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Research Article: Wireless Control System for Power Theft Detection

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Abstract:
The theft of electricity in developed and developing countries is getting worse compared to the past. Public electricity supply companies estimate that power theft costs them millions per year. To resolve the theft problem, this paper introduces a system that is based on Arduino techniques to detect the power theft in residential households and businesses. The proposed system was projected to continuously monitor and analyze energy consumption data collected from energy meters to automatically classify consumption into legal and illegal consumptions and ultimately detect the theft location. A novel automated control system was introduced to make use of Arduino based on fuzzy logic Toolbox in MATLAB. Aims achieved by the system are optimization of data collection, predictive monitoring of energy metering systems in real-time and handling of anomalies, and automation with smart devices from real- data that are collected by energy meter. This project presents the role of an Arduino with GSM module in preventing electricity theft. Giving the possibility to cut off the stolen electricity from power thieves either by the employed fuzzy logic utility or by a relay switching mechanism. Once a theft has been detected, a notification message will be sent to alert the electricity provider via wireless module. GSM technology was chosen as a possible wireless solution to the connectivity issue. The designed system is capable of executing process within a fraction of a second. This paper shows how microcontrollers based Arduinos communicate over a network and how to program the code for the wireless connection.

Keywords: ARDUINO UNO, ACS712, GSM, ADC, FIS, Sugeno.

1. Literature Review:

Power theft problem has become a world-wide concern in the transmission and distribution supply of electricity. There are several different techniques to identify power problems ranging from illegal consumption to faulty metering equipment [1]. Studies were conducted for designing and implementing models of electrical energy theft detection aspect in developing and developed countries. Their communication system of energy meter was implemented using ZIGBEE, RF, and GSM. These methods were mainly used to secure the communication channel and used for the transmission of data in a serial process. The drawback of using ZIGBEE and RF systems for transferring metering information is that the meter readings can be transferred in a small range of area [2], [3] and they do not provide a cost-effective solution [4], [5]. However, for lager remote distance the GSM communication system is much efficient than others [6]. This paper presents a solution for power theft problem based on GSM communication media.

In 2017, a GSM based system was developed to identify the fault location and power theft. The developed model worked on the principle of the signal transmission

from one place to another. To implement the model an Arduino controller is using. When a load was changed from a full load to overloading, the system sensed any abnormal conditions through current sensors and the interfaced GSM modem. The GSM module was chosen to receive power consumption data and then send this data from a distribution side to a substation side and the microcontroller instantly initiates a message to be sent to the area operator and the control station states the exact pole to pole location by the input signals [7].

In 2018, there was a collaborative work between two Chinese colleges and Pakistani University. The authors mentioned that they modeled and designed the hardware prototype of automated anti-theft electricity distribution system. They stated that through their proposed system, they could send a high voltage signal to burn an illegal usage whenever detected. The high voltage signal was sent from a capacitor bank. What makes their system interesting and promising is that they could control the power energy with keeping the legal load safe without disrupting while stopping and then burning the illegal one. The GSM technology was chosen in their system to transfer collected power consumption data from electricity users to a substation to be stored in and processed. They projected their own energy meter to be worked instead of the conventional meter, they suggested that the collected consumption data of electricity were recorded by their projected energy meter. Their proposed system was successfully done and their targets were achieved [8].

In 2019 in China, a novel hybrid convolutional neural network-random forest (CNN-RF) model was created for automatic electricity theft detection. In this model, a convolutional neural network (CNN) firstly is designed to learn the features between different hours of the day and different days from massive and varying smart meter data by the operations of convolution and downsampling. In addition, a dropout layer is added to retard the risk of overfitting, and the backpropagation algorithm is applied to update network parameters in the training phase. And then, the random forest (RF) is trained based on the obtained features to detect whether the consumer steals electricity. To build the RF in the hybrid model, the grid search algorithm is adopted to determine optimal parameters. Finally, experiments were conducted based on real energy consumption data, and the results show that the proposed detection model outperforms other methods in terms of accuracy and efficiency [9].

In 2020, a study was projected in India to present real-time electricity theft detection using energy consumption data of all legal consumers and outgoing distribution transformer energy meter data. In order to prevent the hook-line activity, a fuzzy inference based scheme was implemented in LabVIEW to operate electricity theft prevention system (ETPS). The ETPS develops unsuitable voltage across illegal consumer and hinders normal operation of their appliances. The consumer care unit (CCU) interlocked with ETPS maintains normal supply voltage at legal consumers end. The suitability, flexibility in operation and effectiveness of the proposed ETPS and CCU based theft prevention scheme is experimentally and practically demonstrated as case study under various voltage regulation and energy loss scenarios [10].

2. Proposed Solution

This paper proposes a control method that provides a solution of power theft problems. The proposed system was implemented in both software as well as in hard-ware with focus on legal and illegal usage. If the measured data does not exceed the maximum value, then usage is considered normal. Otherwise, power theft mode will be activated. This system is connected with an energy meter to automatically detect and prevent the power theft using: Arduino UNO kit, screen to display, and current sensor all pieced together to form an electronic circuit. A Master circuit If it is interfaced between the energy meter, that is located at a substation, and a mobile communication network- GSM module. A Slave circuit if it is interfaced between the energy meter, that is connected to a home and a GSM module. Some of the power theft prevention systems proposed previously only discover the power theft but they do not stop it [11]. While, the proposed system can stop it immediately once theft identified. The Master's functionality is to compare the power delivered from the substation (Master reading) with the power consumed by the customer. Any difference between Master and Slaves boards, means the power theft has occurred. In such case, a signal will be sent wirelessly from the Slave circuit to the Master circuit via GSM. Then the GSM sends a text message to inform an electricity provider of the theft. Two methods were introduced to open the circuit between the substation and thieves once theft has occurred. The open circuit stops the current flow into that particular home. The first of the two methods is with the use of relays which act as a switch that opens and closes the circuit. Second method is by utilizing a fuzzy inference system based on Sugeno- type inference acting just like a relay.

2.1 Prevention of Power Theft using Relays

In this section we shall investigate the use of relays in the open circuit. Relays are switches that open and close circuits electronically. A relay is connected to the Master circuit. When theft occurs, the Arduino sends a command to the relay to open the circuit to cut-off the electricity where the theft is taking place, shown in figure 1.

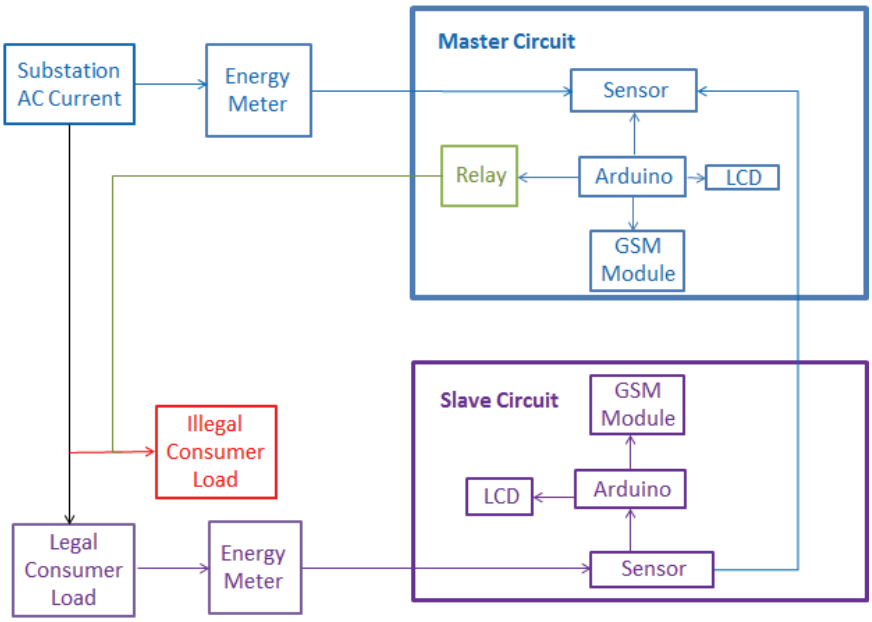

Figure 1. Relay based System block diagram

2.1.1 System Components

The proposed system contains an electronic circuit that monitors and controls the power system. The electronic circuit consists of two Arduinos, current sensors, screens, a relay, a GSM module. A series of actions then take place consequently in order to detect the theft, which when stopped, saves electricity and helps stabilize the power grid. The components of the proposed system are:

A). ACS712-30A Current Sensor

The consumer end is occupied with an ACS712-30A current sensor that reads the data consumption from home's energy meter and sends these readings to the Arduino. In the source end there is also a same type of the current sensor to read data that is collected by substation's energy meter.

Although the type of a current sensor we used is ACS712-30A has an electric isolation property [12] that protects the system from damaging whenever the system has exposed suddenly to high voltage, any value under 30A would be safe, but the Master circuit will calculate voltage for a number of houses, this means that it will calculate the value higher than 30A. in this case the ACS712 won't be suitable, and we have to use another type of sensor that could be a current transformer CT [13] and as a result, we need to make some changes in the source code.

B). Arduino UNO

Arduino board [14] gives complete access to tasks to be performed by an ATmega328P microcontroller [15]. In the proposed system, under normal load condition, the Arduino at the consumer part sends information about current consumption to the Arduino at the source end which then compares it with its own measured line current. If both reading are similar, no power theft signal is generated. However, if this data is not similar, then power theft must have taken place. The Arduino-ADC takes the input voltage signal from the sensor and converts it into a digital value to be displayed on the LCD.

C). Relay

In this paper, kwmobile 2 Channel Relay Module (10V) [16] is used to stop the current flow into that home whenever is needed. The relay is controlled directly by an Arduino via two channels (NC configuration) [17], [18].

D). GSM Module

The GSM technology is deployed to manage the data acquisition between devices. The proposed system was projected for detecting illegal signals on the electricity network. The process starts with the aggregation of the data at a home side and ends with the actuation of the proposed model. Data gathered from various Slave boards is stored in the controller's memory of the Master board. This data is stored in the Master Arduino and it is used for identifying consumption categories. A GSM modem requires a SIM card and operates over a network range subscribed by the network operator. The SIM card mounted on the GSM modem sends data by SMS from the Slave to the Master circuits [19], [20].

Information for Interfacing the GSM and relay with Arduino is retrieved from [21].

E). Liquid Crystal Displays

The LCD has pins, each pin is connected to an Arduino to function a specific task [22]. The LCD screen is used to display theft text message that is connected to the Master in which is located on the substation which indicates the line and location

of the theft. Also, there is another LCD that is connected to the Slave circuit.

2.1.2 System Flow Chart

The proposed system consists of two different wireless circuits: Master and Slave circuits. Each circuit has its own functionality that differs from the other in tasks. The system, thus, requires two different codes programmed using C/ C++ languages which are compatible with Arduino based on GSM module.

A). Wireless Master Flow Chart

The Master wireless code will be uploaded to the Master Arduino is shown in figure 2.

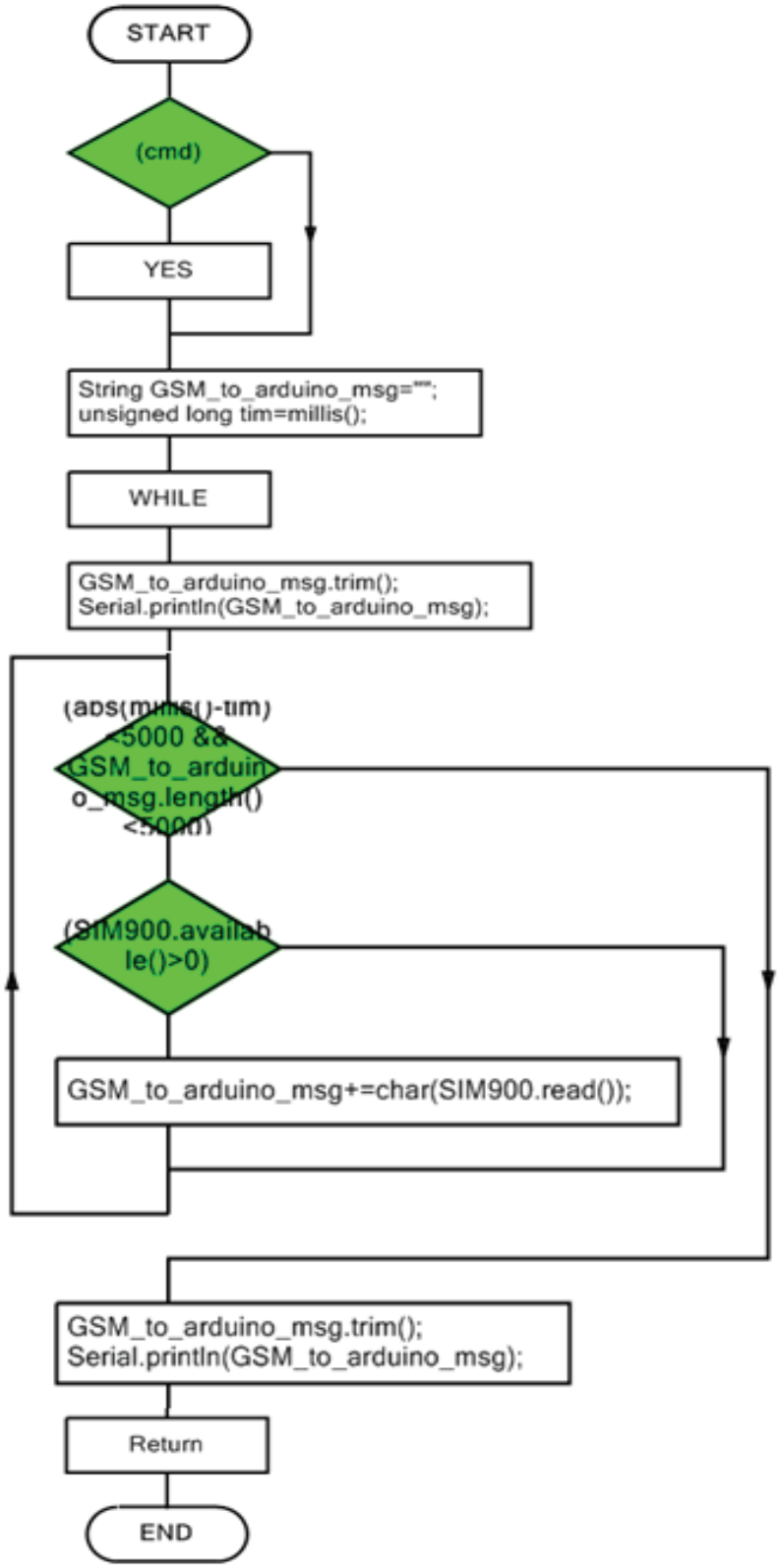

Figure 2. Wireless Master Flow Chart.

To display results on the Master's LCD, the flow chart below is considered, figure 3

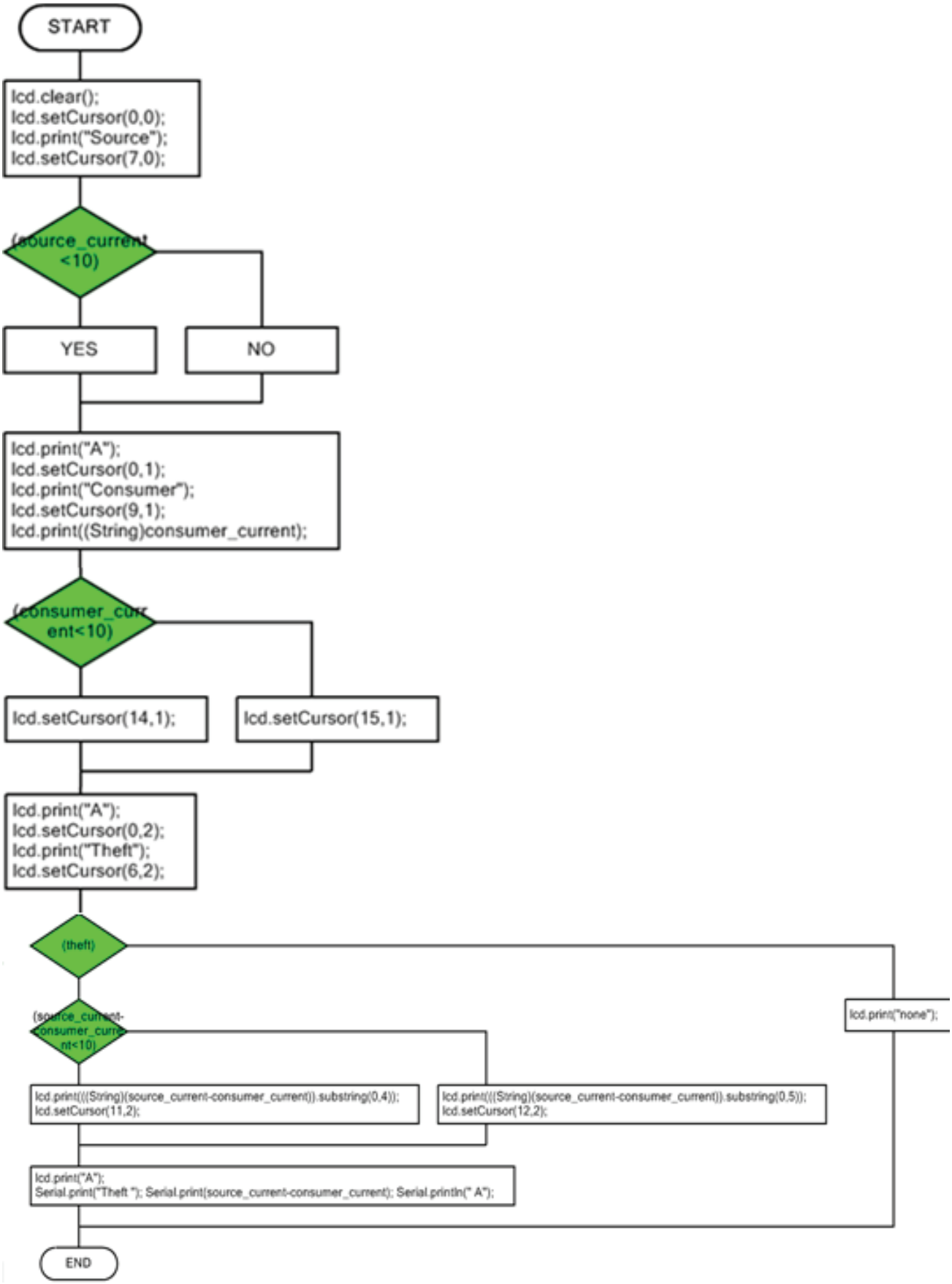

Figure 3. Flow Chart for Displaying Results.

B). Wireless Slave Flow Chart

The Slave code will be uploaded to the Slave Arduino board is shown in figure 4.

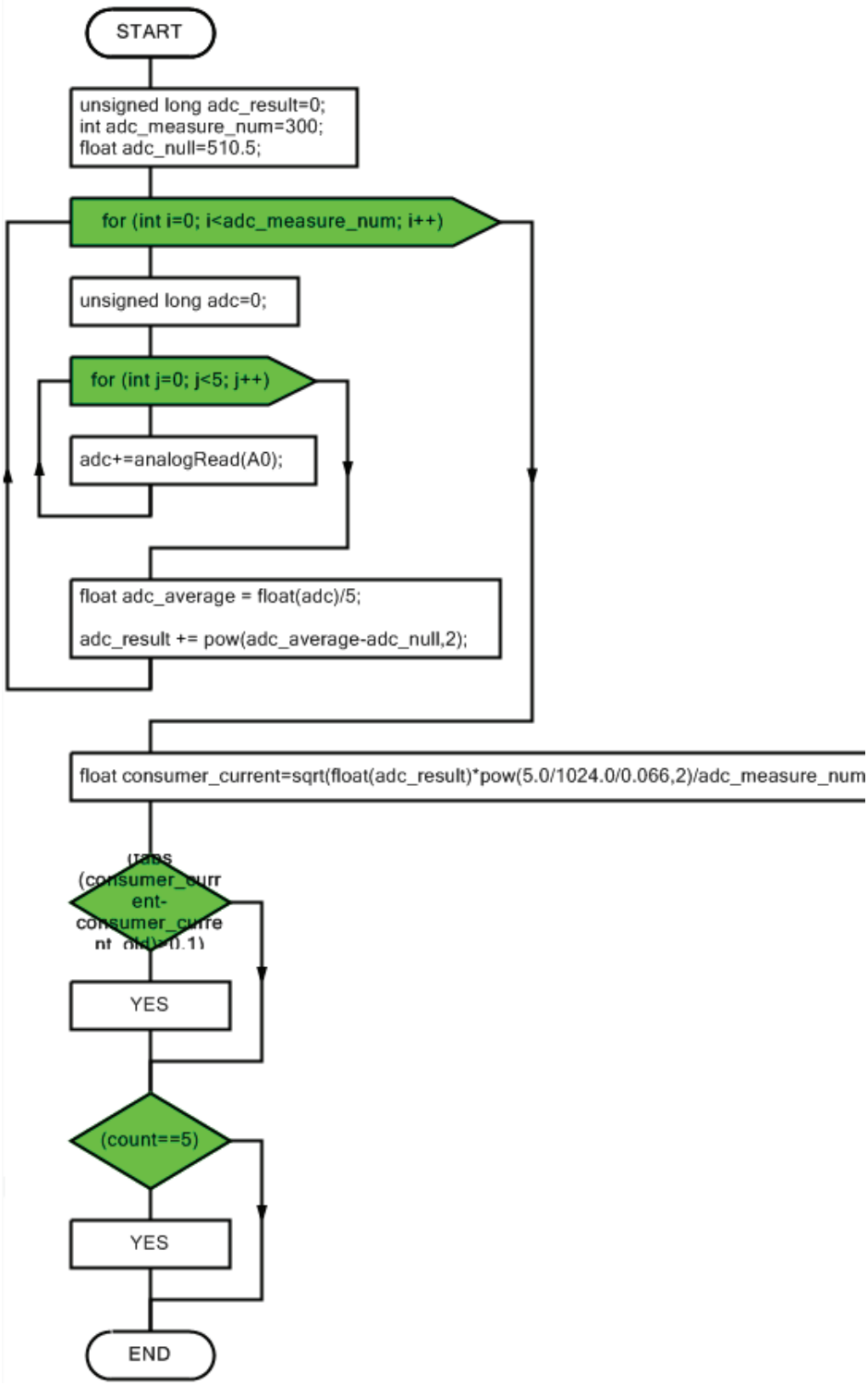

Figure 4. Wireless Slave Flow Chart.

2.1.3 Evaluation and Results of Power Theft Prevention using Relays

The Master's functionality is to compare the power delivered from the substation (Master reading) with the power consumed by the customer (Slave reading). The difference noticed between readings will be displayed on LCDs as shown in figure 5.

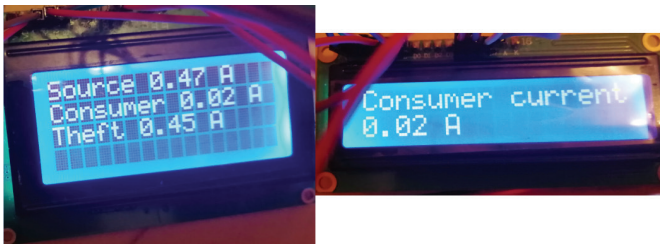

Figure 5. Sample of Data for Theft Case.

Then simultaneously, the Master shall detect the theft and immediately send the signal to the relay to stop the current flow into that particular home. Accordingly, the statement will then turn to be "Theft none" on the LCD, indicating that the theft has been stopped, as directed by red arrows shown in figure 6.

Figure 6. Sample of Data for No Theft Case.

From the results above, it can be seen that the proposed system performed as planned classifying the type of electricity usage (legal or not). The system could effectively and accurately identify the type of data consumption. The system has the potential to help Electricity utilities identify and stop power theft on the spot as it occurs.

2.2 Prevention of Power Theft using Fuzzy Inference System

In this section we shall see how fuzzy logic based control systems can be employed. To model a system using fuzzy logic to prevent power theft, the first step is to determine the inputs and outputs. The Master board is able to precisely detect where the probable power theft has occurred. Any difference noticed between the Master and Slave boards suggests illegal power usage. This difference is fed as input to the fuzzy logic controller and the corresponding change in output load, which is provided by the controller, will be fed as input to the illegal user to stop the theft.

2.2.1 Construction of the Simulation System

This system below is simulated in order to automatically detect and control power theft. The system consists of three circuits as demonstrated in figure 7.

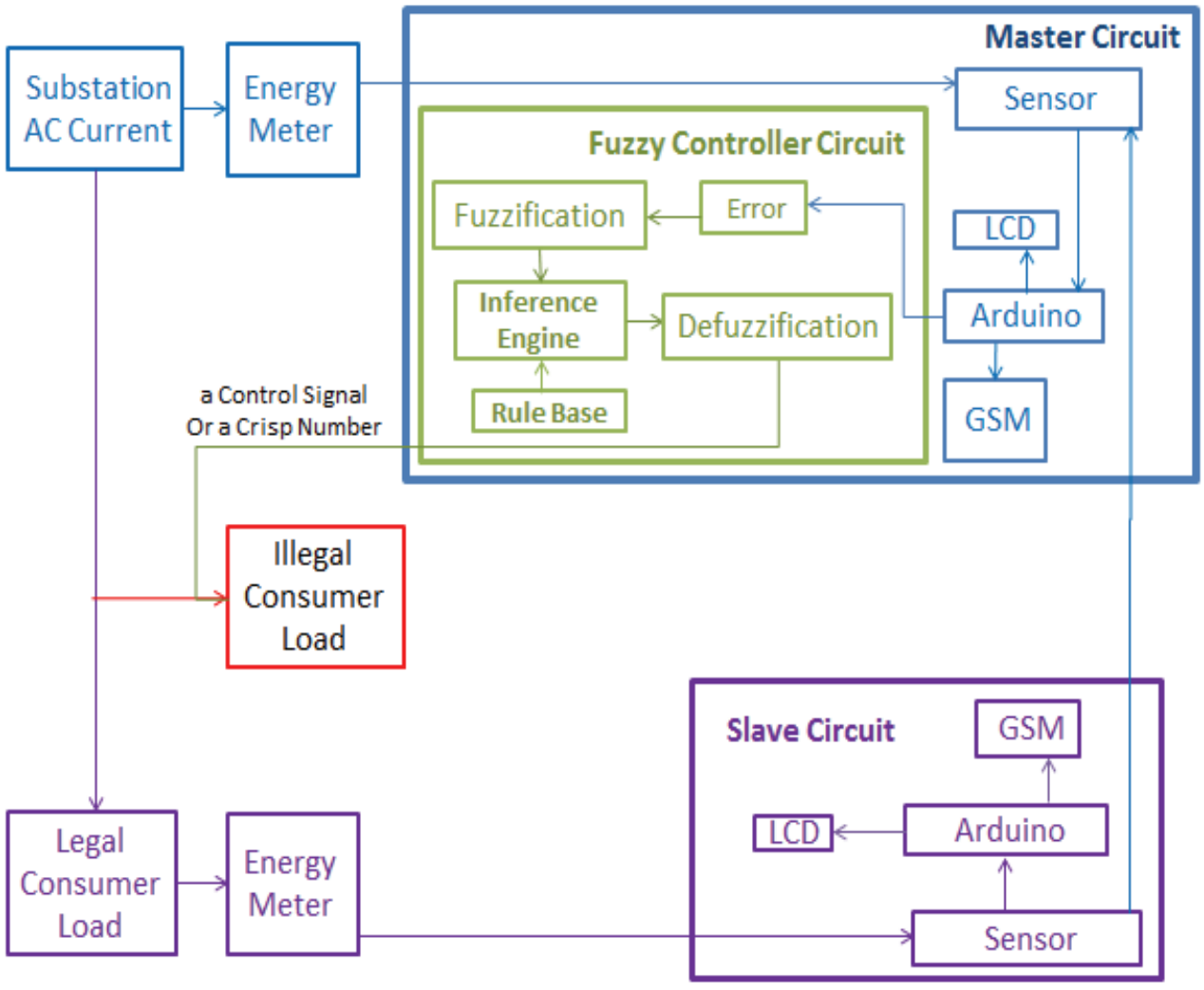

Figure 7. System block diagram for Preventing Power Theft using Fuzzy Logic.

The control logic is used to check the system continuously and execute the electricity-cut off operation whenever power theft has been identified as a result of comparing data between the Master and Slave. The actuation of the Sugeno controller is the prevention of this illegal use.

2.2.2 System Simulation Design and Implementation

The proposed system supports normal-load and power theft modes. The fuzzy logic designer software was used to interactively design the proposed system and visualize its results as shown in figure 8.

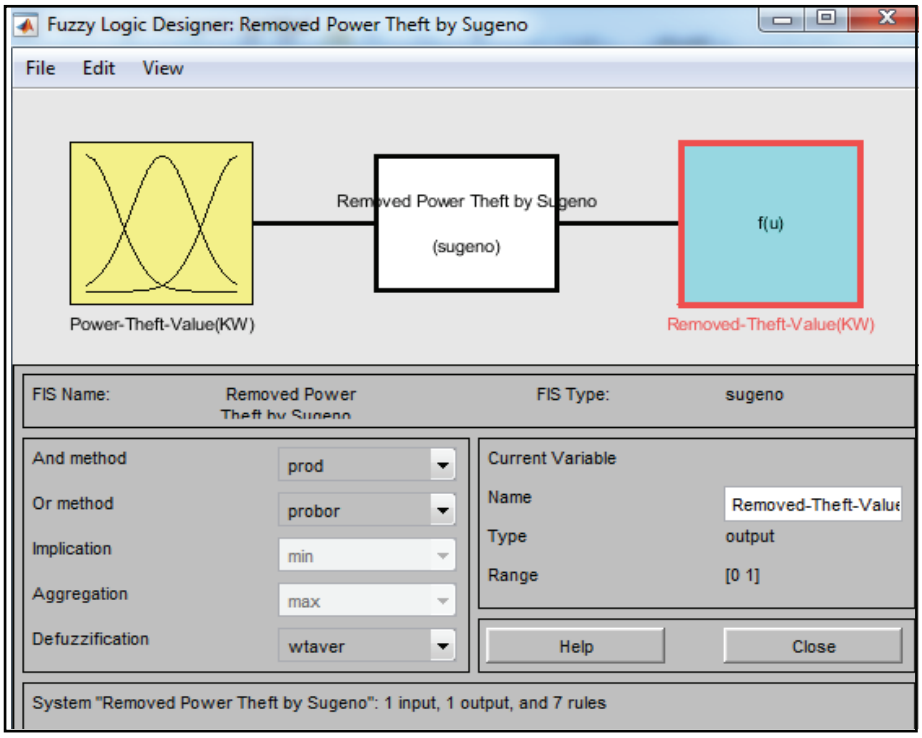

Figure 8. Showing the Sugeno Designer.

A). Fuzzy Inputs

Crisp numbers (inputs) are turned into fuzzy inputs. Membership functions (MFs), thus, are generated to represent each crisp number according to linguistic terms and their ranges [23]. In the proposed model, seven input variables have been simulated and specified as input membership functions as shown in figure 9.

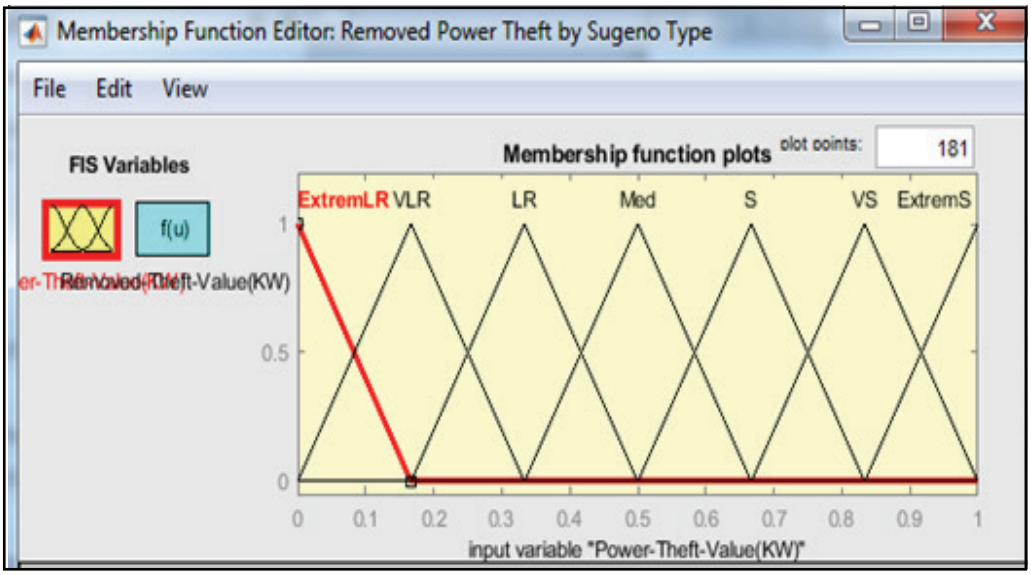

Figure 9. MFs for Fuzzy Sugeno's Inputs to Prevent the Power Theft.

The linguistic terms and their range of membership functions for fuzzy Sugeno's inputs are as shown in table 1.

Input (Power Theft Value)	Fuzzy logic Linguistic term	KW Range
Extremely Small Value	ExtremS	[0.8333 1 1.167]
Very Small Value	VS	[0.6667 0.8333 1]
Small Value	S	[0.5 0.6667 0.8333]
Medium Value	Med	[0.3333 0.5 0.6667]
Large Value	LR	[0.1667 0.3333 0.5]
Very Large Value	VLR	[0 0.1667 0.3333]
Extremely Large Value	ExtremLR	[-0.1667 0 0.1667]

B). Fuzzy Outputs

Fuzzy outputs are obtained from membership functions [23]. Seven output variables have been simulated and specified as output membership functions as shown in figure 10.

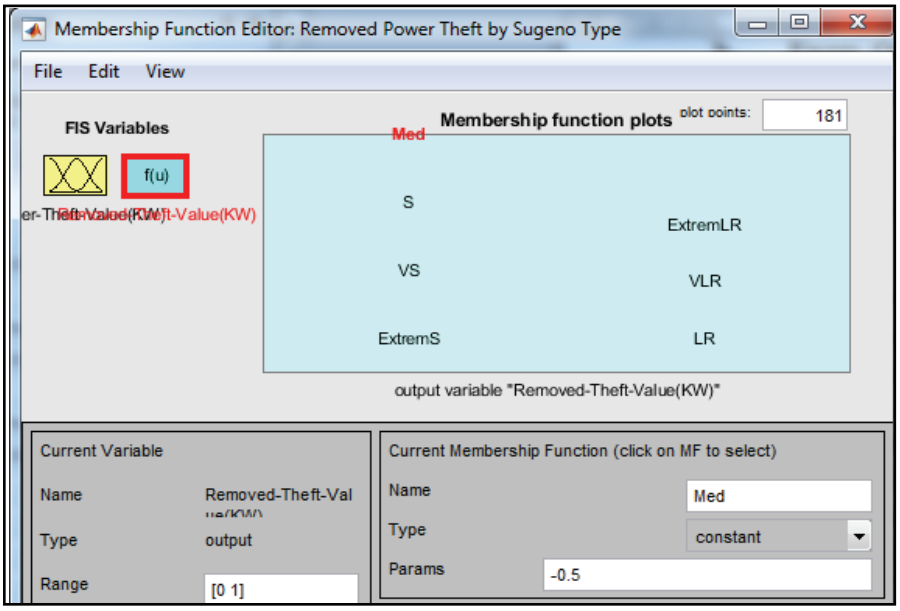

Figure 10. MFs for Fuzzy Sugeno's Outputs to Prevent the Power Theft.

For fuzzy outputs, linguistic terms and their values are shown in table 2.

Output (Remove Theft Value)	Fuzzy logic Linguistic term	KW Range
Extremely Large Value	ExtremLR	0
Very Large Value	VLR	-0.1667
Large Value	LR	-0.3333
Medium Value	Med	-0.5
Small Value	S	-0.6667
Very Small Value	VS	-0.8333
Extremely Small Value	ExtremS	-1

The Sugeno FIS has only two steps to perform a task [24]. These steps are: fuzzification method and to create control rules, as follows:

1. Fuzzification Method

The conversion process from crisp inputs into fuzzy input sets using membership functions kept in the knowledge base is called Fuzzification method. The fuzzy input sets will then be fed to the inference engine [25].

2. Control Rules

The evaluation rules in fuzzy design for prevention power theft are created in order to derive the output. The fuzzy control rules below (figure 11) shall be fed to the inference engine to make a decision [26]. The system will operate under these rules. The inference engine, thus, will generate the fuzzy output value using these rules. Accordingly, a decision will be made. The fuzzy logic, then, will operate as a relay and immediately disconnect the stolen current, thus, any illegal usage shall be stopped immediately.

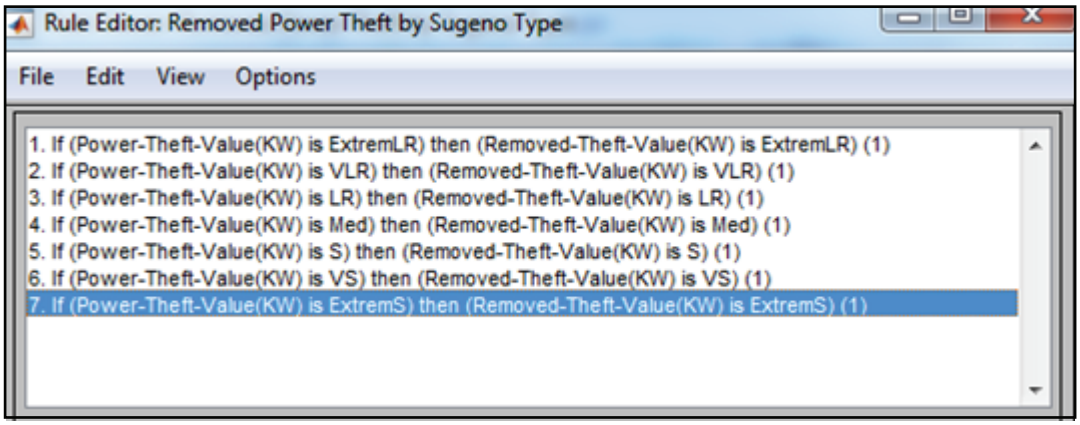

Figure 11. Rule Editor for Prevention of Theft using Sugeno Method.

Sugeno method generates fuzzy rules from a given input-output data set works. Due to Its consequent (then part) is a mathematical function, there is no need for aggregation process. Accordingly, it works without defuzzification. The Sugeno-type is all about the relative importance of precision [27].

Should any theft occur, an error message shall be generated between the Master and Slave, a message will then be sent from the Master Arduino to the fuzzifier. This message will be converted into a fuzzy input sets to be sent further to the inference engine and then a decision will be made, and since the output membership functions in the Sugeno systems are standard, there is no need for a defuzzifier.

2.2.3 Results Toolbox/MATLAB for Power Theft using Fuzzy Logic

Based on the Sugeno inference system steps, the output obtained from the Sugeno controller is the stolen current amount which is to be prevented, this amount is the difference between the Master and Slave readings. This allows Sugeno type to be distinguished from other fuzzy inference types. Results of a Sugeno-type FIS are presented in two forms, namely: the Rule Viewer and Surface Viewer, as follows:

A). Rule Viewer

In the Rule Viewer figures, each column shows a set of membership functions for a particular variable. Figure 12 presents that the error, named “Power Theft Value” coincides and agrees with an output value, named “Removed Theft Value”. This constitutes the solution in the problem using fuzzy logic.

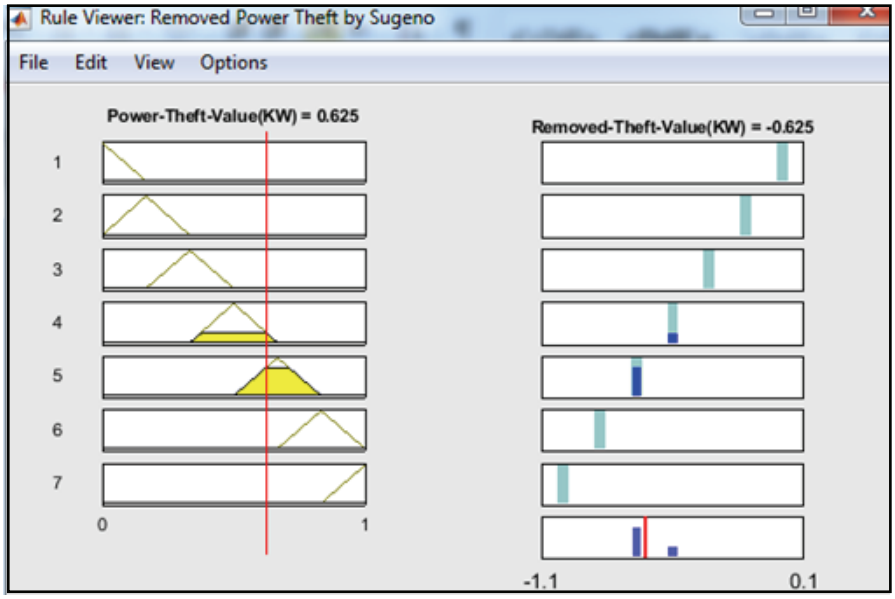

Figure 12. Rule Viewer to Prevent Error equals to 0.625 KW by Sugeno.

The first column (the seven yellow plots) shows the membership functions referenced by the if-part of each rule. The column represents errors that came out from the Master board and were fed to the Sugeno controller in relation to the removing quantity. The second column of each Rule Viewer (the seven blue plots) shows the membership functions referenced by the then-part of each rule. This column represents the aggregate weighted decision for the given inference system. This decision

will depend on the input values for the system. The defuzzified output is displayed as a bold vertical line on these figures. The variables and their current values are displayed on top of both columns.

The output of Sugeno style is quite accurate and reliable with negligible error. For instance, if the error value (input), which represents the current that we desire to subtract, is ($1*e^{-12}$) KWatt, then the value that will be subtracted from this error is exactly the same value as input, as shown in figure 13.

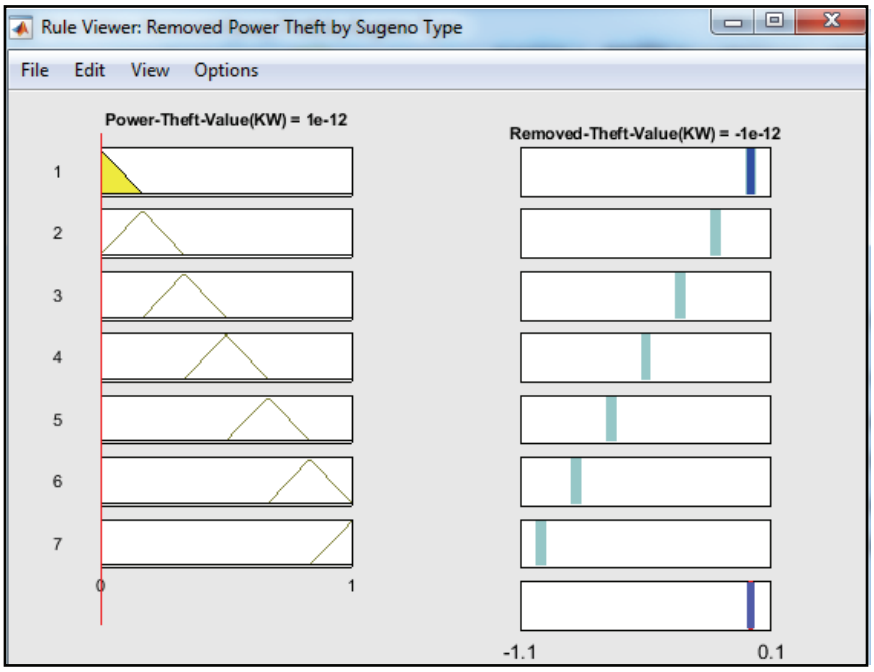

Figure 13. Rule Viewer to Prevent Error equals to ($1*e^{-12}$) KW by Sugeno.

Whenever there is an error in readings between Master and Slave circuits, this error is forwarded as input to the fuzzy controller and the controller's actuation (output load) will be fed as input to an illegal user to prevent stealing the power.

The fuzzy logic in this operation acts as a relay in order to cut-off the electricity and stop the theft. Once FIS has been created, it can be evaluated and visualized. The rule viewer displays a roadmap of the whole fuzzy inference process.

B). Surface Viewer

The surface viewer based on Sugeno's reaction is shown in figure 14. The output shows the amount to be controlled which depends on the input (the stolen power value). The Surface Viewer creates and plots the system's output surface mapping.

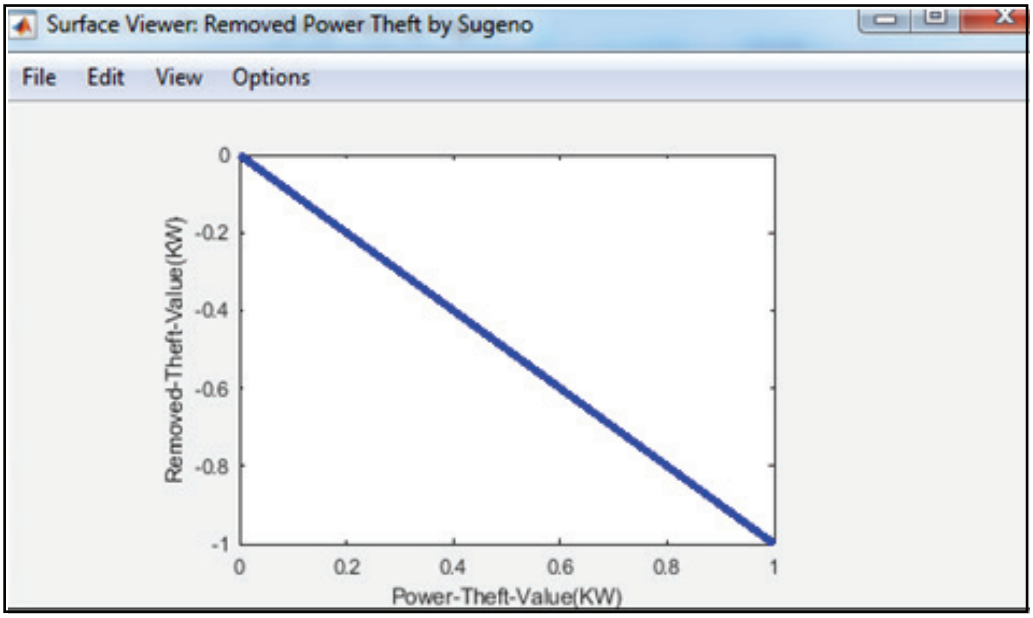

Figure 14. Surface Viewer for Prevention of Power Theft by Sugeno.

The curve represents an one-input one-output case and shows the relationship between system's input to the system's output is linear and inverse, the value of the input is equal to the value of the output but in the opposite trend. The negative sign which appears in a rule viewer means the subtraction operations have been executed to eliminate the theft.

3. Conclusion

The project discusses two control methods to identify and prevent power theft. All phases of the design interact with each other. Thus, all the objectives of the research defined in the paper were accomplished with satisfactory results. The proposed system has been installed into the Arduinos' memories. The Slave board is configured to work automatically with the Master board. Electricity power theft is prevented by utilizing two control methods. The First technique is performed with the help of a relay switching mechanism for preventing electric current passing through the main feeding line. Then, a message will be sent to the distribution station and as a result, the electricity provider will be informed while the second technique is done using fuzzy logic utility where power theft has occurred. The system is modeled using a fuzzy inference system Toolbox MATLAB to be operated as a switch to open the circuit to prevent the power theft.

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