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Prevention of Power Theft and Reduction of Excessive Power Usage Using Fuzzy Logic for Residential Consumers

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ABSTRACT

This paper shows a control method to prevent users from stealing power and also to reduce excessive power usage with assist of fuzzy inference system. Power theft can be detected by comparison between substation energy meter reading and the total load supplied by the electricity poles. Excessive power usage can also be detected by comparison between the power delivered from the substation with the power consumed by the customer. The Arduino board, namely Slave board is connected to the energy meter of each home. Another Arduino board, namely Master board is connected to the energy meter of the substation. The Master board is used to continuously monitor the load consumption that calculated by Slave board. Any difference noticed in collected data means either power theft has occurred or excessive power usage has occurred which is legal use but may cause troubles for the power grid, such troubles may put the electricity network in the collapse condition. This difference of readings is fed as input to the Fuzzy logic control system and the corresponding change in output load is provided by the controller will be fed as input to Slave board to cutoff the electricity for preventing stealing the power and also to reduce excessive power usage. Both of Master and Slave are Arduino boards with same structure of components with different generated codes. In this paper, fuzzy logic acts as a relay in electricity theft condition and as a regulator in excessive usage condition. The simulation of both processes, including cutting off the electricity in the theft condition and regulating the amount of electricity in the extreme consumption condition, have been done by Toolbox/MATLAB using fuzzy logic controller named Mamdani. For more accurate results, simulation also has been done using another fuzzy logic controller named Sugeno Controller.

1. Introduction

There is no doubt that the electricity is an extremely important energy for our everyday life; as the demand on the electricity is increased. The power theft is increasing especially across domestic

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electricity connection that harms economically the GECOL utility and causes damaging effects in power sector across the whole country, and leads to load shading problems repeatedly. This work will be designed to reduce such effects. This research is interesting because as ways of the electricity stealing are numerous, it could be impossible in real-life to keep track of how a theft is occurring. The objective and motive of this project is to design a fuzzy control system based toolbox/ MATLAB, to prevent theft in order to keep the power grid in safe to achieve system stabilizer. Many studies related to electricity theft have been done. In 2011 Depuru, and Devabhaktuni paid attention on the reasons that make people compulsory stealing the electricity. They present different methods with help of smart meter circuit to finding out the theft by providing data related to the currently consumed power [1]. In 2013, Pandey, Gill, and Sharma proved that applied Zigbee technology to wirelessly detect the electricity theft, give high efficient and inexpensive method [2]. Moreover, in this year, Patil, Gopal, and Kirtikumar made a real time system to identify wirelessly where exactly the location of illegal tapping is done on a specific distribution line in case a theft is done by tapping. The model was tested for varying amounts of power thefts and also for different types of circuit approximations [3]. By the year 2014, Prashanthi, and Prasad made an organization model to calculate exactly the power consumed in a household consumers from a main source connected on that area at a certain time. This work is detecting the illegal use but not for finding out where exactly it is [4]. In 2015, Dike, et. al. made a system to send a message instantaneously when the theft is done at a certain location [5]. In 2018, Saini stated that a primary cause of high distribution losses in India state is a power theft and presented a solution [6]. In 2010, Patel stated a method using fuzzy logic system to make sure the power system is always in balance [7]. In 2012, Rengarajan and Loganathan have done simulations using MATLAB. They could stop supplying electricity from the transformer in order to prevent power theft using Fuzzy Logic and also they could improve the power quality by changing the tab changer to the secondary voltage of the transformer using Fuzzy Logic and the results of the simulations are provided. From their results they analyzed the efficiency of intelligent control in electrical systems. [8]. In 2017, researchers proposed HEM algorithm enables any end-user to manage his electricity consumption with a high degree of flexibility and transparency, and "reshape" the load profile [9].

2. the Proposed system and its methathology

2.1 General Idea

This work is a control system that provides a solution of power theft problem by placing the system which will be constructed utilizing the Arduino with relays, current and voltage sensors. These devices will be formed as a number of Master and Slave boards to detect exactly where the probable excessive power usage and power theft have occurred. They will assist in the distinction of the illegal consumption. However, the Microcontroller will be interfaced between the energy meter and a GSM module A signal will be sent from the Microcontroller to the GSM module in case there is a difference in the compared values. Then The GSM wirelessly sends a notification message to inform GECOL that there is an additional unexpected consumption detected in that specific home or in that particular electricity pole. As a result, GECOL can ensure whether or not this detected power is authorized by the company. Consequently, both of the excessive power usage and the power theft once detected the procedures will be taken by the company. The Master and Slave boards consist of same components. As each board has a different functionality, the difference between them is the code written in C/ C++ language.

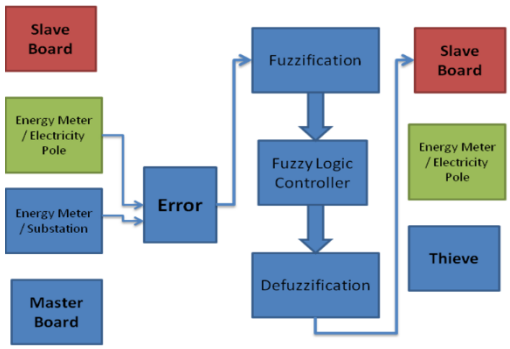
2.2 The Designed System

As the Master board is located on substation, the Slave board is located on electricity pole. Both are Arduino. The Master's functionality is comparing the substation energy meter reading (Master reading) with the real delivered power. To model a system using fuzzy logic to prevent power theft, the first step is to determine the inputs and outputs of it. The Slave board is able to detect exactly where the probable illegal use has occurred in a certain home. Any difference noticed between Master and Slave boards, means either power theft or excessive usage have occurred. This difference is fed as input to the Fuzzy logic controller and the corresponding change in output load is provided by the controller will be fed as input to Slave board to prevent illegal use. By the fuzzy inference system, the electricity will be cut off from that thieve.

3. Fuzzy logic modeling of preventing power theft Using Mamdani controller

In this paper, the control logic was used to checks the system continuously and execute the electricity-cutoff operation whenever power theft detected by comparison between the Master and Slave boards. The actuation of the Mamdani controller is prevention of this illegal use.

Figure 1: Block diagram of Preventing Power Theft.



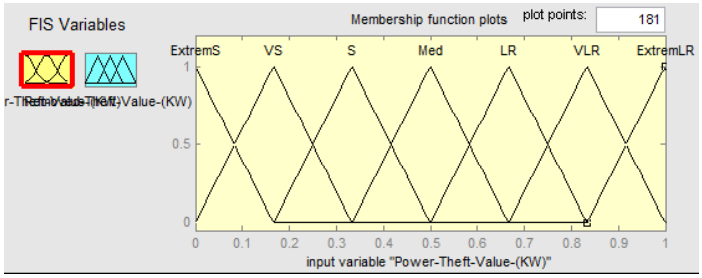
3.1 Crisp Input

The crisp input to the system is the difference between the substation energy meter reading and the energy meter reading that is installed on the electricity poles. Where the difference is defined as error: **"Error = Substation Energy Meter Reading – Energy Meter Reading on the electricity poles"**. As the power delivered from the substation is the reference value set by GECOL that supposed to be enough to supply a certain area according to users' contracts and as well as stored in the Microcontroller's memory in the Slave board, which is installed on the electricity pole. If the Slave board Reading is bigger than the Master board Reading, then we need to stop supplying electricity to that area where theft has occurred. This operation is done by using fuzzy logic.

3.2 Fuzzy inputs

In fuzzy logic, crisp inputs are converted into fuzzy inputs as shown in figure 2.

Figure 2: Membership function for fuzzy inputs



These membership functions are created to represent each crisp input depending on linguistic terms and their ranges are shown in table below:

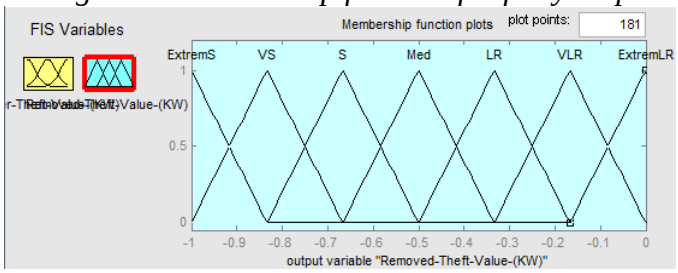
Table 1: fuzzy logic linguistic term with ranges for fuzzy input

Input description (Error)	Fuzzy logic Linguistic term	KW Range
Very Small Theft	VS	320- 420
Small Theft Value	S	390- 490
Medium Theft Value	Med	460- 560
Large Theft Value	LR	530- 630
Very Large Theft Value	VLR	600- 700
Extremely Large Theft Value	ExtremLR	670- 770

3.3 Fuzzy outputs

The membership functions of "Removed Power Theft Consumption" (output changes) of the fuzzy logic are related to the input. For example, if the Error (input) is not zero, then changes (output) will be that value we need to eliminate this Error. So ranges of the output will be same as input. The membership function for fuzzy outputs are shown in figure 3.

Figure 3: Membership function for fuzzy outputs



For fuzzy outputs, linguistic terms and their ranges are shown in table below:

Table 2: fuzzy logic linguistic term with ranges for fuzzy output

Fuzzy logic Linguistic term	Output description (Error)	KW Range
ExtremLR	extremely large removing value	0.833 → 1.167
VHLR	very large removing value	0.666 → 1
LR	large removing value	0.500 → 0.8333
Med	medium removing value	0.333 → 0.6667
S	small removing value	0.166 → 0.5
VS	very small removing value	0. 000 → 0.3333

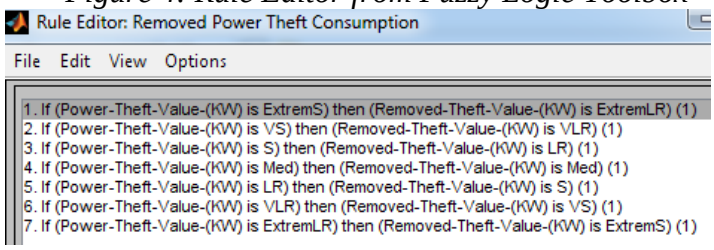
3.4 Fuzzification method

The type of controller used in this model is "Mamdani". The Aggregation is Max. The Implication is Min. The membership functions are triangular, and they are symmetrical.

3.5 Control Rules

If there is no Error, then the no theft has occurred and no need to eliminate any value from the electricity cable that connected to electricity pole. If there any Error even extremely small, then the power theft has occurred. So, no electricity will feed that illegal user. Therefore the rule in fuzzy design for prevention power theft is as shown in figure.4.

Figure 4: Rule Editor from Fuzzy Logic Toolbox



3.6 Results Toolbox/MATLAB

Figure 5: Rule Viewer from Fuzzy Logic Toolbox

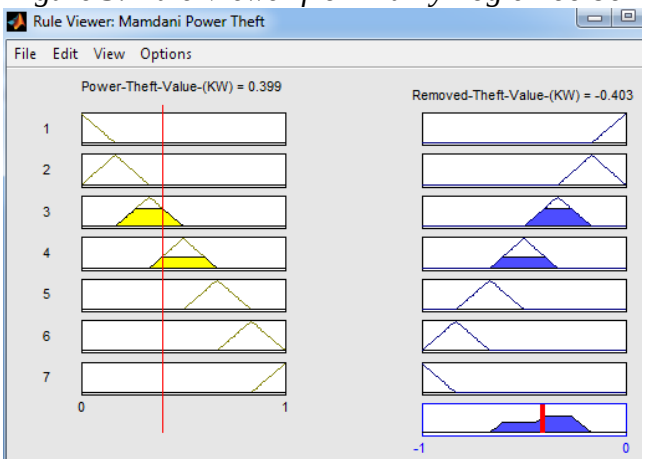
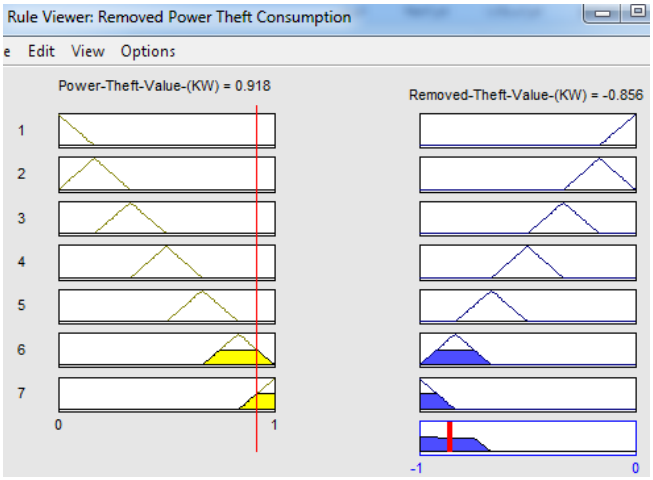
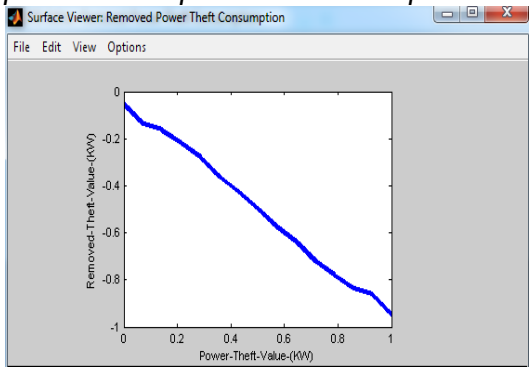


Figure 6: Rule Viewer from Fuzzy Logic Toolbox



3.7 Surface Viewer

Figure 7: Surface Viewer of Prevention Theft Modeling by Mamdani



4. Modeling of preventing power theft Using Sugeno Controllers

For more accurate results, simulation also has been done using another fuzzy logic controller named Sugeno controller as shown in next figures.

Figure 8: Rule Viewer from Fuzzy Logic Toolbox

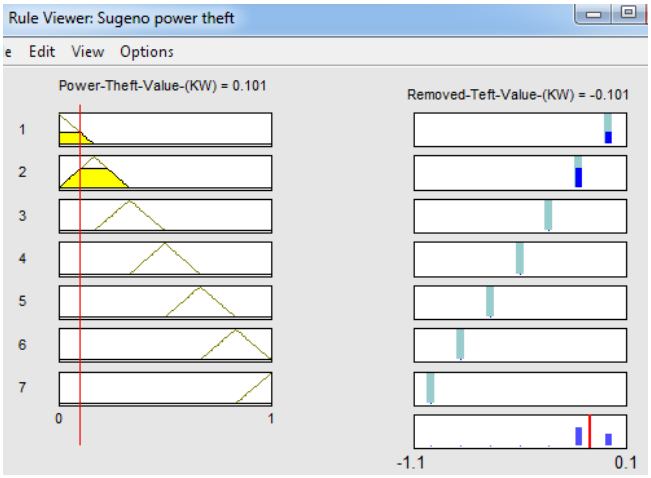


Figure 9: Rule Viewer from Fuzzy Logic Toolbox

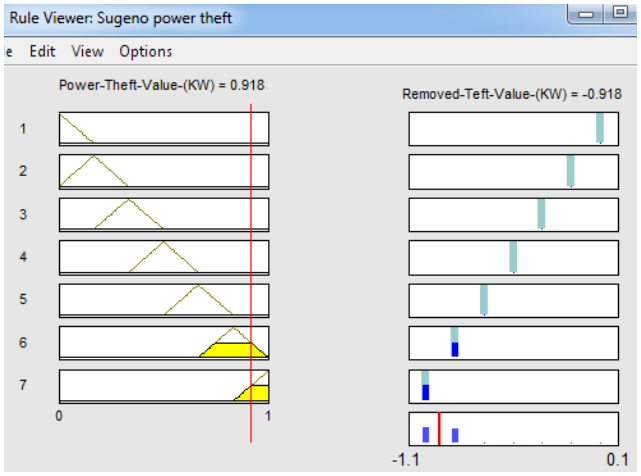
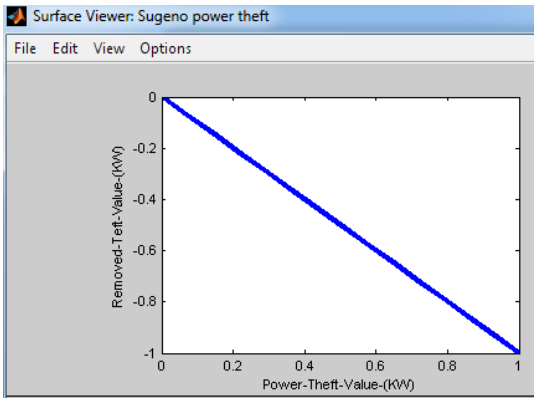


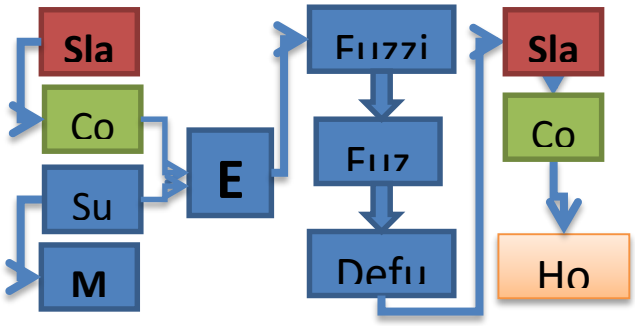
Figure 10: Surface Viewer of Prevention Theft Modeling by Sugeno



5. Fuzzy logic modeling of REDUCTION EXCESSIVE POWER USAGE Using Mamdani Controller

To model a system for reduction excessive usage, the first step is to determine the inputs and outputs of it. The difference in readings between Master and Slave is fed as input to the Fuzzy logic controller and the controller's response depending on its inputs is given to Slave board to reduce excessive power usage of that home. By the fuzzy inference system, the demand of electricity will be compulsory reduced from that specific user. As a result, GECOL can ensure no excessive power usage will be occurred.

Figure 11: Block diagram of Reduction Excessive Power Usage



5.1 Crisp input

The crisp input to the system is the difference between power delivered from the substation with the power consumed by the customer. Where the difference is defined as error:

Error = Substation Energy Meter Reading – Consumer Energy Meter Reading

As the power delivered from the substation is the reference value set by GECOL that supposed to be enough to supply that specific home according to user's contract and as well as stored in the Microcontroller's memory in the Slave board. If the Consumer Energy Meter Reading is bigger than the Reference Value set by GECOL to a user, then we need to remove this extra usage. So, fuzzy logic is required to perfectly loaded. Removing some electricity quantity before getting into

the house is defining as controllers' response (output) with negative value. Output with negative values means the subtraction of the extra load has done by Mamdani controller.

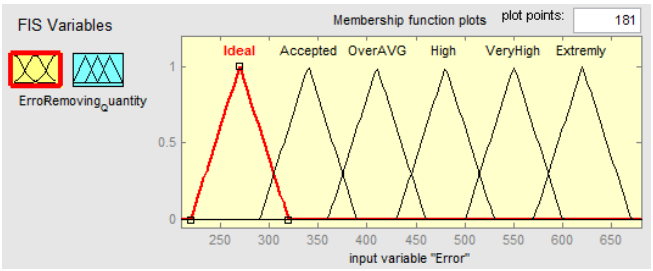
5.2 Fuzzy inputs

In our Fuzzy Logic Modeling of Reduction Excessive Power Usage, linguistic terms and their ranges are shown in table 3, and The MF for fuzzy inputs are shown in figure 12.

Table 3: fuzzy logic linguistic term with ranges for fuzzy input

Input description (Error)	Fuzzy logic Linguistic term	KW Range
Ideal Power Usage	Ideal	220- 320
Accepted Power Usage	Accepted	290- 390
Over Average Power Usage	Over AVG	360- 460
High Power Usage	High	430- 530
Very High Power Usage	Very High	500- 600
Extremely High Power Usage	Extremely	570- 670

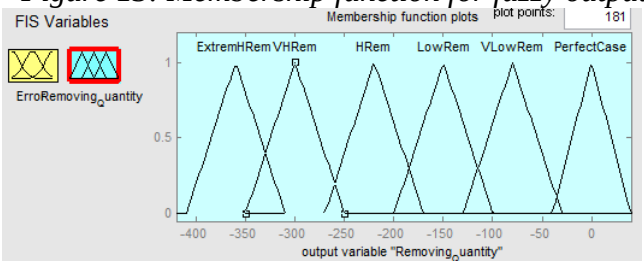
Figure 12: Membership function for fuzzy inputs



5.3 Fuzzy outputs

The MFs of "Removing Quantity" (output changes) of the fuzzy logic are related to the input. For example, if the load (input) of the system is accepted loaded (within normal), then changes (output) will be very low removed value. If the load is very high loaded, then changes will be very high removed value. So ranges of the output will be same as input.

Figure 13: Membership function for fuzzy outputs



For fuzzy outputs, linguistic terms and their ranges are shown in table 4:

Table 4: fuzzy logic linguistic term with ranges for fuzzy output

Output (Removing Quantity)	Fuzzy logic Linguistic term	KW Range
Extremely High Removing	ExtremHRem	(- 310) - (- 410)
Very High Removing	VHRem	(- 350) - (-250)
High Removing	HRem	(- 270) - (-170)
Low Removing	LowRem	(- 200) - (-100)
Very Low Removing	VLowRem	(- 130) - (-30)
Perfect Case	PerfectCase	(+40) - (- 40)

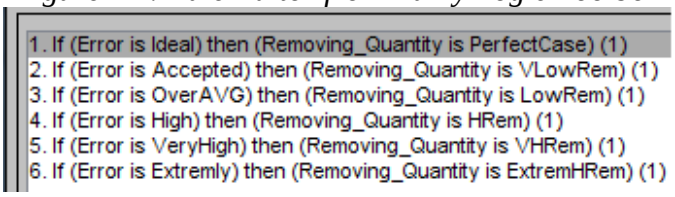
5.4 Fuzzification method

Same as that used in prevention power theft modeling.

5.5 Control Rules

If there is no Error, then the load is perfect and no need to remove any value from the load. If there is the Error is high, then the excessive usage has occurred. So, this extra load need to be removed from the electricity cable that will supply a specific home. Therefore, no extra electricity will get into the home. Thus the rule in fuzzy design for reduction the excessive power usage is as shown in figure 14.

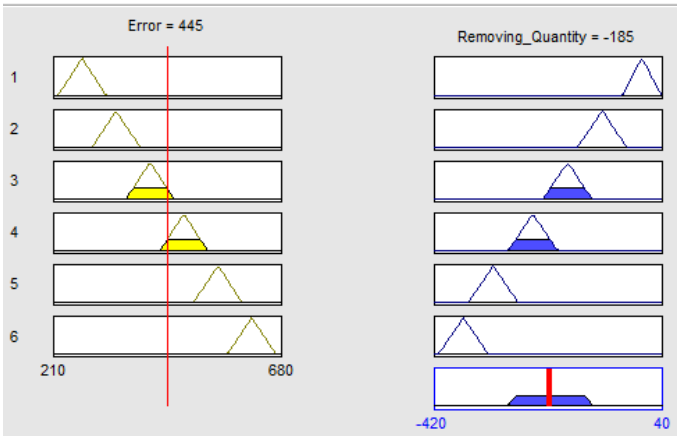
Figure 14 : Rule Editor from Fuzzy Logic Toolbox



5.6 Results Toolbox/MATLAB

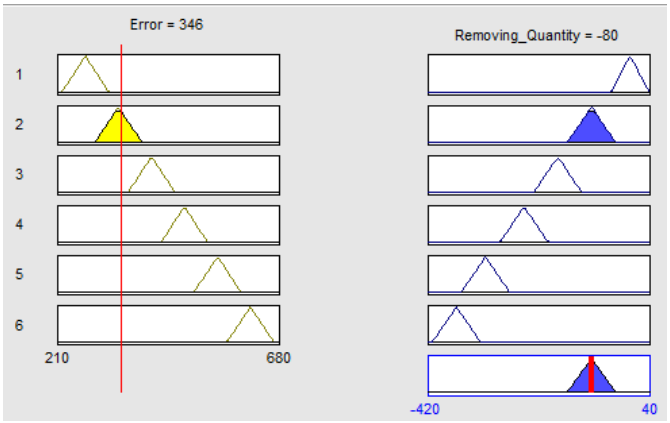
From Rule Viewer (figure 15), if Error = 445, then the Removing Quantity should be 185 to eliminate the Error and enforce the load to be always 260 W (load to be consumed into any house). The negative sign in the controller's response means the subtraction operation in order to reduce the excessive power usage was done.

Figure 15: Rule Viewer from Fuzzy Logic Toolbox



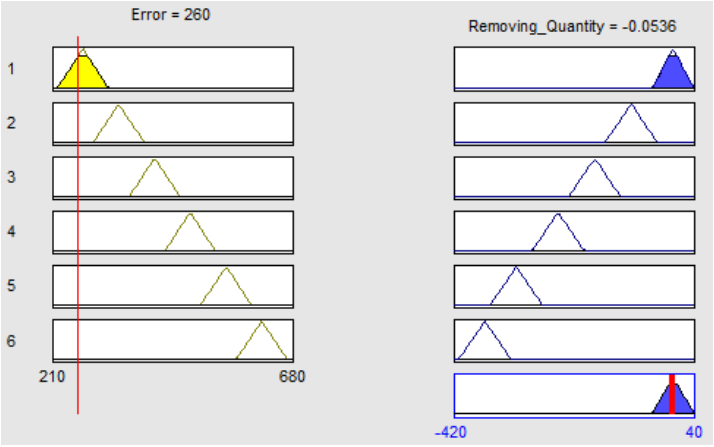
If Error =346, then the excessive usage has occurred. So, the fuzzy controller will reduce this Error to be around 260. Illegal user who demand high power to use an amount that exactly equal to that value which was agreed and written in his contract with the GECOL. The fuzzy inference system will enforce this illegal user to use a limited quantity of electricity, by removing the extra value that exceed the value which was written into his contract. Figure 16 shows the subtraction operation:

Figure 16: Rule Viewer from Fuzzy Logic Toolbox



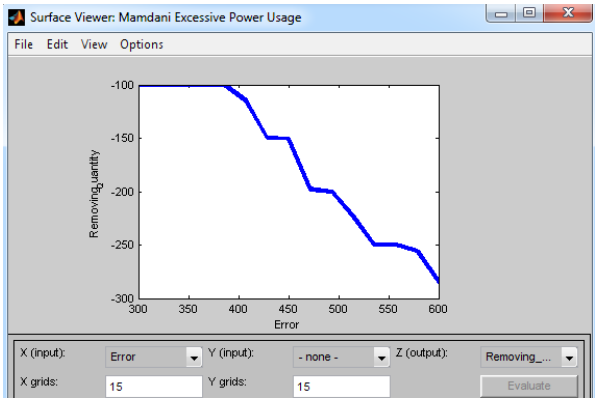
If the Error = 550, this means that energy meter reading of a home is bigger than the reference value set by GECOL and stored in Slave board' memory. In this context, the user demands the higher value than he should be. In order to reduce this value (550) to become 250, fuzzy control system will subtract 300 from 500. As the current flows into the energy meter of the home, the control logic checks the system again and finds that the user exceeded his limit, the actuation of the Mamdani controller is reduction of this high usage and adjust it to an agreement value. Whenever the fuzzy controller finds the usage is equal to 260 which is the ideal load consumption, then no need to execute a subtraction operation. The figure 17 shows the perfect case.

Figure 17: Rule Viewer from Fuzzy Logic Toolbox



The surface rule view of the fuzzy logic rules for reduction excessive power usage is shown in figure 18.

Figure 18 : Surface Viewer of Reduction Excessive Usage Modeling



6. Conclusion

The so-called Smart Grid (SG) has captivated researchers' attention for that it is seen by many to be the key for a sustainable grid future. Smart grid is a terminology that indicates a whole new use of technology applied on the current traditional grid, plus the addition of modern components to the grid for sufficient grid functionality. The paper has considered a number of points: Addition intelligent components to the Libyan power grid to be smart. Reduction of excessive power usage and prevention of power theft could be done using fuzzy control systems based Toolbox/ MATLAB. So, GECOL can adjust the electricity that comes into all homes and enforce the user to use a limited amount of electricity depending on the value set by GECOL and wrote in consumer's contract. Also, GECOL can cutoff the electricity from illegal user to punish him. Operations weather adjustment electricity from a specific home or cutoff electricity by fuzzy inference system is the contribution of this paper.

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