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# DESIGNING A CONTROLLER FOR RESIDENTIAL WATER HEATER USING FUZZY LOGIC

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**ABSTRACT**

Over the years, there has been a growing concern about Nigeria's electricity supply which has been under stress for a long time. This is partly due to the fact that electricity demand is rising rapidly, which has exceeded capacity for generation. Therefore, it is very important to assess the contribution of potential numerous measures of demand-side to off-peak load. In the housing sector, water heating is the area with the highest consumption of electricity. This gives the highest chance to generally save consumption of power and reduce high power consumption. This paper, therefore, proposes a model that can automatically disconnect residential water heaters during the day's peak periods. An hourly model for consumption of electricity was used to assess the effects on the disconnection load. This proposed model is a control strategy that is fuzzy logic-based to adjust the regular power requirement of the conventional water heater from the high demand of electricity to low peak periods. This work concludes by presenting a review of results and analysis of simulation result from a certain experiment which shows that the strategy proposed in this work can swing the average demanded power from water heater to expand the residential load profile load factor.

**Keywords:** demand, electricity consumption, electric water heater, fuzzy logic, high-peak, off-peak, temperature.

## 1. INTRODUCTION

For many years, Nigeria's electricity supply has been insufficient. This insufficiency is due to a constant increase in demand and the use of electricity, which is far more than the capacity for the generation of electricity. The institution of rolling blackouts has in recent year demonstrated incidences where demand has exceeded the capacity of generation in a bid to ensure that the stability of the grid is maintained [1]. There is a need to manage the demand via scheduled power outages to avoid a total national blackout. This crude way of grid management that sheds load to avoid blackout is still the major practice in Nigeria. When the power generated in a power network exceeds load demand at any given point in time, the system can cope with additional load this is referred to as surplus capacity. The extra charge that can be supported by the power network is given as the percentage of the current charge. A relatively very cold weather period reveals a vulnerable system with respect to it producing and distributing mode because consumption was close to capacity in such peak situations. This requires a demand side that is very flexible with the ability to reduce loads in high-peak conditions to avoid possible system collapse. Thus, this demand response possibly will defer any need for an expensive increase in the electricity grid or power generation. In the interim, Eskom has instituted Demand Side Management (DSM)'s the shorter-term solution. Demand Side Management (DSM) can simply be articulated as reducing the demand for power by changing the behaviour of consumers. This is accomplished by supplying consumers with gadgets that probably use less power as incentives. These incentives are provided to fund the production of the aforementioned additional generation capacity by implementing power tariff increase [2], [3]. Additional incentives like smart meters were provided that monitor and shed a load of a household's consumption of power if a power threshold is surpassed [4]. To date, it has included the installation low energy bulb, ripple - controlled EWHs and water heaters that are solar-powered in various workplaces and households, also structures to lessen power consumption was introduced in peak load periods. Applications that assist with the deployment of DSM have a great ability to mitigate the short - term state of excess power demand. This will also contribute to a more energy-efficient environment. This would be best accomplished by the engineers that are already in the system because they are conversant with the procedures and encouraged by the rise in tariffs for electricity mentioned above. It was therefore decided to design a housing sector aid, the one that used up the second largest quantity of electricity.

In the housing sector, the area with very high electricity consumption is water heating is. It offers an immense opening to save the overall consumption of power and reduce peak-power consumption at 34% [5], [6]. As shown in Figure-1. there is currently no control unit in 76.5% of water heating. The proposed solution should address this 72%, which has no control system yet. Focusing on the highest consumption area will increase the installed maximum return per unit. Large families can use 14 kWh when all members shower, requiring the heating element to operate for seven hours.

The heating of water is usually obtained through electric water heaters (EWHs) in Nigeria. The electric water heater is made up of a tank for storage and an immersed heating element. Usually, they are fixed just below the roof in homes. This proposed solution will be in the form of a unit that can be retrofitted to an already installed EWH facility. This unit will offer measurement and control to the user. Another advantage of targeted energy consumption is the ability of EWHs to store hot-water (heat energy) in its storage tank. This can be

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leveraged to move the consumption of power from high demand periods to the periods of off-peak. Eskom stated that the electricity usage peaks are between 6.30 am to 9.30 am and 5 pm to 9 pm are results of high water heater usage [7].

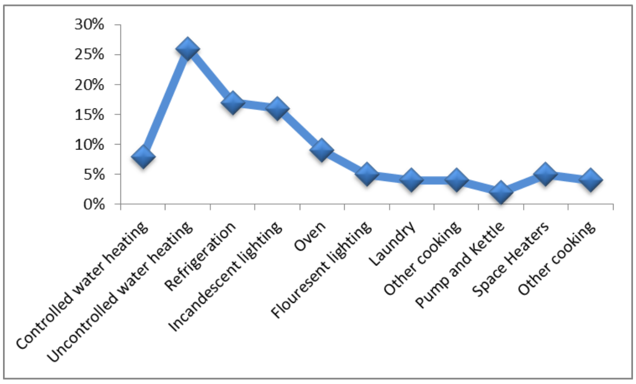


**Figure-1.** Electricity Consumption Breakdown Case Study [6].

A concept system proof for remote control and monitoring of EWH in proximate - real-time was portrayed. The aim is to enable users to assess and monitor consumption data on an online platform and set temperature and schedules. This has been done to enable more users to manage energy efficiently and to understand better users' demand. In addition, attempts were made to lessen the harm that may occur if the EWH's structure fails and also offer users with information that indicate the structural integrity of their EWH's. This is intended to benefit the insurance companies that regularly bare the cost whenever an incident of EWH failure occurs [8], [9].

This proposed model is a control strategy based on fuzzy logic to adjust the regular power requirement of domestic water heaters from peak electricity demand period to lower than peak periods. Minimum temperature is the control variable used relative to hot water, and is defined as the level of comfort of the customer. The water temperature cannot fall below the customer's minimum set temperature. The simulation result shows that the suggested scheme can move the average demanded power of an electric water heater to ensure improvement of the residential profile of the load factor [10].

### 1.1 Water Heaters and Load Control

When direct load control is achieved using water heaters, when they are reconnected, basically all the unsupplied energy to the water heaters will be required when not connected to the power supply. When turned on, all the heaters affected which is meant to be turned on throughout the period of control start recovering simultaneously from the being interrupted. An undesirable new peak may be created in the electricity system by this payback effect if not properly handled. It is therefore important to discuss some reasons for these experienced effects when the load is controlled using water heaters. Some of these factors are described in this section [10]. The heating and storage of hot water are done by using water heaters. A normal water heater designed for residential use has a storage tank of 200 liters and a rated 2 kW heating element. A tank's heat loss is about 100Wh / h at 75 ° C. A full heated tank takes about 2.3 hours to drop by 1 ° C when nothing is used or taken from the stored hot water. A dead-band bimetallic strip with of about 4 ° C is usually used as the thermostat of the water heater. This means that when the temperature drops below 73 ° C, the heating element will start to operate but stop as the temperature go beyond 77 ° C. Because of the thermostat's dead - band, it will take about nine hours before the heating element is activated by the thermostat due to heat-loss for fully heated storage-tank in stand-by mode [11], [12].

Most heaters operate because of water use by households rather than heat loss. When hot water is used in a household it is always taken from the top of the tank, freshwater refills the tank bottom simultaneously. The thermostat can be placed a few centimeters from the tank bottom and by activating the heating element, it will respond to a drop in temperature. A very little quantity of hot water is needed for a hand wash. Therefore, the consumption of energy is low so the water heater only has to work for a short period to restore the used energy. These examples stated above depict a range of consumption of energy in different households due to the use of hot water during morning hours. The target is to switch off the power supply to most or all of the water heaters during peak periods [13], [14].

## 2. METHODOLOGY

Hot water can be stored in a well-insulated tank for long period with little or no heat loss. The method of heating water at a time and using the water at any other suitable time of the day is necessary. Therefore, the peak load was widely reduced by using water heaters direct load control. The target is to switch off the power supply to most or all of the water heaters at the peak periods. Water heaters once powered, are either off or consume 4.5kW (a fixed quantity of power). Presented in this report is a variable power control scheme which is fuzzy logic-based, where the consumed heater power is regulated according to the available information about the device such as distribution level power demand, water temperature and minimum and maximum water temperature permitted [15]. The maximum percent of the permissible power that can be consumed by the heater is determined by the status of the above variables. The supplied voltage to the water heater will be controlled by a control signal based on this information.

The method is a simple control approach that is used to control some class of systems that are nonlinear containing uncertain variable. This type of control approach suits water heater control exercising non-linearity between water heater power consumption and water temperature. The Figure-2 shows a block diagram a Fuzzy controller with twenty-two rules, having a signal output and four inputs. The rule and inputs are given in this section. There is also considerable amount of uncertainty in the system variables as illustrated in Figure-

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3 below. The inputs include; Demand: Average demand for electric water heater in residential buildings, Comfort level: a customer set lowest hot water temperature and the temperature of water should not fall below this value, Water temperature: temperature of water per time, Max Temp: Maximum permitted water temperature.

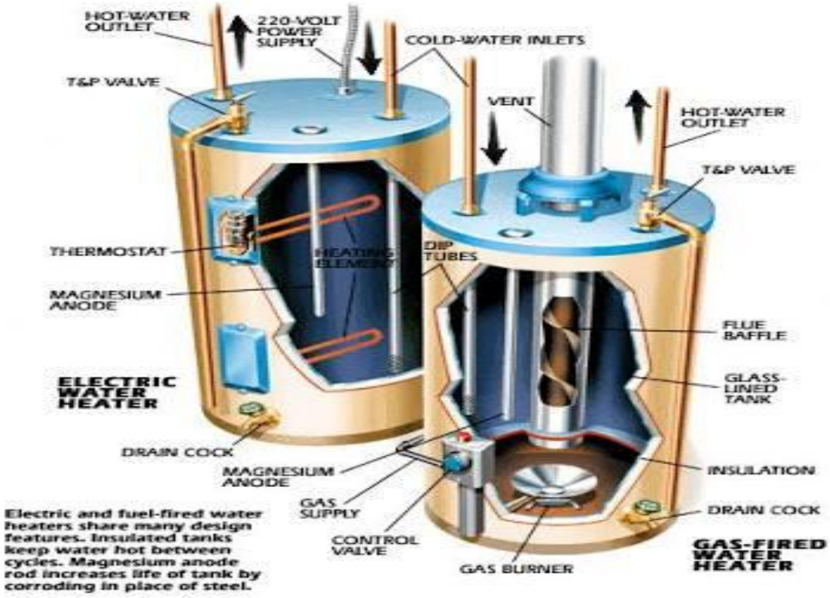


**Figure-2.** Conventional electric water heater [14].

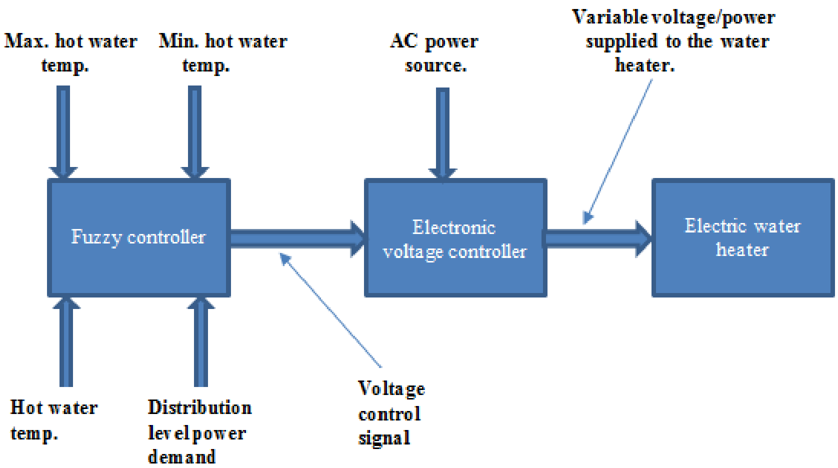


**Figure-3.** Block diagram of a fuzzy controlled water heater.

The controller fuzzifies four input values that is; it gives a fuzzified controlled signal to the water heater with applied voltage based on the affiliation functions and allotted rules. The conversion of the control signal is then done by defuzzifying it to a crisp signal. A set of linguistic rules determines the decision-making process by mapping individually the input signal separately to the affiliated set of features corresponding to it. The signals can then be mapped to a matching output signal. At any time, the applied voltage to the heater resulted from the output command of the fuzzy controller. At any given time also, the applied voltage to the heater is the extract from any output command of the fuzzy controller. This is given as a number from zero to one, with the rated possible voltage of the water heater. The heating element's power consumption is proportional to its now variable voltage square, assuming that the heating element of the water heater is entirely resistive. Consequently, the power consumption of the water heater becomes variable.

### 2.1 Fuzzy Rule's Membership Function

For the output variable and all corresponding input variables, Fuzzy membership functions are required to define the linguistic rules governing the relationship between them. For input, temperature demand and power output signals, a bell-shaped Gaussian membership features were used. This membership function type results in a very smooth shift in the water heater demand profile, while sharp membership functions were chosen due to sharp constraints on these variables for maximum

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temperature, comfort level and input variables. The temperature of the water should not fall lower than the level of comfort and should not go beyond the customer's maximum temperature. Figure-4. Shows the range, shape, and expressions applied as the input variables and output variables of the system installed [16], [17].

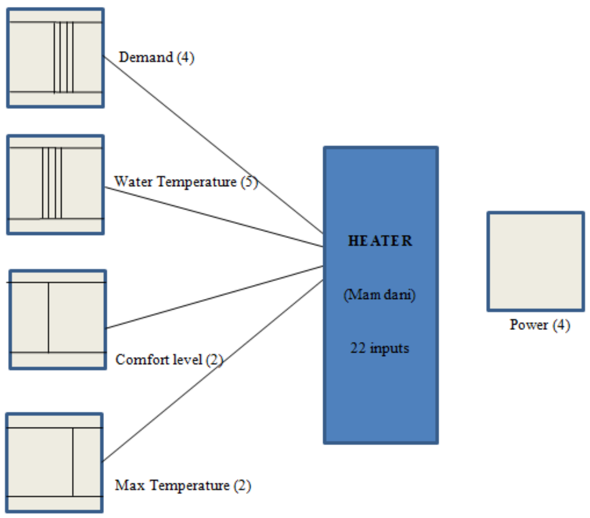


**Figure-4.** Conventional Electric Water Heater.

### 2.2 Fuzzy Rule

It is a very important task to develop the fuzzy rules in fuzzy controller design for the interest at hand. The development of the rules is largely dependent on the expertise and knowledge of the designer system. In this situation, the fuzzy controller will move the heater's demand profile peak to times when total demand is small. At the same time, it is necessary to meet the hot water maximum and minimum temperature conditions given by the customer. Taking into account the desired water heater demand profile, the following rules are given in Table-1.

The minimum and maximum temperature limits were set by rules 21 and 22. It should be noted that the temperature was assumed not to go above a particular limit in this study. Therefore a limit is placed on the power quantum that water heater can be supplied with even though heating of water is done during off-peak periods when there's low electricity demand.

## 3. RESULT AND ANALYSIS

Simulation processes were carried out to assess the fuzzy controller efficiency to move the daily average power demand of residential water heater making use of the rules and membership functions set out as shown in the section above. The comparison was made between fuzzy controlled and uncontrolled demand for water heaters. Their graphical figures show clearly that a great percentage shift of heater's demand under fuzzy control from high electricity demand periods to low demand periods as shown in the sample given in Figures 5 and 6. It is understood that the customers using this fuzzy logic-based DSM strategy are expected to cooperate and draw out a plan for the hot water usage. The fuzzy controlled average demand profile is significantly improved from the figures; the load factor can be defined.

**Table-1.** Attributes of Cleveland dataset.

| S/N | Rule |
|---|---|
| 1 | If (demand is low) and (water _temp is cold) then (power is high) |
| 2 | If (demand is low) and (water _temp is Warm) then (power is high) |
| 3 | If (demand is low) and (water _temp is M_warm) then (power is avg ) |
| 4 | If (demand is low) and (water _temp is H_warm ) then ( power is avg) |
| 5 | If (demand is low) and (water _temp is hot) then (power is low) |
| 6 | If (demand is L_avg ) and ( water _temp is cold ) then ( power is avg) |
| 7 | If (demand is L_avg) and (water _temp is L_warm) then (power is avg ) |
| 8 | If (demand is L_avg) and (water _temp is m_warm) then (power is avg ) |
| 9 | If (demand is L_avg) and (water _temp is H_warm) then (power is low) |
| 10 | If (demand is L_avg ) and ( water _temp is hot) then ( power is very low ) |
| 11 | If (demand is H_avg) and (water _temp is cold) then (power is low) |
| 12 | If (demand is H_avg) and (water _temp is L_warm) then (power is low) |
| 13 | If (demand is H_avg) and (water _temp is M_warm) then (power is low) |
| 14 | If (demand is H_avg) and (water _temp is H_warm) then ( power is very low) |
| 15 | If (demand is H_avg) and (water _temp is hot) then (power is very low) |
| 16 | If (demand is high) and (water _temp is cold) then (power is very low) |
| 17 | If (demand is high) and (water _temp is L_warm) then (power is very low) |
| 18 | If (demand is high) and (water _temp is M_warm) then (power is very low) |
| 19 | If (demand is high) and (water _temp is H_warm) then (power is very low) |
| 20 | If (demand is high) and (water _temp is hot) then (power is very low) |
| 21 | If (max_temp is above) then (power is very low) |
| 22 | If (comfort level is below) then (Power is high) |

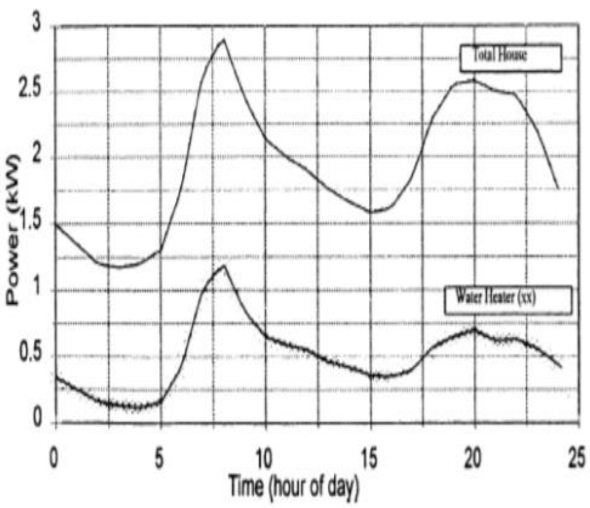


**Figure-5.** Daily average, electric water heater and total residential demand.

## 4. CONCLUSION

A Demand Side Management (DSM) based fuzzy logic strategy for controlling the daily average power demand of the water heater of a residential apartment was presented in this report. The method of applied voltage control is used by a DSM strategy according to variable water heater consumption of power. The controller of the fuzzy logic makes use of input variables like the maximum and minimum permitted temperature of hot water, level of distribution demand, and hot water temperature and outputs adjustment signal controlling of the water heater input voltage magnitude. When using the customer's interactive DSM strategy, the results of simulation show that the average residential water heater profile demand peaks can be reduced and moved from high electricity demand periods to off-peak periods. The strategy can also assist customers to get involved in the kind of DSM programs, especially in an environment of real-time pricing. Customers participating in such a DSM program need some use of hot water cooperation and planning.

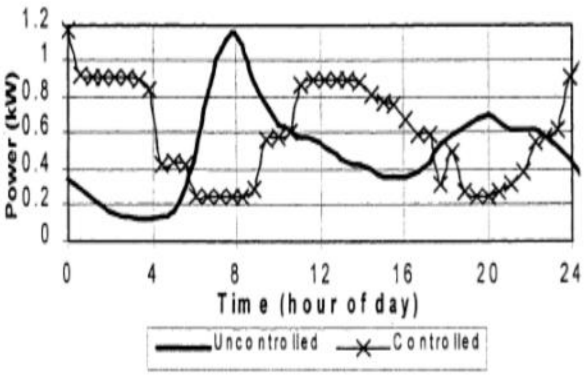


**Figure-6.** A single fuzzy controller and uncontrolled daily average water-heater power demand.

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