Fuzzy-Logic Based Control for Battery Management in Micro-Grid

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***Abstract*— In this paper, a Fuzzy-Logic based control framework is proposed for Battery Management in Micro-Grid System. The Micro-Grid system operates synchronously with the main grid and also has the ability to operate independently from the power grid. Distributed renewable energy generators including solar, wind, and batteries supply power to the consumer in the Micro-Grid network. The goal is to control the amount of power given to the storage system in order to minimize a cost function based on payment/profit and distribution loss through reasonable decision making using predefined profiles of system variables such as Load Demand, Electricity Price, and Renewable Generation.**
Simulation results are presented and discussed. The proposed intelligent control system turns out to be capable of achieving effective energy management.

***Index Terms*—Micro-Grid, Control, Power Flow, Fuzzy-Logic, Load Demand.**

I. Introduction

Micro-Grid is can be referred to as a small scale grid that is designed to provide power for small communities. A Micro-Grid is an aggregation of multiple distributed generators (DGs) such as renewable energy sources, conventional generators, and energy storage systems which work together as a power supply network in order to provide both electric power and thermal energy for small communities which may vary from one common building to a smart house or even a set of loads consisting of a mixture of different structures such as buildings, factories, etc. Typically, a Micro-Grid operates in parallel with the main grid. However, there are cases in which a Micro-Grid operates in islanded mode, or in a disconnected state [1]. In this article, in addition to both of the states already mentioned, a third state is assumed for operation of Micro-Grid in which excess power in the Micro-Grid is delivered to the main grid, i.e. the excess power is sold to the grid.

II. System Model

A three bus system is used to model the Micro-Grid network for simulations in this article. One of the busses in the distributed generation system model is assumed to serve the renewable generators which include either solar farm, wind farm, or any other renewable generation units. Another bus is assumed to be working as the grid (utility) bus which will provide the complement part of the power demand that renewable generation system cannot afford to the load. The third bus will be the specific load to which the demanded power is to be provided. This load can be anything from a common building or a smart house, to even a group of plants and factories or a mixture of all of them. Figure 1 shows an overall Micro-Grid schematic including Renewable Electricity Generators and Storage Unit, Utility, and Typical Load.

Figure 1 Micro-Grid Schematic

There are two scenarios assumed for simulation in this article, scenario 1 deals with a Micro-Grid which includes the renewable generation unit without any battery storage unit. Therefore there will not be any approaches required for controlling the battery storage system in this scenario. The second scenario deals with the same Micro-Grid system as mentioned in scenario 1 but with the battery storage unit considered to be connected to the same bus as the renewable generators. These two scenarios will be described in more detail in the next section "Problem Statement". The characteristics of busses in each of the two scenarios are as follows:

Scenario 1:

- Bus1 is of type PQ and is used as the renewable generation unit's bus
- Bus2 is of type Slack (reference) and is used as the Utility (grid) bus
- Bus3 is of type PV and is used as the Load bus

Scenario 2:

- Bus1 is of type PQ and is used as the bus for renewable generation unit and the Battery storage unit
- Bus2 is of type Slack (reference) and is used as the Utility (grid) bus
- Bus3 is of type PV and is used as the Load bus

III. Problem Statement

Important point on this first idea is that we have assumed the time-varying pricing for electricity. The update duration of pricing is assumed to be 15 mins, which means that the price per killowatt-hour of electricity consumed by the customers of the load region is updated every 15 minutes, and there will be a cost function determined by us as:

$$C = \sum_{t=1}^{T} (Pr(t).(S_U + S_L)) \quad (1)$$

where the electricity price is determined by the CPS energy every 15 minutes for the next 15 minute period. $S_U(t)$ is the amount of power transferred to/from the Grid during each 15 minute period. If power is received from the Grid $S_U(t)$ will be positive, and if power is delivered to the grid in case of excess power generation by the renewable generation system $S_U(t)$ will appear in the equations with a negative sign. $S_L(t)$ is the amount of distribution loss which will occur on the branches we have between these three Busses in the Micro-Grid system during each 15 minute period. Depending on whether the load is getting how much of its demanded power from renewable generation system and how much from the Grid, and also depending on whether the renewable generation system is producing excess power and is selling the excess power to the Grid, this power Loss will vary.

The simulation is done on the Micro-Grid system considering two scenarios. In the following the summary of the two scenarios is given:

Scenario 1: Analysis of the Micro-Grid system profits and costs under time-varying electricity pricing policy; in this scenario, the simulation, analysis and study will be done Micro-Grid which includes the renewable generation unit without any battery storage unit. Therefore there will not be any approaches required for controlling the battery storage system in this scenario.

Scenario 2: Fuzzy Control of the Micro-Grid system under time-varying electricity pricing policy; the cost function assumed in this scenario is the same as the cost function described in the scenario 1. The main difference here is that the storage system exists in the network and will appear to be on the same bus with the renewable generation unit.

The power flow calculation in the Micro-Grid is the key to simulate the whole system. There are a number of well-known methods for calculation of power flow in the distributed generation network [2]. There are four different types of busses considered in a distributed generation network, the characteristics of which will be calculated in power flow algorithms. These four types include PQ, PV, Slack, and isolated [3,4].

IV. Fuzzy Control Approach

The control strategy implemented in this paper is to use the Fuzzy Logic [5] approach for controlling the power flow to/from the battery storage unit in order to minimize the cost function introduced in previous section “Problem Statement”. The three input variables to the fuzzy inference engine are Price, Renewable Generation, and Load Demand.

The numerical values for these three input variables are normalized to the [0 1] interval, and then are Fuzzified using three fuzzy sets defined as Low, Medium, and High. The input variables after fuzzification will be fed to a fuzzy inference engine where the rule-base is applied to the input-output variables and the output will be determined by human reasoning. There is only one output variable which determines the amount of power to be stored in the battery, or to be drawn from battery. Output variable fuzzy set is assumed to have five membership functions called Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Large (PL). The power drawn from the batteries can be used to provide the load in order to complement the renewable generation power for providing the load's demand, can be sold to the Grid, or can be partially used for both reasons [6]. The role of fuzzy inference engine is critically important for obtaining satisfactory results. For example, if the *Price* is *Low*, the *Renewable Generation* is *High*, and the *Load Demand* is *Medium*, then, the amount of *Power to Battery* storage system should be *Positive-Large*, even if this requires the system to get power from grid and store it in the battery storage unit, because the main point here is that Price is low, which means that by storing the energy in the batteries during low price times, the system will have enough stored energy in order to sell to the Grid during high-price periods. Even under cases of High Load demand this will be a good strategy. Therefore, having feasible rules predefined for the fuzzy system will help to minimize the cost function drastically. The proposed approach may sometimes result in making the cost function value negative, which means that the system is even making some profit out of this control approach instead of paying to the utility.

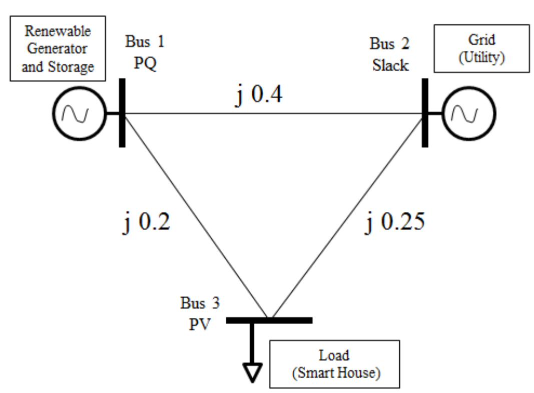

Figure 2 Three Bus Model for Micro-Grid

V. SIMULATION RESULTS & DISCUSSIONS

The simulation is done on the three bus system for power flow calculation. The Gauss-Seidel algorithm is implemented using Matlab for power flow calculation. Some typical data are generated for dynamic Load Demand and Renewable Generation rate.

The power demand of the Load on bus 3 (Smart House) is supplied by two generators on buses 1 and 2. Bus 1 includes solar panel and storage and bus 2 is slack which is connected to utility as shown in figure 2.

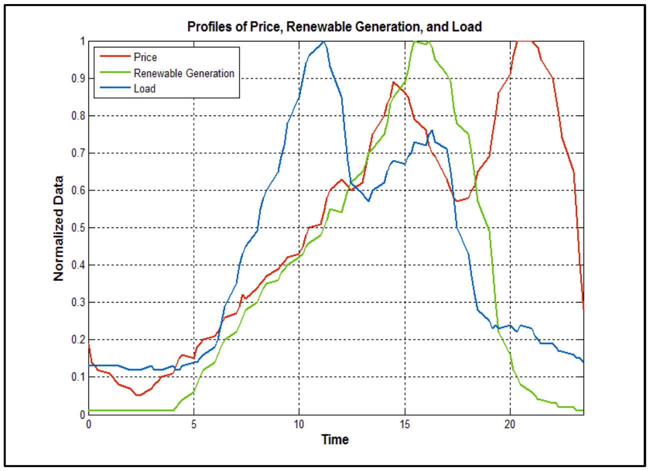

Figure 3 Profiles of Price, Renewable Generation, and the Load during a typical day for each 15min period

The numerical values of the data profile for the three input variables to the *fuzzy inference engine* are shown in figure 3. These variables include electricity price, renewable generation rate, and load demand. The data is generated typically for simulation purposes only with regard to the fact that the peak electricity consumption duration of the whole region of interest is around 8:30 pm where the price gets to its peak value. The simulation results for scenario 1 are represented in figures 4 to 6.

As it can be inferred from figure 4, the value of reactive power for bus 1 is constantly zero which corresponds to the assumption that the renewable generators do not provide reactive energy. Figure 5 shows that the active power is taken from the Utility during first half of the day time, and during the most of the second half of the day the active power is being delivered to the grid. Load is evidently consuming active power regarding the blue curve represented in figure 6.

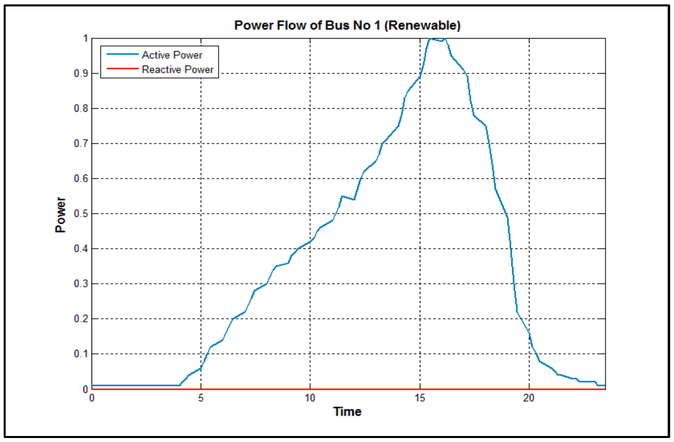

Figure 4 The Power Flow of Bus 1 including Solar Panel in a typical day for each 15min period

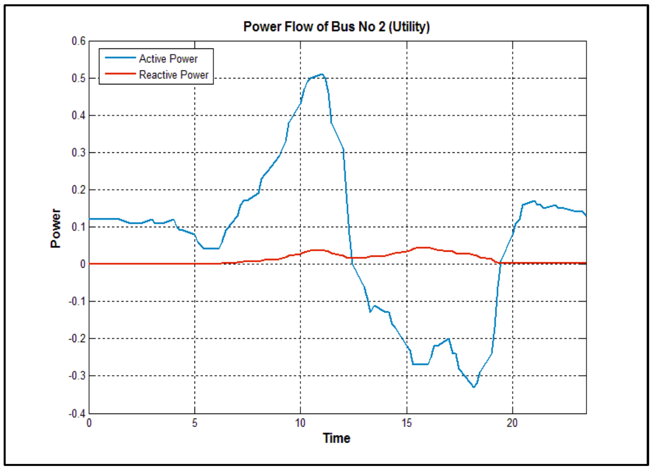

Figure 5 The Power Flow of Bus 2 connected to utility in a typical day for each 15min period

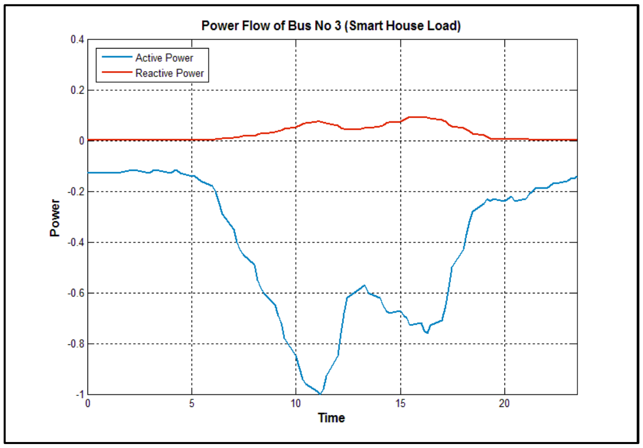

Figure 6 The Power Flow of Bus 3 including Load in a typical day for each 15min period

Output of the fuzzy inference engine which represents the power rate given to battery is shown in figure 7. Whenever the value of this variable is positive it means that power is delivered to the storage unit and if the power is drawn from the storage unit, the value will be negative.

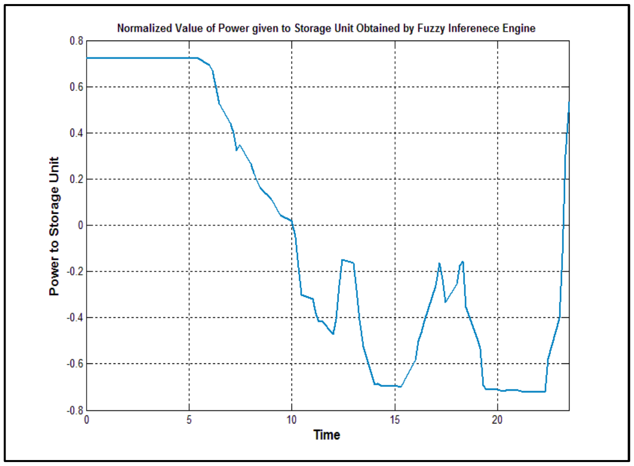

Figure 7 The normalized Value of Power given to Storage obtained by Fuzzy Inference Engine

Simulation results for scenario 2 which includes storage on bus 2 are represented in figures 8 to 10.

As one can infer from figure 8, the value of reactive power for bus 1 is again constantly zero – the same as it was in scenario 1 - which corresponds to the assumption that the renewable generators do not provide reactive energy. Figure 9 shows that the active power is taken from the utility during first half of the day time, and during the most of the second half of day the active power is being sold to the grid. The point is that the first part of the active power diagram is raised dramatically due to fuzzy decision making which means that the system is absorbing more active power from the grid during low-price hours and stores the power in the storage unit. Also, the second part of the active power diagram has fallen more in comparison to the same section of figure 5 which denotes on increase in the amount of power drawn from storage unit and using this power for partially charging the load and also selling the excess power to the grid during high-price hours. This strategy results in minimization of cost function or in other words maximizes the profit function. As shown in figure 10, load (smart house) is consuming active power.

Remembering that the pricing periods are assumed to be 15 minute periods and one day is 24 hours overally there will be 96 periods of pricing during one day period. The summation of payment/profit and the loss during each of the periods will give us the overall value of cost function for one day. The process can be extended to one week, one month, one year etc.

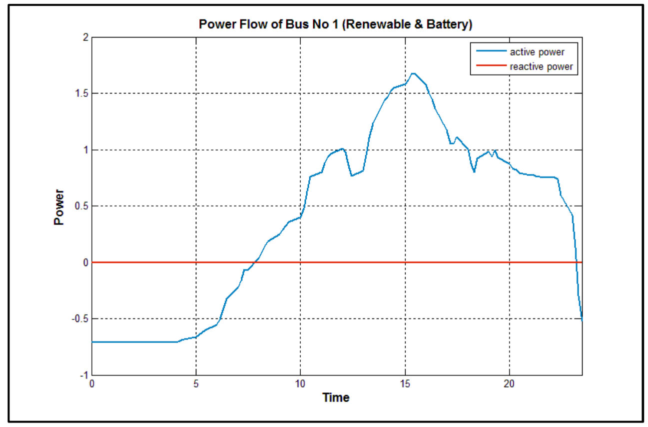

Figure 8 The Power Flow of Bus 1 including Solar Panel in a typical day for each 15min period with storage on bus 2

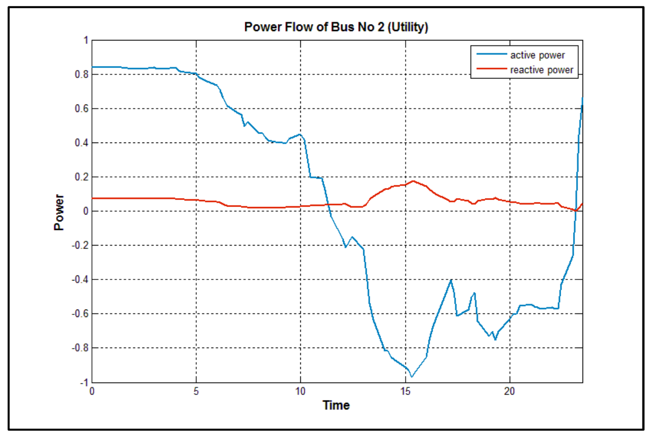

Figure 9 The Power Flow of Bus 2 connected to utility in a typical day for each 15min period with the Storage on bus 2

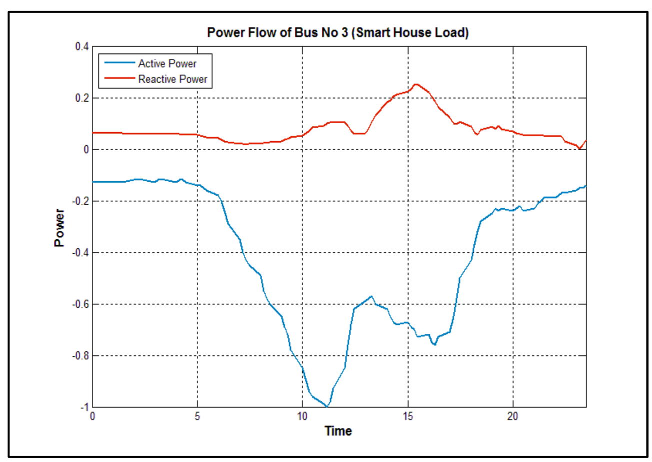

Figure 10 The Power Flow of Bus 3 including Load (Smart House) in a typical day for each 15min period with storage on bus 2

In table 1, total values of distribution loss, payment/profit, and the cost function on one typical day for the two scenarios mentioned in section III are summarized. It must be mentioned that the values in the table are dimension-less, and they can be regarded as the costs or the prices that the end-user should pay to the utility because of regular operation of Micro-Grid, or earns due to improved operation and control of the Micro-Grid.

Table 1. The simulation results for Loss, Payment, and Cost

	Loss	Payment	Cost
Scenario 1	0.1286	2.3433	2.4719
Scenario 2	6.3430	-11.8192	-5.4761

The Cost is equal to summation of Payment and Loss. Payment is simply the overall summation of power from/to grid multiplied by the relevant price for all 15 min periods, and the overall summation of multiplication of the price and consumed power on distribution branches for all 15 min periods is defined as Loss for one typical day. With no loss of generality, it is assumed that the active and reactive power have the same price.

VI. CONCLUSION

The proposed Fuzzy-Logic based control method is applied for Battery Management in Micro-Grid System. In the micro-grid system three buses are considered as renewable generator and Storage, utility, and load (smart house). The goal was to minimize the cost function which is based on distribution loss and payment/profit. The Micro-Grid was simulated under first scenario 1 without any storage units involved. Simulation results obtained for the same Micro-Grid under scenario 2 where the storage system is included with the Fuzzy controller show that scenario 2 outperforms the first scenario where no storage system with fuzzy controller is incorporated. Therefore, using fuzzy controller it is possible to reduce the cost of the Micro-Grid system, and even let the customers make profit from selling the excess power to the utility.

REFERENCES

[1] Cho, C.; Jeon, J.; Kim, J.; Kwon, S.; Park, K.; Kim, S., ‘Active Synchronizing Control of a Microgrid’ IEEE Transactions on Power Electronics, issue 99, PP, 2011

[2] N. L. Srinivasa Rao, G. Govinda Rao, B. Ragunath, “Power Flow Studies Of The Regional Grid With Inter State Tie-Line Constraints” IEEE Conference on Power Quality, pp. 165-171, 2002.

[3] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER's Extensible Optimal Power Flow Architecture," Power and Energy Society General Meeting, 2009 IEEE, pp. 1-7, July 26-30 2009.

[4] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education," Power Systems, IEEE Transactions on, vol. 26, no. 1, pp. 12-19, Feb. 2011.

[5] Chang, Sheldon S. L. ; Zadeh, Lofti A. ; “On Fuzzy Mapping and Control”, IEEE Transactions on Systems, Man and Cybernetics, pp. 30-34, 1972.

[6] Zhu Wang, Rui Yang and Lingfeng Wang,” Intelligent Multi-agent Control for Integrated Building and Micro-grid Systems” IEEE PES Innovative Smart Grid Technologies (ISGT), pp.1-7, 2011.