCC as shown in fig 1. The PV and PEMFC are modelled as non linear voltage sources. The output of PV and PEMFC 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 discussed 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 (dP/dV) is equal to zero. The maximum power point can be achieved by changing the reference voltage by the amount ofΔV_{ref}.

B. PV Array Model

The mathematical model can be expressed as

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

Equation (1) shows that the output characteristics of 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

$$I_{ph}(G_a)=I_{sc}\frac{G_a}{G_{as}} \quad (2)$$

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

$$I_{sc}(T)=I_{scs}[1+\Delta I_{sc}(T-T_s)] \quad (3)$$

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

$$I_{ph}(G_a,T)=I_{scs}\frac{G_a}{G_{as}}[1+\Delta I_{sc}(T-T_s)] \quad (4)$$

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

$$I_{sat}(G_a,T)=\frac{I_{ph}(G_a,T)}{e^{(\frac{V_{oc(T)}}{V_{t(T)}})-1}} \quad (5)$$

C. PEMFC Model

The PEMFC steady-state feature of a PEMFC source is assessed 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)

$$V_{out}=E_{Nerst}-V_{act}-V_{ohm}-V_{conc} \quad (6)$$

Where E_{nerst} 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

$$V_{act}=T[a+b\ln(I)] \quad (7)$$

Where a and b are the constant terms in the Tafel equation (in volts per Kelvin)

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

$$V_{ohm}=IR_{ohm} \quad (8)$$

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

The concentration voltage drop V_{conc} is expressed as

$$V_{conc}=-\frac{RT}{ZF}\ln(1-\frac{I}{I_{limit}}) \quad (9)$$

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 facilitates good performance under rapidly changing atmospheric conditions. However, four sensors are necessary to perform the computations. If the sensors need more convention 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 system loss will decrease. Moreover, this method only requires two sensors, which results in a reduction of hardware requirements and cost. Therefore, the P&O method is used to control the MPPT process.

In order to attain maximum power, two different applied control methods are often chosen are voltage-feedback control and power-feedback control. Voltage-feedback control utilises the solar-array terminal voltage to control and keep the array operating near its maximum power point by regulating the arrays voltage and matching the voltage of the array to a desired voltage. The demerit of the voltage-feedback control is its negligence of the effect of irradiation and cell temperature. Therefore, the power-feedback control is utilised to achieve maximum power. The P&O and MPPT algorithm with a power-feedback control is shown in fig.2.

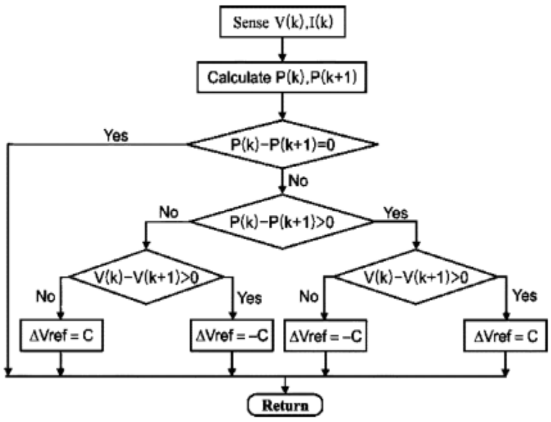

Fig.2 P&O MPPT algorithm

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PV voltage and current are determined, the power is calculated at the maximum power point, and 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} .

E. Buck-Boost Converter

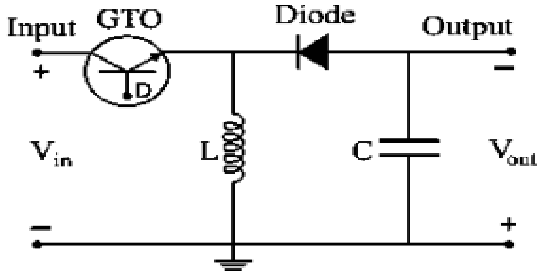

Fig.3 Buck-Boost Converter

In order to implement the MPPT algorithm, a buck-boost dc/dc converter is used as shown in fig .3

The parameters L and C in the buck-boost converter must satisfy the following condition

$$L > \frac{(1-D)^2}{2f}R \quad ; \qquad C > \frac{D}{Rf(\Delta V/V_{out})} \; .$$

The buck-boost converter comprises one switching device (GTO) that enables it to turn on and off depending on the applied gate signal D. The gate signal for the GTO can be obtained by comparing the saw tooth waveform with the control voltage. The change of the reference voltage ΔV_{ref} obtained by MPPT algorithm becomes the input of the pulse width modulation (PWM). The PWM generates a gate signal to control the buck-boost converter and thus maximum power is tracked and delivered to the ac side of via a dc/ac inverter.

III. CONTROL OF THE HYBRID SYSTEM

The control modes in the micro-grid comprise 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 (hybrid source in the system) regulate the voltage magnitude at the connection point and the power that source is Injecting. In this mode if load increases anywhere in the micro-grid, the additional power come from the grid, since hybrid source regulates to a constant power. In 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_{feeder}. With this control mode, extra load demands are compensated by the DGs. which maintain a constant load from the utility view point. In 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 FFC mode. Both of these concept were considered in this paper, a coordination of the UPC mode and FFC mode was investigated to determine when each of the two control modes were 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 described in the next section is also based on the minimization of mode change. This proposed operating strategy will be able to enhance performance of the system's operation and system stability.

IV. OPERATING STRATEGY OF THE HYBRID SYSTEM

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 available to work at maximum output power and the constraints are fulfilled. Once the constraints ($P_{FC}^{LOW}\, P_{FC}^{UP}$ *and* P_F^{max}) are known, the control mode of hybrid source (UPC mode and FFC mode) depends on load variations and the PV output. The control mode is decided by the algorithm shown in fig.7 subsection B. In the UPC mode, the reference output power of the hybrid source P_{MS}^{ref} depends on the PV output and the constraints of the FC output. The algorithm determining P_{MS}^{ref} is presented in subsection A and is shown in fig .4

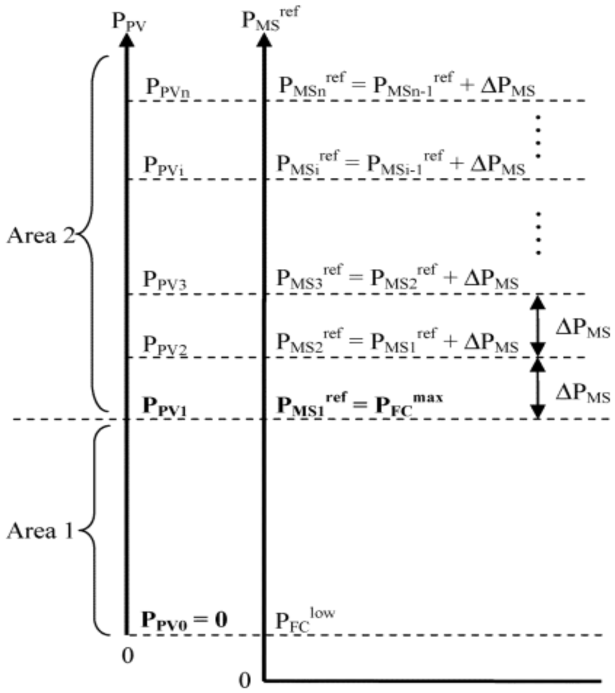

Fig.4 Operation Strategy of Hybrid Sources in UPC Mode

A. Operating Strategy for the Hybrid System in the UPC Mode

In this subsection, the presented algorithm 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 regulates the output to the reference value. Then

$$P_{pv} + P_{FC} = P_{MS}^{ref} \qquad (11)$$

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Equation (11) shows that the variation 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.4 show 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} then the reference power $P_{MS!}^{ref}$ is set at P_{FC}^{UP} where

$$P_{PV1} = P_{FC}^{UP} - P_{FC}^{LOW} \quad (12)$$

$$P_{MS1}^{ref} = P_{FC}^{UP} \quad (13)$$

If PV output is zero, then (11) deduces $P_{FC}$to be equal to P_{FC}^{UP}.if the PV output increases to P_{PV1}.then from (11) and (12), we obtain P_{FC} equal toP_{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 the maximum power point and the FC within its limit, the reference power must be increased. As depicted in fig 4. If PV output is larger than P_{PV1},the reference power will be increased by the amount of ΔP_{MS}, and we obtain

$$P_{MS2}^{ref} = P_{MS1}^{ref} + \Delta P_{MS} \quad (14)$$

Similarly, if P_{PV} is greater than P_{PV2}, the FFC 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 P_{PV} is less than P_{PV2} and greater than P_{PV1} where

$$P_{PV2} = P_{PV1} + \Delta P_{MS} \quad (15)$$

It is noted that ΔP_{MS} is limited so that with the new reference power. The FC output must be less than its upper limit P_{FC}^{UP} then, we have

$$\Delta P_{MS} \leq P_{FC}^{UP} - P_{FC}^{LOW} \quad (16)$$

In general, if the PV output is between $P_{PV1}\ and P_{PVi-1}$ where (i=2, 3, 4 ...), then we have

$$P_{MSi}^{ref} = P_{msi-1}^{ref} + \Delta P_{MS} \quad (17)$$

$$P_{PVi} = P_{PVi-1} + \Delta P_{MS} \quad (18)$$

Equations (17) and (18) show the method of finding the reference power when the PV output is in Area 2. The relationship between $P_{MSi}^{ref}\ and\ P_{PVi}$ is obtained by using (12),(13) and (18) in (17),and then

$$P_{MSi}^{ref} = P_{PVi} + P_{FC}^{min} \text{ (i=2,3,4....)} \quad (19)$$

The determination of P_{MS}^{ref} in Area 1 and Area 2 can be generalized by starting the index i from 1. Therefore,if the PV output is

$$P_{PVi-1} \leq P_{PV} \leq P_{PVi} \text{ i=1, 2, 3....}$$

Then we have

$$P_{MSi}^{ref} = P_{PVi} + P_{FC}^{min} \text{ (i=1, 2, 3.)} \quad (20)$$

$$P_{PVi} = P_{PVi-1} + \Delta P_{MS} \text{ (i=2, 3, 4.)} \quad (21)$$

It is noted that when i=1,P_{PV1} is given in (12), and

$$P_{PV-1} = P_{PV)} = 0 \quad (22)$$

In brief, the reference power of the hybrid source is determined according to the PV output power. If the PV output is in Area 1, the reference power will always be constant and set atP_{FC}^{UP}. Otherwise, the reference value will be changed by the amount of ΔP_{MS}, according to the change of PV power. The reference power of the hybrid source P_{MS}^{ref}in Area 1 and Area 2 is determined by (20) and (21). $P_{PV0}, P_{PV1}\ and\ \Delta P_{MS}$ are shown in (22),(12), and (16), respectively.

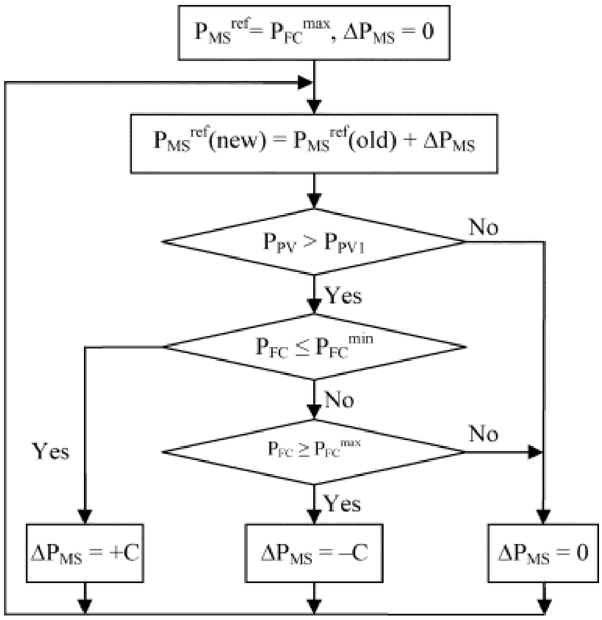

Fig.5 Control Algorithm Diagram in the UPC mode

Fig.5 shows the control algorithm diagram for determining the reference power automatically. the constant C must satisfy (16). If C increases the number of change of P_{MS}^{ref} will decrease and thus the performance of system operation will be improved. However, C should be small enough so that the frequency does not change over its limits ($\pm$5%) .

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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 P_{MS}^{ref}.At the boundary of change in P_{MS}^{ref} 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 P_{MS}^{ref} is depicted in fig 6.

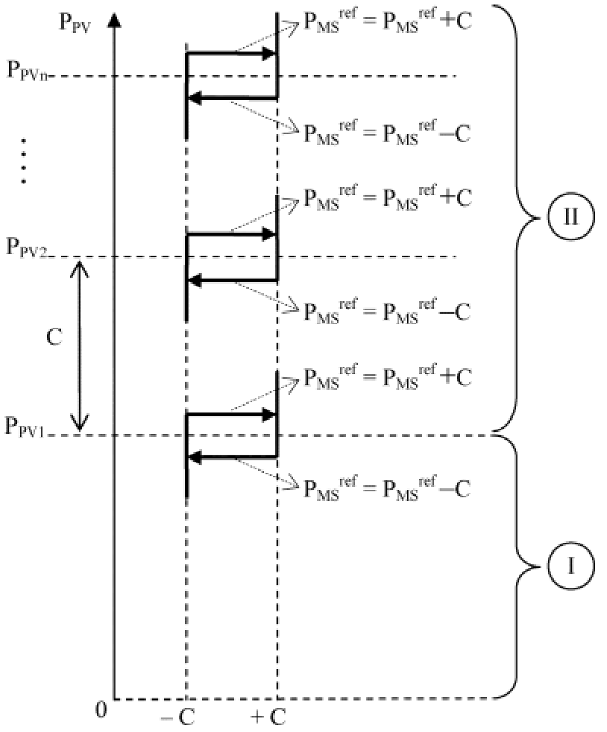

Fig.6 Hysteresis Control Scheme for P_{MS}^{ref} Control

B. Overall Operating Strategy for the Grid- Connected Hybrid System

It is well known that in the micro-grid, each DG as well as the hybrid source has two control modes: 1) the UPC mode and FFC mode. In the aforementioned subsection, a method to determine the UPC 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 P_{MS}^{ref} proposed in subsection A. The constraints of FC and PV are always satisfied. Therefore, only the constraint of the 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 P_{feeder}^{ref} 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 .7.

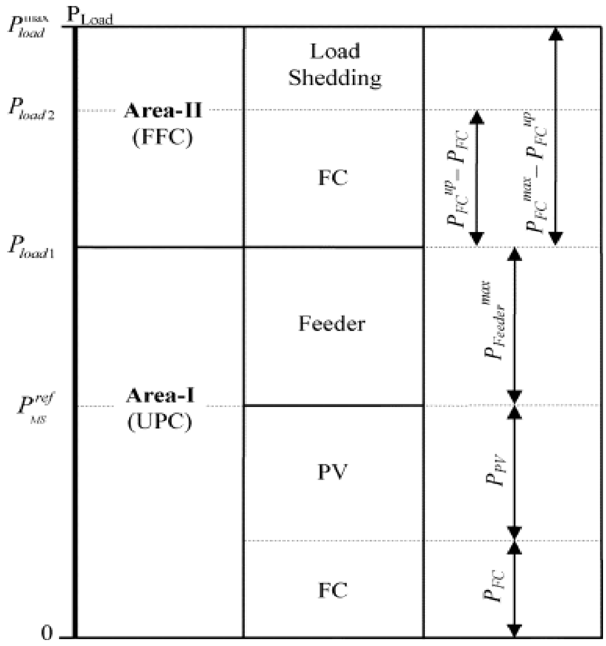

Fig.7 Overall Operating Strategies for the Grid-Connected Hybrid System

The operation algorithm in fig.7 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 isP_{MS}^{ref}. If the load is lower thanP_{MS}^{ref}, the redundant power will be transmitted to the main grid. Otherwise, the main grid will sent 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 P_{feeder}^{max}, 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 $P_{load\ 1}$ is

$$P_{load\ 1} = P_{Feeder}^{max} + P_{MS}^{ref} \qquad (23)$$

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 atP_{feeder}^{max}, then we have

$$P_{Feeder}^{ref} = P_{Feeder}^{max} \qquad (24)$$

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

$$P_{Load\ 2} = P_{FC}^{UP} + P_{Feeder}^{max} + P_{PV} \qquad (25)$$

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Equation (25) shows that $P_{Load\ 2}$ is minimal when PV output is at 0 KW. Then

$$P_{Load\ 2}^{min} = P_{Feeder}^{UP} + P_{Feeder}^{max} \quad (26)$$

Equation (26) means that if load demand is less than $P_{Load\ 2}^{min}$, load shedding will never occur.

From the beginning, FC has always worked in the high efficiency band and FC output has been less than P_{FC}^{UP}. If the load is less than $P_{Load\ 2}^{min}$, load shedding is ensured not to occur. However in severe conditions, FC should mobilize its availability, P_{FC}^{max} n, to supply the load. Thus, the load can be higher and the largest load is

$$P_{Load}^{max} = P_{FC}^{max} + P_{Feeder}^{max} \quad (27)$$

If FC power and load demand satisfy (27), load shedding will never occur. Accordingly, based on load forecast, the installed power of FC can be determined by following (27) to avoid load shedding. Corresponding to the FC installed power; the width of Area II is calculated as follows:

$$P_{Load-II} = P_{FC}^{max} - P_{FC}^{UP} \quad (28)$$

In order for the system to work more stably, the number of mode changes should be decreased. As seen in Fig .7, the limit changing the mode from UPC to FFC is $P_{Load\ 1}$, which is calculated in (23) shows that $P_{Load\ 1}$ depends on P_{Feeder}^{max} *and* P_{MS}^{ref}. P_{Feeder}^{max} is a constant, thus $P_{Load\ 1}$ depend on P_{MS}^{ref}. Fig. 4 shows that in Area II P_{MS}^{ref} depends onΔP_{MS}. Therefore, to decrease the number of mode changes,P_{MS}^{ref} changes must be reduced. Thus, ΔP_{MS} must be increased. However, ΔP_{MS} must satisfy condition (16) and, thus the minimized number of mode change is reached when ΔP_{MS} is maximized

$$\Delta P_{MS}^{max} = P_{FC}^{UP} - P_{FC}^{Low} \quad (29)$$

In summary, in a light-load condition the hybrid source works in UPC mode, the hybrid source regulates output power to the reference valueP_{MS}^{ref}, and the main grid compensates for load variations. P_{MS}^{ref} Is determined by the algorithm shown in Fig. 4 and thus, the PV always works at its maximum power point and the PEMFC always works within the high efficiency band ($P_{FC}^{Low} \div P_{FC}^{UP}$). In heavy load conditions, the control mode changes to FFC, and the variation of load will be matched by the hybrid source. In this mode, PV still works with the MPPT control, and PEMFC operates within its efficiency band until load increases to a very high point. Hence, FC only works outside the high efficiency band ($P_{FC}^{UP} \div P_{FC}^{max}$) in severe conditions. With an installed power of FC and load demand satisfying, load shedding will not occur. Besides, to reduce the number of mode changes, ΔP_{MS} must be increased and hence, the number of mode changes is minimized when ΔP_{MS} is maximized, as shown in (29). In addition, in order for system operation to be seamless, the reference value of feeder flow must be set at P_{Feeder}^{max} .

Table1. 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

V. SIMULATION RESULTS AND DISCUSSION

A. Simulation Results in the Case Without Hysteresis

A simulation was carried out by using the system model shown in Fig .2 to verify the operating strategies. The system parameters are shown in Table I.

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_{MS}^{ref} , P_{Feeder}^{ref} and the operating mode were determined by the proposed operating algorithm. Fig 8,9 and 10 are shows the simulation results of the system operating strategy. The changes of P_{PV}(Red-line) is shown in Fig.8 and P_{Load} (Yellow-line) show in Fig. 9 respectively.

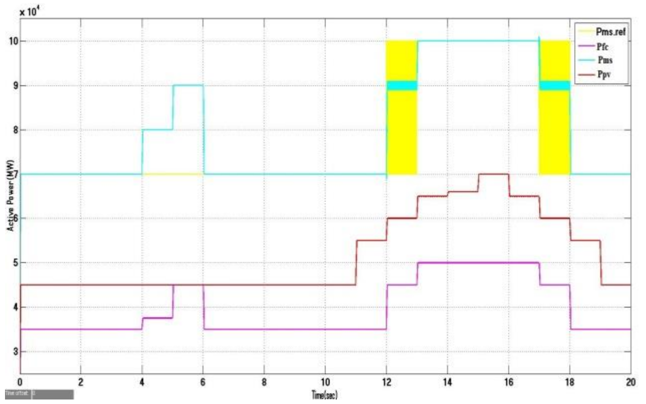

Fig. 8 Operating Strategy of the Hybrid Sources

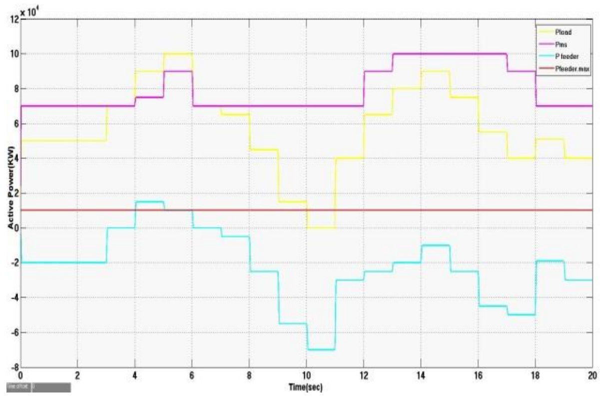

Fig.9 Operating Strategy of the Whole System

Based on P_{PV} and the constraints of P_{FC} show in Table I, the reference value of the hybrid source output P_{MS}^{ref} (Yellow-line) is determined as depicted in Fig.8. From 0s to 10s, the PV operates at standard test conditions to generate constant power and thus, P_{MS}^{ref} is constant. From 10s to 20s, P_{PV} changes step by step and, thus, P_{MS}^{ref} is defined as the algorithm shown in fig. 4 or 5.

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The PEMFC output P_{FC} (Magenta-line) as shown in Fig.8, changes according to the change of P_{PV} *and* P_{MS}.

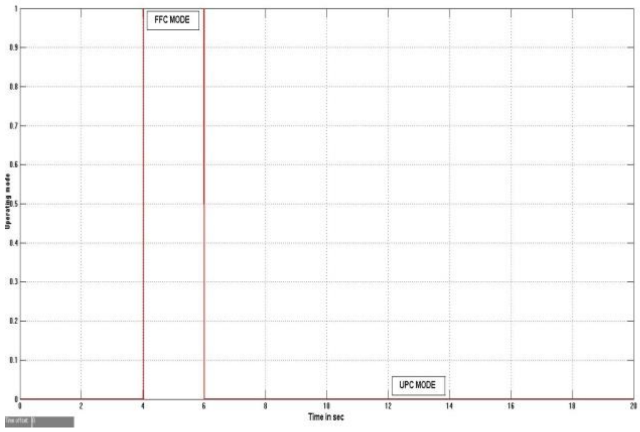

Fig.10 Change of Operating Modes

Fig.10 shows the system operating mode. The UPC mode and FFC mode correspond to values 0 and 1, respectively. From 4s to 6s, the system works in FFC mode and, thus, P_{Feeder}^{ref} 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. 9.On the contrary, in UPC mode, P_{MS} changes followingP_{MS}^{ref}, as shown in Fig.8.

It can be seen from Fig.8, 9, and 10 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. 8 that at 12s to 17s, P_{MS}^{ref} changes continuously. This is caused by variations of P_{PV} in 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_{MS}^{ref}, as shown in Fig.6.The simulation results of the system, including the hysteresis , are depicted in Fig.11,12 and13.

B. Improving Operation Performance by using Hysteresis

Fig.11, 12 and 13 are shows the simulation results when hysteresis was included with the control scheme shown in Fig. 6.

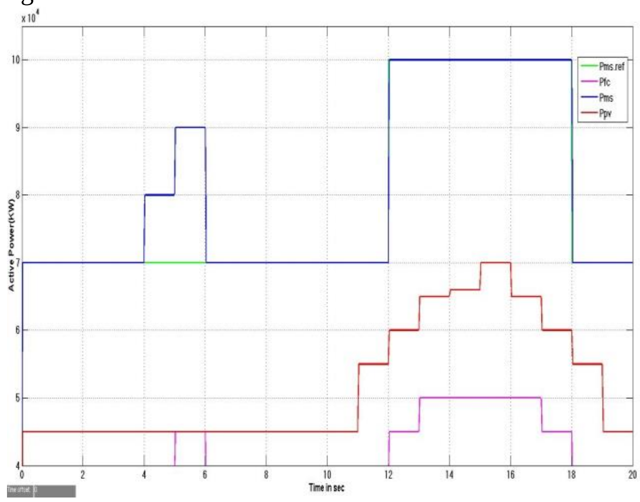

Fig.11 The Operating Strategy of The Hybrid Sources using Hysteresis

From 12s to 13s, and from 17s to 18s, the variations of P_{MS}^{ref} (Green-line) and FC (magenta-line) output are shown in Fig. 11.

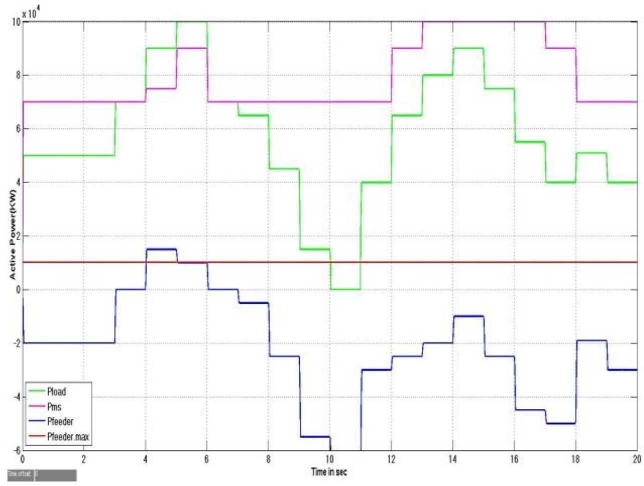

Fig.12 Operating Strategy of The Whole System using Hysteresis

Feeder flow P_{feeder}(Blue-line) as shown in Fig. 12 are eliminated and, thus, the system works more stably compared to a case without hysteresis (Fig.8 and 9). Fig.14 shows the frequency variations when load changes or when the hybrid source reference power P_{MS}^{ref} changes (at 12s and 18s). The parameter C was chosen at 0.03MW and, thus, the frequency variations did not reach over its limit ($\pm 5\% * 60 = \pm 0.3Hz$).

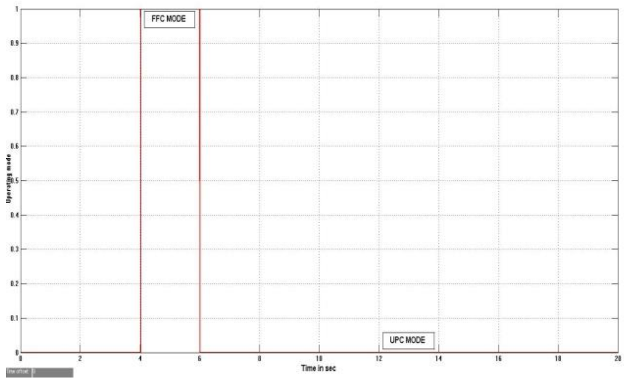

Fig.13 Change of Operating Modes

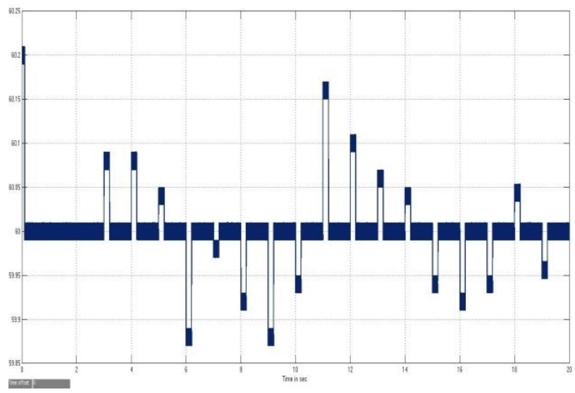

Fig.14 Frequency Variations Occur In the System

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C. Discussion

It can be seen from Fig.12 that during the UPC mode, the feeder flow (Blue-line) changes due to the change of load (Green-line) and hybrid output(Magenta-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 micro-grid should be a constant load from the utility viewpoint. In reality, the micro-grid includes some DGs connected in parallel to the feeder. There, 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 to P_{Feeder}^{max} a very low value and, thus, 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 micro-grid with multi DGs.

VI. CONCLUSION

This paper has described a method to operate a hybrid grid-connected system. 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. With the proposed operating algorithm PV always operates at maximum output power, PEMFC operates with in the high-efficiency range ($P_{FC}^{low} \div P_{FC}^{up}$), and feeder power flow is always less than its maximum value P_{Feeder}^{max}. When load is light, the UPC mode is selected and, thus, the hybrid source works more stable. 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 $P_{MS}^{ref}$is eliminated by means of hysteresis.

In brief, the proposed operating algorithm is a simplified and flexible method to operate a hybrid source in a grid-connected micro-grid. 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 improve operation performance of the system, will be considered. Moreover, the application of the operating algorithm to a micro-grid with multiple feeders and DGs will also be studied in detail.

REFERENCES

1. J. Larmine and A. Dicks, Fuel Cell Systems Explained. New York: Wley, 2003
2. 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
3. W. Xiao, W. Dunford and A. Capel, "A novel modeling method for photovoltaic cells," in Proc. IEEE 35th Annu. Power Electronics Specialists Conf., Jun.2004, vol.3, pp.1950-1956.
4. Hua and C. Shen, "Comparative study of peak power tracking techniques for solar storage system," in Proc.13th Annu. Applied Power Electronics Conf. Expo., Feb.1998, vol.2,pp.679-685
5. 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 J.R. Lin, " DSP –based controller application in battery storage of photovoltaic system," in Proc.22nd IEEE Int.Conf. Industrial Electronics, Control and Instrumentation, Aug 5-10, 1996, vol.3,pp. 1750-1810
7. 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 C.
8. E.Koutroulism and K. Kaalitzakis, "Development of a micro controller-based, photovoltaic maximum power point tracking control system." IEEE Trans. Power Elctron, vol.16, no.1,pp. 46-54, Jan 2001
9. C. Hu, C. Shen and J. Lin " Implementation of a DSP-controlled photovoltaic system with peakpowertracking," IEEE Trans. Ind Electron, vol.45, no.1,pp. 99-107, Feb.1998.
10. N. Mohan, T.M. Undeland, and W.P. Robbins, Power Electronics Converters, Applications and Design , 2nd ed New York: Wiley 2003.

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