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Power Flow Managing in a Stand Alone Hybrid Power System

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Abstract: This study presents power flow management in a stand alone mode-connected hybrid power system comprising of solar system and energy storage system fuel cell/battery using controller between the energy resources. The proposed controller is focused with structure in order to manage the power flow. The Maximum Power Point Tracking (MPPT) design is achieved by using adaptive neuro-fuzzy inference system control design with respect to variation of solar insolation and temperature. To optimize the battery managing of charge and discharge of the current flow in the battery it is accomplished by advance fuzzy logic controller. Finally, in the design of local control is done in order to adjust the fuel cell/battery set points. The comparison of adaptive neuro-fuzzy inference system with standard PI based controller is demonstrated through series of simulation results with variation of solar irradiance and at various load resistance. This hybrid topology of the controller design exhibited excellent results under various operating conditions which obviously reflect the robustness with respect to parameter variation. Thus, it's concluded the proposed model augmented by the control strategy improves management of power flow in a stand alone system connected hybrid power system.

Key words: PV, FC, battery, fuzzy control, adaptive neuro-fuzzy inference system, hybrid

INTRODUCTION

Now a days a stand alone system is using renewable sources, like Photo Voltaic (PV), fuel cell, wind power. The reduction of greenhouse emissions gas and protect the environment from further degradation. V-I characteristics of PV system (D'hulst and Peeters, 2010; Wu *et al.*, 2012). The poor efficiency and cause overvoltage problems to overcome above problems, along with storage, can improve system performance. Multi RES, connected PV and FC storage system but they can't respond to electrical load as fast as thermo dynamics responses (Lin *et al.*, 2011; Giraud and Salameh, 2001; Ramakumar *et al.*, 1992). To overcome the FC problems by using batteries are used to supply energy, when FC is starting up and when there is deficit or surplus energy supplied by hybrid system, Battery Energy Storage System (BESS). A typical Hybrid Renewable Energy System (HRES) combines several RES such as Photo Voltaic (PV) panels, fuel cell with BESS in this study. The numerous techniques and developed to optimize server power consumption and maintaining quality of service (Hoff *et al.*, 2007; Thounthong *et al.*, 2009; Dulal *et al.*, 2012). An effective EMS and simulated in virtual test bed situation for a PV/FC/Battery system (Li *et al.*, 2009; Jiang, 2006; Tofighi and Kalantar, 2011; Ahmed *et al.*, 2011; Hsieh *et al.*, 2012; Zhong *et al.*, 2008). An overall PMS is designed for manage to system power flows with the similar energy sources. A battery is also used for short-time backup to supply transient power (Abdulkadir *et al.*, 2012; Wang and Nehrir, 2007; Kumaravel and Ashok, 2012; Tant *et al.*, 2013; Kaabelhe *et al.*, 2011; Ferret and Simoes, 2006; Wang and Singh, 2008; Dalton *et al.*, 2008; Shaahid and Elhadidy, 2007).

MATERIALS AND METHODS

Hybrid power system configuration

PV system: The stand alone connected hybrid power system, the power plants of Hybrid Renewable Energy System (HRES). When solar cell is irradiated by sunlight; it generates hole and electron pairs which leads to power generation. The principle of PV power generation is explained by the equivalent model as shown in Fig. 1. Whether the solar cell is in series or parallel connection, its mathematical equation can be simply expressed as connected solar cells. The characteristics of PV array can be formulated as given in Eq. 1:

$$I = I_p - I_s\left(e^{\frac{q}{aKT}(v+IR_s)} - 1\right) - \frac{1}{R_p}(v+IR_s) \quad (1)$$

The photo current IP depends on the solar insolation and cell temperature:

$$I_p = \frac{S}{S_{ref}}[I_{p,ref} + C_T(T - T_{ref}) \quad (2)$$

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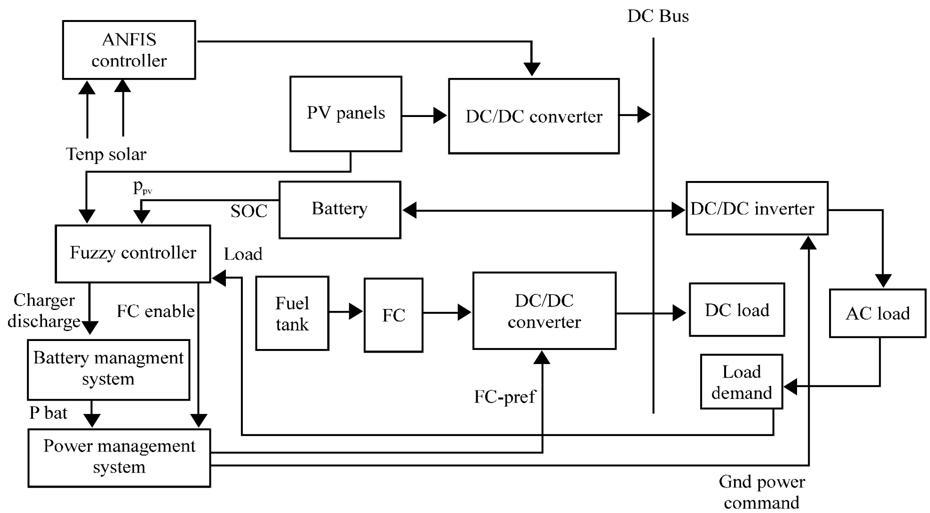

Fig. 1: Hybrid power system integration PV system

$$I_s = I_{s,ref}\left(\frac{T}{T_{ref}}\right)^3 e^{\left(\frac{qE_g}{aK}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\right)} \quad (3)$$

where, s is the cell's reverse saturation current.

Battery model: The storage battery is directly connected across the DC-link. The aim of battery is to maintain the constant DC link voltage. The battery system should be able to operate in two directions, i.e., charge the battery to store the supplementary energy and also can discharge the energy to the load, making it enable to provide a continuous power. With a battery storage system connected, there are three operating modes for the PV generation system:

- When P_{PV}>P load the PV panel will drive the load and charge the battery simultaneously
- When P_{PV} = P load, the battery will operate in no charging and no discharging state
- When P_{PV}<P load the battery will discharge to supply the load

The output of boost converter is given in Eq. 4:

$$\frac{V_o}{V_i} = \frac{1}{(1\text{-}D)} \quad (4)$$

Fuel cell model: A FC is converts the chemical energy from a fuel in to electrical energy through a chemical reaction and it is low power applications. The power sources such as batteries are used in this study to allow the FC stack to be operated under controlled and safe dynamic operating regions. This combination also prevent fuel starvation caused when a FC is forced to respond to load transient while not being supplied which the gases at desired flow rate. The fuel cell output voltage is is a function of activation loss (V_{act}), concentration loss (V_{con}) and Ohmic loss and is given by Nernst equation given below:

$$V_{out} = E_{Nerst} - V_{act} - V_{ohm} - V_{con} \quad (5)$$

where, E Nerst is the "thermodynamic potential" of nerst which represents the reversible (or open-circuit) voltage of the FC. In Eq. 6, voltage of FC stack (Durr *et al*., 2006):

$$V_{fc} = \left(E_{oc}\text{-}NA_T \ln\left(\frac{I_{fc}}{I_c}\right)\frac{1}{s\frac{T_d}{3}+1}\right)\text{-}RI_{fc} \quad (6)$$

Where ENerst is the "thermodynamic potential" of Nerst which represents the reversible (or open-circuit) voltage of the FC. In Eq. 6, voltage of FC stack (Kumaraval and Ashok, 2012). Where Eoc is the open circuit voltage, N is the number of cell, AT is the Tafel slope, Ie is the exchange current, Ifc is the fuel cell current, Td is the response time and R is the internal resistance. The power flow management system is high efficiency and high reliability. PMS is to balance the power flow in hybrid system and to prevent the battery from over charging or over discharging. Power fluctuation in the stand-alone system has been suppressed using storage battery system. The hybrid system should have independent control unit for each energy source to manage the power fluctuations and maintain constant DC bus voltage (Fig. 1).

Table 1: Load power comparison with PI, PBC and ANFIS

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Irradiance (W/m^2)	750	800	850	900	900	900	850	800
Load (Ω)	20	20	17-20	17	17-23	23	23-15	15
PI	600	590	900	650	980	400	800	650
PBC	500	580	600	600	700	405	680	620
ANFIS	500	580	590	600	600	415	620	610

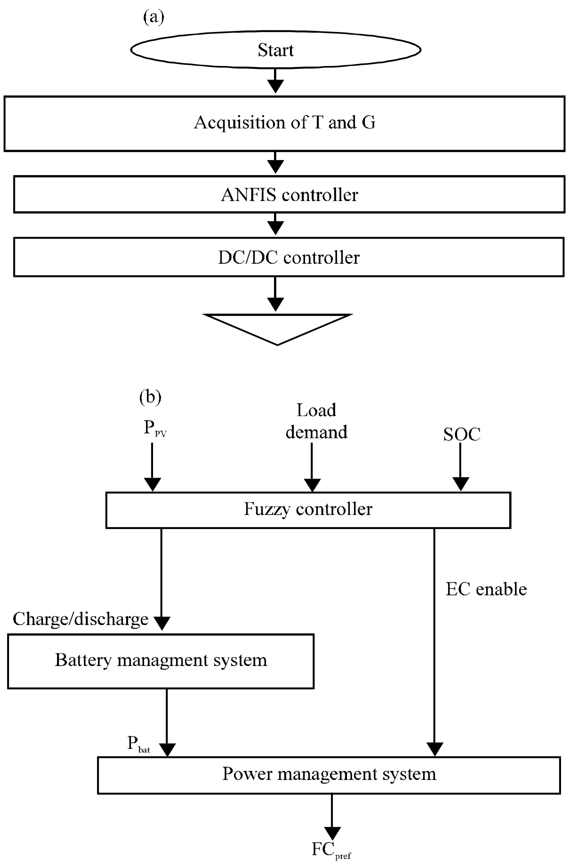

Fig. 2: a) ANFIS alghrithm flow char and b) Proposed fuzzy system for PMS

Power management and control system

PV MPPT based ANFIS controller: The AI control technique by using ANFIS is connected to a maximum power point tracing controller to improve tracking response and efficiency. The MPPT controller was achieved by neural network, however there is problem of controlled being trapped at local minimum in this contest ANFIS controller is designed to improve the efficiency of MPPT (Jang, 1993). The proposed ANFIS is with MPPT consists of two inputs which are solar insolation G and cell temperature T and one output shown in Fig. 2. The input variables are Indian data collected from National Renewable Energy Laboratory (NREL) (Natsheh *et al.*, 2013). The fuzzy inference system using the back propagation and tested it. The current reference is controlled the PV current. The power flow management system is high efficiency and high reliability. PMS is to control the power flow in hybrid system and the battery charging or discharging. Power fluctuation in the stand-alone system has been suppressed using storage system. The hybrid system should have independent control unit for each energy source to manage the power fluctuations and maintain constant DC bus voltage.

Fuzzy inference system: The proposed FLC consists of three inputs which are solar energy, Load demand and battery SOC. The inputs variables are expressed in terms of linguistic are charge/discharge of battery and FC enable. Where low, medium and high using basic fuzzy subset.The control algorithm, namely fuzzification, inference method and defuzzification. Centroid method of defuzzification is proposed with 27 rules given in Table 1. The nonlinear subsystems added to the complexity of the structure of hybrid power system:

$$P_{PV} = P_L + P_{FC} \pm P_{Bat} \tag{7}$$

High solar irradiation (P_{PV} > PL): The excess power is consumed by the battery storage:

$$P_{Ex} = P_L - P_{PV} = -P_{Bat} \tag{8}$$

Low solar irradiation (P_{PV}<PL): The power deficit from the solar irradiation can be supplied by the FC and battery storage as given:

$$P_{def} = P_L - P_{PV} = P_{FC} \pm P_{Bat} \tag{9}$$

The BMS maintains its state of charge at required scale (40-80%). The low voltage protects can be controlling the power demand and storage systems:

- 1-3 if P_{PV} is low and P load is low/medium/high and SOC is low then FC is ON and battery is charge

- 4-6 if P_{PV} is medium and P load is low/medium/high and SOC is low then FC is Off/ON/ON and battery is charge
- 7-9 if P_{PV} is high and P load is low/medium/high and SOC is low then FC is Off/ON/ON and battery is charge
- 10-12 if P_{PV} is low and P load is low/medium/high and SOC is medium then FC is Off/ON/ON and battery is charge or discharge
- 13-15 if P_{PV} is medium and P load is low/medium/high and SOC is medium then FC is Off/ON/ON and battery is charge or discharge
- 16-18 if P_{PV} is high and P load is low/medium/high and SOC is medium then FC is Off and battery is charge or discharge
- 19-21 if P_{PV} is low and P load is low/medium/high and SOC is high then FC is Off and battery is discharge
- 22-24 if P_{PV} is medium and P load is low/medium/high and SOC is high then FC is Off and battery is discharge
- 25-27 if P_{PV} is high and P load is low/medium/high and SOC is high then FC is Off and battery is discharge

The PMS controls the PFC_{ref} of the FC stack. The FC/battery powers are limited in charge or discharge of the battery. The system already described as in Fig. 1, It consists of three layers, ANFIS, fuzzy logic controller and power management. The set of inputs of fuzzy logic controllers are battery SOC, load demand and solar power. According load demand the PMS is accomplished with charge/discharge mode of the battery. The output of PMS is to develop PFC_{-ref}. Once P_{ref} is obtained then PMS is done by investigation of the status of battery charge. The FLC is used to estimate the FC operating point and battery charge and discharge status which corresponding to load demand.

RESULTS AND DISCUSSION

The PMS of PV/Battery hybrid system is carried out by integration of hierarchical control. The hierarchical control is comprised of three parts MPPT controlled obtained using ANFIS controller fuzzy logic controller and power management with knowledge of state of charge of battery. The charge/discharge of SOC is also done for power management objective. The comparative asset of the PMS done with that of passivity based controller (Tofighi and Kalantar, 2011). The PV/ battery of solar insolation and load resistance is shown in Fig. 3. Photo exhibit a smooth and fast response is shown in Fig. 4. The two inputs which are solar insolation G and cell temperature T values are loaded the 'ANFIS' has to be voltaic, battery system, load power and load resistance when, the changes in solar system insolation is shown in Fig. 4. The PV output VL and output IL based on variable

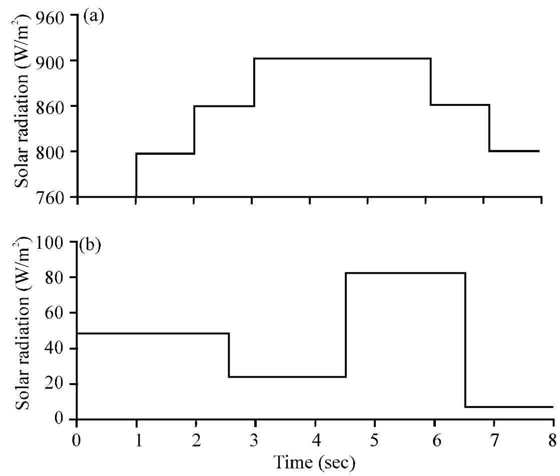

Fig. 3: Input disturbance applied to PV/battery system; a) Soalr insolation and b) Load resistance

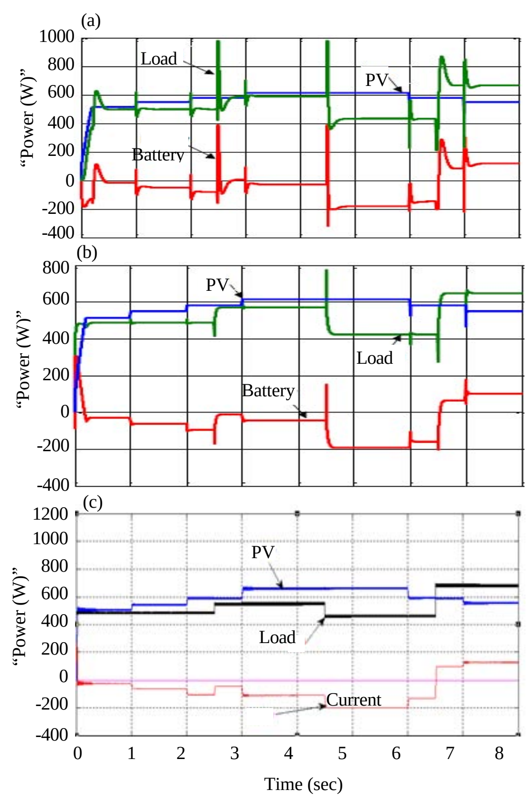

Fig. 4: PV output voltage and output current with respect variable irradiance at constant temperature

solar insolation G and constant cell temperature T is shown in Fig. 5. The PBC and ANFIS controller can be trained by selecting a back-propagation algorithm with number of epochs is shown in Fig. 6. In the initial point,

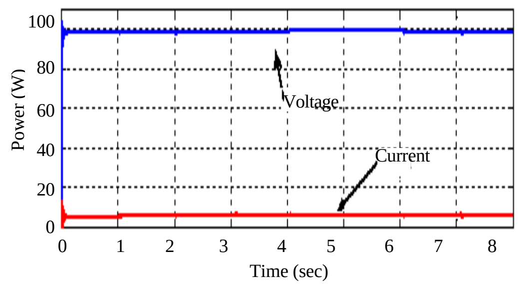

Fig. 5: PV output voltage and output current with respect variable irrdiance at constant temperature

small load power and the balance power send to battery for charging ($P_{bat} = P_{pv} - P_{Load}$) are shown in Fig. 5. The trained data are again export to the workspace. The developed ANFIS model structure with 2 input data and one output data with input membership function are shown in Fig. 7. The trained output data after applying ANFIS controller given to PMS is shown in Fig. 8. The battery voltage and current based on fuzzy controller has less overshoot and the steady-state value faster than PI controller. The DC bus voltage, current and SOC 40%, the battery can supply load power and absorb from the PV system depending on the variable load results are shown in Fig. 12. The proposed fuzzy controller for PMS is shown in Fig. 2b input data are trained and send the output to PMS resultant membership function are shown in Fig. 9-11.

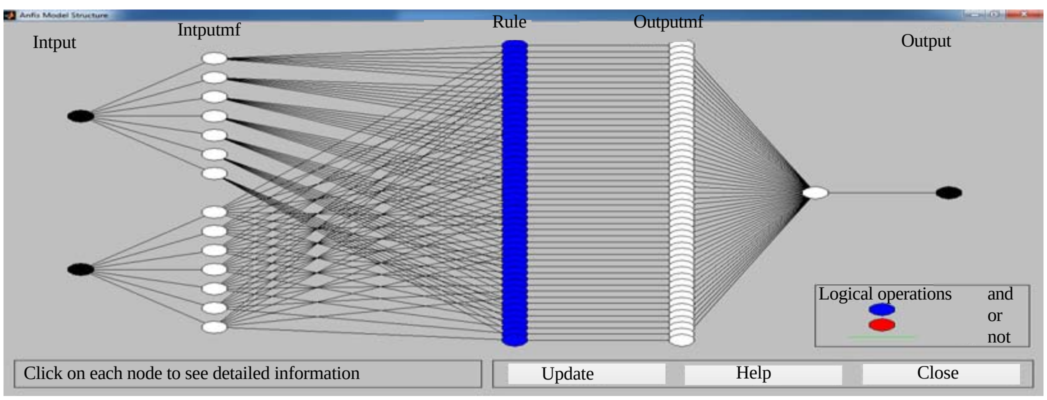

Fig. 6: G, T input FIS structur of ANFIS

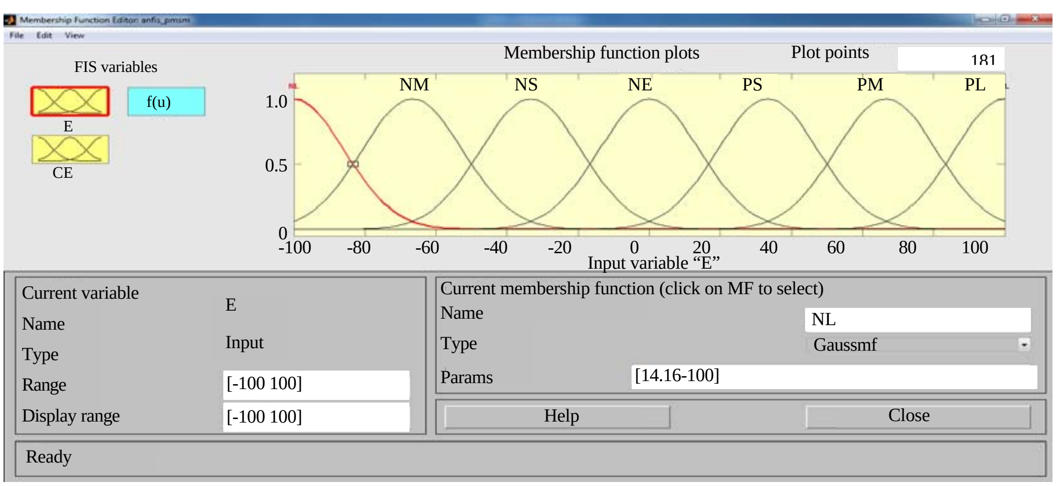

Fig. 7: ANFIS input membership functions

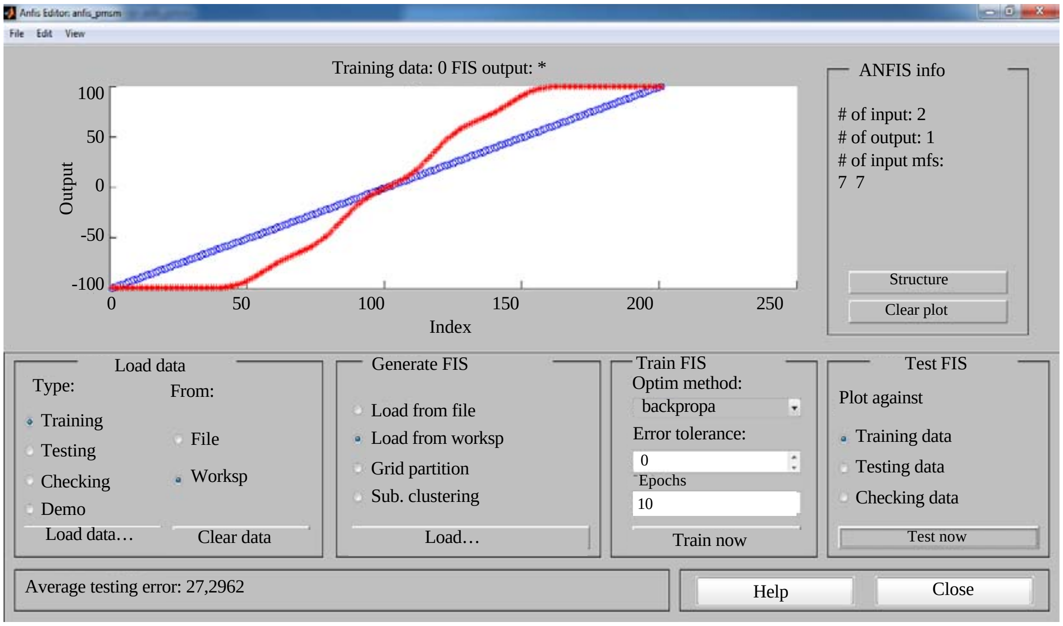

Fig. 8: Trained output data after applying ANFIS

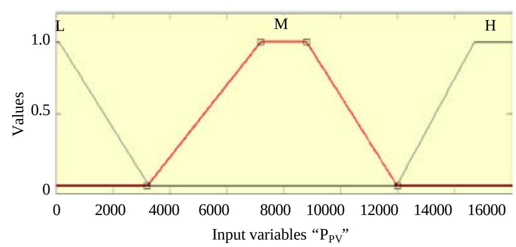

Fig. 9: FLC membership function of solar power

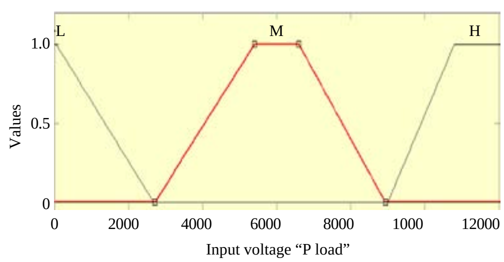

Fig. 10: FLC membership function of load power

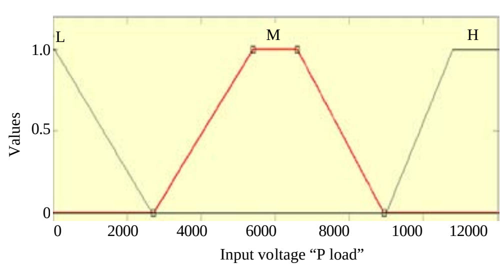

Fig. 11: FLC membership function of pattery SOC

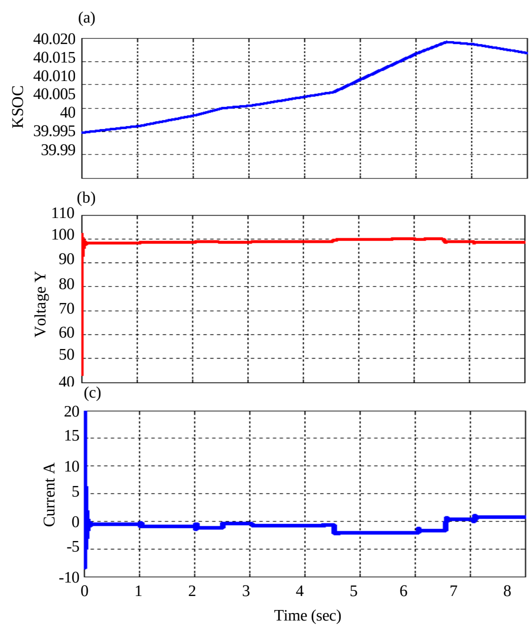

Fig. 12: a) Battry SOC; b) Voltage and c) Current

The proposed hybrid PMS and control strategy developed and simulated using MATLAB Software, the behavior of the system is observed under various operating conditions. The main objective of is feed energy to loads continuously without interruption. Load power Comparison shown in Table 2. The PMS system has been proposed to reduce power discontinuity and overvoltage and under-voltage operations, so that, the loads operate properly.

The normal loads consider critical and non-critical loads. In Fig. 4, the power profile are shown due to different loads are increasing and decreasing. However, weather conditions are varied, the PV power output varies from 0-680 W, it can't meet the load demand. Therefore, a PEMFC with a reversible BESS was added to the HRES. The battery bank system is capable of sustaining the extra load during peak load demand period. The PEMFC could meet the peak load demand and battery protect by from fully charging. Hence, when:

- If SOC≤40% and remaining required power drawn from PEMFC stack
- If SOC≤80% and at this instant battery bank discharges current is very high and terminal voltage decreases
- If 40≤SOC≤80% and remaining required power is provided by either the battery bank or PEMFC

When the Ibat is positive energy is transferred to the load and current is negative the battery bank is recharged. If the PV power>load demand and the SOC of the battery in between 40≤SOC≤80%, extra power will be used to charge the battery bank. If the excess power available in the hybrid system, goes to the dump load.

CONCLUSION

The proposed novel hierarchical control strategy for hybrid renewable energy with solar power, FC and battery system for stand alone system. The performance of the proposed control strategy is performed under random solar insolation and temperature. To obtained maximum power by using ANFIS at different conditions. FLC has been developed to the distributed of the PMS. The load/battery management system provide in order to regulate the FC/battery set points for improve the performance. The battery storage system is successful controlled by a bidirectional converter and maintained SOC level within limits.

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