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Power Technique of Grid-Connect PEMFC 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, Micro-grid, photovoltaic, power management.**

I. INTRODUCTION

The conventional fossil fuel energy sources such as petroleum, natural gas, and coal which meet most of the world’s energy demand today are being depleted rapidly. Also, their combustion products are causing global problems such as the greenhouse effect and pollution which are posing great danger for our environment and eventually for the entire life on our planet. The renewable energy sources (solar, wind, tidal, geothermal etc.) are attracting more attention as an alternative energy. Among the renewable energy sources, the photovoltaic (PV) energy has been widely utilized in low power applications. It is also the most promising candidate for research and development for large scale users as the fabrication of low cost PV devices becomes a reality. Photovoltaic generators which directly convert solar radiation into electricity have a lot of significant advantages such as being inexhaustible and pollution free, silent, with no rotating parts, and with size-independent electric conversion efficiency. Due to harmless environmental effect of PV generators, they are replacing electricity generated by other polluting ways and even more popular for electricity generator where none was available before. With increasing penetration of solar photovoltaic devices, various anti-pollution apparatus can be operated by solar PV power; for example, water purification by electrochemical processing or stopping desert expansion by PV water pumping with tree implantation.

From an operational point of view, a PV power generation experiences large variations in its output power due to intermittent weather conditions. Those phenomena may cause operational problems at the power station, such as excessive frequency deviations. In many regions of the world, the fluctuating nature of solar radiation means that purely PV power generators for off grid applications must be large and thus expensive. One method to overcome this problem is to integrate the photovoltaic plant with other power sources such as diesel, fuel cell (FC), or battery back-up. The diesel back-up generator for PV power is able to ensure a continuous 24-hour. However, it has a number of significant disadvantages such as noise and exhaust gases pollution. In addition, reasonably reliable diesel back-up generators are available only for the power range above about 5kW, which is too much high for a large number of applications. In the middle and small power range this technology cannot be used in an effective way.

The fuel cell beak-up power supply is a very attractive option to be used with an intermittent power generation source like PV power because the fuel cell power system is characterized with many attractive features such as efficiency, fast load-response, modular production and fuel flexibility. Its feasibility in co-ordination with a PV system has been successfully realized for both grid-connected and stand-alone power applications. Due to the fast responding capability of the fuel cell power system, a photovoltaic-fuel cell (PVFC) hybrid system may be able to solve the photovoltaic’s inherent problem of intermittent power generation. Unlike a storage battery, which also represents an attractive back-up option, such as fast response, modular construction and flexibility, the fuel cell power can produce electricity for unlimited time to support the PV power generator. Therefore, a continuous supply of high quality power generated from the PVFC hybrid system is possible day and night.

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Environmental impacts of the fuel cell power generation are relatively small in contrast to other fossil fuel power sources. Since chemical reactions inside the fuel cell stack are accomplished by catalysts, it requires a low sulphur-content fuel. Low-emission characteristics of the fuel cell power system may allow some utilities to offset the costs of installing additional emission control equipment. Moreover, their high efficiency results in low fossil fuel CO_2 emissions, which will help in reducing the rate of global-warming. Therefore, the fuel cell power system has a great potential for being coordinated with the PV generator to smooth out the photovoltaic power's fluctuations. So by connecting PV-FC hybrid system to the conventional main grid we can supply high loads and we can maximize usage of renewable resources.

II. DESCRIPTION GRID-CONNECTED HYBRID POWER SYSTEM

The system 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. The P&O algorithm with power feedback control. 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 of ΔVref.

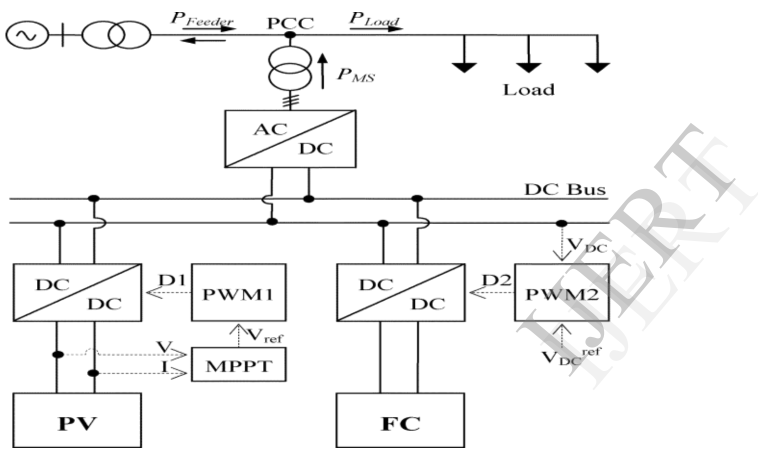

Fig.1. Grid-connected PV-FC hybrid system

The system consists of photovoltaic cell and the PEMFC 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. In this section, a brief description of the system components will be given to make the grid connected PV-FC hybrid system easy to understand in this dissertation.

The photovoltaic system design: A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance.

There are two main system configurations – Figure 2 shows the stand-alone and Figure 3 shows the grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid.

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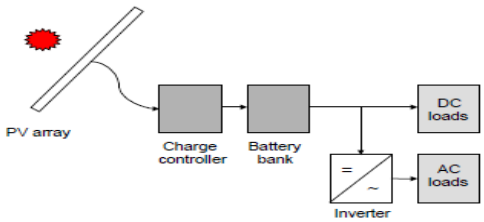

Fig.2. Schematic diagram of a stand-alone photovoltaic system

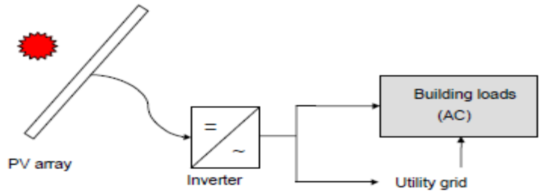

Fig. 3. Schematic diagram of grid-connected photovoltaic system

It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as 'hybrid' systems. Figure 4 shows the Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.

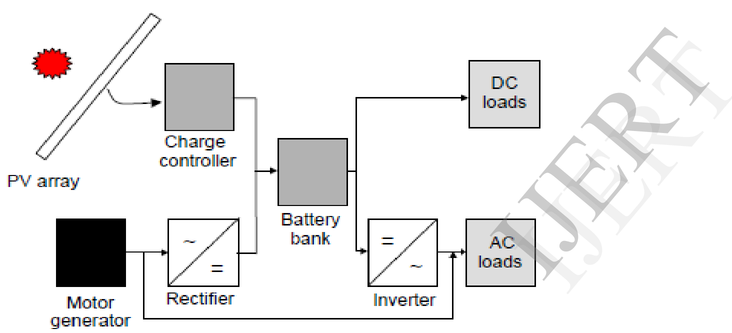

Fig.4. Schematic diagram of hybrid system

III. OPERATING STRATEGY FOR THE HYBRID SYSTEM IN THE UPC MODE

A In this subsection, the presented algorithm shown in fig. 5.1 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

$$P_{PV} + P_{FC} = P_{MS}^{ref} \qquad (1)$$

Equation (1) 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.

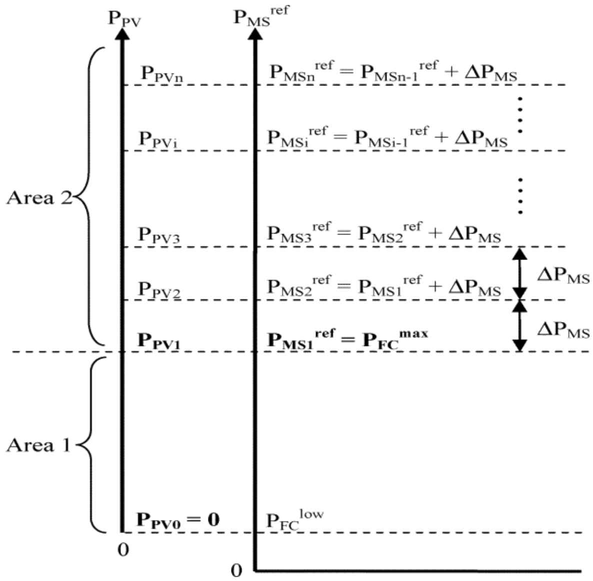

Fig.5. Operation strategy of hybrid source in the UPC mode

Fig.5. 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

$$P_{PV!} = P_{FC}^{up} - P_{FC}^{low} \qquad \text{... (2)}$$

$$P_{MS1}^{ref} = P_{FC}^{up} \qquad \text{.... (3)}$$

If PV output is zero, then equation (1) deduces P_{FC} to be equal to P_{FC}^{up}. If the PV output increases to P_{PV1}, then from equations (1) and (2), we obtain P_{FC} equal to P_{FC}^{low}. In other words, when the PV output varies from zero to P_{PV1}, then 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. (1), if PV output is larger than P_{PV1}, the reference power will be increased by the amount of ΔP_{MS}, and we obtain

$$P_{MS2}^{ref} = P_{MS1}^{ref} + \Delta P_{MS} \qquad \text{.... (4)}$$

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 P_{PV} is less than P_{PV2} and greater than P_{PV1} where $P_{PV2} = P_{PV1} + \Delta P_{MS}$ .... (5)

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

$$\Delta P_{MS} \leq P_{FC}^{up} - P_{FC}^{low} \qquad \text{.... (6)}$$

In general, if the PV output is between P_{PVi} and P_{PVi-1} and, then we have

$$P_{MSi}^{ref} = P_{MSi-1}^{ref} + \Delta P_{MS} \qquad \text{.... (7)}$$

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$P_{PVi} = P_{PVi-1} + \Delta\, P_{MS}$ .... (8)

Equations (7) and (8) 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 (2), (3), and (8) in (7) and then

$P_{MSi}^{ref} = P_{PVi} + P_{FC}^{min}$ i=2, 3, 4…… .... (9)

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

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

Then we have

$P_{MSi}^{ref} = P_{PVi} + P_{FC}^{min}$, i=1, 2, 3…. ... (10)

$P_{PVi} = P_{PVi-1} + \Delta\, P_{MS}$, i=2, 3, 4…. ... (11)

it is noted that when i=1, P_{PV1} is given in (2), and

$P_{PVi-1} = P_{PV0} = 0$ ... (12)

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 at P_{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 in Area 1 and Area 2 is determined by (10) and (12). , and are shown in (12), (2), and (6), respectively. Fig. 5.2 shows the control algorithm diagram for determining the reference power automatically.

The constant must satisfy equation (6). 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 5%.

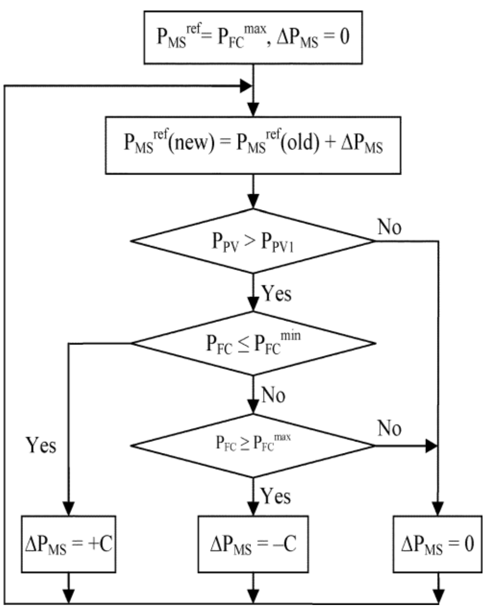


Fig.2. Control algorithm in the UPC mode P_{MS}^{ref} automatically changing

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 is depicted in Fig.5.3

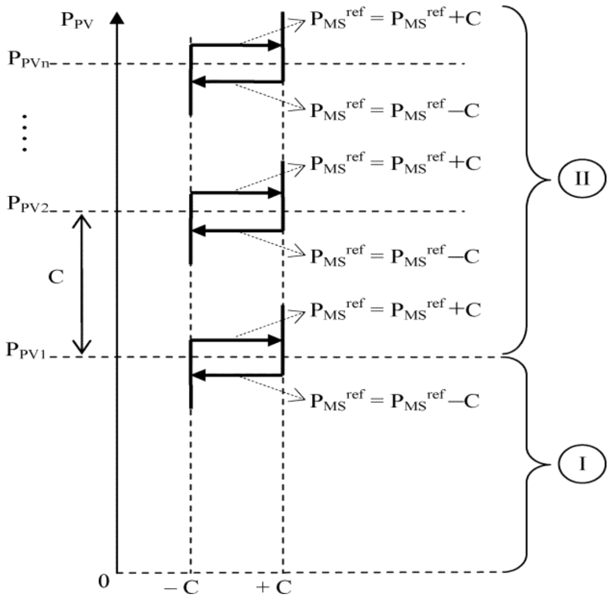


Fig.3. Hysteresis control scheme for P_{MS}^{ref} control

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 2) the FFC mode. In the aforementioned section, a method to determine in 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 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.4.

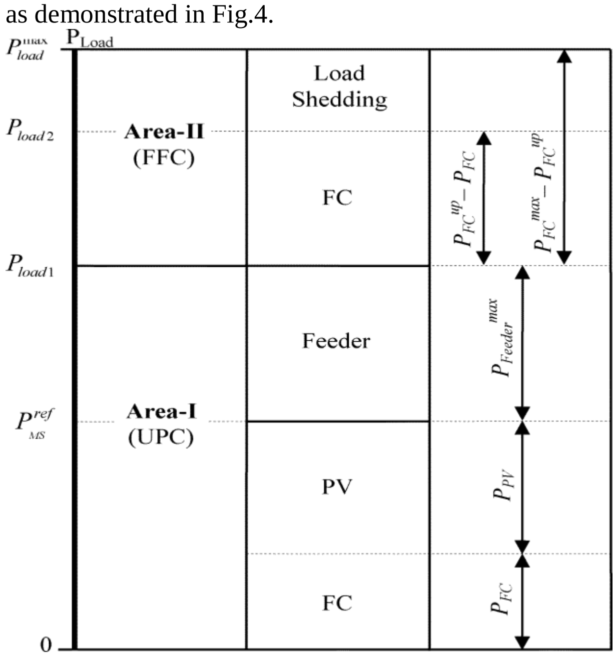


Fig.4. overall operating strategies for the grid-connected hybrid system

The operation algorithm in Fig.4 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 is P_{MS}^{ref}. If the load is lower than P_{MS}^{ref}, 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 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 is

$$P_{Load1} = P_{Feeder}^{max} + P_{MS}^{ref} \qquad \text{....... (13)}$$

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 P_{Feeder}^{max}, then we have

$$P_{Feeder}^{ref} = P_{Feeder}^{max} \qquad \text{...... (14)}$$

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

$$P_{Load2} = P_{Feeder}^{max} + P_{FC}^{up} + P_{PV} \qquad \text{... (15)}$$

Equation (15) shows that is minimal when PV output is at 0 kW. Then

$$P_{Load2}^{min} = P_{FC}^{up} + P_{Feeder}^{max} \qquad \text{... (16)}$$

Equation (16) means that if load demand is less than P_{Load2}^{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. If the load is less than P_{Load2}^{min} then 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

$$P_{Load}^{max} = P_{FC}^{max} + P_{Feeder}^{max} \qquad \text{.... (17)}$$

If FC power and load demand satisfy equation (17), 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:

$$P_{Area-11} = P_{FC}^{max} - P_{FC}^{up} \qquad \text{... (18)}$$

In order for the system to work more stably, the number of mode changes should be decreased. As seen in Fig.4, the limit changing the mode from UPC to FFC is P_{Load1}, which is calculated in equation (13). Equation (13) shows that P_{Load1} depends on P_{Feeder}^{max} and P_{MS}^{ref}. P_{Feeder}^{max} Is a constant, thus P_{Load1} depends on P_{MS}^{ref}. Fig.1 shows that in Area 2 P_{MS}^{ref} depends on ΔP_{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 equation (6) and, thus, the minimized number of mode change is reached when ΔP_{MS} is maximized

$$P_{MS}^{max} = P_{FC}^{up} - P_{FC}^{low} \qquad \text{.... (19)}$$

In light-load condition, the hybrid source works in UPC mode, the hybrid source regulates output power to the reference value P_{MS}^{ref} and the main grid compensates for load variations. P_{MS}^{ref} is determined by the algorithm shown in Fig.1 and, thus, the PV always works at its maximum power point and the PEMFC always works within the high efficiency band P_{FC}^{low} to 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}^{low} to P_{FC}^{up} in severe conditions. With an installed power of FC and load demand satisfying (17), load shedding will not occur. Besides, to reduce the number of mode changes must be increased and, hence, the number of mode changes is minimized when maximized, as shown in equation (19) is. In addition, in order for system operation to be seamless, the reference value of feeder flow must be set at P_{feeder}^{max}.

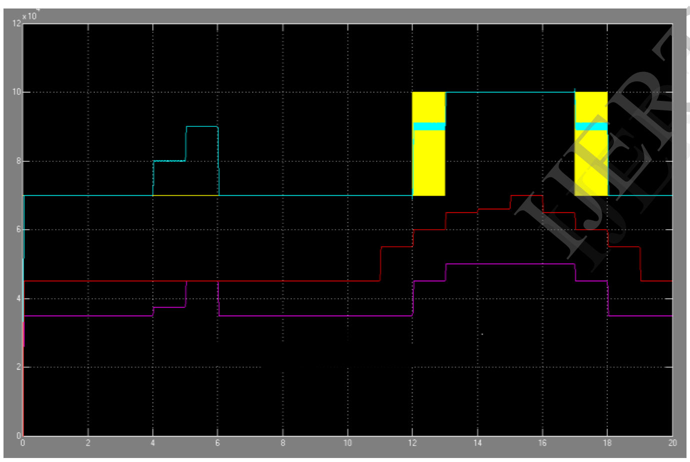
IV. SIMULATION RESULTS IN THE CASE WITHOUT AND WITH HYSTERESIS

A simulation was carried out by using the system model. To verify the operating strategies the system parameters are shown in Table.1

Table 1: 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

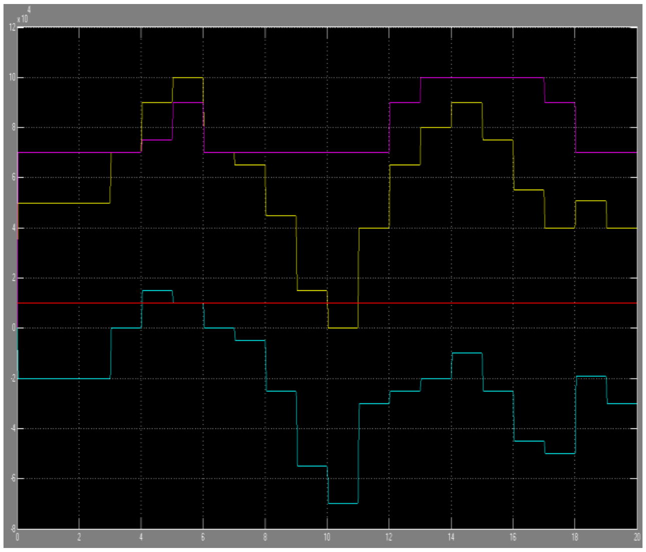
CASE WITHOUT HYSTERESIS: In order to verify the operating strategy, the load demand and PV output were time varied in terms of step. According to the load demand and the change of PV output, P_{FC}, P_{Feeder}^{ref}, P_{MS}^{ref} and the operating mode were determined by the proposed operating algorithm. Fig.5, Fig.6 shows the simulation results of the system operating strategy.



Pink→P_{FC}, Red → P_{PV} Yellow →P_{MS}^{ref} Blue → P_{MS}

Fig.5: Simulation result of operating strategy of the hybrid source without hysteresis

The changes of P_{PV} and P_{Load} are shown in Fig. 6.2 (red line) and Fig.6. (Yellow line), respectively. Based on and the constraints of shown in Table 6.1 the reference value of the hybrid source output is determined as depicted in Fig. 5 (yellow line). From 0 s to 10 s, the PV operates at standard test conditions to generate constant power and, thus P_{MS}^{ref} constant. . From 10 s to 20 s, P_{PV} changes step by step and, thus, P_{MS}^{ref} is defined as the algorithm shown in Fig. 5. The PEMFC output P_{FC} as shown in Fig.5 (pink line) changes according to the change of P_{PV} and P_{MS}.



Pink→P_{MS}, Red → P_{Feeder_Max} Yellow → P_{Load} Blue → P_{Feeder}

Fig.6: simulation result of operating strategy of the whole system without hysteresis

Fig.7 shows the system operating mode. The UPC mode and FFC mode correspond to values 1 and 0, respectively. From 4 s to 6 s, the system works in FFC mode and, thus, P_{Feeder}^{max} becomes the feeder reference value P_{Feeder}^{ref}.

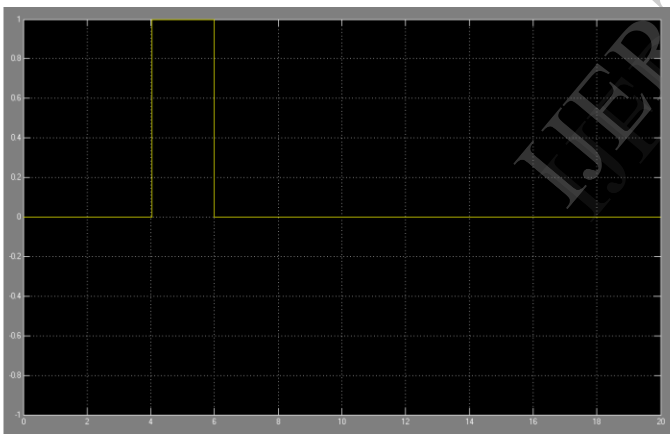


Fig.7: Simulation result of Change of operating modes without hysteresis

During FFC mode, the hybrid source output power changes with respect to the change of load demand, as in Fig. 6. On the contrary, in the UPC mode, P_{MS} changes following P_{MS}^{ref} as shown in Fig.5. It can be seen from Figures5, 6, 7 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.6.2 that at 12 s and 17 s, P_{MS}^{ref} changes continuously. This is caused by variations of P_{PV} in the MPPT process. As a result, P_{FC} and P_{MS} 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. 6.3. The simulation results of the system, including the hysteresis, are depicted in Fig. 6, 7.

CASE WITH HYSTERESIS: Figures 6, 7 shows the simulation results when hysteresis was included with the control scheme shown in Fig.6. MATLAB model of Grid Connected PV-FC Hybrid System with hysteresis

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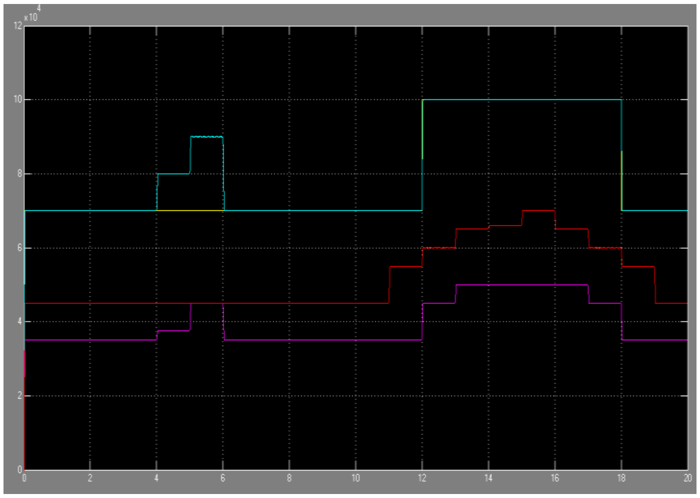
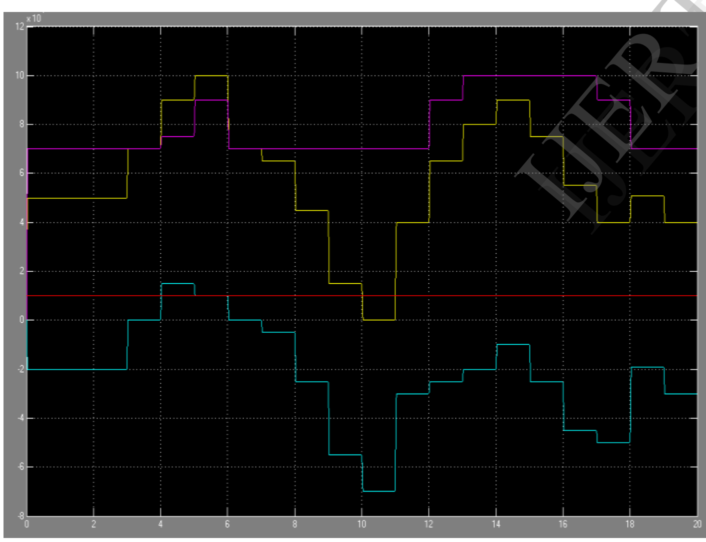


Pink→P_{FC}, Red → P_{PV} Yellow → P_{MS}^{ref} Blue → P_{MS}

Fig.8. Simulation result of operating strategy of the hybrid source with hysteresis

From 12 s to 13 s and from 17 s to 18 s, the variations of hybrid source reference power, [Fig.8, yellow line], FC output [Fig.8, pink line], and feeder flow [Fig.9, blue line] are eliminated and, thus, the system works more stably compared to a case without hysteresis.



Pink→P_{MS}, Red → P_{Feeder}^{max} Yellow → P_{Load} Blue → P_{Feeder}

Fig.9: Simulation result of operating strategy of the whole system with hysteresis

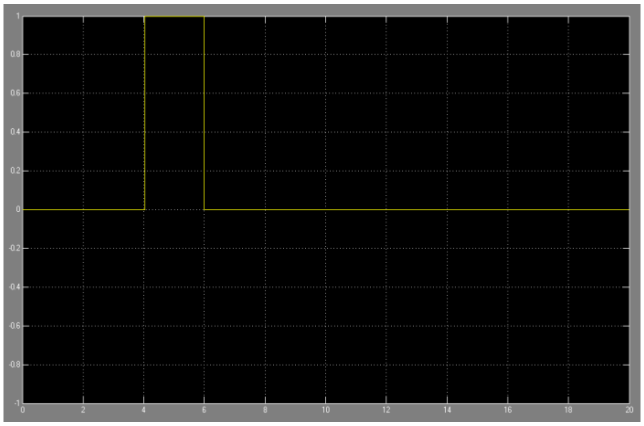


Fig.10 Simulation result of Change of operating modes with hysteresis

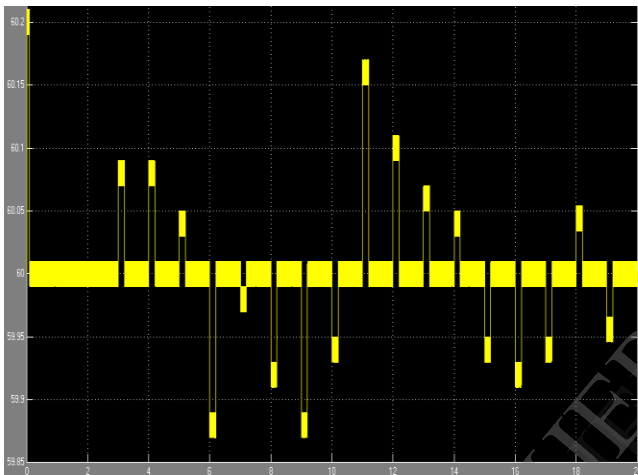


Fig.11 Frequency variations in the system with hysteresis

DISCUSSION ON THE PERFORMANCE OF RESULTS

It can be seen from Fig.8 that during the UPC mode, the feeder flow (blue line) changes due to the change of load (yellow line) and hybrid source output (pink 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. 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 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 micro grid with multi DGs.

V. CONCLUSION

The overall goal of this thesis is to investigate the operation of a grid connected PVFC hybrid system. The hybrid system, composed of a PV array and PEMFC, was considered. This project has presented an available method to operate a hybrid grid-connected system. A comparison between different system operating strategies such as UPC mode and FFC mode are studied. The main conclusions and recommendations drawn from this work are summarized next.

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, shown in Fig. 5.4 is to specify the control mode; the algorithm shown in Fig. 5.1 is to determine the reference power of hybrid system 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 is always less than its maximum value. The change of the operating mode depends on the current load demand, 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 otherwise; the operating mode is either UPC mode or FFC mode. Besides, the variation of hybrid source reference power 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 micro grid. It can improve the performance of the system's operation; the system works more stably while maximizing the PV output power.

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