Fuzzy Logic Based Control of a Grid Connected Hybrid Renewable Energy Sources

S.Merlin Joys Mary, S.Rajesh Babu, Dr.D.Prince Winston

Abstract—Renewable energy, such as wind, solar energy, is desirable for power generation due to their unlimited existence and environmental friendly nature. This paper deals with system integration and fuzzy logic based controller design for power management of a grid connected Hybrid renewable energy source (HRES). The hybrid system is the combination of photovoltaic (PV) array, wind turbine, and battery storage via a common current source interface multiple-input dc-dc converter. This converter is used to integrate the renewable energy sources to the utility grid. A two- level control system is implemented, comprising a Fuzzy logic controller, which ensures the power management between intermittent RE generation, energy storage, and grid, as well as local controllers for the photovoltaic, wind unit. Simulations are performed in MATLAB/Simulink.

Keywords— Renewable source, Fuzzy logic controller, power management.

1 INTRODUCTION

Renewable energy (RE) sources will become an increasingly important part of power generation as the reserves of fossil fuels get closer to depletion. Among available RE technologies, wind and solar energy sources are the most promising options, as they are omnipresent, freely available, and environmentally friendly. Although these technologies are improving in various aspects, the drawbacks associated with them, such as their intermittent nature and high capital cost, remain the main obstacles to their utilization. Hybrid power system with energy storage can enhance system reliability, power availability, quality, and operational efficiency.

Several hybrid wind/PV power systems with Maximum Power Point Tracking (MPPT) control have been proposed earlier [5]. They used a separate DC/DC buck and buck- boost converter connected in fusion in the rectifier stage to perform the MPPT control for each of the renewable energy power sources. These systems have a problem that, due to the environmental factors influencing the wind turbine generator, high frequency current harmonics are injected into it. Buck and buck-boost converters do not have the capability to eliminate these harmonics. So the system requires passive input filters to remove it, making the system more bulky and expensive [6]. This paper uses multi-input DC-DC converter to incorporate both wind and solar energy sources together using a

combination of Cuk and SEPIC converters, so that if one of them is unavailable, then the other source can compensate for it. The Cuk-SEPIC fused converters have the capability to eliminate the HF current harmonics in the wind generator.

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This eliminates the need of passive input filters in the system and also step-up or step-down the input voltage [11].

Dynamic interaction between the load demand and the renewable energy source can lead to critical problems of stability and power quality. Therefore, managing the flow of energy throughout the hybrid system is essential to increase the operating life of the membrane and to ensure the continuous energy flow. The increasing number of renewable energy sources and distributed generators requires new strategies for their operations in order to maintain the energy balance between the renewable sources and utility grid or micro-grid [12].

In the literature, there are a few studies related to energy management of hybrid power system. Among them, Wang and Nehrir [4], proposed a power management strategy for an ac-linked hybrid wind/PV/FC energy system. Ahmed et al. [5], presented a power management strategy which studied power fluctuations in a hybrid PV/wind turbine/FC power system. Onar et al. [6], proposed a power management strategy algorithm which dealt with a hybrid PV/wind/FC power system containing an ultra capacitor bank. However, all of the early mentioned methods have used conventional approaches for controlling hybrid power systems, such as linear PI controller which has afterwards been proven its instability in handling various changes in weather conditions [9]. Lei Zhang et al [10] present the two scale dynamic programming for power management which has the drawback of large time consuming and not adaptive for change of inputs. This resulted in developing other approaches led to more robust algorithms with ability to handle various changes dynamically without any major problems by establishing new management criteria depending upon informational data and the environmental changes.

This paper presents the modelling of HRES and investigates the energy management optimization for a battery, grid and HRES. A new converter topology for hybridizing the wind and solar energy sources has been

proposed, it eliminate the requirement of MPPT for each source. The average output voltage produced by the system will be the sum of the inputs of these two systems. Two level control strategies implement which are Fuzzy logic controller for energy management, and local PV and Wind controller for best performance.

2 PROPOSED ARCHITECTURE

Fig. 1 shows the overall architecture of the proposed wind/PV resources with grid. The main sources are Wind and PV which are combined by multi-input CUK & SEPIC converter with DC sources. This converter is more effective for maximum power point (MPP) tracking in PV modules and for the input current control method used in this grid.

Energy storage system (ESS) like Battery is also connected to the main dc bus in order to overcome the intermittent properties of renewable energy sources and to support local power production in an islanded mode particularly during blackouts or natural disasters. Fuzzy logic controller degied energy flow to the grid and charge control.
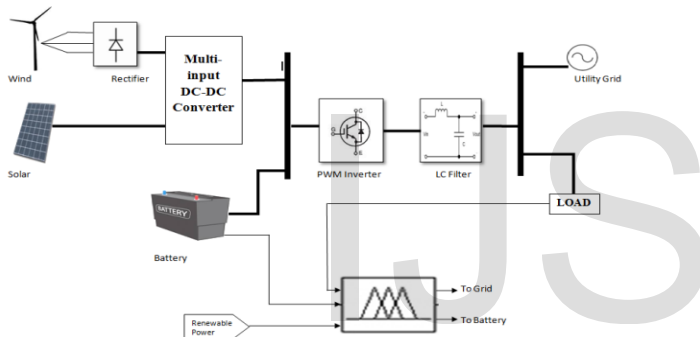

Fig. 1. Control block diagram of the proposed scheme.

DC voltage is converted into AC voltage by the PWM inverter and then fed to the local AC loads whose voltage is 240Vrms. Three phase utility grid is considered for this analysis which has voltage level of 11KV, which is also tied to the three phase 230/11kv transformer. LC filter used to reduce the harmonics presented in inverter voltage.

3 MODELING OF COMPONENT

This section review the modeling of major component presented in this work.

3.1 PV Model

Photovoltaic (PV) cells are made of, semiconducting materials that can convert incident radiation in the solar spectrum to electric currents. PV cells are most commonly made of silicon, and come in two varieties, crystalline and thin-film type. When a photon is absorbed by a semiconducting material, it increases the energy of a valence band electron, thrusting it into the conduction band. This occurs when the energy of incident photons is higher than the band gap energy.

The conducting band electron then produces a current that moves through the semiconducting material [3].
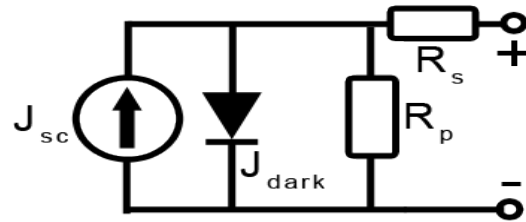

Fig. 2. Equivalent circuit of PV model.

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation (1).

$$V_c = \frac{Ak T_c}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - R_s I_c \quad \text{----- (1)}$$

Where the symbols are defined as follows:
e: electron charge (1.602×10^{-19} C).
k: Boltzmann constant (1.38×10^{-23} J/oK).
Ic: cell output current, A. Iph: photocurrent, function of irradiation level and junction temperature (5 A).
I0: reverse saturation current of diode (0.0002 A). Rs: series resistance of cell (0.001 Ω).
Tc: reference cell operating temperature (20 °C). Vc: cell output voltage, V.

Both k and Tc should have the same temperature unit, either Kelvin or Celsius. The solar cell can be seen as a current generator which generates the current (density) J_{sc}. The dark current flows in the opposite direction and is caused by a potential between the + and - terminals. In addition it would have two resistances; one in series (R_s) and one in parallel (R_P). The series resistance is caused by the fact that a solar cell is not a perfect conductor. The parallel resistance is caused by leakage of current from one terminal to the other due to poor insulation.

3.2 Wind model

Wind turbines convert mechanical energy produced by the wind to electrical energy. To use this electrical energy, voltage and frequency regulation are needed. The model of a wind turbine is developed on the basis of the steady-state power characteristics of the turbine [8]. The mechanical power produced by a wind turbine is shown in Eq. (2).

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \rho A_v^3 \quad \text{------- (2)}$$

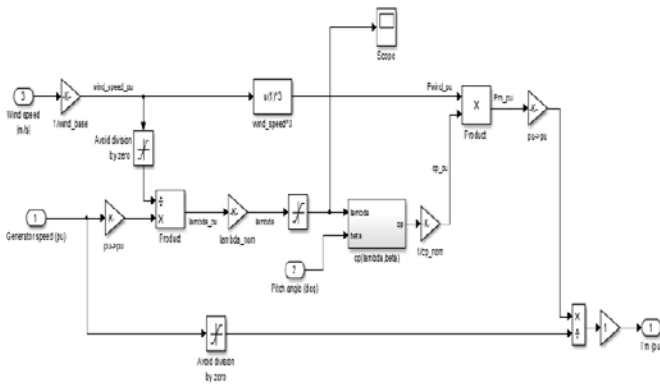The Simulink model of the studied wind turbine is shown in Figure 3.

Fig. 3. Wind turbine model.

Fig. 4. Multi-input converter model.

In Eq. (1), Pm is the mechanical output power of the turbine (W), Cp is the performance coefficient of the turbine, λ is the tip speed ratio of the rotor blade tip speed to the wind speed (in degrees), β is the blade pitch angle (in degrees), ϱ is the air density (kg/m3), A is the turbine swept area (m2), and v is the wind speed (m/s). The expression "Cp(λ, β)" is calculated by using Eqs. (3) and (4).

$$C_P(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_1} - C_3\beta - C_4\right)e^{\frac{C_3}{\lambda_4}} + C_6\lambda \quad ---- (3)$$

$$\frac{1}{\lambda_1} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad ----- (4)$$

Coefficients C1 through C6 are: C1 =0.5176,C2 =116,C3 =0.4,C4 =5,C5 =21, and C6 =0.0068. β is equal to 0, but, if necessary, this value can be changed.

3.3 Direct-Driven PMSG

The wind generator considered here is a gearless direct-driven PSMG. This PMSG does not require frequent mechanical maintenance because it does not use gears between wind blades and the generator. Another advantage of the direct-driven PMSG is that a permanent magnet eliminates the dc excitation circuit that may complicate the control hardware [6]. For the simulation study, the internal model of a PMSG in MATLAB Simulink/ Sim power systems is used.

3.4 Multi-input converter

Multi-input CUK and SEPIC converters are used in this simulation. These MI CSI converters provide nearly continuous input current waveforms due to their CSI input legs. Hence, these converters provide more operational flexibility than an MI buck- boost converter [1] because they allow the integration of input sources that require a relatively constant current], such as the input current control.
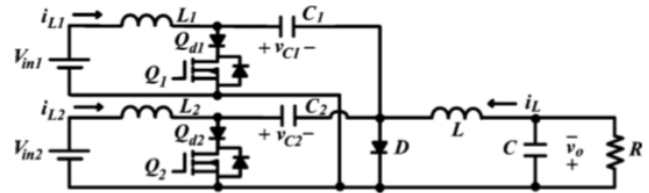
An MI Ćuk converter [7] is similar to an MI SEPIC converter [7][11] except for the output voltage inversion. This analysis focuses on the MI Ćuk converter shown in Fig. 4.

3.5 Battery model

The mathematical modeling of Li-Ion battery is used in the simulation. The open voltage source is calculated with a non- linear equation based on the actual SOC of the battery as follows [13](5)-(7):

$$V_{batt} = E_{batt} - R_i \quad ------ (5)$$

During discharge:

$$E_{batt} = E_e - K\frac{Q}{Q-it}it - k\frac{Q}{Q-it}i* + A\exp(-Bit) \quad ----- (6)$$

During charge:

$$E_{batt} = E_e - K\frac{Q}{Q-it}it - k\frac{Q}{it+0.1Q}i* + A\exp(-Bit) \quad -- (7)$$

where Ebatt is the no-load voltage, Eo is the battery constant voltage, K is the polarization constant, Q is the battery capacity, it is the actual battery charge, i* is the low frequency current dynamics, A is the exponential zone amplitude, B is the exponential zone time constant inverse (Ah)-1, Vbatt is the battery voltage, and i is the battery current. The main feature of this battery model is that the parameters can easily be deduced from a manufacturer's discharge curve [13].

3.6 The Fuzzy Logic Concept

Fuzzy logic arose from a desire to incorporate logical reasoning and the intuitive decision making of an expert operator into an automated system. The aim is to make decision based on a number of learned or predefined rules, rather than numerical calculations. Fuzzy logic incorporates rule-base structure in attempting to make decisions. However, before the rule-base can be used, the input data should be represented in such a way as to retain meaning, while, still allowing for manipulation. Fuzzy logic is an aggregation of rules based on the input state variables condition with a corresponding desired output. A mechanism must exist to decide on which output or combination of the different outputs will be used since each rule could conceivably result in a different output action. Fuzzy logic can be viewed as an alternative form of input-output mapping.

The fuzzy rule representation is based on linguistic [14]. Thus, the input is a linguistic variable that corresponds to the state variable under consideration. In fuzzy logic control,

the term "linguistic variable" refers to whatever state variables the system designer is interested. The fuzzy variable is perhaps better described as a fuzzy linguistic qualifier.

Once, the linguistic and fuzzy variables have been specified, the complete inference system can be defined as developing a FIS and applying it to a control problem involves several steps:

    a. Fuzzification.
    b. Fuzzy rule evaluation (fuzzy inference engine).
    c. Defuzzification.

4 FUZZY LOGIC CONTROL STRATEGIES

Several techniques are available for the implementation of the energy management algorithm [4][9][10]. Among them fuzzy logic technique has low power dissipation, an optimized cost, and reliable and stable. Fuzzy systems (FS) are based on fuzzy set

theory and it is a non-linear control method, which attempts to apply the expert knowledge of an experienced user to the design of a fuzzy-based controller.

The energy management strategy (EMS) should determine the split power between the photovoltaic, wind turbine, grid and battery while satisfying the load power requirement. Power demand is unpredictable in nature and varying frequently, so load profile is unavoidable. If adding this, to the nonlinear subsystems the system becomes complex of the structure of hybrid system. Hence, an advance fuzzy demand and SOC is presented. Figure 4 shows the proposed fuzzy expert system. expert system according to the weather variations, load
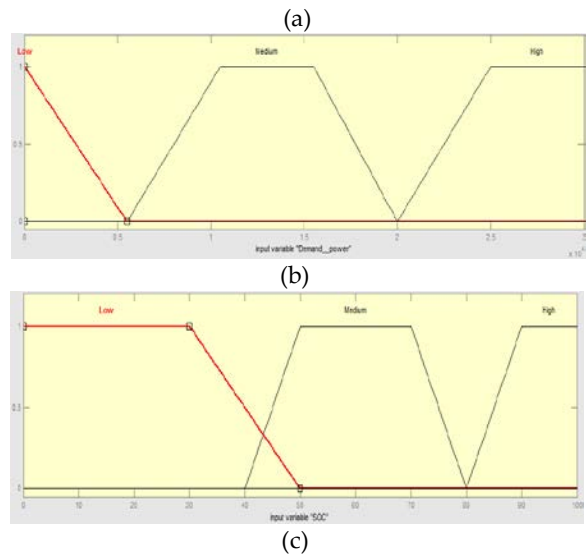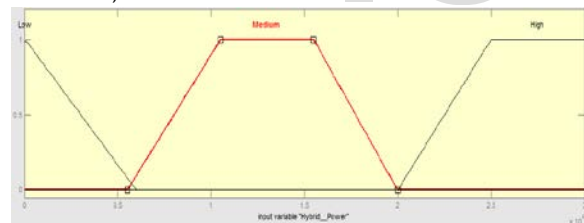
(a)

(b)

(c)

Fig 5. Membership functions of FLC. (a). Generated power (b). Load demand (c). Battery state.

When in normal operation, system power changes smoothly so that the grid operating point deviation is minimized. The battery management system maintains the SOC at a reasonable level (40% - 80%). Also, it protects against voltage collapse by controlling the power level required from the battery.

The power management system controls the reference power of the grid by splitting the power demand (PL) as a function of the available power of the battery and the PV/Wind system (PG). The FLC relates the outputs to the inputs using a list of IF-THEN statements called rules. The if-part of the rules describes the fuzzy sets (regions) of the input variables. In this work, the fuzzy input variables are PG, PL, and SOC and output variables are GD, BS.

The degrees of membership are evaluated to obtain the output controller, and the then-parts of all rules are averaged and weighted by the degrees of membership.

Table 1. Fuzzy logic rules

1-3	IF PG is L and PL is L\M\H and SOC is L, THEN GD is OFF and BS is CO	4-6	IF PG is M and PL is L\M\H and SOC is L, THEN GD is OFF and BS is CO
7-9	IF PG is H and PL is L\M\H and SOC is L, THEN GD is OFF and BS is CO	10-12	IF PG is L and PL is L\M\H and SOC is M, THEN GD is OFF and BS is CD
13-15	IF PG is M and PL is L\M\H and SOC is M, THEN GD is OFF and BS is CD	16-18	IF PG is H and PL is L\M\H and SOC is M, THEN GD is OFF and BS is CD
19-21	IF PG is L and PL is L\M\H and SOC is H, THEN GD is ON and BS is DO	22-24	IF PG is M and PL is L\M\H and SOC is H, THEN GD is ON and BS is DO
25-27	IF PG is H and PL is L\M\H and SOC is H, THEN GD is ON and BS is DO		

5 SIMULATION RESULTS

The electrical subsystem consists of primary sources of energy unit like PV unit and wind unit, battery bank unit act as auxiliary source of energy. Fuzzy logic is developed to control the power management between different sources and the load. The FLC control unit designed to control the battery current, grid power flow according to the supplement of the load with the required power. FLC has three inputs and one output. The inverter unit is used to convert the DC generated power from renewable energy sources to feed the load with the required AC power. The overall simulation diagram is shown in fig.
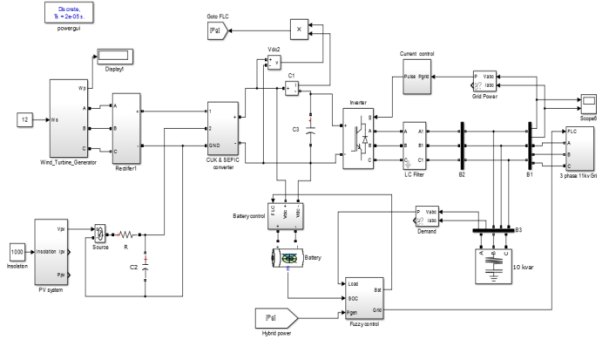
Fig.6. Simulink model for Fuzzy logic based energy management system.

5.1 Isolated mode

The initial SOC of the battery storage is 50%. Hence, the SOC is medium, the low load demand is satisfied by the RS, and the extra power will be used to charge the battery. The battery is charged/ discharge and average current flow through it. The renewable system is isolated from grid. The Current and voltage waveforms of PCC and grid are shown in fig.
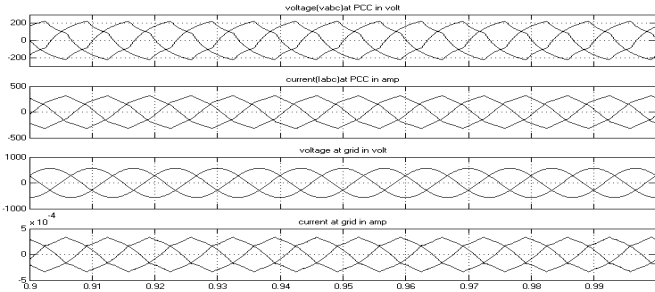
Fig 7. Voltage and current waveforms at PCC and grid.

5.2 Grid interacted mode

In this case SOC of battery storage is 80%, this will indicate battery fully charged. In this mode excess energy supply to the grid, the battery only discharge and cannot charge in this mode. The Current and voltage waveforms of PCC and grid are shown in fig.
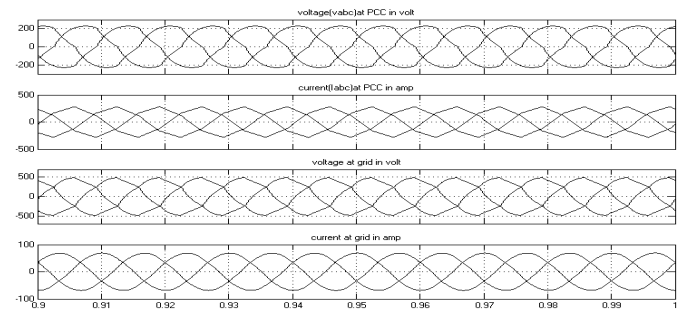
Fig 8. Voltage and current waveforms at PCC and grid.

6 CONCLUSION

The power management between PV array, wind generator, battery bank and the load was controlled using FLC. The simulation results using FLC in MATLAB/SIMULINK showed the high performance of the proposed system. The results showed that the PV and wind generator were capable of feeding the load with the required energy and charge the battery with its demands during night hours. During day time high power generated from the PV system, due to that excess power send to the utility grid after battery fully charged. FLC has three input signals which are hybrid power, demand and state of charge. 27 rule bases, the COG and Max-Min method were used.

REFERENCES

1. B. G. Dobbs and P. L. Chapman, "A multiple-input DC-DC converter topology," IEEE Power Electron. Lett., vol. 1, no. 1, pp. 6–9, Mar. 2003.

2. Chen et al., "Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System", *IEEE Transactions on Power Electronics*, vol. 22, May 2007.

3. Altas, I.H. Sharaf.A.M, "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment", IEEE International conference on Clean Electrical power, May 2007, pp 341-345.

4. C. Wang and M. H. Nehrir, "Power Management of a Stand-Alone Wind/PV/Fuel Cell Energy System," IEEE Energy Conversion, Vol. 23, No. 3, 2008, pp. 957-967.

5. N. A. Ahmed, M. Miyatake and A. K. Al-Othman, "Power Fluctuations Suppression of Stand-Alone Hybrid Generation Combining Solar Photovoltaic/Wind Turbine and Fuel Cell Systems," Energy Conversion and Management, Vol. 49, No. 10, 2008, page no 2711-2719.

6. O. C. Onar, M. Uzunoglu and M. S. Alam, "Modeling, Control and Simulation of an Autonomous WT/PV/FC/ Ultra-Capacitor Hybrid Power System," Journal of Power Sources, Vol. 185, No. 2, 2008, pp. 1273-1283.

7. A. Kwasinski, "Identification of feasible topologies for multiple-input DC-DC converters," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 856–861, Mar. 2009.

8. S. Li, T. A. Haskew, and L. Xu, "Conventional and novel control designs for direct driven PMSG wind turbines," Elect. Power Syst. Res., vol. 80, no. 3, pp. 328–338, Mar. 2010.

9. A. Tofighi and M. Kalantar, "Power Management of PV/ Battery Hybrid Power Source via Passivity Based Control," Renewable Energy, Vol. 36, No. 9, 2011, pp. 2440- 2450.

10. Lei Zhang, Yaoyu Li, "Optimal Energy Management of Wind-Battery Hybrid Power System With Two-Scale Dynamic Programming", *IEEE transaction on sustainable energy*, Volume 4, No 3, July 2013, Page No 765-773.

11. Tripti Saha, Deependra Kumar Jha, "Fused Converter Topology for Wind-Solar Hybrid Systems", *IEEE* ,2013.

12. Luis Valverde, Felipe Rosa, Carlos Bordons, "Design, Planning and Management of a Hydrogen-Based Microgrid", *IEEE transactions on industrial informatics*, vol. 9, No. 3, august 2013.

13. MathWorks,"Documentation Center," 2012. http://www.mathworks.co.uk/help/stateflow/gs/a-look-at-t he-physical-plant.html

14. L.A. Zadeh, "Fuzzy sets", Information Control, Vol. 8, pp. 338-353, 1965.