A Fuzzy Logic based Residential Electrical Energy Optimisation System based on Time of Use Tariffs

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ABSTRACT

Globally energy management has become a challenge and concern due to rapid increase in energy demand and energy security. In South Africa, electricity supply problems has resulted in load shedding and steep increase in electricity cost. The objective of this paper is to optimise the residential electricity consumption by scheduling the household appliances in line with the time of use (TOU) tariffs. This was done through a fuzzy logic electrical energy controller. The optimisation was achieved by varying load consumption per hour. The fuzzy rules were designed to make intelligent decisions considering the time of use tariff, the remaining daily limit and load consumption. The preferred number of days were set by the consumer and the system calculated the daily limit considering the available amount of electricity in smart meter. The findings showed that the fuzzy logic optimised the residential electricity consumption by scheduling the household appliances in line with the time of use (TOU) tariffs. The fuzzy logic may provide a way in which the smart meter could optimise and enhance the electricity user consumption.

1. INTRODUCTION

Globally, the energy management has become the challenge and concern due to rapid increase of energy demand and energy security. Among the five sectors, the residential sector, in South Africa, is the second in electricity consumption and is responsible of about 17% of the total generated capacity with high contribution during peak demand [1]. In order to mitigate this increase, policy and legislations have been implemented. Apart from the policy documents introduced, utilities have further introduced the demand side management (DSM) initiatives such as demand response (incentive based and price based) to encourage the load reduction during peak hours. Manually, managing peak hour consumption is a tedious process. Also, it is difficult for the users to manually respond to the offered incentives and price-based tariffs. This paper seeks to incorporate the fuzzy logic controller in residential energy consumption to make intelligent decisions without the interaction of the consumer. Generally, the idea of fuzzy logic was designed to formalise the mathematical approach to deal with complex decisions. It is in form of many valued logics in which truth values of variables may be real numbers between 0 and 1 in contrast with the classical or discrete values of either 0 or 1 (true or false). Fuzzy systems are useful in two general contexts: in a situation involving high complex systems whose behaviour is not well understood and, in a situation, where approximate, and where a fast solution is needed.

The fuzzy logic system (FLS) consists of three main parts linguistic variables, membership functions and rules. The inputs in FLS which are linguistic form are made from words or sentences from natural language and are mapped by sets of membership function. This process of converting the input crisp to fuzzy value is fuzzification. Given mapping of input crisp values to fuzzy membership functions and truth tables, the rules are made for actions to be taken based on set of rules. These rules are constructed to control the output variable. A fuzzy rule in its simplest form is a simple IF-THEN rule with a condition and conclusion. The steps in reasoning of FLS is referred to as inference, which is the part of taking decision by combining the rules and input crisp of the system to generate the fuzzy output crisp. After inference, the overall result is fuzzy value which is defuzzified to obtain final crisp output. To design the fuzzy controller, the following steps, need to be followed: Firstly, the input and output variables whose values are in words and sentences from natural language are mapped with membership functions. Each linguistic variable has the range of expected values that corresponds to their terms. Secondly, the membership functions are numerical values corresponding to the linguistic terms. Membership functions defines how each point in a point is mapped to a membership value (degree of membership) between 0 and 1. There are several shapes of membership functions in fuzzy systems. The most used types and shapes are triangular, trapezoidal and gaussian. Thirdly, fuzzy are in series linguistic statements that describe how the decisions are made by the fuzzy controller. In fuzzy logic the

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condition of the rule is fulfilled to certain degree, and each rule will influence the result of the set of rules in accordance with the grade of fulfilment [2]. Generally, defuzzification is the process of converting the degrees of membership of output linguistic variables within their linguistic terms into crisp numerical values. There are many defuzzification methods that can be used by the fuzzy controller, but the accuracy of the method depends on the control application. The most used methods are the centroids methods and the maximum of mean method.

2. THEORETICAL BACKGROUND

To maintain the economic growth, the electricity demand continues to rise, particularly in South Africa, that is coal dominated, remains the energy intensive country where the electricity consumption and Gross Domestic Production (GDP) are directly related [3]. More than 70% of electricity in South Africa is generated by coal which contributes to an increasing world energy carbon emission. Usually, carbon emissions are high during peak periods, during which electricity consumption is also high. This increase has necessitated certain studies such as one carried out by [4]. Also, peak demand has been investigated by in recent studies (see for example [5]– [8]). To mitigate the ever-increasing electricity demands and rising carbon footprint, demand side management strategies are promising in addressing the shortage of electricity and ever-increasing carbon footprint. Demand side management is the process whereby an electricity supplier influences the way on how the electricity is used by customers. DSM means planning, implementation and monitoring of end-user activities designed to encourage consumers to modify timing and level of electricity demand [9]. In the essence, the consumer, during DSM, implement techniques through direct or indirect control [10]. Any DSM technique implemented may result in one of the following forms of electricity demand reduction: Peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape [11]. DSM can be classified into two parts namely Energy Efficiency (EE) and Demand Response (DR). Figure 1 shows the strategies of DSM. DR is classified into two main categories and subcategories of incentive bases ad price-based techniques.

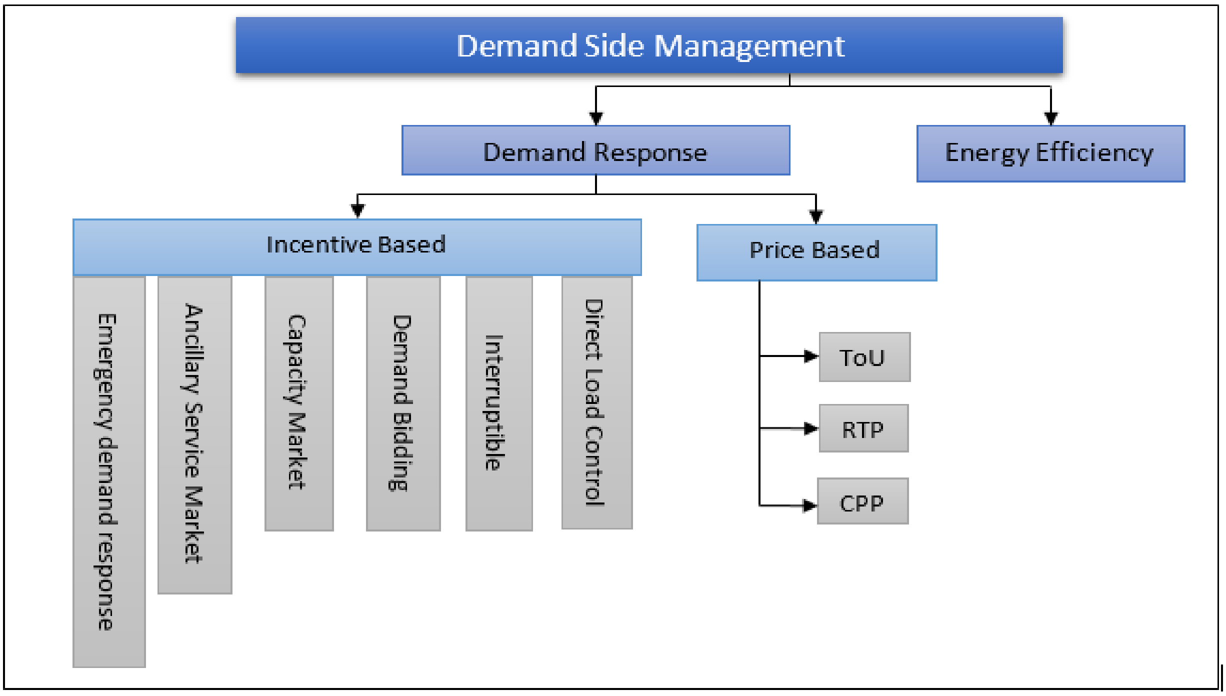

Fig. 1. Strategies of demand side management.

EE is the DSM tool which is used to reduce energy consumption by replacing normal appliances by energy efficient appliances [12]. While EE is defined in [13] as the theoretical minimum energy requirement for performing task and amount of actual energy used. Authors in [5], [14] define DR as the changes in electricity usage by the end user from their normal consumption patterns in response to changes in electricity price over some period of time. The core element of DR schemes is to motivate customers to change electricity usage through incentives offered by the utility company. DR schemes are classified into two types namely incentive based scheme and price-based scheme [15].

2.1 *Incentive based Scheme*

Studies put forward by [15] explains that in incentive based the customers are encouraged to reduce their energy consumption upon request or according to the contractual agreement. It is the agreement between the customer and the utility company, which provides the program administrator some degree of authority to directly schedule, reduce, or disconnect to save cost.

2.2 Price based Scheme

In price based, the customer is offered time varying rates that reflect the value and cost of electricity for different time periods [6]. The retailers offer the time varying tariffs such as Time of Use (ToU), Real Time Pricing (RTP) and Critical Peak Pricing (CPP). In ToU the electricity price depends on the time of the day and is pre- established and set in advance. On one hand, ToU pricing divides the day into intervals and charges a fixed rate with each time frame, while on the other hand CPP is a variant of ToU in which, especially during emergency situations such as high demand, the price is substantially raised. However, in RTP, electricity prices can change as often as hourly, reflecting on the utility cost of the supplying energy to customers at that specific time.

3. PEER REVIEW

The use of demand response strategies has emerged as powerful DSM tool to optimise the energy consumption pattern of consumers and simultaneously improve the overall efficiency at the energy market [6]. However, in order to achieve these benefits from DR programmes a certain level of automation is required both for uncertainty in consumer response to price signals and complexity for consumer to react to fluctuating daily electricity price [16]. The integration of wireless sensors, optimisation techniques (artificial intelligent technologies), mathematical models to make intelligent decisions that link RTP and or TOU incentives with energy efficiency was recently studied.

Optimisation-based Automatic Demand Response (ADR) controller was implemented in home energy management system to optimally co-ordinate the operation for different types of domestic appliance in response to dynamic electricity pricing [17]. The authors in [6] presented the mathematical game theory-based model which was developed to achieve an efficient price-based demand response technique so as to maximise benefit for both consumers and utilities. In this study, the utility sets the price and the consumer responds to it accordingly. The mathematical programming language Automated Demand Response (ADR) was presented by [16] to try and find the best scheduling of controllable appliances across a finite time horizon in a single day. This was done to minimise the daily bill below the willingness of the consumer. The model predictive control (MPC) framework was designed to optimally determine the control profiles of HVAC systems as demand response was presented in [18]. In this study, a nonlinear autogressive neural network that models the thermal behaviour of building zone with an optimal control problem was formulated by mixed integer nonlinear programming (MINLP).

Authors in [19] proposed an intelligent optimal energy management system for reducing potential energy waste during the start-up of a fuel cell system. In their study, they designed an intelligent optimal energy management system. Their system could be applied to a realistic hybrid power system, which incorporates adaptive fast-charging control, fuzzy hydrogen control, and fan temperature control. Most of the studies in energy management system (EMS) were done from the generation of power perspective. Evident of such studies are as discussed in [20] and [21]. A multiperiod artificial bee colony optimization technique was implemented by the authors in [20] for economic dispatch, considering creation, storage, and responsive load offers. The suggested method outperformed the modified traditional EMS in terms of performance, and its effectiveness is empirically demonstrated on a microgrid test bed. artificial bee colony with many periods of activity. In [21], the authors use dynamic programming method to solve the problem of determining the best power split between the two sources of energy, with realistic cost calculations for all power trajectories for the combined APW generator, electric machines, and battery efficiencies, as well as a penalty function formulation for the deviation from the ideal state-of-charge to be sustained. However, their approach did not address intelligent, complex decision making using fuzzy logic controller which this study seeks to address by incorporating the fuzzy logic controller in residential energy consumption.

The fuzzy logic approach (FLA) utilising the wireless sensors and smart grid incentives has been presented in [22] for load reduction in residential HVAC system. The FLA is embedded into PCTs for intelligent decision in load reduction while maintaining the thermal comfort considering price, outdoor temperature and occupancy. Other developments in the analysis performance of dynamic thermostat controller of HVAC system in home with dynamic electricity pricing were studied in [23]. Based on price signal, the dynamic thermostat controller would set the thermostat temperature to save electricity and cost.

Generally, most of studies in DSM, focused on demand control and in predicting the users` behaviour and monitoring the HVAC systems against the argument that HVAC systems are the most consuming load [22]-[24] in buildings. However, the consumption of other daily used electrical appliances can also add up and increase of energy consumption in the building. Inclusion of these devices or appliances in energy management can lead to effective energy saving. It is observed from the studies as presented in [6], [16], [18] that, mostly, mathematical models have been used in finding solutions towards demand side management problems. However, these models usually become limited when the size of the problem increases with high computational complexity and nonlinear relationship between inputs and outputs. Although most studies show positive results in load reduction during peak period, managing the peak to average ratio, it may also have a negative impact on load diversity which might potentially result in new peaks for the least price [16]. The authors in [5] devised a system based on organisational multi-agent system (MAS) for distributed control system. The system addressed peak load problem using cyber-physical system. The system was composed of Energy Supply Node (ESN) that has maximum energy level and number of controlled devices to it. Also, the authors in [6] maximised peak load reduction for residential and commercial sector by 10% and 5% respectively by their game theory applied to model price-based demand response with three tire pricing models (real time pricing, time of use and day night pricing).

The authors in [8] investigated the potential of consumers in lowering the community level peak demand by regulating the air conditioner use with operation of time shifted appliances. The model predictive control (MPC) scheme minimised peak air conditioning energy use by altering the thermostat set point in individual homes while scheduling the operation of appliances was done by applying mixed integer linear program (MILP). Within this ambit of methodology, there is a need to manage daily used appliances using the system that will provide the accurate control of electricity consumption, not only during peak period but also reach the optimal operation of electrical management. Authors in [24] presented an adaptable local control and intelligent decision making for a home automation using multi-agent techniques. Each agent used a fuzzy logic controller to manage consumer`s energy consumption taking into consideration all kinds of residential load. They designed a scheduling policy algorithm AG_0 that made joint decisions with respect to the user comfort and desire. The developed AG_0-FLC successfully altered the load curve shape and results showed the energy saving up to 58% of the total residential energy consumption during times of high-power demand. The integration of adaptive neuro fuzzy inference system (ANFIS), cost generator (CG), economic model predictive controller (EMPC) and Hidden Markov Model was investigated in [25] to model behaviour and compute the sum of personalised cost, time of use charges prediction from load curve and fixed energy of heat, ventilation and air conditioning (HVAC) in their personalised energy management system (PEMS). In essence, the EMPC optimised the energy consumption using the constrained optimisation routine which included the comfort margins specified by occupant. The behaviour not only did rely on temperature, humidity, but also relied on historical information based on occupant and behaviour. The results of PEMS showed energy consumption reduction of 9.7%-25% and cost reduction for 8%-18.2%.

Consumer demand for renewable energy sources such as solar and wind has recently risen rapidly around the world. Renewable energy encompasses a wide range of energy sources, such as wind energy, water energy, and solar energy [26]. Although South Africa (SA) is recognized to have a high renewable energy potential, there has been no systematic investigation to determine this power generation potential. Among all the available energy sources, in SA, solar energy has a potential of being the main source of energy, should government make policies towards research and development. The development will call for more advanced IT-based monitoring systems as pointed out by authors in [26]. Furthermore, authors in [26] addressed the challenge of customer risk by proposing a smart grid utility that knows the precise generation of each renewable resource at a given period. Their shortfall was in addressing customer privacy, and issue which was later proposed by authors [27] - [28]. In [27], a survey was done on different smart metering to address customer privacy. The survey led authors to propose an operational metering that addresses attributable fine-grained measurements. Their utility, known as “Differential Privacy based real time Load Monitoring approach (DPLM)” maintains consumer privacy by concealing load values in such a way that the utility is unable to assess the consumption of specific renewable energy resources or the daily routine of any smart meter user and proposed an improved customer privacy by categorising their privacy studies based on type of measurements.

4. METHODOLOGY

This paper, based on design science research methodology, designed a fuzzy based energy optimization system to optimise and enhance the residential electricity consumption based on the current values of the input variables. The input variables included the load consumption, remaining daily limit and electricity price. Triangular membership functions were used in this paper. The load consumption was the manual fuzzy logic controller input while price was in real time. Given the scenario, the used electricity was calculated by the model system in real time as electricity was consumed during the day. The desired number of days was set before the simulation with the desired amount of electricity. The system calculated and allocated the daily limit using the available electricity on a smart meter. The simulation was run for 24 hours.

4.1 Problem Formulation

The research design followed in this paper was the design science research methodology mapped with the current work as shown in the following Figure 2.

4.2 System Design

The MISO heuristic rule based fuzzy controller and fuzzy system were designed and implemented using the fuzzy controller and visual instrument (VI) coding that are programmed in LabVIEW 2019.

4.3 Designing the Fuzzy Logic Controller

The fuzzy logic controller consisted of three main parts namely: linguistic variables, membership functions and rules. To design the fuzzy controller, we followed the following steps:

4.3.1 Identifying the input and output variables

The values of the input and output variables are in words and sentences from natural language and mapped with membership functions. Each linguistic variable has the range of expected values that corresponds to their terms. For example, in this paper, variable price includes terms peak, standard peak and off peak while the output load status includes terms such as ON or OFF.

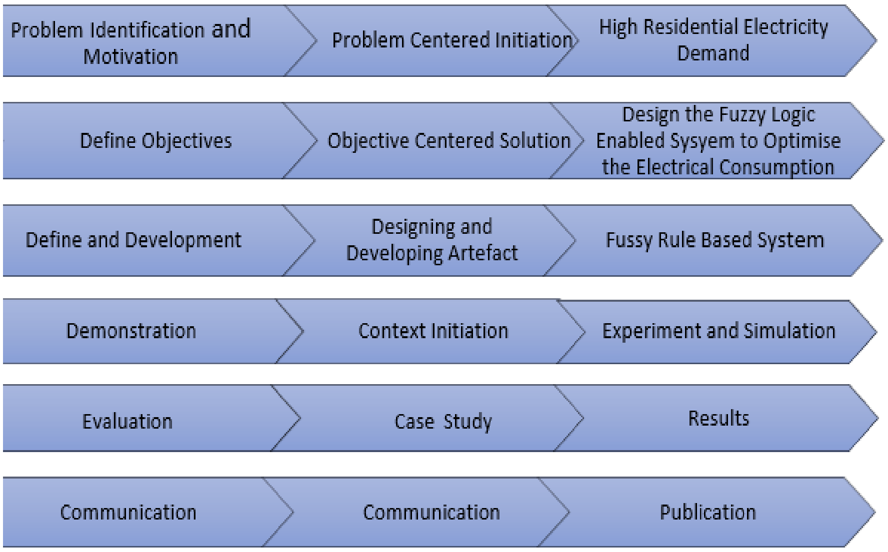

Fig. 2. Design science research mapped with current work [29], [30].

4.3.2. Creating and labelling the membership functions

The triangular membership function has been chosen for its simplicity and it is computationally fast. In our paper there were four inputs and based on their combination, the output was obtained. The membership functions and mathematical expression for the input variables are shown in figures below.

a) Input 1: Load consumption in kwh

The consumption of the load was identified as the one of the variables that had an impact in high usage of energy and thus increasing energy cost in households. For that reason, the input control was sampled to a total consumption of 15 kw/h. The consumption amount was converted to percentage in respect to the remaining daily limit using Equation 1.

$$\text{Load consumption}\,\% = \frac{\text{Load consumption}}{\text{Remaining Daily Limit}} \times 100 \qquad (1)$$

The membership function parameters for the consumption were sampled as shown in Figure 3 where the range was restricted to between 0 to 100%.

b) Input 2: Electricity Price (P) in cents

Advanced meter infrastructure (AMI) normally known as smart meters has an advantage of providing the consumers with the real time energy consumption, energy cost information to assist the customers on how they can effectively manage their consumption. Reducing consumption during peak periods can result in cost and high demand reduction. In this paper, to facilitate the two-way communication that AMI is capable of, Figure 4 shows the membership functions of electricity price read from the smart meter during peak, standard and off-peak periods. The prices are fixed in cents for each period and charged per second.

Three membership functions in Figure 4 were designed to separate the demand response tariffs namely off-peak costs of 15c, standard costs of 45c, and peak cost of 80c.

Fuzzy logic controller was designed to manage the available amount of electricity as desired by the consumer for a given time frame and enhance the electricity consumption by scheduling the household appliancces in response to the Time of Use (ToU) tariffs

The three parameters for the time of use tariffs used in this paper are tabulated on Table 1.

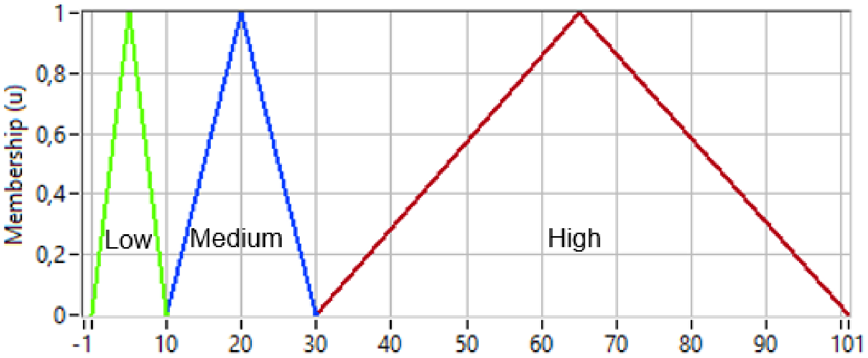

Fig. 3. Appliance load consumption MF.

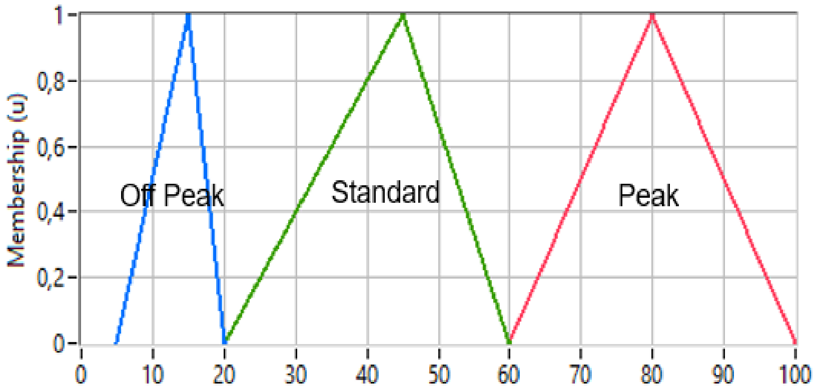

Fig. 4. Electricity price MF in cents.

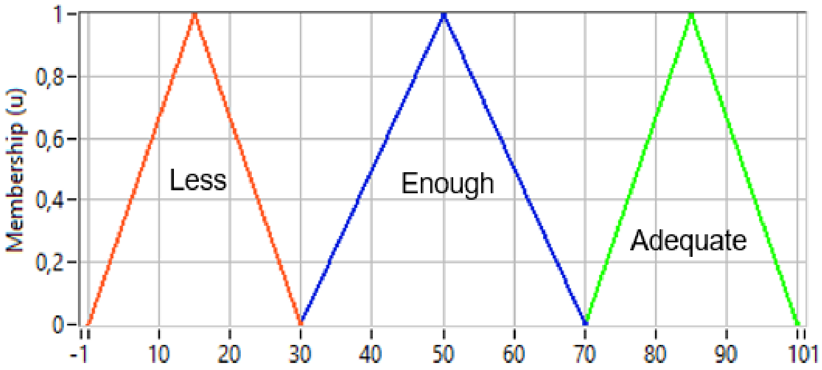

Fig. 5. Remaining electricity daily limit MF.

Table 1. Parameters for the price tariffs.

Price	Time	Parameters in cents
Off Peak	22:00-07:00	15
Standard	07:00-08:00 10:00-18:00 20:00-22:00	45
Peak	08:00-10:00 18:00-20:00	80

c) Input 3: Remaining daily electricity limit in kwh

The prepaid meter for this study was chosen with the amount of electricity and user's desired number of days. The remaining electricity daily limit was calculated by subtracting the used electricity from the initial daily limit. The remaining daily limit in percentage became the input of fuzzy controller with three triangular membership functions (less, enough and adequate), and the word "enough" refers to moderate for this study as shown in Figure 5.

d) Output: Load Status (LS)

The load status was the output of the controller. Figure 6 shows the membership function of the of system output. The defuzzified value of the output specified if the appliance should be ON or OFF during that particular period based on aggregation of outputs from all the defined rules. For presentation purposes in this study, the ON and OFF values were converted to percentage.

4.3.3 Building fuzzy rules

The state evaluation fuzzy rules in this study were derived using the heuristic method in which the collection of rules was formed by analysing the behaviour of the controlled process. The summary of designed rules in this study as shown in Table 2.

There are many variables that can fulfil the objective to optimise and enhance the electrical energy consumption but for this paper only the price of electricity, load consumption, remaining electricity of the electricity for the day and consumer desired number of days to use given amount of electricity for period of time were investigated. The rules were fired using the min-max method (AND) where the minimum value of the antecedents was taken to enable the controller to fire more than one rule condition at the same time but with varied strengths. The rules are structured as follows:

Rule 2: IF Consumption is "Medium" AND Price is "Off-peak" AND Available Electricity is "Adequate" THEN Load Status is "ON".

4.3.4 Choosing deffuzzification method

Center of gravity also known as the center of area or centroids method has been chosen the suitable method for the controller by its capabilities of no large change in output with small change in input and defuzzified output lied in the middle of the support of resulting membership function and had a high degree of membership function.

4.3.5 Simulation (Rule testing) of the fuzzy controller

The final step in designing the fuzzy controller is to test the rules if they meet the objective of the system. The test system command on LabVIEW fuzzy system design was used to test the relationship between the input and output variables. The input variables were set manually, and the controller calculated the weight of input variables to assign the output value. For this paper every output greater or equal to 50% is true, that is the appliance is ON else condition is false.

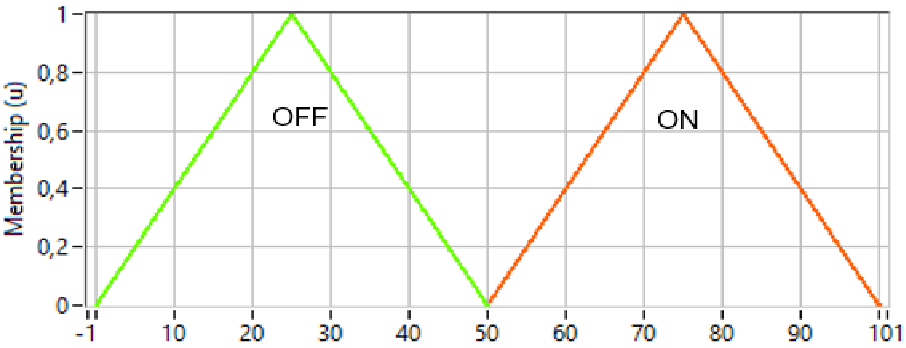

Fig. 6. Load status of the appliance MF.

Table 2. Summary of designed fuzzy logic controller rules.

Rule	Load Consumption	Price	Remaining Daily Limit	Load Status (Output)
1	Low			ON
2	Medium	Off-Peak	Adequate	ON
3	Medium	Off-Peak	Enough	ON
4	Medium	Off-Peak	Less	OFF
5	Medium	Standard	Adequate	ON
6	Medium	Standard	Enough	ON
7	Medium	Standard	Less	OFF
8	Medium	Peak	Adequate	OFF
9	Medium	Peak	Enough	OFF
10	Medium	Peak	Less	OFF
11	High	Off-Peak	Adequate	ON
12	High	Off-Peak	Enough	ON
13	High	Off-Peak	Less	OFF
14	High	Standard	Adequate	ON
15	High	Standard	Enough	ON
16	High	Standard	Less	OFF
17	High	Peak	Adequate	OFF
18	High	Peak	Enough	OFF
19	High	Peak	Less	OFF

5. SIMULATION SCENARIOS AND RESULTS

Table 3 shows the summary of the invoked rules as represented from Figure 7 to 12.

5.1 Scenario 1: Off Peak Price and Adequate Electricity

The data presented in Figure 7 was from a selected period in the morning from 04:49:10 to 06:59:01. The figure below represents the medium load consumption of electricity during the off-peak periods from 04:49:10 to 04:54:10 and from 05:02:31 to 05:03:01. There was a change in load consumption to high between 04:58:00 to 05:02:31. From 04:54:10 to 04:57:30 and from 05:02:31 to 06:59:01 the load consumption was low. Data show that the remaining daily limit was adequate and that allowed the load status to be "On" throughout the selected period. The low and medium load consumption occurred at different times during this selected off peak period.

Table 3. Summary of simulation rule involved.

Time Frame	Condition	Rule Invoked
04:59 – 07:00	Off-peak price and adequate electricity	1, 2, 3, 11 and 12
07:00 – 08:00	Standard price and adequate electricity	1, 5 and 14
08:00 – 10:00	Peak price and adequate electricity	1, 8 and 17
10:00 – 15:32	Standard price and enough electricity	1, 6 and 15
15:32 – 18:00	Standard price and less electricity	1, 7, and 16
18:00 – 20:00	Peak price and less electricity	1, 10 and 19
20:00 – 22:00	Standard and less electricity	1, 7 and 16
22:00 – 23:59	Off-peak and less electricity	1, 4 and 13

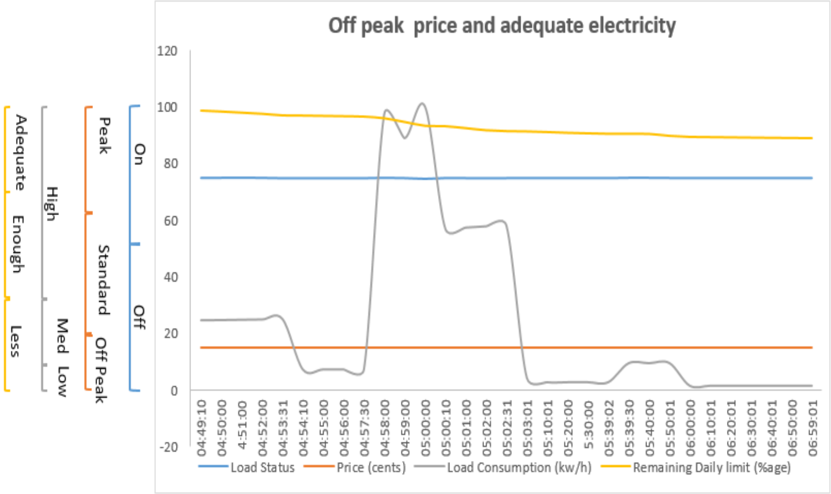

Fig. 7. Off peak price and adequate electricity.

5.2 *Scenario 2: Standard Price and Adequate Electricity*

The off-peak period ended at 07:00:00 as presented in Figure 7. Figure 8 presents the standard tariffs from 07:00:00 to 08:00:00 and the daily limit was adequate. Data presented show the linear approach to load consumption from low, medium and high. Data show that from 07:00:00 to 07:10:00 the load consumption was low. There was a shift from low to medium load consumption at 07:10:00. Thereafter, from 07:10:00 to 07:22:02 load consumption was medium. There was another shift at 07:22:02 from medium to high load consumption, from 07:22:02 to 07:59:02 the load consumption was high. Data show that the load consumption increased from low to high and continued to increase till the end of the selected period. This suggests that the fuzzy logic enabled system scheduled the consumption towards off peak price periods.

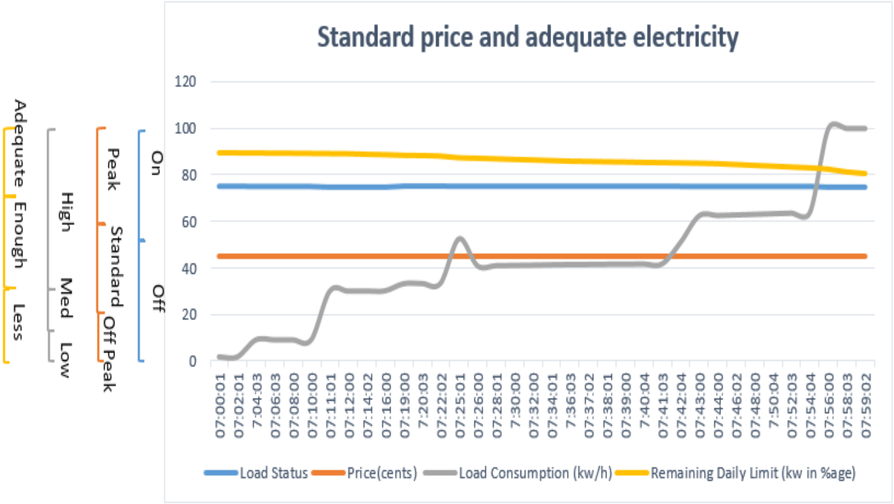

Fig. 8. Standard price and adequate electricity.

5.3 Scenario 3: Peak Price and Adequate Electricity

Figure 9 presents the data that continued from Figure 8. From 08:00:02 to 08:01:01 the load consumption dropped from high to low and the load status changed from "off" to "on". The change was due to fuzzy logic rules that restricted medium and high load consumption and only allowed the low load consumption when the price tariff was in the peak period. Data showed that there was a constant load consumption during the selected peak period. This suggests that the fuzzy logic enabled system scheduled the consumption towards peak price periods.

5.4 Scenario 4: Standard Price and Enough Electricity

Figure 10 presents the data when the price tariff changed from peak to standard. When this happened there was a change in remaining daily electricity limit from adequate to enough from 10:30:06 to 15:30:07. Data showed that from 10:00:00 to 15:30:07 the load consumption was constantly high and the load status was "on" throughout the selected period. There was a noticeable decrease in the remaining daily electricity limit during this period due to high load consumption.

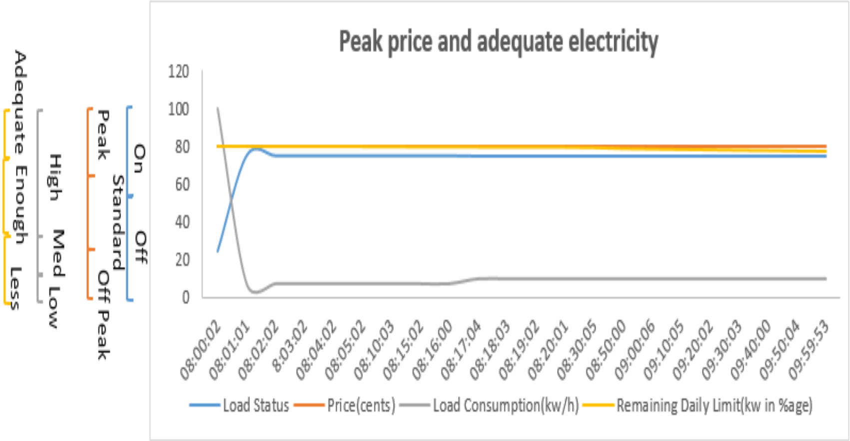

Fig. 9. Peak price and adequate electricity.

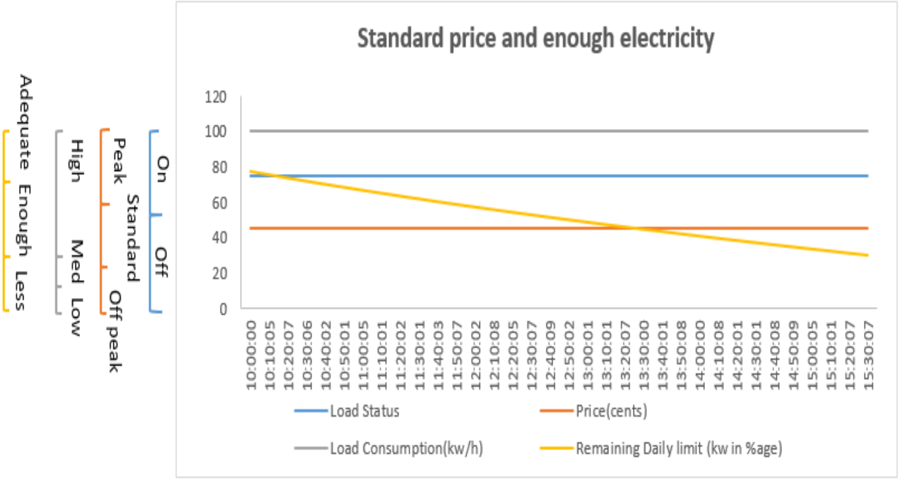

Fig. 10. Standard price and enough electricity.

5.5 Scenario 5: Standard, Peak Price and Less Electricity

Figure 11 is the continuation of Figure 10 and presents the results when the price tariff was standard between 15:32:15 and 18:00:00 and from 20:00:00 to 22:00:00, peak from 18:00:00 to 20:00:00, off peak from 22:00:00 to 23:59:46 for the selected data period. In this regard the remaining daily electricity limit was set to less. From 15:32:15 the load consumption dropped to low load consumption due to fuzzy rules that do not allow medium and high consumption when the remaining daily electricity limit was less and the load status remained "off". At 23:59:46, the remaining daily electricity limit was recalculated and reloaded in preparation for the following day. The results showed the load status resumed to be "on" and no load consumption was restricted during this period.

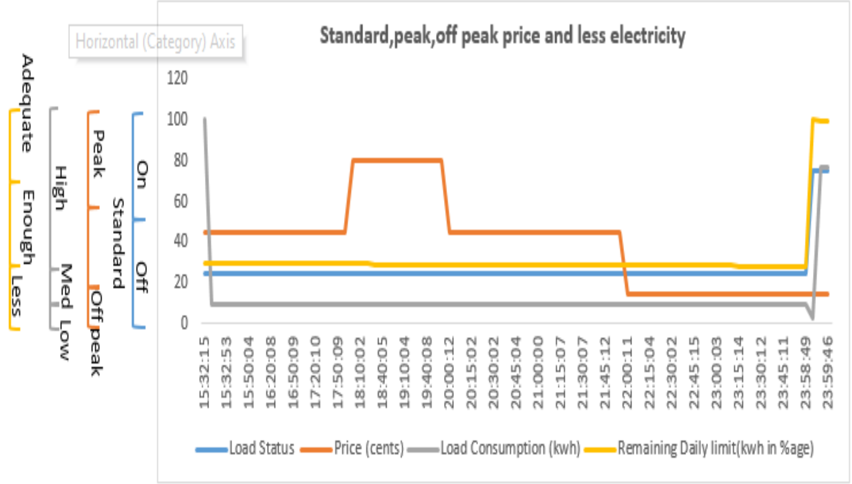

Fig. 11. Standard, peak price and less electricity.

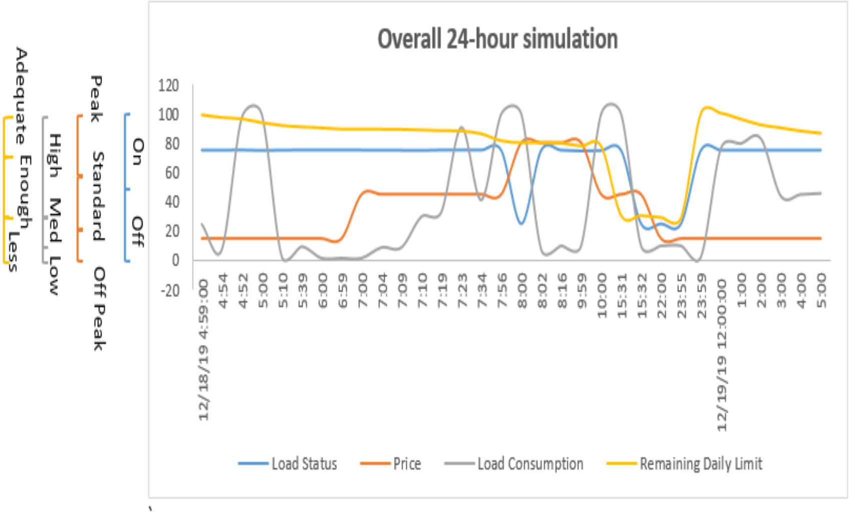

Fig. 12. 24-hour simulation graph.

Figure 12 shows the collected data over 24 hours in five scenarios of price tariffs and remaining daily limits. The different fuzzy controller rules were invoked for different scenarios and varied appliance load consumption. The invoked rules with each scenario are tabulated on Table 3. The data shows that when electricity is less, the appliance load consumption were restricted even though it was it automatically switched to 10% of remaining electricity daily limit. The limitation of fuzzy in this study is that when electricity is less it shuts off the appliances.

6. CONCLUSION

The simulator enabled us to investigate the opportunities using the scheduling of load consumption to save electricity consumption and costs under different scenarios. Time of Use tariff and daily limit were applied. The 24-hour period was simulated to demonstrate the optimisation of electricity consumption considering the price and amount of electricity remaining for the day. The results showed that fuzzy logic can optimise the residential load consumption by scheduling the household appliances as desired by the consumer considering the time of use tariffs and amount of remaining daily electricity. The study concludes that fuzzy logic systems may inconvenience the user when the available daily electricity limit is less and allow for low load consumption.

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