

Fuzzy Energy Distribution to a Variable Consumer Load

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Abstract

The paper demonstrates the fuzzy logic based smart distributed system to utilize the available energy optimally. We study the power system with two distributed sources of renewable energy like wind and solar together with normal power grid supply. Through the suitable allotment of the generation ratio from power sources, the distribution generation system, combined with battery bank, can provide user with reliable and constant electric power. Therefore a smart energy distributor is useful to supply energy to consumers such that their demand is supplied optimally depending available energy and battery status. In this work, a new distributor system is tested with fuzzy logic theory to satisfy the load demand constantly at the same time to keep the charging state of the battery at a safe level. Simulation results are also presented to illustrate the potential benefits of the smart distributor by maximizing the usage of renewable energy and depending less on the supply grid.

Keywords: Hybrid power system, Fuzzy logic, Renewable energy, Energy distributor

1. Introduction

As the expense of conventional fossil powers keeps on rising, the expense of power produced by customary means likewise expands. Currently, global warming is focused as most important problems which need to be solved and renewable energy sources (RES) are a solution to generate clean and sustainable energy (Welch *et al.*, 2010; Kheshti *et al.*, 2012). It was reported how alternative energy sources such as solar and wind energy decreases the cost as the technology and manufacturing processes are improved. Additionally these sources are promising toward building a sustainable and environment friendly energy economy in the next decade (Weiss *et al.*, 2003). They have the benefit of being natural and pollution-free, but their maintenance and handling cost is high and, in most applications, they require a battery management to extract the maximum available power from the renewable sources (Natsheh *et al.*, 2013; Kheshti *et al.*, 2011; Zhou *et al.*, 2010). The distinction in expense of power produced by RES and that produced by conventional sources is not inconsequential, therefore making some optimal control of a renewable energy source an exceptional approach to make the overall system more economical. In this type of works the ability of computing algorithms such as fuzzy logic (FL) or neural networks can be useful to set the distribution strategy from the available one.

Traditionally a photovoltaic (PV) power unit and a wind energy unit have made a significant advance to decrease the zero-power interims and became a high degree of standard business variable rate drive component. Weiss *et al.* (2003) also identified some ways to distribute energy to consumers periodically and meet their demand depending on the energy available and the charging condition. With the 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. There exist numerous distinctive topologies of the electric generation hybrid system. Some researchers have presented effective relation between wind and solar energy resources (Hong *et al.* 2000; Yang *et al.*, 2004). The energy was distributed (when restricted in supply) in a particular way in which human beings would do, that is to supply the amount from battery and got remaining energy from the power grid. This decision was made mainly from normal computation law, either 0 or 1.

Using FL one can design a program to make decision between 1 and 0; this is the more humane way of thinking. Evaluating different actions and discarding those which does not work well with the previous conditions is an essential process in any decision making. This was initially proposed in Bellman *et al.*, 1970. In this process, a mathematical model is made to evaluate the performance if the criteria are mathematically computable. Adding on, it is conceivable to diminish the overall expenses of the PV system with an effective control plan figuring out when and what amount of the electrical loads are to be supplied. More effective utilization of the PV system encourages the designer to design a system with smaller and less costly PV arrays and batteries while still allowing the PV system to deliver adequate power to the base (or critical) load (Welch *et al.*, 2007).

In this paper we present the strategy to distribute energy to the consumer load optimally with less usage of power grid. Indirectly we have also focused to reduce the overall maintenance cost of PV systems. First it is necessary to log the energy data for monitoring purpose

from the solar panel and wind turbine. Then, a fuzzy logic based distributor is designed to optimize the distribution of energy to consumer load. The distributor is calculated the output to keep the battery voltages at reasonably safe levels. 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.

2. A Standard Hybrid System

A standard hybrid system has two streams of input energy sources, one from the wind and second from 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 (preferred 240V at 50Hz). The battery meets the consumers demand for energy till it reaches critical level. The frequently discharging of the battery to its critical level leads to gradually reducing the battery life and decreasing the effect of the renewable green energy. The basic block diagram of the standard 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 (Lawson B., 2014)

- 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

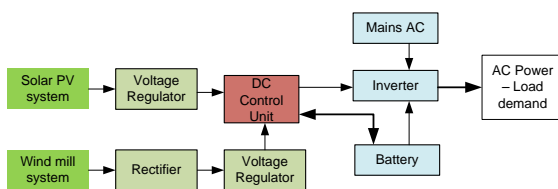


Figure 1. A standard hybrid PV system.

Primarily the consumer's demand must always satisfy via battery backup and/or the power grid in a basic hybrid system. At each sampling period, control unit in Figure 1 supplies the whole energy required by the "Load" from either the "Battery" (renewable energy) or by the "Main AC". Here there is no form of closed controlled system to regulate the amount of energy drawn from the battery or the power grid. Therefore some difficulties are faced in this type of

hybrid system. Second, the optimal usage of the renewable energy sources becomes a critical issue since there is no monitoring and controlling logic as per the variable consumer demand. Also, no forecasting mechanism is formed based on load demand and stored battery voltages. This will cause the wastage of energy generated from the renewable sources if it will not be driven to the proper storage. The consumers' energy cost is also compromised if it drives more energy from the main power grid in place of the renewable sources. It is also observed that a battery critical voltage level drops frequently as per consumer's variable demand supplied from the renewable sources. This will rise the charging and discharging states of the battery (sometimes it pushes the charged level below critical value), which reduces a battery operating life.

In this paper, we use the concept of the fuzzy logic to construct the so called Fuzzy Decision Maker (FDM) in order to improve the performance of the standard PV system. Figure 2 shows the proposed fuzzy based smart energy distribution system. Here the FDM is the main component of the system. It takes the information from two inputs, namely the *consumer load* (energy demand by the consumer) and the *battery status* (current charge level of the battery). Fuzzy rule is designed to calculate the optimal amount of energy which can be drawn from the battery. The remaining energy demand at particular time is to be met from the power grid, so that the consumers' demand is never compromised. The decision made by the FDM is in the form of a value (ratio) between 0 and 1. It is then given to the energy distributor to take the action accordingly. This ratio corresponds to the percentage of the energy that should be taken from the battery. The remaining percentage of energy will be supplied from the grid. In this way the 100% of the consumer demand will be met effectively with maximal possible usage of the renewable energy at each sampling period. Such flexible distribution of the strategy will obviously ensure the cheapest energy supply to the customer load.

3. Fuzzy Smart Energy Distributor Design

The fuzzy smart energy distributor consists of one major module, namely the fuzzy decision maker (FDM). It has internally three sub modules: the fuzzification module, the inference engine and the defuzzification module. Figure 3 shows the block diagram of the standard fuzzy logic controller that is used to design the fuzzy decision maker. The details of each sub module design in FDM are depicted below.

3.1 Fuzzification Process

Fuzzification is the first step in the fuzzy inference process which involves a domain transformation where crisp variables are transformed into fuzzy inputs. In this transformation, a reasonable number (usually 3, 5 or 7)

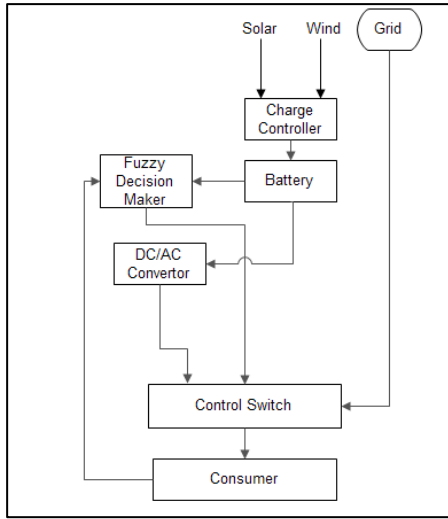


Figure 2. Fuzzy based smart energy distribution system.

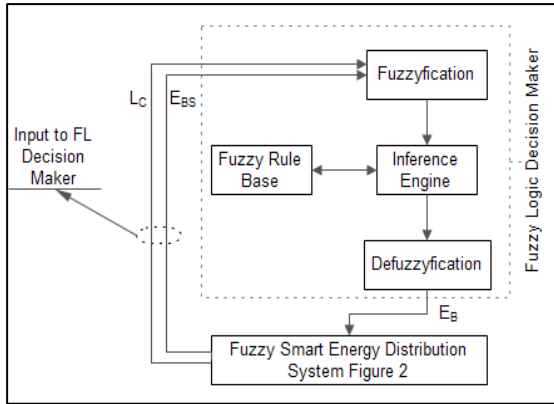


Figure 3. Overall structure of fuzzy logic controller used in presented technique.

of the so called membership functions (MF) is used. These functions are most often in the form of piecewise linear functions, such as triangular or trapezoidal functions. A membership degree μ between 0.0 and 1.0 is produced when a given input is applied to the membership function.

For example the membership functions, shown in Figure 4 take the input as the current “consumer load” (L_C) and associate it to a respective membership degree for each of all 5 fuzzy sets. According to the fuzzy rule base (FRB) table shown in Table 1, “VL” denotes the notion of “Very Low”, “L” denotes “Low”, “M” denotes “Medium”, “H” denotes “High” and “VH” demotes “Very High”. For example, the normalized input for the “consumer load” $L_C = 0.75$, the membership degrees for all five membership functions are: $\mu(VL) = 0$, $\mu(L) = 0$, $\mu(M) = 0.24$, $\mu(H) = 0.76$, $\mu(VH) = 0$.

We have considered the MFs of consumer load input and battery status as shown Figure 4 and Figure 5, respectively.

3.2 Fuzzy Rule Base (FRB)

The Fuzzy rule base is determined by the experimental consideration of the influence of each of the switching logic input parameters to the output parameters. It represents the individual’s knowledge about the particular problem. Different designers of the FRB usually adopt FRB with different content. A respective program in C++ is developed to decide the most suitable fuzzy rule base. This program reads different possible FRBs from an external file. This gives a flexibility to experiment with different types of fuzzy rules. After several experimental readings, the fuzzy rule table as given in Table 1 is adopted in this study.

3.3 Defuzzification

Defuzzification is a process by which the fuzzy consequent is transformed to a *singleton* or crisp scalar value, which is further on assumed as a real output from the fuzzy decision maker.

3.4 Response Surface of the Fuzzy Decision Maker

The response surface is a three-dimensional plot, as shown in Figure 6, which represents the numerical value of the output of the FDM for all possible combinations of values of the two Inputs. As clearly seen from Figure 6., the fuzzy logic, assumed in the fuzzy rule base from Table 1 has led to a highly nonlinear response surface, which means that the corresponding FDM is very flexible in taking different decisions.

Table 1. Fuzzy rule base.

<i>Very High</i>	VL	L	M	H	VH
<i>High</i>	VL	L	H	H	VH
<i>Medium</i>	VL	M	H	VH	VH
<i>Low</i>	VL	M	VH	VH	VH
<i>Very Low</i>	VL	H	VH	VH	VH
	<i>Very Low</i>	<i>Low</i>	<i>Medium</i>	<i>High</i>	<i>Very High</i>

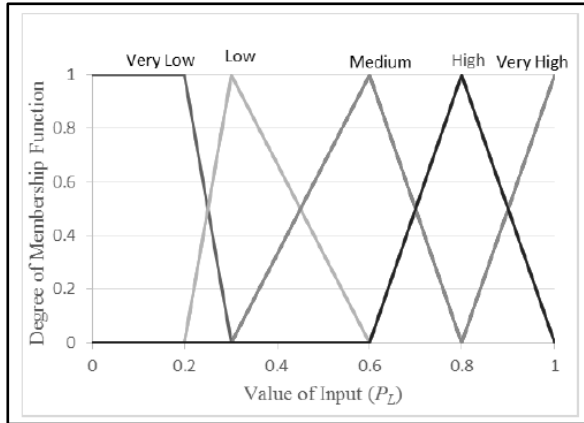


Figure 4. Five Membership functions defined for the input “consumer load”.

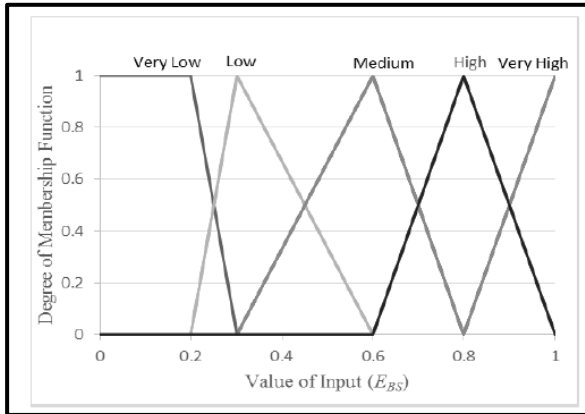


Figure 5. Five Membership functions defined for the input “battery status”.

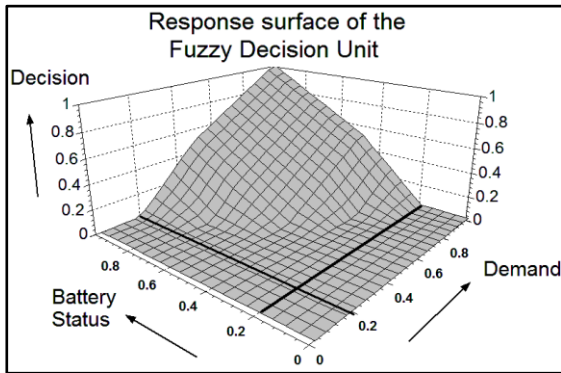


Figure 6. Fuzzy response surface for controller design.

4. Results and Discussion

Aiming to make use of maximum renewable energy stored in the battery. It is necessary to monitor the current battery levels and to satisfy the consumer load demand efficiently. We have simulated the proposed scheme from the available real-time data captured from

the solar and wind. The data is normalized for ease of analysis. Figure 7 shows the behavior patterns of the energy obtained and used as 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 indicates 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 the natural resources suggests the need of an optimal distributor of the energy. Another input data for the fuzzy based distributor controller is shown in Figure 8, in the form of normalized typical load demand for the same period.

Both data types were used to demonstrate the efficacy of the presented technique. The results are plotted in Figure 9 together inputs and outputs data patterns for two days after applying to the fuzzy based decision maker. The analysis is carried out with initial hold charged by the battery of 75%. The result shown in Figure 10, illustrates at some places the entire consumer demand is supplied through the battery source and at the same time, it protects the battery level to be reached to critical level. Furthermore, whenever the battery voltages below the critical value, the energy is drawn completely from the power grid, allows charging the battery at some sufficient value.

Table 2 shows the simulation result of different initial battery levels. The aim is to prove the algorithm maximizes the usage of renewable sources irrespective to initial battery level. The simulation is carried out for same energy demand; here for example 14.91 kW for two days and same supplied green energy. It can be shown from the table that percentage usage from the battery is even optimal when the battery is fully discharged. The energy utilization from the battery system is about 37% during the fully charged. This illustrates that the optimal fuzzy switching for energy distribution is less dependent on the grid in the sense that it tries to draw the energy as much as from the renewable sources.

Table 2. Results from simulation with different initial battery levels.

Start Battery Level (%)	Percentage from battery (%)
0	27.585
25	30.100
50	32.615
75	35.130
100	37.645

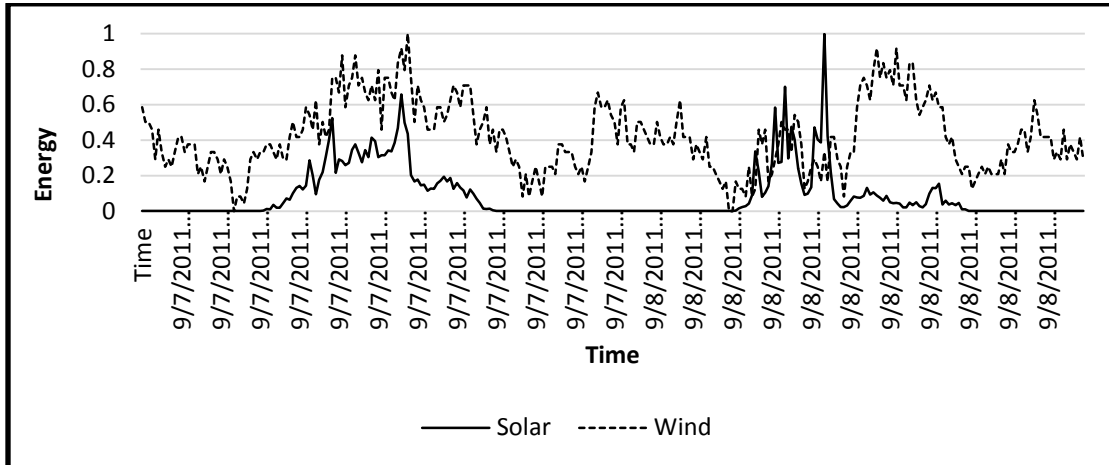


Figure 7. Normalized solar and wind data inputs.

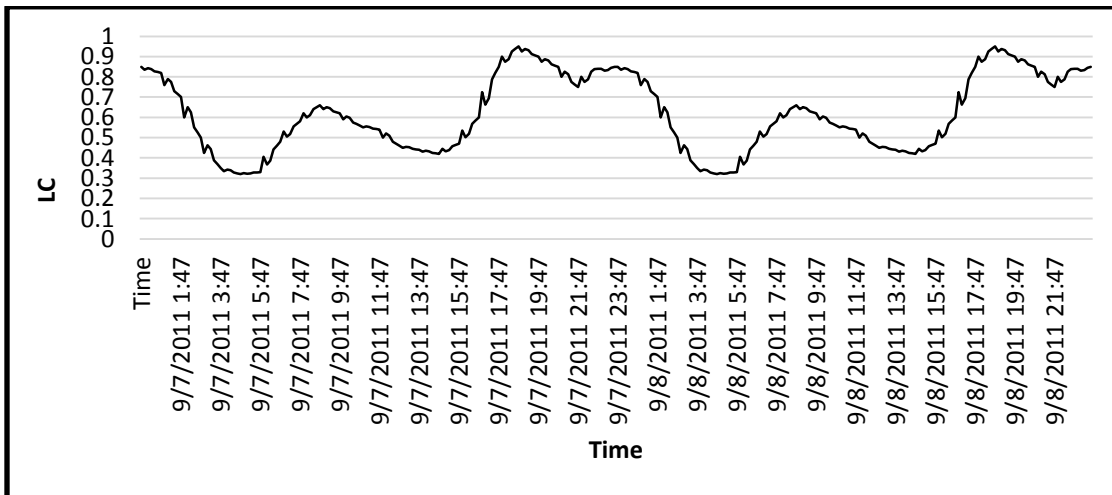


Figure 8. Typical load demand data.

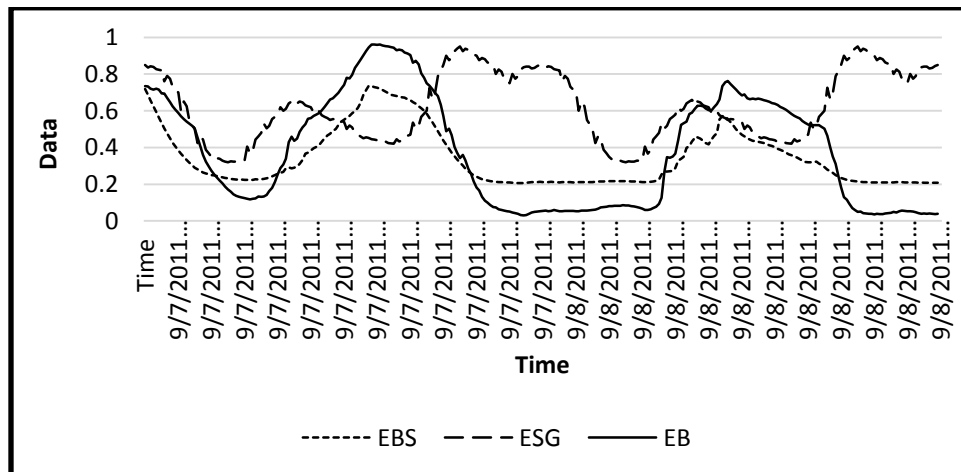


Figure 9. Output pattern from the FDM in line with the input data (with 75% starting battery level).

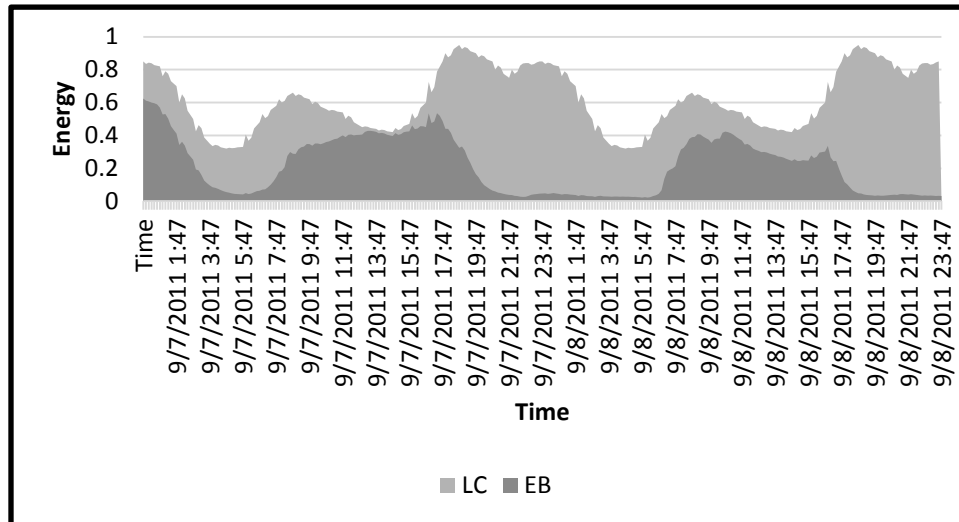


Figure 10. Energy supplied from the battery in line with the demand.

5. Conclusion

The fuzzy logic was used to design a smart distributor to make sure that whatever the amount of energy was collected from the renewable sources, should be utilized optimally with a minimum loss. This simulation results proved that the load demand was satisfied with optimal utilization of renewable sources. A smart decision was taken online by the system based information of current demand and energy status. The outcome of this result also proved that how simply a new system protects the battery by reaching to critical upper and lower levels. Also it was noted that the entire consumer demand was satisfied with a minimal use of the energy from the supply grid. Possible further developments of this work include the optimal tuning of the fuzzy rule base and the parameters of the membership functions, as well as finding a numerical way for estimation of the energy efficiency.

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