Power Management Strategies for PV-Wind-FC Hybrid System in Grid Connected Mode

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ABSTRACT:-The reliability of the power system can be best achieved by integrating different energy sources to meet the load demands while accommodating various natural conditions. In this paper a hybrid renewable energy system consisting of three power generation systems photovoltaic (PV) panels, Wind-generator and a fuel cell (FC) is connected to the grid. PV and wind are the primary sources for the system and due to the effects of intermittent cloud and changes in temperature cause a randomly fluctuated output of a photovoltaic (PV) system and due to change in the wind velocity the output of a Wind generator fluctuates for which a fuel cell performs as a backup power source. For the continuity of energy supply there is requirement of energy storing devices for which the grid itself acts as energy storage. In this paper with the synchronization of the Unit Power Control (UPC) mode and Feeder flow control (FFC) mode allows the hybrid source to compensate for the load variations and the coordination of the PV,FC, Wind makes the hybrid system to operate stably with minimum number of mode changes.

KEYWORDS:-Photovoltaic Generator, Wind Generator, Fuel Cell, Micro-grid, Power management

I. INTRODUCTION :

The demand for energy increased from the last few decades due to the increase in the global energy consumption and industrialization which led to the gap between the supply-demand in the power sector. The rise in the fuel prices and harmful emissions from the burning of fossil fuels has made power generation from conventional energy sources unsustainable and unavailable. The fossil fuels- coal, oil, gas are of limited amount and cannot be. replaced and it is difficult to estimate how long these fuels will last. In order to overcome the supply-demand gap the need for the Renewable energy resources such as solar, wind, tidal etc., have gained a lot of importance. The drivers for hybrid renewable energy systems development are economic factor, shortage of electric supply, availability of renewable energy sources and utilization of energy storage systems. Hybrid Renewable Energy Systems (HRES) is a unit of one or more renewable source and with one conventional energy source or without having any conventional energy sources, that works either in the stand alone mode or grid connected mode [1].

The incorporation of the multiple renewable energies operates the system most reliably and therefore the wind which is most widely used renewable energy because of the technological advancements and government incentives will be integrated with PV to obtain better performance of the system [2].

The Photovoltaic array along with a MPPT(Maximum Power Point Tracker) is most widely used to track the maximum power under varying irradiations and temperature. The drawback of the PV array is that due to the continuous change in the cell temperature and irradiation, the output power becomes uncontrollable. In order to overcome this drawback the need for an alternative source such as Proton exchange membrane fuel cell (PEMFC) arises. The PEMFC along with the PV array and wind makes the hybrid source output controllable. The PEMFC usually operates at high efficiency within a specific range of power. The power to the load is delivered by connecting the hybrid source (PV, wind and PEMFC) to the grid at the common point of coupling .When there is a change in the load demand the power supplied from the hybrid source and the main grid must be properly coordinated. The hybrid source is operated under two control modes: UPC (Unit Power Control) mode and FFC(Feeder Flow Control) mode. In the UPC mode the hybrid source output is regulated to the reference power and thereby the variations of the demand met by load are compensated by the grid. Therefore in the Unit Power Control mode the reference power of the hybrid source must be known so that in the FFC mode the extra demand met by load is collected by the hybrid source by regulating the feeder flow to a constant.

The operating strategy coordinates the two control modes in such a way that the constraints are satisfied and the system operates at high efficiency and minimizes the number of mode changes to enhance the system stability.

II. SYSTEM DESCRIPTION:

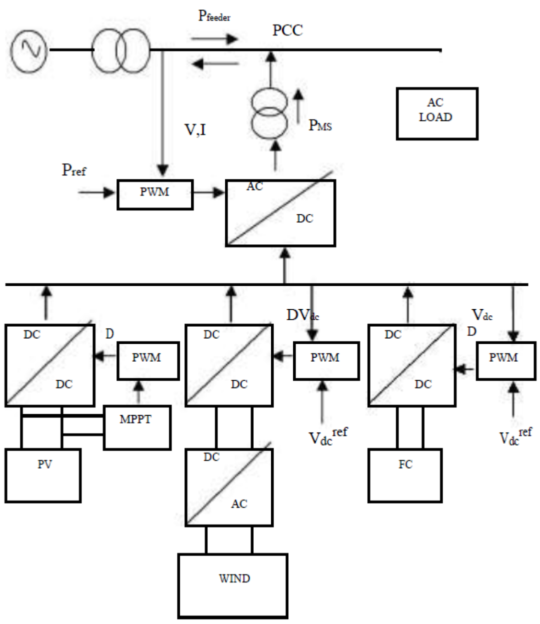

Fig. 1: Grid-Connected PV-Wind-FC Hybrid Power System.

A. GRID-CONNECTED POWER SYSTEM:

The system indulged in this consists of PV-PEMFC-wind (hybrid source) integrated at the common point of coupling with the grid. The PV, Wind and PEMFC are connected to the DC/DC converter and are coupled to the DC side of the DC/AC inverter. The maximum power from the PV array is obtained by using a MPPT such as Perturb and Observe, Incremental Conductance, Constant Voltage and Fuzzy logic controller. Due to the change in the irradiance of the PV array and the change in the velocity of the wind speed the output power obtained will be varying. In-order to overcome this drawback the PEMFC which acts as the alternative energy source is operated in such a way that it operates within the limits so that it operates at high efficiency band.

B. MODELING OF PV ARRAY:

The PV array consists of a current source dependent on the incoming irradiance, a reverse diode which regulates the voltage of the cell, a series resistor Rs which determines downward slope of the I-V curve near Voc and the value of the series resistor determines the internal resistance of the cell and controls the internal losses, a shunt resistor Rsh which determines the slope of the line at the top of the I-V curve near Isc and the shunt resistor value controls the leakage current from cell to ground [3,4].The output current is achieved by the Kirchhoff's current law as follows:

$$I = I_{ph} - I_D \quad (1)$$

$$I = I_{ph} - I_{sat}\left[e^{\left(\frac{q}{AkT}(V+IR_s)\right)} - 1 \right] \quad (2)$$

I_{ph} is the photon current

$$I_{ph}(G_a) = I_{sc}\left(\frac{G_a}{G_{sc}}\right) \quad (3)$$

I_{sat} is the saturation current

$$I_{sat}(G_a, T) = \frac{I_{ph}(G_a, T)}{e^{\left(\frac{V_{oc}(T)}{V_t(T)}\right)} - 1} \quad (4)$$

I_{sc} is the short-circuit current

$$I_{sc}(T) = I_{scs}\left[1 + \Delta I_{sc}(T - T_s)\right] \quad (5)$$

C. MODELING OF WIND TURBINE:

The wind generator consists of a turbine coupled to a Permanent Magnet Synchronous Generator (PMSG) with a rectifier [5]

Wind Power is given by:

$$P_w = \frac{1}{2}\rho A v^3 C_p(\lambda,\theta) \quad (6)$$

Where P_W is the output power of the Wind turbine.

v is the wind velocity in m/sec

ρ is the air-density in kilogram per cubic meter

A is the area swept by the rotor blades in square meter

C_p is the power coefficient which is the function of tip speed ratio and pitch angle.

D.MODELING OF FUEL CELL:

The fundamental structure of a PEMFC consists of two electrodes (anode and cathode) which are separated by a solid membrane acting as a electrolyte. The characteristic curve known as polarization curve is of three regions shows the relationship as non linear between the current and voltage. Proton exchange membrane fuel cell output includes the activation voltage drop, ohmic voltage drop and the concentration voltage drop [6]. The PEMFC output voltage including the three voltage drops is given by:

$$V_{fc} = E_0 - V_{act} - V_{ohm} - V_{conc} \quad (7)$$

E_0 represents the open- circuit voltage of the fuel cell

V_{act} the activation voltage drop given by the Tafel equation as:

$$V_{act} = T\left[a + b\ln(I)\right] \quad (8)$$

V_{ohm} Is the ohmic voltage drop

$$V_{ohm} = IR_{ohm} \quad (9)$$

V_{conc} is the concentration voltage drop

$$V_{conc} = \frac{-RT}{zF}\ln\left(1 - \frac{I}{I_{limit}}\right) \quad (10)$$

E. MODELING OF CONTROLLER:

The maximum power under varying irradiances can be achieved by implementing Maximum Power Point tracking algorithms such as the Perturb and Observe, Incremental Conductance, Constant voltage. Among all these algorithms Perturb and Observe MPPT Controller is implemented as it requires only two sensors whereas the INC MPPT controller requires four sensors. The two different control techniques used for the maximum power point are based on voltage and power feed back control techniques [7,8]. The most commonly used technique is the Power-feedback control as the voltage-feedback control neglects the effect of solar irradiation and temperature[8],[9].The change in the derivative (i.e., the change in at kth and (k-1)th instant)is taken as the input to the MPPT controller in order to generate duty cycle as the output. The duty cycle obtained from the MPPT Controller is used to generate the gate signal to control the DC-DC converter. The Buck-Boost Converter is used in-order to step-up or step-down the voltage based on the reference power. The parameters L and C of the Buck-Boost converter must satisfy the conditions as follows:

$$L > \frac{(1-D)^2 R}{2f};\ C > \frac{D}{Rf\left(\frac{\Delta V}{V_{out}}\right)} \quad (11)$$

The step up-step down converter along with the MPPT controller makes PV to attain maximum power and the maximum power tracked is delivered to the ac side via dc/ac inverter.

III. CONTROL MODES IN THE MICRO-GRID:

The control modes implemented for the control of the hybrid source are Unit Power Control (UPC) mode, Feeder Flow Control (FFC) mode and mixed control mode. Lasserter first proposed the two control strategies UPC and FFC mode [10].The control mode used is a coordination of the UPC and FFC modes in which the same distributed generator can act in either of the two modes. The two modes were considered in [11-15].

In the UPC mode the Distributed Generation unit (hybrid source) is regulated to a constant power and hence whenever there is an increase in the load at anyplace in the micro-grid the power that is excess is supplied from the main-grid. The active power supplied by the distributed generator is measured and fed back to the controller.

In the FFC mode the feeder power flow and the voltage magnitude at the connection point i.e., at the point of common coupling are regulated by the each distributed generation unit. With the implementation of the FFC configuration the load demands that are excess are picked-up by the generation units by regulating the feeder power flow to a constant and thereby indicating a constant load to the main grid.

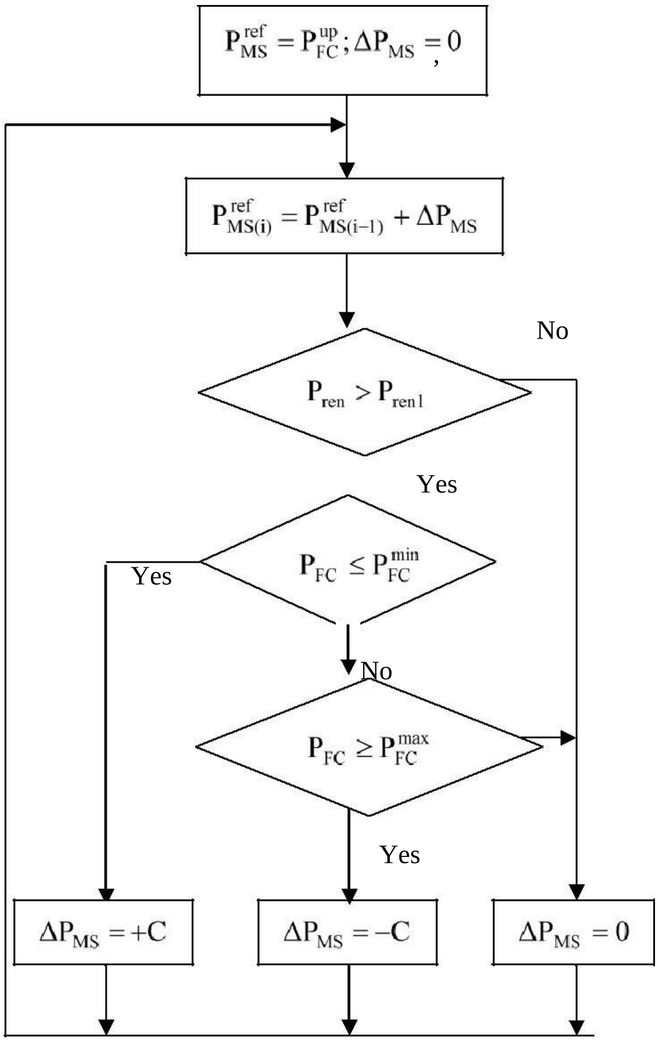

Fig. 2. Control Algorithm to determine reference power in UPC mode.

The algorithm depicted in this section determines that the micro-grid operates in the UPC mode. The algorithm implemented makes the renewable energy sources together to operate at its maximum power and the fuel cell to work at its high efficiency range. The output of the hybrid source in the UPC mode is regulated to the reference value as.

$$P_{PV} + P_W + P_{FC} = P_{MS} \quad (12)$$

In the above equation it is clear that whenever the P_{ren} source output is not equal to the reference power, it is compensated by the fuel cell output power. The operating strategy to determine the reference power in the UPC mode is as shown in the fig.2.

The operating algorithm depicted in this section operates under two regions: Area-1 and Area-2.While operating in Area1 P_{ren} is less than Pren1 so the reference power P^{ref}_{MS} is set at P^{up}_{FC}. With the increase of the P_{ren} from 0 to P_{ren1} the fuel cell output decreases from P^{up}_{FC} to P^{low}_{FC} .

$$P_{ren2} = P_{ren1} + P^{up}_{FC} \quad (13)$$

$$P^{ref}_{MS1} = P^{up}_{FC} \quad (14)$$

In Area2 the P_{ren} is greater than P_{ren1} .Whenever P_{ren} is greater than P_{ren1} , the P_{ren} reaches to P_{ren1} and thereby the fuel cell output power reaches to its lower limit P^{low}_{FC} . If the renewable output keeps on increasing then the fuel cell output reaches below its limit i.e., P^{low}_{FC} . In-order to overcome this condition i.e., to operate the renewable source at its maximum power and fuel cell within its range, the increase of reference power has to be done. If P_{ren} is greater than P_{ren1} then the reference power P^{ref}_{MS} is increased by ΔP_{MS} as mentioned below:

$$P^{ref}_{MS2} = P^{ref}_{MS1} + \Delta P_{MS} \quad (15)$$

Similarly, if P_{ren} is greater than P_{ren2} , the output of fuel cell comes to less than its lower limit P^{low}_{FC} and thus the reference power will be increased by a factor of ΔP_{MS} . The reference power will remain unchanged and equal to P^{ref}_{MS2} if P_{ren} is less than P_{ren2} and greater than P_{ren1} where

$$P_{ren2} = P_{ren1} + \Delta P_{MS} \quad (16)$$

With the new reference power, the FC output must be less than its upper limit for which ΔP_{MS} is limited as

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

In general, the operation of the hybrid source when the renewable source output is between $P_{ren(i)}$ and $P_{ren(i-1)}$ $(i=2,3,4....)$ can be stated from the following equations:

$$P^{ref}_{MS(i)} = P^{ref}_{MS(i-1)} + \Delta P_{MS} \quad (18)$$

$$P_{ren(i)} = P_{ren(i-1)} + \Delta P_{MS} \quad (19)$$

The reference power in the Area1 and Area2 can be determined in the generalized form by starting the index i from 1

$$P_{ren(i-1)} = P_{ren} + P_{ren(i)} \; ; i = 1,2,3... \quad (20)$$

$$P^{ref}_{MS(i)} = P_{ren(i)} + P^{min}_{FC} \; ; i = 1,2,3... \quad (21)$$

$$P_{ren(i)} = P_{ren(i-1)} + \Delta P_{MS} \; ; i = 2,3,4... \quad (22)$$

The operating strategy of the hybrid source determines that in the Area1 the reference power is always equal to P_{FCup} and with the change of the renewable source output power, the reference power changes by an amount of ΔP_{MS} .

A. OPERATING STRATEGY FOR THE GRID CONNECTED PV-WIND-FC SYSTEM:

The operating algorithm is to coordinate the system between the two modes: UPC mode and FFC mode. In the UPC mode the hybrid source output is regulated to a constant and if there is excess of power it will be transmitted to main-grid and if there is extra load demand to be met main-grid will supply to match the load demand. When there is an increase in the load, there will be increase in the feeder flow correspondingly. When the feeder flow reaches

to the maximum P_{Feeder}^{max}, then the feeder flow cannot meet the load demand if the load keeps on increasing. In-order to meet the load demand in this case the control mode is shifted from UPC to FFC mode and the feeder reference power is set to P_{Feeder}^{max}.

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

In the FFC mode the variation in the load is matched by the hybrid source power. The variations in the load and the renewable source power are compensated by the PEMFC .If the fuel cell operates upto its maximum limit and even then if the load demand is not met then the load shedding will occur. The load shedding will occur when:

$$P_{Load2} = P_{FC}^{up} + P_{Feeder}^{max} + P_{n} \qquad (24)$$

The load shedding will not occur when the FC power and the load demand are satisfied i.e., below P_{Load2}.
The value of C must be chosen in such a way that the frequency doesn't change over its limits(±0.5).The minimum number of mode changes occur when the C is maximized.

$$\Delta P_{MS}^{max} = P_{FC}^{up} - P_{FC}^{low} \qquad (25)$$

Due to MPPT process of the PV there will be oscillations in the reference power. A hysteresis is included in-order to eliminate the oscillations and to make the hybrid source operate stably.

Table 1. System Parameters:

Parameter	Value
PFC^{min}	0.01MW
PFC^{max}	0.06MW
$PFeeder^{max}$	0.01MW
ÄPMS	0.03MW

IV. SIMULATION RESULTS:

A. SIMULATION RESULTS WITHOUT HYSTERISIS:

The PV, wind and load were varied in terms of steps in-order to validate the strategy of operation. The PV and wind are operated under standard conditions from 0s to 11s and then varied in terms of step as shown in fig 3(a). The load demand to be met is as shown in fig.3(b). With the change of the PV output and PMS output the fuel cell output is obtained as shown in fig.3(a). The change of the operating modes is as shown in fig.3(c). From 4s to 6s the grid connected hybrid system operates in Feeder Flow Control mode and thus the feeder reference power is set to the feeder maximum value as given by the system parameters. The reference power contains oscillations from 13s to 14s due to the MPPT process of PV due to which the fuel cell contains oscillations. In-order to overcome these oscillations a hysteresis parameter is included.

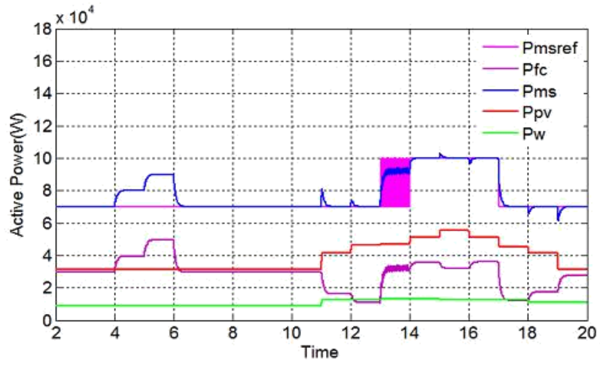

Fig. 3(a).Operating Strategy Of the Hybrid Source.

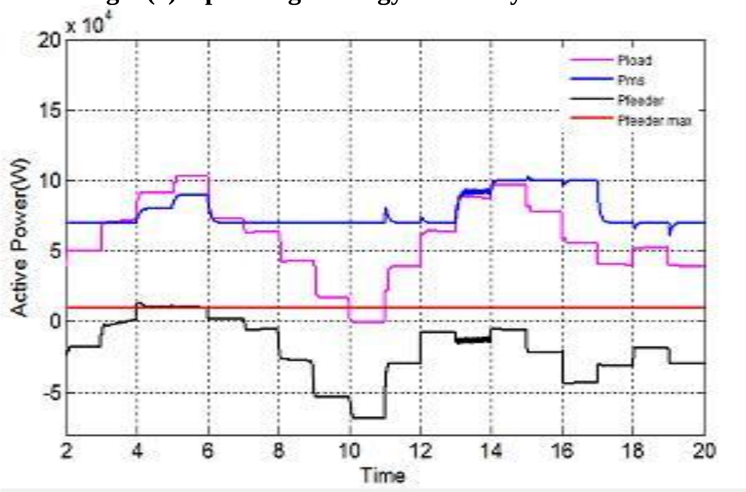

Fig. 3(b). Operating Strategy Of the Grid Connected system.

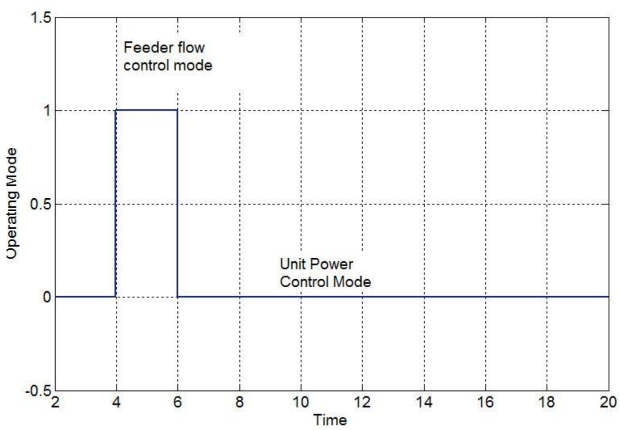

Fig. 3(c). Change Of Operating Modes.

B. SIMULATION RESULTS BY USING HYSTERISIS:

The oscillations in the PMS, PFC and Pfeeder from the 13s to 14s are eliminated by including the hysteresis parameter. The hysteresis parameter was chosen at C=0.03MW. With the hysteresis parameter chosen at 0.03MW the frequency variations did not reach over its limit (±5%*60=±0.3Hz). The numbers of mode changes are minimized and the frequency variations do not cross over its limit by choosing the ÄPMS value as maximum.

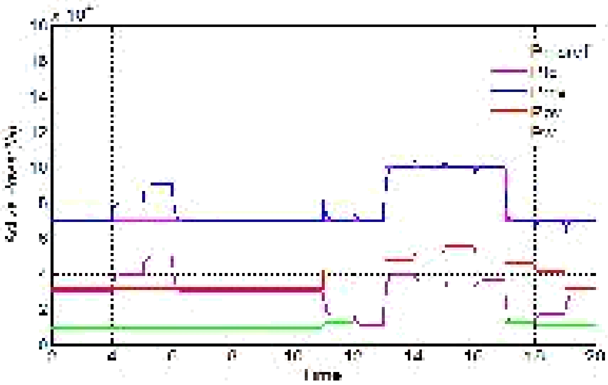

Fig. 4(a).Operating Strategy Of the Hybrid Source.

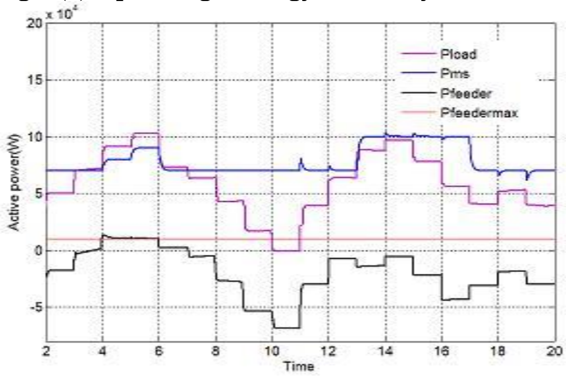

Fig. 4(b). Operating Strategy Of the Grid Connected system.

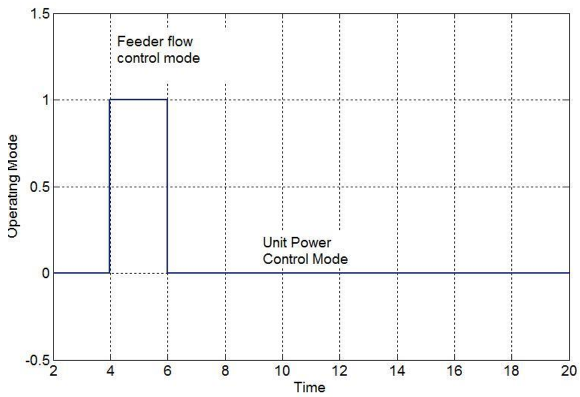

Fig. 4(c). Change of Operating Modes.

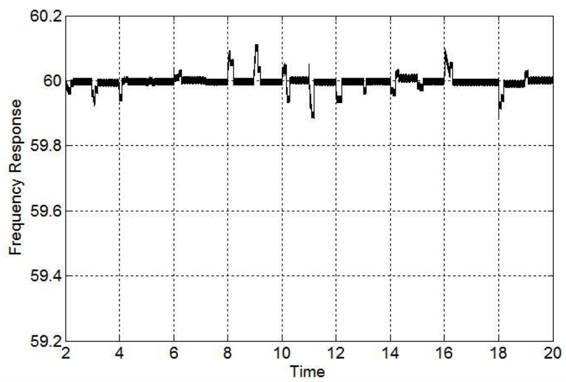

Fig. 5. Frequency variations in the system.

V. CONCLUSION:

This paper has presented the grid connected PV-Wind-PEMFC hybrid system. The grid connected hybrid system is operated under two control modes: UPC mode and FFC mode. The purpose of the implemented operating strategy is to minimize the number of mode changes and to operate the PV and wind reliably and PEMFC at its high efficient band. With the change of the value C the number of mode changes will be maximized or minimized. With the C=0.03MW it is seen that the number of mode changes are minimum. Whenever the load increases the extra power is supplied by the hybrid source as the feeder flow is synchronized to a constant value which resembles that it operates in FFC mode. The hybrid system operates more stably in the UPC mode as the hybrid source output is regulated to a constant. The oscillations due to the MPPT process of PV can be eliminated by including the hysteresis. By choosing the value of C as 0.03MW the frequency variations didn't exceed its limits.

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