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Grid-Connected Pv-Fc Hybrid System Power Control Using Mppt And Boost Converter

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Abstract—
This paper proposes a method for operating a grid connected hybrid system. This system composed of a Photovoltaic (PV) array and a Proton exchange membrane fuel cell (PEMFC) is considered. As the variations occur in temperature and irradiation during power delivery to load, Photo voltaic (PV) system becomes uncontrollable. In coordination with PEMFC, the hybrid system output power becomes controllable. Two operation modes are the unit-power control (UPC) mode and the feeder-flow control (FFC) mode, can be applied to the hybrid system. All MPPT methods follow the same goal that is maximizing the PV system output power by tracking the maximum power on every operating condition. Maximum power point tracking technique (Incremental conductance) for photovoltaic systems was introduced to maximize the produced energy. The coordination of two control modes, coordination of the PV array and the PEMFC in the hybrid system, and determination of reference parameters are presented. The proposed operating strategy systems with a flexible operation mode change always operate the PV array at maximum output power and the PEMFC in its high efficiency performance band. Also thus improving the performance of system operation, enhancing system stability, and reducing the number of operating mode changes.
Index Terms—Distributed generation, fuel cell, hybrid system, micro grid, photovoltaiic.

I. INRODUCTION

Demand has increased for renewable sources of energy. One of these sources is solar energy. The photovoltaic (PV) array normally uses a maximum power point tracking (MPPT) to continuously deliver the highest power to the load when there are variations in irradiation and temperature. The disadvantage of PV energy is that the PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. In order to overcome these inherent drawbacks, alternative sources, such as PEMFC, should be installed in the hybrid system. By changing the FC output power, the hybrid source output becomes controllable. However, PEMFC, in its turn, works only at a high efficiency within a specific power range $(P_{FC}^{low} \div P_{FC}^{up})$[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 order to implement the MPPT algorithm, a buck-boost dc/dc converter is used. 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 saw tooth waveform with the control voltage [3]. The output voltage is of the opposite polarity than the input in the buck-boost converter.

This is the main drawback of the buck-boost converter, to overcome this draw back boost converter is used. In a boost converter, the output voltage is always higher than the input voltage.

II. SYSTEM DESCRIPTION

Structure of Grid-Connected Hybrid Power System

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.

PV Array Model

The mathematical model [4], [5] for PV array can be expressed as

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

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

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

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

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

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

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

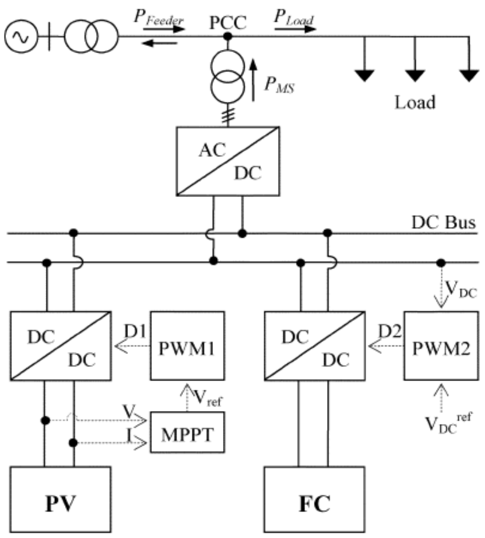


Fig.1 Grid-connected PV-FC hybrid system

PEMFC Model

The PEMFC steady-state feature of a PEMFC source is assessed by means of a polarization curve, which shows the

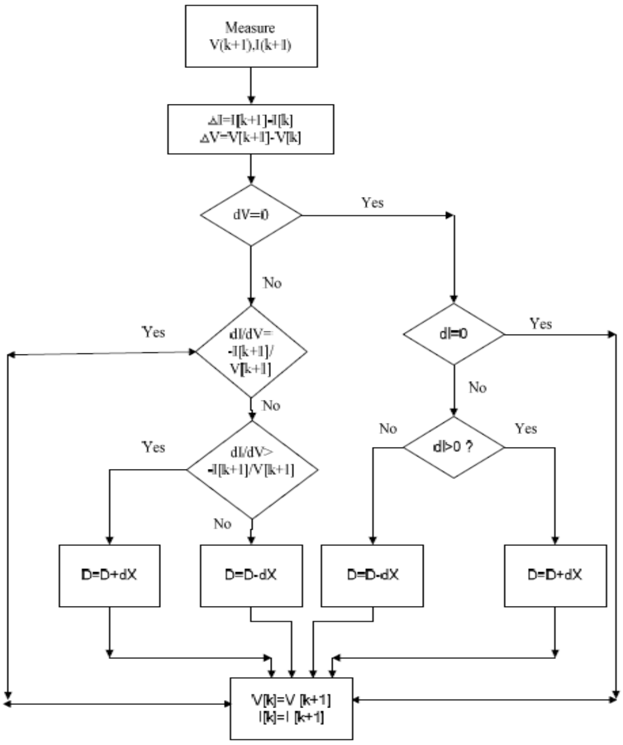


Fig 2 Flow chart of incremental conductance method

Nonlinear relationship between the voltage and current density. The PEMFC output voltage is as follows [6]:

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

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, 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 of PEMFC consists of the resistance of the polymer membrane and electrodes, and the resistances of the electrodes.
The concentration voltage drop is expressed as

MPPT Control

Maximum power point trackers (MPPTs) play a main role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT [19] can minimize the overall system cost. There are many MPPT methods available the most widely-used technique is incremental conductance method described in the following sections. They also vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima and their applications [7-8]. Specifically the Power Point Tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the loads. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with very high efficiency transformers and small components.

Some MPPTs are more rapid and accurate and thus more impressive which need special design and familiarity with specific subjects such as fuzzy logic or neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibits better performance in contrast with P&O control method [11]; however the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule base table. It is greatly dependant on the how designer arranges the system which requires skill and experience.

Incremental Conduction Algorithm

The Incremental Conductance method [9-13] offers good performance under rapidly changing atmospheric conditions. The derivative of output power P with respective to panel voltage V is equal to zero at Maximum Power Point(MPP). MPP. The basic equations of this method are as follow.

$$\frac{dP}{dV} = 0 \quad \text{for } V = V_{mp} \qquad (10)$$

$$\frac{dP}{dV} > 0 \quad \text{for } V < V_{mp} \qquad (11)$$

$$\frac{dP}{dV} < 0 \quad \text{for } V > V_{mp} \qquad (12)$$

The Incremental Conductance MPPT method works with two sensors measuring panel's operating voltage V and current I. The necessary incremental changes dV and dI approximated by comparing the most recent measured values for V and I with those measured in previous values.

$$dV(k) = V(k) - V(k-1) \qquad (13)$$

$$dI = I(k) - I(k-1) \qquad (14)$$

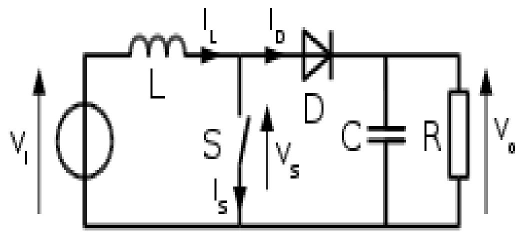


Fig.3 Boost Converter topology

III. CONTROL OF THE HYBRID SYSTEM

The control modes in the micro grid include unit power control, feeder flow control, and mixed control mode. The two control modes were first proposed by Lasserter [14].

In the UPC mode, the DGs (the hybrid source in this system) regulate the voltage magnitude at the connection point and the power that source is injecting. In this mode if a load increases anywhere in the micro grid, the extra power comes from the grid, since the hybrid source regulates to a constant power. In the FFC mode, the DGs regulate the voltage magnitude at the connection point and the power that is flowing in the feeder at connection pointP_{feeder} . With this control mode, extra load demands are picked up by the DGs, which maintain a constant load from the utility viewpoint. In the mixed control mode, the same DG could control either its output power or the feeder flow power. In other words, the mixed control mode is a coordination of the UPC mode and the FFC mode.

Both of these concepts were considered in [15]–[18]. In this paper, a coordination of the UPC mode and the FFC 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 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 able 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 the 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 depicted in Fig. 4.

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

$$P_{Pv} + P_{FC} = P_{Ms}^{ref} \qquad (15)$$

Equation (15) 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. 4 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

$$P_{Pv1} = P_{Fc}^{up} - P_{Fc}^{low} \qquad (16)$$

$$P_{Ms1}^{ref} = P_{Fc}^{up} \qquad (17)$$

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 (15) and (16), 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. 4, if PV output is larger than P_{Pv1} the reference power will be increased by the amount of ΔP_{MS} , and we obtain

$$P_{Ms2}^{ref} = P_{Ms1}^{ref} + \Delta P_{MS} \qquad (18)$$

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

$$P_{Pv2} = P_{Pv1} + \Delta P_{MS} \qquad (19)$$

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

$$\Delta P_{MS} \leq P_{Fc}^{up} - P_{Fc}^{low} \qquad (20)$$

In general, if the PV output is between P_{Pvi} and between P_{Pvi-1} (i=1, 2, 3, 4………..), then we have

$$P_{Msi}^{ref} = P_{Msi-1}^{ref} + \Delta P_{MS} \qquad (21)$$

$$P_{Pvi} = P_{Pvi-1} + \Delta P_{MS} \qquad (22)$$

Equations (21) and (22) 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 (16), (17), and(22) in (21), and then

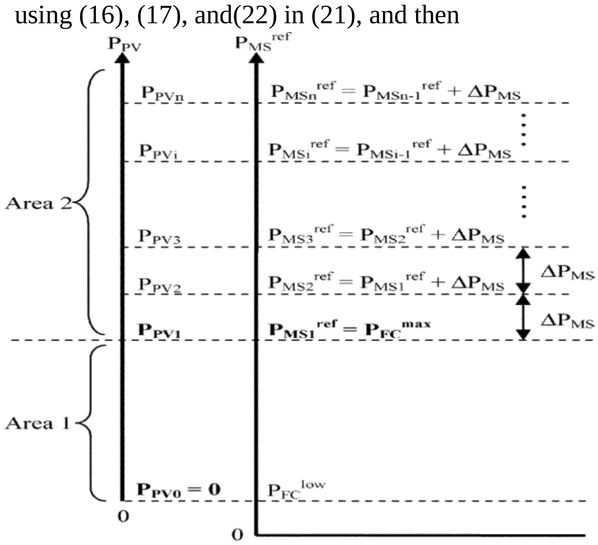


Fig. 4. Operation strategy of hybrid source in the UPC mode

$$P_{Msi}^{ref} = P_{Pvi} + P_{Fc}^{min} \quad , \quad i=1, 2, 3, 4\ldots\ldots\ldots. \quad (23)$$

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

$$P_{Pvi-1} \leq P_{Pv} \leq P_{Pvi} \quad , \quad i = 1, 2, 3, 4\ldots\ldots\ldots.$$

then we have

$$P_{Msi}^{ref} = P_{Pvi} + P_{Fc}^{min} \quad , \quad i = 1, 2, 3, 4\ldots\ldots\ldots. \quad (24)$$

$$P_{Pvi} = P_{Pvi-1} + \Delta P_{MS} \quad , \quad i = 1, 2, 3, 4\ldots\ldots\ldots \quad (25)$$

it is noted that when is given in (16), and

$$P_{Pvi-1} = P_{Pv0} = 0 \quad (26)$$

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 (24) and (25). P_{Pv0}, P_{Pv1} and ΔP_{MS} are shown in (26), (16), and (20), respectively.

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_{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%).

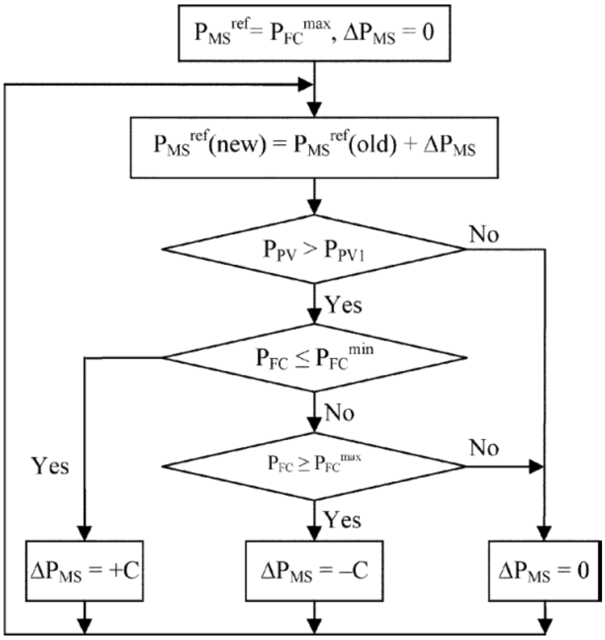


Fig. 5. Control algorithm diagram in the UPC mode (P_{ref} automatically changing).

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. At the boundary of change in P_{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_{ref} is depicted in Fig. 6.

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 subsection, a method to determine P_{ref} 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.

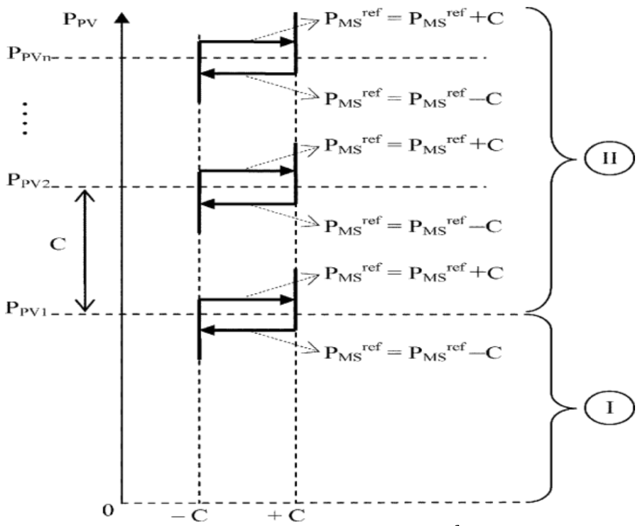


Fig 6 Hysteresis control scheme for P_{Ms}^{ref} control

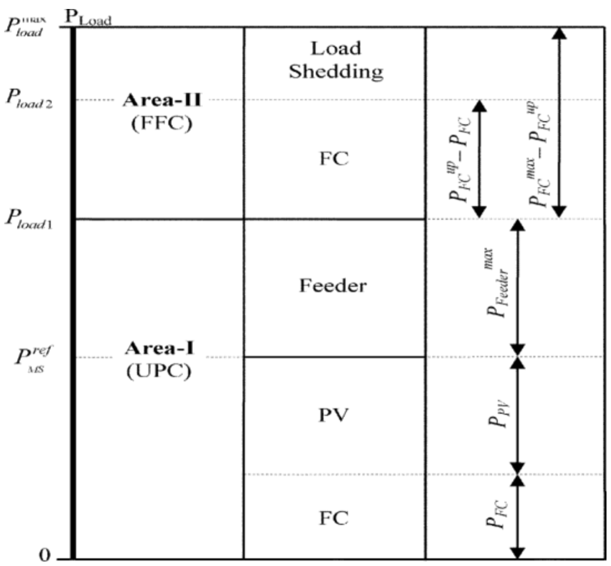


Fig 7 Overall operating strategy for the grid-connected hybrid system.

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_{ref} pro-posed before, 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 system works in the FFC mode, the feeder flow is controlled to a reference value $P_{ref_{feeder}}$ 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.

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.

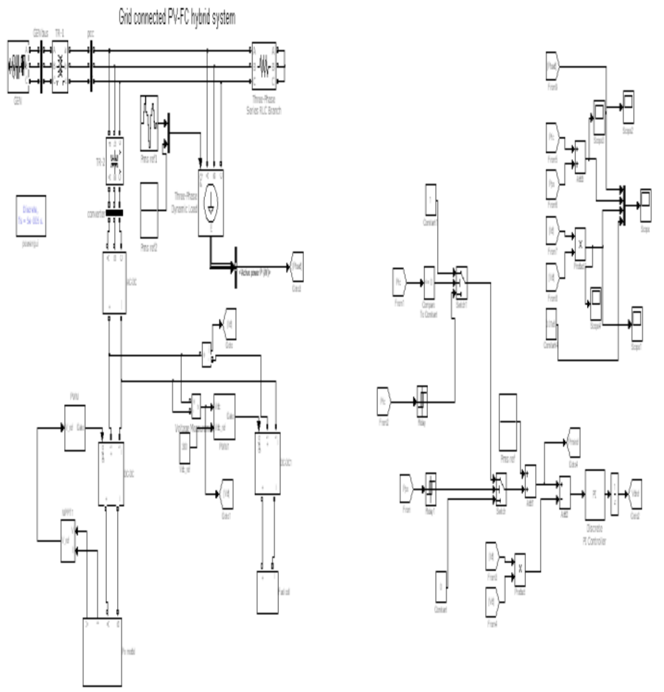
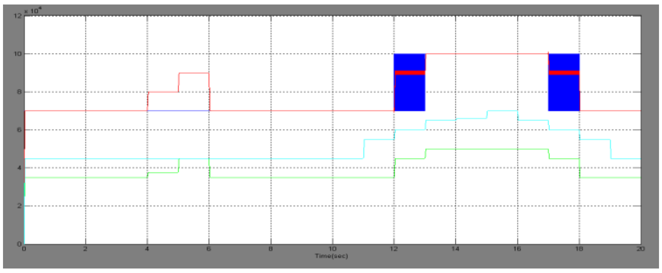
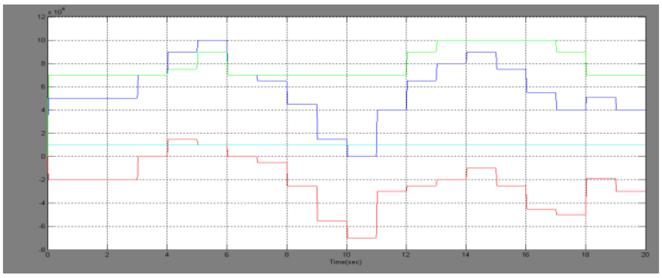


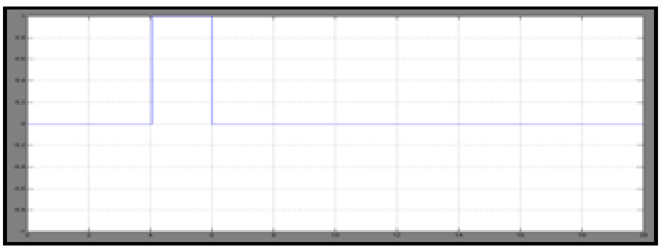
Fig 8 Simulation Block with hysteresis



(a)

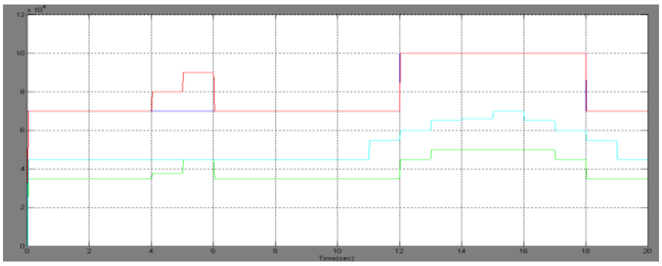


(b)



(c)

Fig 9 simulation result without hysteresis Controller (a) Operating strategy of the hybrid system (b) Operating strategy of the whole system (c) Change of operating modes



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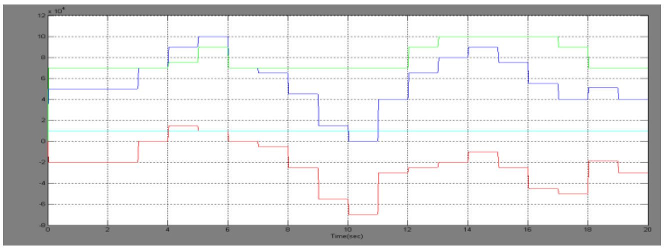

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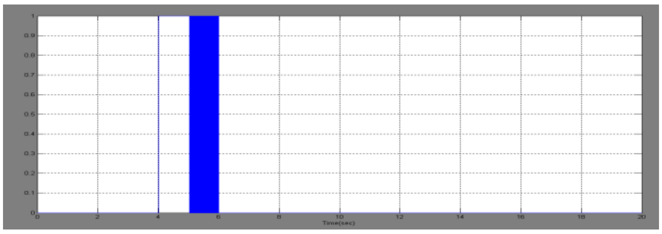
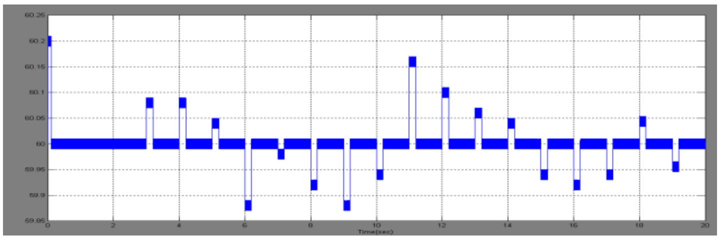


(c)



(d)

Fig 10 simulation result hysteresis Controller (a) Operating strategy of the hybrid system (b) Operating strategy of the whole system (c) Change of operating modes (d) Frequency variation occur in the system

V. RESULTS & DISCUSSIONS

A. Simulation Results in the Case Without Hysteresis Controller

It can be seen from Fig. 9 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. During FFC mode, the hybrid source output power changes with respect to the change of load demand, as in Fig. 9(b). On the contrary, in UPC mode, P_{Ms} changes following P_{Ms}^{ref} , as shown in Fig. 9(a). It can also be seen from Fig 9(a) that at 12 s and 17 s, 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 10.

B. Improving Operation Performance by Using Hysteresis Controller

Fig. 10 shows 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_{Ms}^{ref} [Fig10(a)], FC output [Fig 10(a)], and feeder flow [Fig10(b)] are eliminated and, thus, the system works more stably compared to a case without hysteresis (Fig 10). Fig. 10(d) shows the frequency variations when load changes or when the hybrid source 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 ($\pm 5\% * 60 = \pm$ 0.3 Hz).

VI. CONCLUSION

A hybrid system composed of a PV array and PEMFC, connected to grid is considered. The operating strategy of the system is based on the UPC mode and FFC mode. The purposes of the proposed operating strategy presented in this paper are to determine the control mode, to minimize the number of mode changes, to operate PV at the maximum power point, and to operate the FC output in its high efficiency performance band.

The proposed 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.

In brief, the proposed operating algorithm is a simplified and flexible method to operate a hybrid source in a grid connected micro grid. It improves 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 micro grid with multiple feeders and DGs will also be studied in detail.

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