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Energy Dispatch Fuzzy Model in Hybrid Power System

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Abstract – *A hybrid power system is observed as a reliable alternative to the traditional system. However the managing different energy sources have some practical issues like optimal power delivery and battery management. As a consequence, the control of energy distribution should be improved to protect the battery energy storage. This paper gives the fuzzy logic based smart power delivery concept to utilize the available energy optimally. An online monitoring and load demand information can provide the user with reliable and constant electric power. Practically, consumer load demand always varies frequently and unpredictably. Therefore smart energy dispatch unit is required to distribute the energy to consumers and meet their demand depending on the energy available and charging condition. Simulation on real time data is used to illustrate the potential benefits of the proposed fuzzy based dispatch unit so that it maximizes the usage of renewable energy and depends less on the main grid.*

Keywords – Energy dispatch, fuzzy logic, renewable energy, solar-wind hybrid, variable load.

1. INTRODUCTION

In present era, people are more concerned about fossil fuel exhaustion and global warming problems caused by conventional power generation and renewable energy sources (RES) than ever before. Among the renewable resources, photovoltaic (PV) panels and wind generators are primary runners. It has been depicted that RES are promising toward building a sustainable and environment friendly energy economy in the next decade [1-3]. They have the benefit of being natural and pollution-free, but their maintenance and handling cost is high. Most applications, a battery management is required to extract the maximum available power from the renewable sources. In line with this, the dynamic relations between the load demand and the supply energy from RES can lead to perilous problems of power quality that are not very common in conventional power systems. Therefore, managing the flow of energy throughout the hybrid power system is required to increase the operating life and to ensure the quality of energy flow [3]. Here we consider an electrical power generating system it makes economic sense to specify a hybrid power system (PS) with both solar and wind power systems together rather than a single energy source.

In the literature, several efforts have been made to study the energy management and power delivery using the artificial intelligence and computing techniques such as fuzzy logic (FL) or neural networks (NN). In general these techniques were used to control and to deliver the available energy in an optimal way. Also, the growth of alternative energy sources such as solar and wind energy exponentially increases to overcome the expenses. In this way an optimal energy dispatch is necessary to make the overall system more economical.

Natsheh and Albarbar [3] discussed an adaptive management strategy for power flow in stand-alone hybrid power systems based on FL and NN. An online energy management was introduced to control four different energy sources and also aim was to maintain the battery state-of-charge (SOC) at a reasonable level. Kheshti *et al.* [2], [4] presented novel approaches for solar and/or wind energy for distributed systems using the aid of a fuzzy controller. Mainly their methods regulate the modulation index of PWM inverter in an AC-DC-AC converter. It has been also reported [5] that a traditional PV power unit with a wind system decreases the zero-power interims and could be made to high degree out of standard business variable rate drive components. The consumer demand was satisfied by either distributing energy or optimally switching energy from supply grid to battery source. Onar *et al.* [6] proposed a power management algorithm which dealt with a hybrid PV/wind/Fuel cell power system. But this method has implemented based on conventional approach of PI control for hybrid power systems. Recently, it has been reported that the conventional approaches can result in instability while handling various changes in weather conditions [7]. Therefore it has been required to develop other kind of robust techniques to handle various changes dynamically without any major problems; by establishing new energy distribution depending upon usual available data. With a standard hybrid system (solar and wind grid), a consumer has been engaged with variable demand of energy and the energy at certain times may not be enough to cater the consumers need. Several distinctive topologies [8], [9], [14]-[18] of the electric generation hybrid system were reported while a few were based on new computational techniques. They showed the energy was distributed (when restricted in supply) in a particular way in which human beings would do, that was to supply the amount from battery and remaining energy from the power grid. Decisions were made by

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normal computational and were too edgy like either 0 or 1. In the literature [10], the hybrid power system was discussed for the residential sector for more energy conscious houses. Variability of climate, specifically of sunlight, is perhaps the fundamental challenge confronted by PV establishment and the goal that great gauging devices are needed for the proper integration of renewable energy into the power system [11]. Amina *et al.* [19] proposed a novel hybrid model and validated its performance on the prediction of the electricity consumption of the power system. A fuzzy logic based PV energy dispatch controller [20] using a swarm intelligence algorithm was presented and compared with the standard energy dispatch controller.

It has been reported [16]-[17] that the structure of hybrid system is complex to control due to fact that consumer load profile always fluctuates frequently. Hence, there is a need of advance intelligent system according to the weather variations, load demand and SOC. A fuzzy theory can decide the optimum operation of the overall power system especially in hybrid system like as discussed above. This is mainly due to fuzzy logic theory helps to make a decision between 1 and 0 and this is the more humane way of thinking [12]. Therefore we have adopted a fuzzy reasoning logic to develop a simple energy dispatch to see how the hybrid PS more effective.

In our study, two distributed sources of renewable energy like wind and solar together with normal power grid supply are considered. Real-time practical data of consumer load demand and battery voltage are used as inputs to the proposed method. We have considered two cases with primary goals of utilizing optimum power grid and reducing maintenance of battery system. Minimum charging-discharging cycle of a battery is another goal of this simulation study. First, a basic power delivery system is designed with aim of distributing energy to consumers periodically and meets their demand by use of grid and battery. A consumer demand is satisfied through a DC control unit of the generation ratio from power sources, the distribution generation system, combined with battery bank. Second case is considered with a constraint of optimal switching between power grid and renewable backup. A technique is developed to take a decision as to when to switch to the supply grid and when to switch to the renewable source (battery) according to the battery charged condition. Fuzzy DC control unit keeps the battery voltage at a safe level. The charging and discharging states of the battery are monitored continuously so that one can use the renewable energy maximum and depend less on the power grid. It has been found that the fuzzy based controlled system exhibits excellent performance under various initial battery levels, and maintain the battery SOC at a reasonable level.

2. BASIC PRACTICE IN HYBRID SYSTEM

A basic hybrid power system is one that uses more than one energy sources. Say for example this type of system has two input energy sources, one from the wind and second from the sun. These two streams of energy are summed and used to charge the battery (typically much larger when compared to charge input). The energy from the battery is now delivered on to the DC/AC convertor which converts the DC voltage into domestic usable AC voltage. The battery meets the consumers' demand for energy till it reaches critical level. The frequently discharging of battery to the critical level is reduced the battery life and will be affected on the performance of the renewable green energy in a long run. A basic block diagram of solar-wind based hybrid system is shown in Figure 1.

This type of system with different energy sources is managed by a DC control unit which has the following functions [13]:

- Accepts the DC power from generating units
- Controls the power delivery to the load
- Monitors the battery voltage and charges the battery as required
- Cuts off the charger when the battery is fully charged and diverts the power to a suitable load

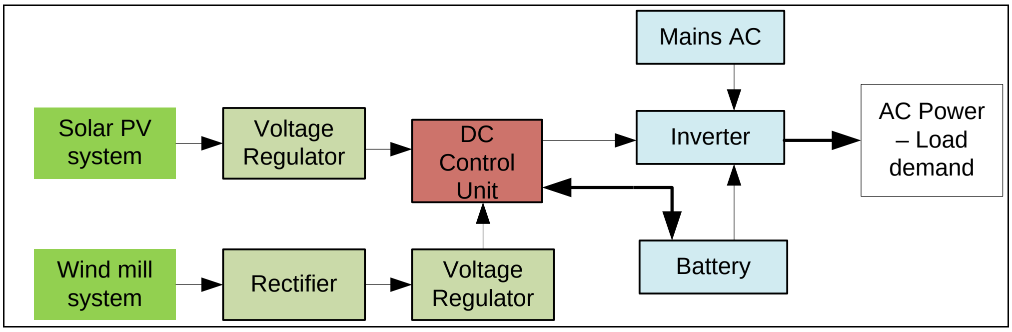

Fig. 1. ***A basic hybrid power system***

Basically the consumer's load demand is satisfied by the battery backup and/or the mains. There is no smart mechanism how much energy should regulate from battery backup or from a grid. Hence it is not considered to be a smart controlled system. Some difficulties are also associated with this type of hybrid system like battery gets fully discharged or over-charged. Also, the optimal RES usage becomes a critical issue since there is no monitoring and controlling logic as per the variable load demand. Further no forecasting mechanism is formed based on load demand and stored battery voltages. This may result in energy-loss obtained from RES. If the power is delivered always from RES, a battery critical voltage level drops frequently. This can push more the charged level below a critical value, which reduces a battery operating life.

Considering discussed points above, a smart switching DC control unit based on fuzzy logic is suggested in the following section.

3. PROPOSED SMART DC CONTROL UNIT BASED FUZZY LOGIC

Aim is to design an improved smart dispatch model to control the supply of energy effectively. A technique is developed for DC control unit so that it satisfies the load demand constantly at the same time to keep the charging state of battery at a safe level. It is conceivable to diminish the overall expenses of the hybrid PS with a simple controller that decides automatically when and what amount of energy required. Similarly it is more significant to utilize the RES even with small and less costly PV arrays while still allowing the system to deliver adequate power to the consumer demand.

An algorithm was designed to decide power delivery to the load. It was required to improve the performance of the standard hybrid system. Figure 2 shows the proposed fuzzy based smart DC control unit in hybrid power system. Shortly, it is also called a Fuzzy Decision Maker (FMD) in this paper. It takes two inputs, the consumer load (energy demand from the consumer) and the battery status (current charge level of the battery). The real time data were logged for development as received power from wind and solar systems. Two possible distribution types were considered in the following.

3.1 *Case Study One*

A control unit is designed to calculate the optimal amount of power which can be drawn from the battery. The remaining power at particular time is to be met from the main power grid. Considering the consumers' demand is required to satisfy fully. A form of output from the fuzzy controller is modified to take an action accordingly. Suppose a percentage of energy is first used from the battery and then the remaining is supplied from the grid. It also ensures to supply 100% consumer demand effectively with maximum usage of the renewable power.

As per the fuzzy theory and logic, a decision is made by mainly three operations: fuzzification process, inference engine for rule base and defuzzification process. In modified hybrid system, fuzzy DC control unit has now two inputs, load demand denoted by P_L and battery status represented as E_{BS}. A system itself decides how much power should be taken from battery and then remaining added from the regular power grid. In this scenario total supplied power, P_S can be written as

$$Ps = (\%P_G + \%P_B) \quad (1)$$

where P_G is a power supplied from mains and P_B is a power delivered from battery.

Most hybrid power systems are implemented using above logic. Simulation results based on this classical approach discussed in Section 5.

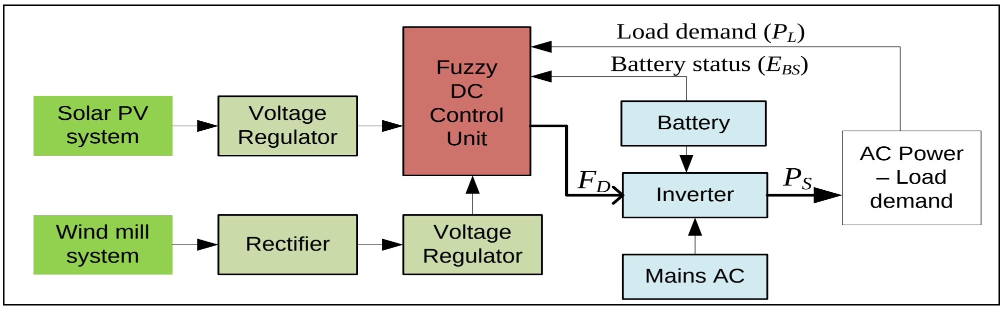

Fig. 2. Fuzzy based smart DC control unit in hybrid PS.

3.2 *Case Study Two*

In the second case, a technique is developed with same objective as in case one but with aim of reducing charging-discharging cycle of battery. Also, an additional constraint is imposed to keep inadequate battery energy and allowing to charge.

Here the fuzzy unit intended to compute the time length the battery can help the present load demand. In the event when the battery is unable to accommodate the full customer demand for a sufficient time, then the power is supplied only from power grid. This means that a fuzzy control unit reduces the switching between battery mode and power grid mode. A smart energy dispatch unit will decide how long battery power should be used to satisfy full load demand. Analytically, if P_B is unable to supply full P_L at particular time, then the power is supplied only from P_G. Now the total supplied power can be re-written as per this logic by

$$Ps = (\%P_G \oplus \%P_B) \quad (2)$$

Results are obtained for this energy dispatcher. It has been noticed that the battery has been protected to go below some critical value and at the same time reduced the charging-discharging process in battery. More detail discussion is given in Section V.

4. METHOD USED IN FUZZY LOGIC

We have developed a program in Matlab®-Simulink® for cases discussed in the previous section. First task is the fuzzification of variables, which involves a domain transformation; crisp variables into fuzzy inputs [12]. In this transformation, reasonable functions are used, called membership functions often piecewise linear functions, such as triangular or trapezoidal functions. A degree of membership function (MF) is produced as input value (typically normalized to 1) to the controller. The input value is usually nominated by symbol μ. For its directness, the triangular function is embraced as the membership evaluation function of input/output.

For example as shown in Figure 3, MF takes an input as the contemporary P_L and associates it to a degree of MF for each fuzzy set in the graph. As shown in the fuzzy rule base (FRB) table in Table 1, "VL" denotes "Very Low", "L" denotes "Low", "M" denotes "Medium", "H" denotes "High" and "VH" demotes "Very High". In this scenario a normalized P_L of 0.75 will give the following degree of MF for each fuzzy set:

$$\mu(VL) = 0,\quad \mu(L) = 0,\quad \mu(M) = 0.24,\quad \mu(H) = 0.76,\quad \mu(VH) = 0. \tag{3}$$

Similarly the membership function for battery status, E_{BS} was considered as shown in Figure 4.

Second, Fuzzy rule base (FRB) is determined by the experimental consideration of the influence of each of the switching logic input parameters and output parameters. It contains individual's knowledge of a particular problem. Designer can adopt to tune the FRB table differently. In our research, a program in C++ was developed to decide the suitable rule base types optimally. It performs the iterative reading of different types of rule tables and evaluates the efficacy of the fuzzy decisions. Several experiments were conducted to finalize the optimum rule base. The adopted fuzzy rule base in our study is given in Table 1. Practically these rules generate a required output in a linguistic variable according to its real value. It has to be transformed to crisp output, real number. Defuzzification is the process by which a fuzzy consequent is reduced to a singleton or crisp scalar value in order to provide an interface to a typically scalar 'action'. That is to say, actions are typically associated with a scalar defining a specific measurable property.

Finally, the output of the fuzzy controller is based on position of the MF and the FRB. The position of the membership function decides the distribution of the set parameters (distribution of VL, L, M, H, VH values of the E_{BS} and P_L). The output (decision) is actually an illustration of the FRB table. A relation between inputs (Battery status and load demand) and output (fuzzy decision) is plotted in Figure 5.

Table 1. Fuzzy rule base.

Very High	VL	L	M	H	VH
High	VL	L	H	H	VH
Medium	VL	M	H	VH	VH
Low	VL	M	VH	VH	VH
Very Low	VL	H	VH	VH	VH
	Very Low	*Low*	*Medium*	*High*	*Very High*

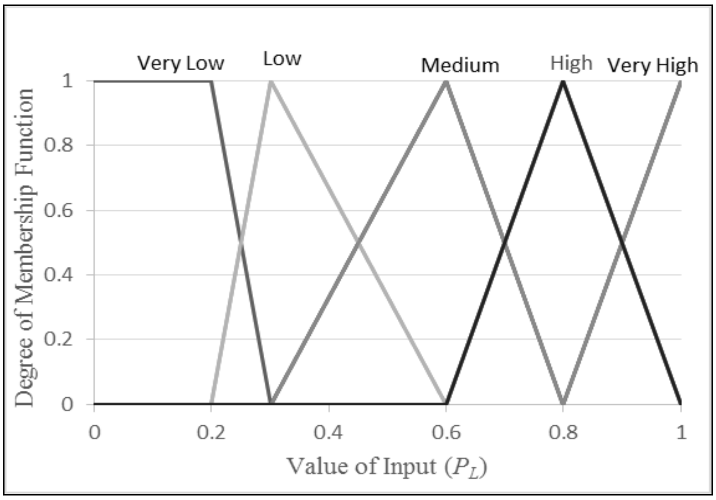

Fig. 3. Membership function for consumer load input.

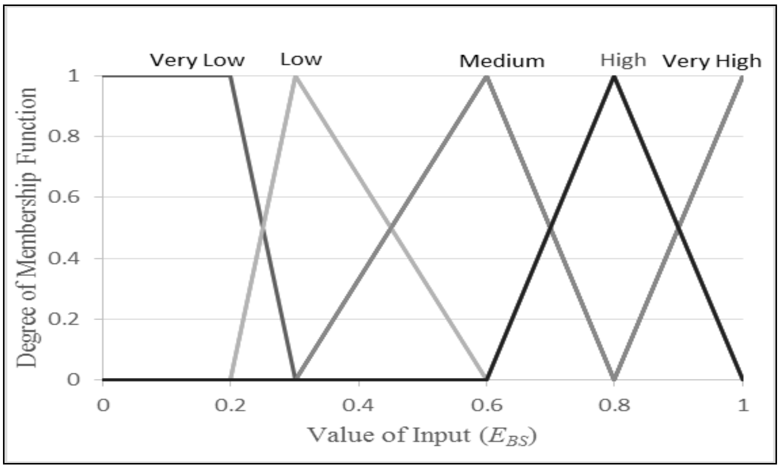

Fig. 4. Membership function for battery status input.

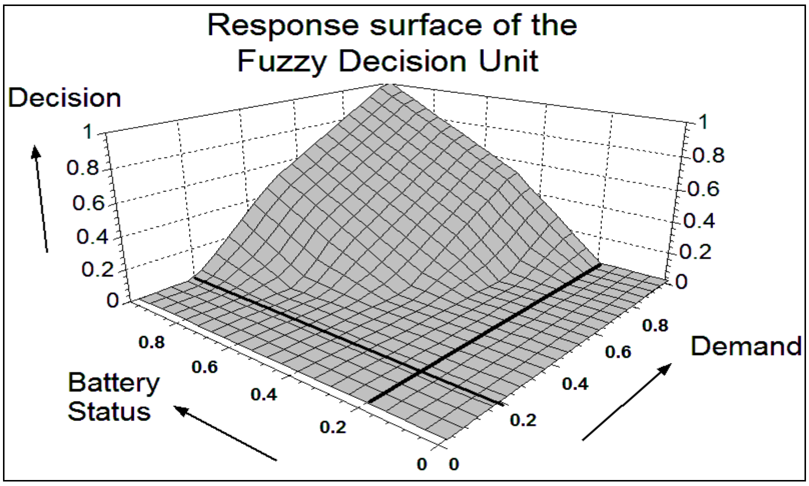

Fig. 5. Fuzzy response surface for controller design.

5. SIMULATION EXPERIMENT

In this section, the simulation experiment on real-time data is presented for cases discussed previously. We have compared two performances; one when fuzzy logic based control unit works on traditional way and other in a smart decisive way. Both the cases are focused on make use of renewable energy optimally. The logic is written to satisfy the consumer load demand fully at the same time monitor the current battery level online. During simulation work, the real-time data captured from the solar and wind system is normalized for ease of analysis.

The data is plotted in Figure 6, which shows the behavior patterns of energy obtained as the charging inputs to the battery system. The X-axis represents the time (total two days used) and the Y-axis represents the scaled energy generated from the solar and wind systems to charge the battery. It also depicts that the energy accumulated through the solar cell is somewhat predictive and sequential in nature whereas the energy generated by the wind is non-predictive and very random. This typical behavior of natural resources arise the need of an optimal use of RES. Another input data for the fuzzy based controller is shown in Figure 7, normalized typical load demand for the same period. Sampling time for each data input is 10 minutes.

Let us consider the case one as outlined Section 3.1. The DC control unit (See Figure 2) between battery and main grid was adopted using fuzzy logical reasoning. The results were plotted in Figure 8. It could be interpreted that the supplied power from the battery; P_B is following the battery status input E_{BS}. However, one can notice that during large time period from 18 to 30 hrs and 42 to 45 hrs, the battery energy completely been used; meaning no energy in battery backup. This system can be failed very often during no grid supply to satisfy the load demand at this situation. Overall system performance is also decreased in spite of battery backup. We have tested this control mechanism with various initial battery voltages. The performance is almost consistence when level varies from 0% to 100%; shown in Table 2. Figure 9 shows that the usage of renewable power to satisfy current load demand followed the battery status; meaning continuous usage of energy. This results in frequent switching in recharging process of the battery. Furthermore, whenever the battery level drops to a critical value, the energy is drawn completely from the power grid.

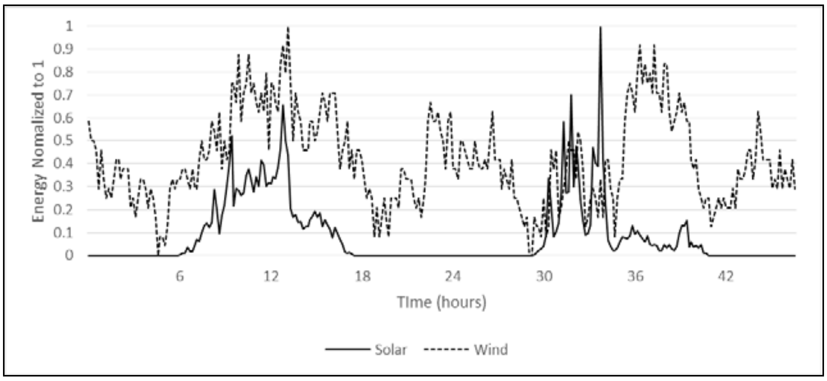

Fig. 6. Normalized solar and wind energy profiles.

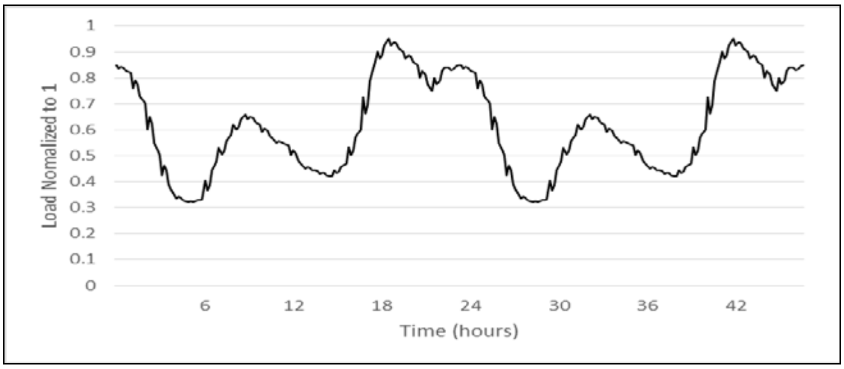

Fig. 7. Typical load demand for two days.

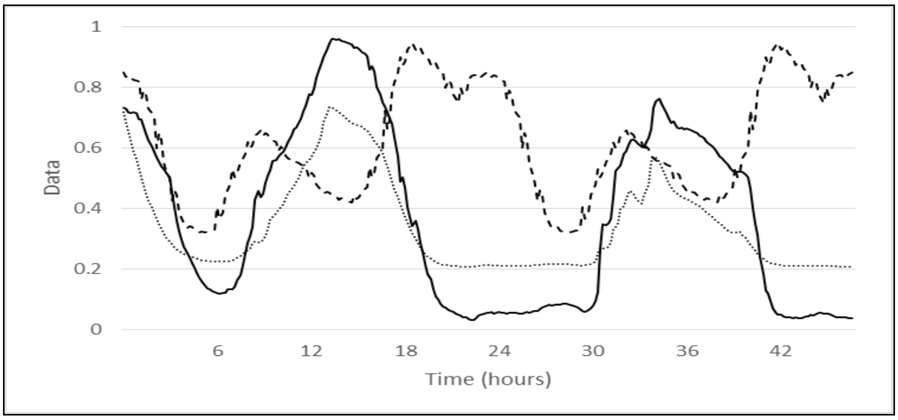

Fig. 8. Case 1: Inputs and Output of FDM (with 75% initial battery level): solid line P_B, dot line E_{BS} and dash line P_L.

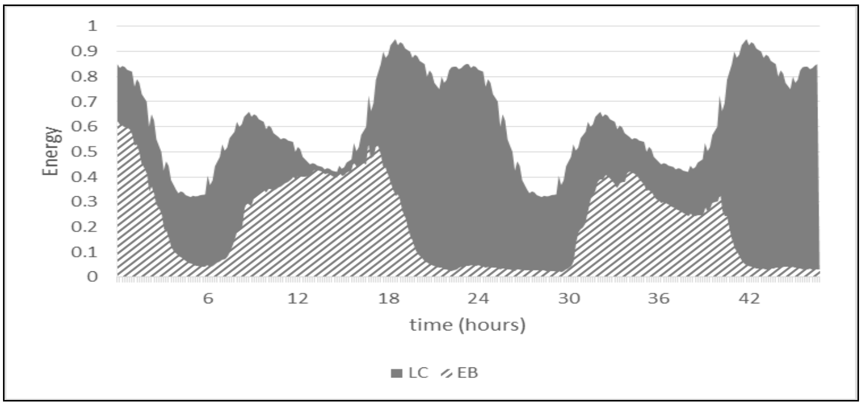

Fig. 9. Case 1: Use of renewable energy in total demand.

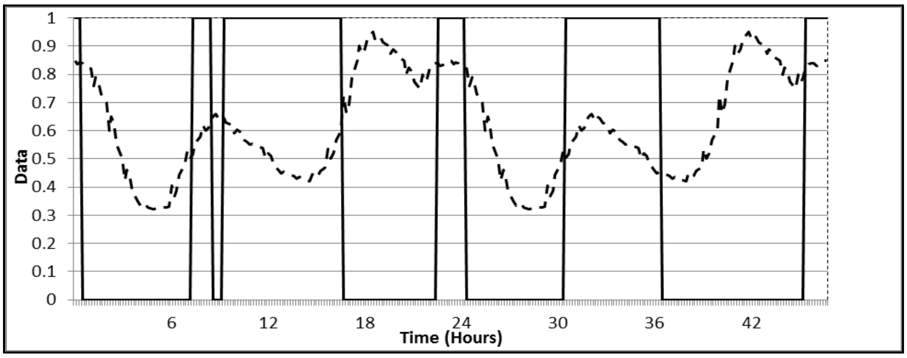

Fig. 10. Case 2: Solid line: F_D and dash line: P_L.

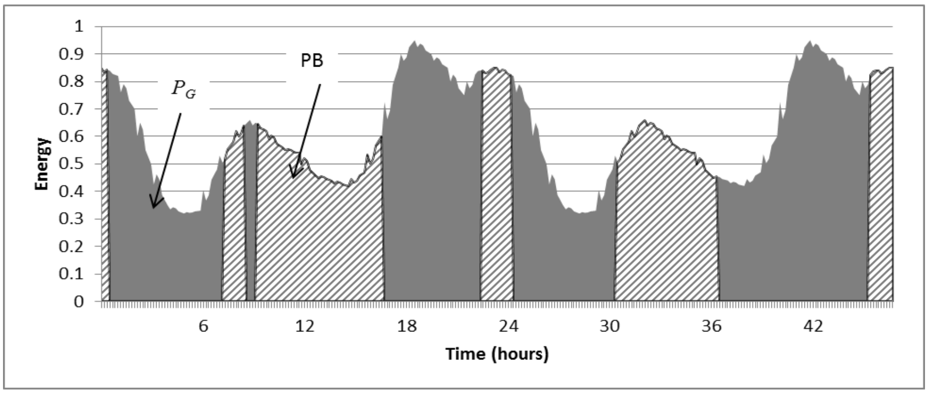

Fig. 11. Case 2: Use of renewable energy in total demand

Table 2. Comparison of two cases for energy usage.

Initial Bat. Lvl (%)	Case I Energy from battery (%)	Case II Energy from battery (%)
0	27.6	29.6
25	30.1	32.1
50	32.6	35.6
75	35.1	38.2
100	37.6	40.6

Case two logic has overcome the drawbacks of case one. A smart dispatcher as discussed was implemented to take energy, either from battery or from main grid. That means that battery energy is used in a discrete form, not continuous. This gives the decision for satisfying load demand with minimum charging-discharging cycle between same time slots. As shown in result Figures 10 and 11, the fuzzy decision for delivered battery power could be utilized fully from the RES for duration when load demand matched with stored power. Here when $F_D = 1$, it shows that the power can be supplied only from battery and not from the power grid. Figure also illustrated some load demands not only were supplied through battery power but also battery level was protected to be reached to critical level. Whenever the battery voltages go below the critical value, energy is drawn completely from grid and allows charging battery. When we compare the results with previous classical logic, percentage energy drawn from the battery is now together with same supplied and available energy in the battery from RES. Table 2 shows the comparison results between two cases. Again the performance is very consistence regardless the battery levels.

6. CONCLUSION

This paper has discussed a computational technique to deliver power effectively from renewable sources. A technique was implemented in Matlab®-Simulink® environment. With regard to experimental verification, we used wind-solar energy profiles with vary load demand. Two different approaches were tested on a fuzzy logic based DC control unit in a hybrid system. It has been shown how simply the presented method can improve the power delivery together with monitoring battery storage. We demonstrated a fuzzy-based power delivery in order to reduce the consumption from mains.

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