Smart Grid Effectiveness with the Implementation of Fuzzy Logic

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ABSTRACT: *Smart grids are extensively addressed in research as they solve numerous issues in the current grids. Using computational intelligence, we have advocated a smart grid which can react in the artificial intelligence environment. In this situation fuzzy logic based control systems can support smart grids. Thus a large number of research fuzzy logic and fuzzy decisions use smart grids for automated management. In the current work we have advocated a fuzzy based decision making system to manage of timeshiftable loads in the residences. The proposed fuzzy decision maker determines optimal starting time of time-shiftable loads in the residential area in order to provide advanced power curve and decrease peak load consumptions by scheduling of these loads. Besides, we have highlighted the design stage of the proposed fuzzy decision maker and described it. During testing we have a simulation of the decision outcome to confirm the new design.*

Keywords: Fuzzy Logic, Fuzzy Decision Maker, Demand Side Management, Load Scheduling

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1. Introduction

Electricity generation methods and electricity grid infrastructure has been evolving for last several decades to compensate increased electricity demand and to decrease climate change issues. Renewable energy sources have been utilized more in the electricity generation and energy efficiency has been attracted great attention in the developed countries. Smart grids promise that smart management of the evolved electrical grid to retain sustainability, to avoid collapse and to increase efficiency of the electrical grid. Demand side management (DSM) is the one of the main component of the smart grids to control electricity usage of the consumers to increase efficiency and to reduce greenhouse effects. DSM is also allow to the consumers to make more informed about their electricity consumptions and to collaborate with them to shape power consumption curves of them [1].

Electricity consumption of residences in European countries (EU-25) have been increased by 10.8% during the period of 1999 to 2004 [2]. Residential electricity consumption has share of 29% in total electricity consumption in EU-28 countries by 2014 [3] and in the OECD countries residential sector has share 32% in final electricity consumption by the year of 2015 [4]. There are many devices in the residences such as washing machine and tumble demand high power from the electrical grid. If these demand high power from the electrical grid. If these appliances engaged at the similar hours of the day, they can occur overload in the electrical distribution system. The overload of the distribution network might decrease the efficiency and might cause instability issues on the distribution network. Therefore, demand side management is significant part of the smart grids [5, 6] and DSM studies can solve these problems mentioned above. In a distribution network, power companies desire to design a decision maker so that the operating times of some loads can be shifted from heavy loading periods of a day to light loading periods of the day.

Many DSM techniques have been proposed in the literature such as price based, incentive based and direct load control based [7]. Heuristic algorithms are applied in demand side management studies to get optimal scheduling according to desired objective functions [8-10]. Direct load control is an important DSM technique and it is proposed in the literature by controlling different loads and considering different objectives [11-14]. Mortaji et al.[11] proposed a smart direct load control by using internet of things (IoT) to control sudden load changes and to decrease peak to average ration (PAR) of the power consumption in the distribution network. They simulated their proposed system by hundred customers and they showed that the peak load can be decrease by 30%. Basnet et al. [12] showed that effect of direct load control by scheduling of HVAC (heating, ventilation and air conditioner). Chen et al. [13] proposed a novel two-layer communication-based distributed direct load control for residential area by allocating control tasks into each home's energy management controller unit, distributively. Martin et al. [14] proposed a decision model to implement direct load control (DLC) on charging of electrical vehicle batteries.

Fuzzy logic (FL) [15] is described by Zadeh as computing technique with words are used in place of numbers for computing and reasoning. FL is utilized on numerous studies about power systems in the literature [16-18]. The main advantage of the FL is to modify and design the system by linguistic variables which are utilized in human decisions. FL based DSM studies are also studied and proposed in the literature such that examples [19-23]. Chandran et al.[19] compared fuzzy logic control(FLC) based demand response with classical Boolean logic based direct load control. They showed that advantages of FLC based DLC over classical DLC and they used forecasted load curves instead of price curve to avoid distributing the customer comfort level. However, they utilize fuzzy logic approach as a controller unit based on customer priorities. Keshtkar et al. [20] proposed a FL based autonomous system to manage residential Heating, Ventilation, and Air Conditioning (HVAC) units by considering outdoor temperature, electricity price, occupant presence and electricity demand of the house.

A fuzzy logic based domestic load management which use comfort, cost and demand response parameters has been proposed by Rahman et al.[22]. However, their proposed system does not consider the consumptions of other residences, it operates for the just one residence by considering the price signal. So, it can be get financial benefits for the one residences but if the all residences act same way considering the same price signal it might be lead adverse results instead of desired demand response effects.

In this paper a fuzzy decision maker (FDM) has been proposed such that determine optimal starting time when a demand is entered to it. The proposed systems assumed that the customer will get financial benefits is they allowed the control of their time-shiftable loads and it operates direct load control approach. Main objective of the proposed system is considering the residential area load curve to inhibit high power consumptions by utilizing the demand power and forecasted load powers. To give an example, if the predicted load in a time ahead is lower than the current load power, then the active demands should be postponed to be operated during these lower demand period hours of the day. The proposed FDM based demand scheduling system has been generated on MATLAB by modifying the generalized fuzzy logic controller design study [24]. So, it can be easily modified and/or improved for the future studies.

The rest of the paper is organized as follows: Section 2 introduces designing of the proposed fuzzy decision maker. Section 3 includes case study and results. Section 4 presents the conclusion.

2. Designing of a Fuzzy Decision Maker to Determine Optimal Starting Time of the Shiftable Loads

The proposed FDM processes demand power and the difference between demand power and predicted future power as two inputs. The overall demand management mechanism of the proposed system is illustrated in Figure 1 and explained below.

Overall process steps of the proposed demand management mechanism:

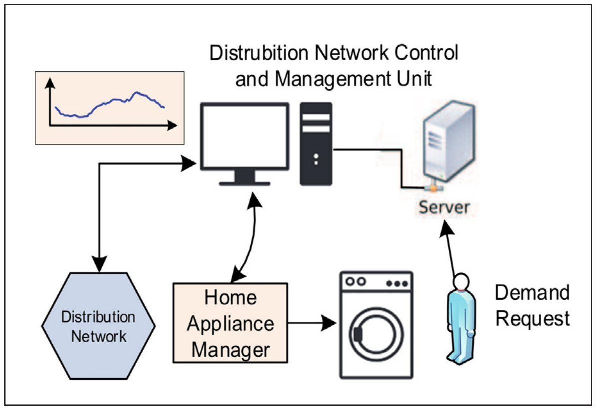

Figure 1. Overall demand management mechanism of the proposed system

1. Customer send the demand request to the server of the distribution network control and management unit (DNC & MU).

2. DNC & MU which includes the proposed FDM processes the forecasted demand loads and the demand request based on the pre-determined fuzzy rules.

3. The FDM generate an optimal operating time of the load which is requested by the customer.

4. Then the optimal operating time information sends to the home appliance manager to execute the operation of the requested load when the time is equal to the optimal operating time.

The flowchart of the proposed system is presented in Figure 2. It is searched that is there any demand request in every control interval loop the system. If there is a demand, the system gets the demand power and evaluates it on FDM to determine optimal starting time for it. After accomplishing the above process current and future load data is updated. The customer notified by the system about the delay time of him scheduled load and the system operate the shifted load automatically at the scheduled time.

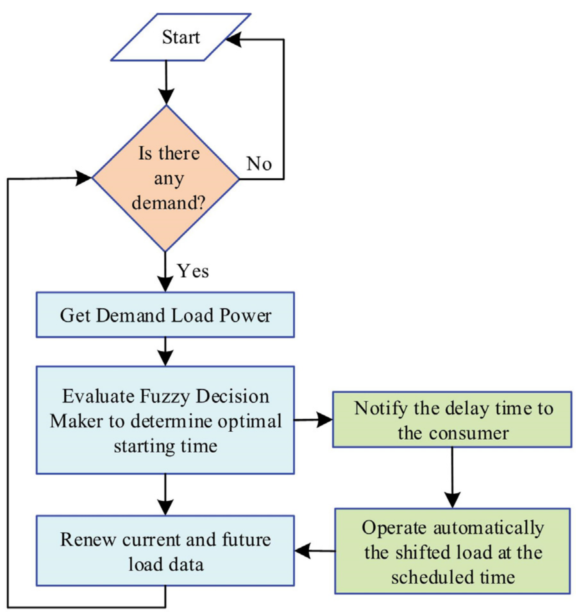

Figure 2. The flowchart of the proposed system

Demand power may be categorized as low (LW), average (AV) and high (HI). Since the difference may be positive, negative and zero depending on demand and predicted power values, the universe of power difference can be portioned into five fuzzy subsets as negative high (NH), negative low (NL), zero (ZE), positive low (PL) and positive high (PH). The output space representing the delay time is divided into three fuzzy subsets as short (SH), medium (ME) and long (LN). A block diagram of the FDM is given in Figure 3. The FDM block includes the fuzzy rule table given by Table 1, which includes 15 fuzzy rules for decision-making.

The FDM given in Figure 3 uses Mamdani fuzzy reasoning algorithm with two crisp inputs and one crisp output. The current power demand (P_D) is represented by variable *x* and the difference (ΔP) between current load power and predicted future depended power is represented by variable *y*. The output is the delay time t_D represented by variable *z*.

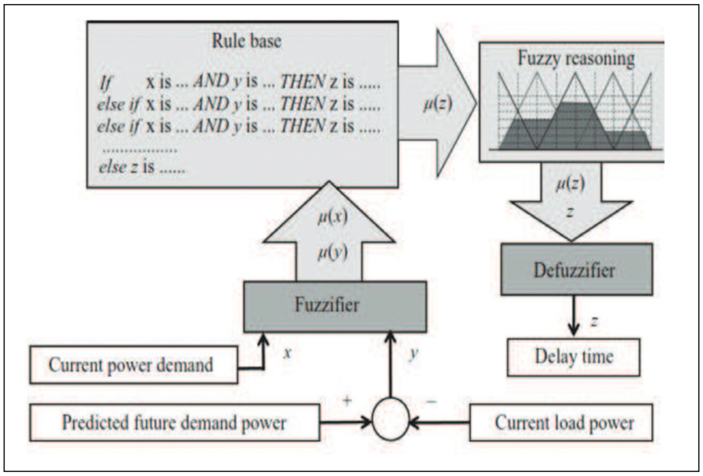

Figure 3. Block diagram of the proposed fuzzy decision maker

If the current demand power is LW and the difference power ΔP is NH, then this load demand can be delayed for LN because negative ”P means that the future power demand will be smaller than the current power dissipation so that the operating time of this power demand can be shifted ahead with a long delay. If current power demand is HI and difference power ΔP is PH, then this load demand should not be delayed because the predicted future power demand will already be high. If this high-power demand is postponed to a later time, the load demand will be much higher such that the generated power might be insufficient as the network faces overloading operating conditions, which cause overheating and higher losses. The other fuzzy rules are generated with a similar point of view to represent the experience of a power network operator.

	ΔP				
$\mathbf{P_D}$	**NH**	**NL**	**ZE**	**PL**	**PH**
LW	LN	ME	SH	ZE	ZE
AV	LN	ME	SH	ZE	ZE
HI	LN	SH	ZE	ZE	ZE

Table 1. Rule Table of the Proposed FDM

Let us assume that the current power demand is 2300 W and the difference power ”P is negative 400 W and try to find the decision about how long the load demand can be delayed. The fuzzy decision process for this example is depicted in Figure 4. Defuzzification process is depicted in Figure 5.

3. Case Study and Results

In this chapter, a case study has been simulated in order to show operation of the proposed system. Three different demand requests (DR1, DR2 and DR3) have been applied and the response of the proposed system has been observed. The results with and without the proposed FDM based scheduling have been compared.

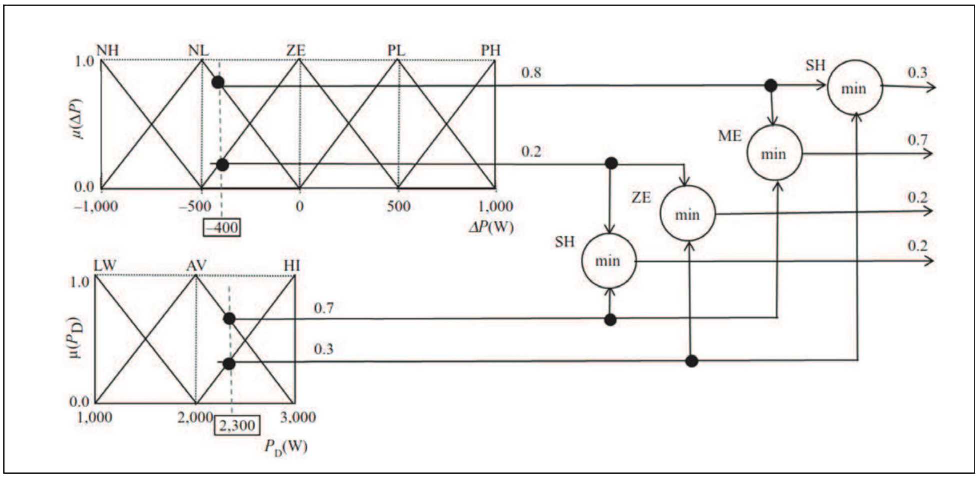

Figure 4. Example of fuzzy decision maker process

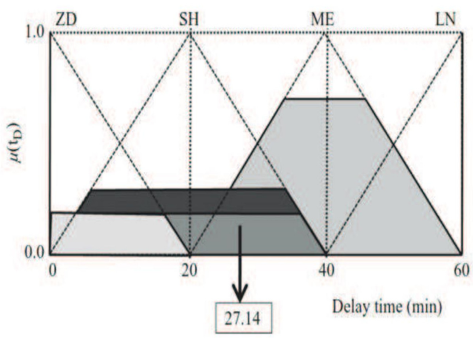

Figure 5. Defuzzification of the fuzzy decision for the example

It is assumed that predicted daily load curve for twenty customers is given for 30 min. time intervals for 24 hours as Figure 6. It is also assumed that there are three demand requests at the specified times as shown in the figure. Let say that the average of demand powers is 1500W and duration time on operation of them 90 minutes.

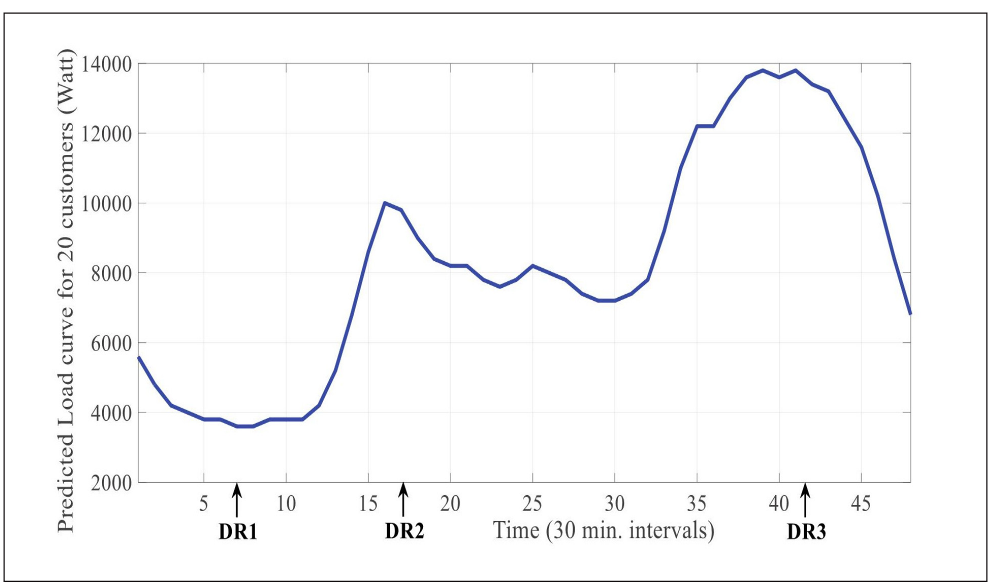

Figure 6. Predicted daily load curve for twenty customers and demand request times in the test case

According to the above predicted daily load curve membership functions of the ΔP have been designed as triangle fuzzy membership functions as shown in Figure 7.

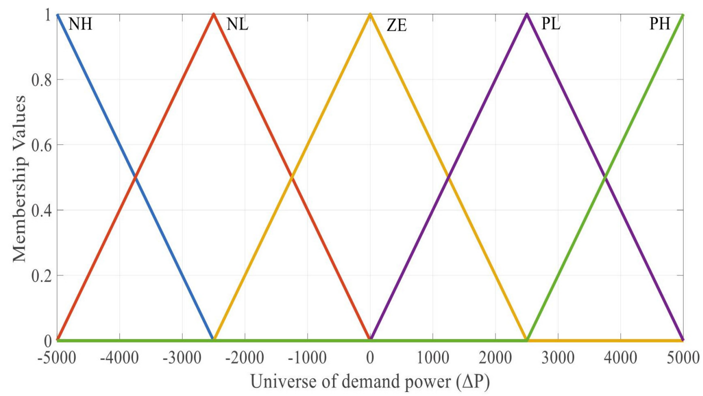

Figure 7. Designed membership functions for ΔP

It is assumed that the means of demand power are change between $1000W$ and $3000W$. So, membership functions of the demand power have been created as triangle membership functions as depicted in Figure 8.

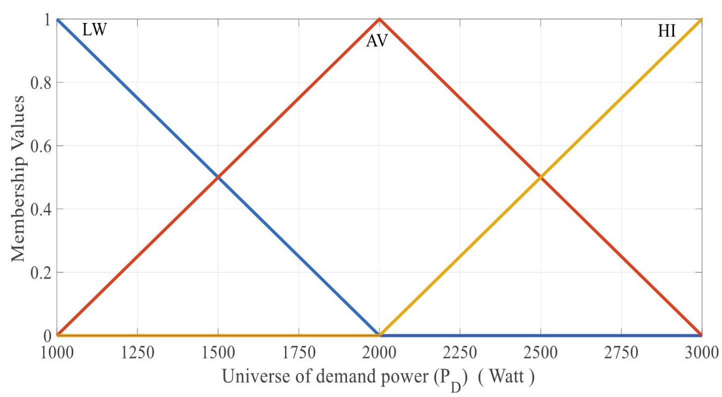

Figure 8. Designed membership functions for demand power(PD)

The range of the delay time (tD) which will be determined by the proposed FDM is designed between 0 and 90 minutes then fuzzy membership functions of it has been created as illustrated in Figure 9.

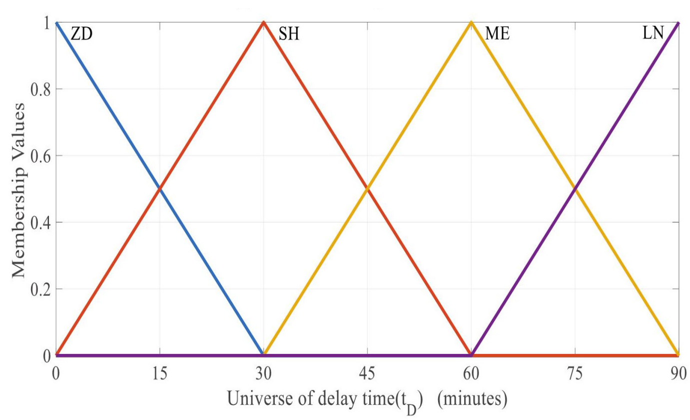

Figure 9. Designed membership functions for delay time (t_D)

In the simulation Case 1, it is assumed that there is no DSM action for the customers and the customers operate their time shiftable loads at the specified times which is shown in Figure 6. In the simulation Case 2, it is assumed that the proposed FDM is active and schedule the demand requests based on the rules on Table 1. According to the both Case 1 and Case 2 simulations, the aggregated power curves are obtained as in Figure 10.

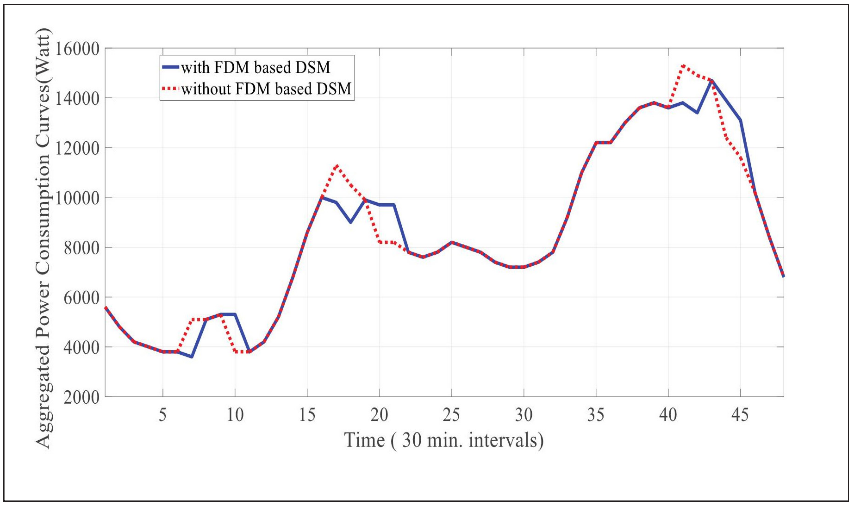

Figure 10. Designed membership functions for delay time (t_D)

Comparison of the results are presented in Table 2. As shown is clearly, PAR and peak power can be reduced the FDM even with three time-shiftable loads. If the participation of the customers to the DSM, the prediction and scheduling will be improved, of course.

	Without DSM	**With Proposed FDM based DSM**
Average power (W)	8527.1	8527.1
Peak power (W)	15300	14700
Peak to Average Ratio (PAR)	1.7943	1.7239

Table 2. Comparison of the Results

4. Conclusion

Demand side management is one of the key components of the smart grids. Distribution networks in residential regions can be faced high power demand at some periods of a day because of high power requested devices of the residences. The drawn high-power causes to engage extra generation units and overloaded the distribution network. However, some high-power demand household devices can be shift to another time periods. DSM studies want to shift these shiftable appliances to lower demand regions of a day by financial incentives. Instead of manual or human controlled management of these appliances fuzzy logic can be good alternative to create automated DSM system which act like human decisions.

In this study a fuzzy decision maker has been developed to determine optimal starting times of time shiftable loads in the residences. The proposed system act as dynamically and can be modified according to the objectives by changing of the fuzzy rules. Bu the case study a mini simulation has been studied to show effects and response of the proposed FDM based dynamic scheduling unit. The results show that the benefits of the scheduling and decisions of the proposed system. This proposed FDM will be good reference for evolving smart grids studies in the future. Of course, the proposed FDM based scheduling system will be improved in the next studies by comprehensive approaches.

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