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EVALUATING OF SHORT-TERM ELECTRICAL LOAD FORECASTING SYSTEM USING FUZZY LOGIC CONTROL: A STUDY CASE IN SUDAN

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Abstract— Generation, Transmission and Distribution sections of the electric power grid system are a function of electric load forecasting. This is because, many benefits can be obtained by using load forecasting, such as reduction in the generating cost and increasing the reliability of the power system due to improving energy management. The objective of this study is therefore to design a fuzzy logic system for short-term electric load forecasting to reduce power losses particularly in times where the electric power generation is higher than the electric load demand. In this study, the independent variables that were applied to the developed short-term load forecasting Simulink model were time, temperature, and similar previous electric day load demand, and they were collected from the specific area load control center in Sudan. Fuzzy rules were prepared using Mamdani implication. The obtained fuzzy logic results were compared with the actual load demand, and it was found that there was an error that ranged between 12% and 0.09%.

I. Introduction

There are many indicators to classify the developing economies, and the power system is the top factor in the classification scale. There is a need to predict correctly the future electric load to achieve perfect planning of generation, transmissions, and distribution of a given electric power grid [1][2]. Load forecasting is the basic technique that is used in predicting the required power that achieved a balance between the generating power and the demand load, as more accuracy obtained from the load forecasting predicts a stable operation of the utility company [3][4]. Usually, a mathematical model must be created for forecasting systems, which can either be sum or multiplication forms [5]. There are several techniques of load forecasting depending on the effective working operating time of each technique. Thus, load forecasting can be used for short planning time, medium planning time, and long planning time [6]. In this study, Matlab was used for short-term electric load forecasting to reduce power wastage, especially when the generation is higher than the load demand using fuzzy logic, which is widely used in the control system in solving a wide range of control [7][8][9]. It is also important an issue for future planning of any company therefore it is an attractive field for researchers. Though most of the published works differed in the technique, application of the forecasting system, or in the place of study where the influence of temperature becomes more noticeable on the grid. For instance, in the study of [5], the long-term forecasting system using fuzzy logic was presented which the input parameters were temperature, humidity, and historical load demand. In [6], a short forecasting system was presented which used fuzzy logic and based on time, temperature, and similar previous day load. However, the paper did not include a calculation of error which is considered an important factor to indicate the performance of the system whereby the system operates with load data from sub-station. The study revealed that the model was able to provide a long prediction of future load. In the case of [11], short-term load forecasting was used in predicting industrial loads, the system examined only for 24 hours. In the study of [12], mid-term forecasting by using the neural networks and the support vector machine were used to forecasting load. The study in [12] compared the two models and the results did not include the Matlab Simulink model and calculating of the error ratio. In [13], weather parameters were used to predict the rainfall using fuzzy logic and a genetic algorithm. Although fuzzy was used, the prediction of rainfall used different parameters than that used in load forecasting. The short-term load forecasting model based on fuzzy logic was presented in [15] using three generators working with different loads.

II. Methodology

This study used fuzzy block techniques as shown in Figure 1 to provide short-term load forecasting by considering the previous values, time, and weather parameters. There are two basic types of fuzzy rules which are often used in computational fuzzy systems: the Mamdani and Takagi-Sugano-Kang-type fuzzy systems. This paper used the Mamdani type of fuzzy rules; due to its ability to modify the relation of input and output in any region individually by making changes in the fuzzy rules and keeping the relationship in the other regions without change. The Mamdani rule structure is shown in Equation (1):

$$IF\ A\ is\ B\ THEN\ C\ is\ Y \qquad (1)$$

where: A = Inputs
B = Condition
C = Process
Y = Outputs

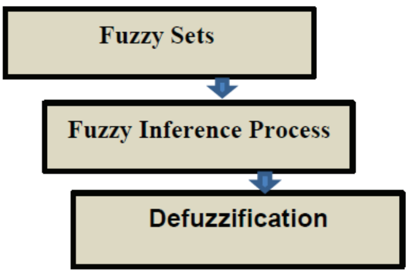

Figure 1: Block Diagram of Mamdani based Fuzzy System

In Figure 1, the interface refers to a fuzzy process based on the fuzzy inputs to select the required output. The output selected by the interface depending on a group of fuzzy rules, which depend on the algorithm presented in Figure 2.

In Figure 2, the first thing to be done is the collection and entering of the electrical load data and other variables. The fuzzy system then classified this data based on the suggested fuzzy rules to forecast the electrical load demand. In this study, for testing, we applied load data in February 2018 as the previous date, February 2019 as the actual date, and the information produced forecasted load value for February 2020. The basic issue in the fuzzy model is the development of the rules which relate to the fuzzy input and the required output. Figure 3 shows the structure of the fuzzy logic system, which includes inputs, rules, and the fuzzy output. Fuzzy rules provide the logic control of the output based on the input.

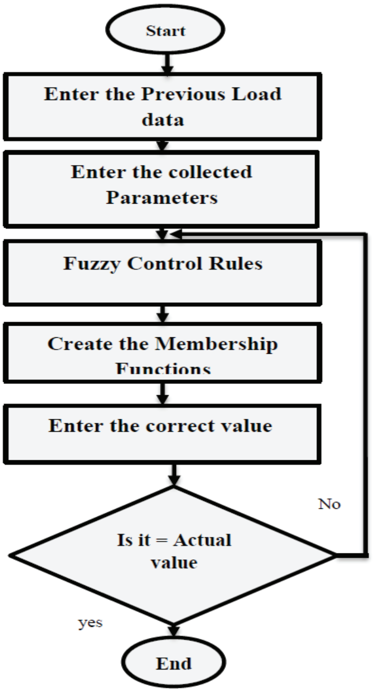

Figure 2: Algorithm

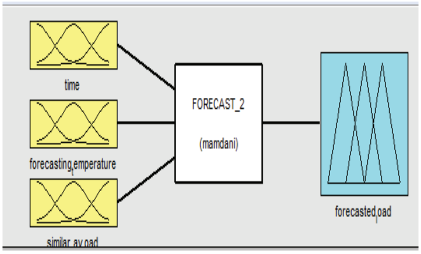

Figure 3: Structure of the Fuzzy Logic System

A. Time Input

The fuzzy time input variable was divided into five triangular membership functions as shown in Figure 4 as illustrated in Table 1.

Table 1: Time Levels

Membership	Symbol
Dawn	(DAWN)
Morning	(MORN)
Noon	(NOON)
Evening	(EVE)
Night	(NIGHT)

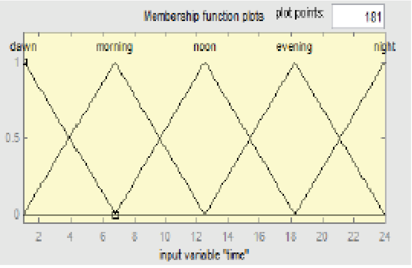

Figure 4: Time Memberships

B. Temperature

The fuzzy model used five triangular memberships to represent the temperature input variable as shown in Figure 5; which are specified in Table 2. Temperature is a very important factor; because as it is known the load forecast is directly proportional to the temperature.

Table 2: Temperature Levels

Membership	Symbol
Very cool	(VC)
Cool	(C)
Medium	(M)
Hot	(H)
Very hot	(VH)

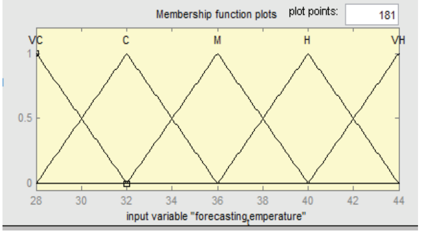

Figure 5: Temperature Membership

C. History of the Load

The history of the load is classified into five triangular memberships as shown in Figure 6. The levels of these inputs are specified in Table 3.

Table 3: History of Load

Membership	Symbol
Very low	(VL)
Low	(L)
Medium	(M)
High	(H)
Very high	(VH)

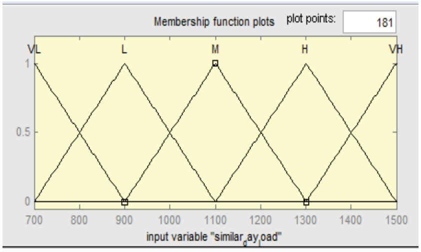

Figure 6: Load History Membership

Similarly, the output forecast load was divided into five triangular memberships as shown in Figure 7. The fuzzy logic controller processed the loaded inputs and based on the fuzzy rules; and gives the forecasted loads corresponding to inputs variables of the fuzzy model.

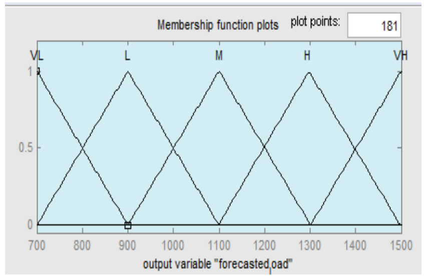

Figure 7: Output Variables of Forecasted Load

The fuzzy system performed as sample inputs in the MATLAB toolbox as illustrated in Figure 8.

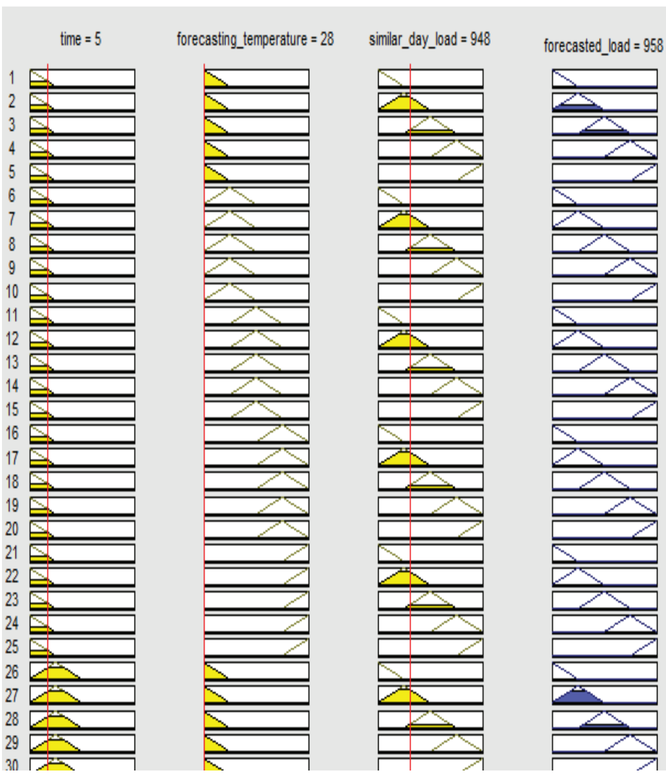

Figure 8: Defuzzified Outputs

III. Results of the Fuzzy Logic Model

Simulink model design as depicted in Figure 9 was prepared to perform the short-term load forecasting. It consists of inputs representing the fuzzy inputs; and two outputs that are, the load forecast and the calculated error ratio.

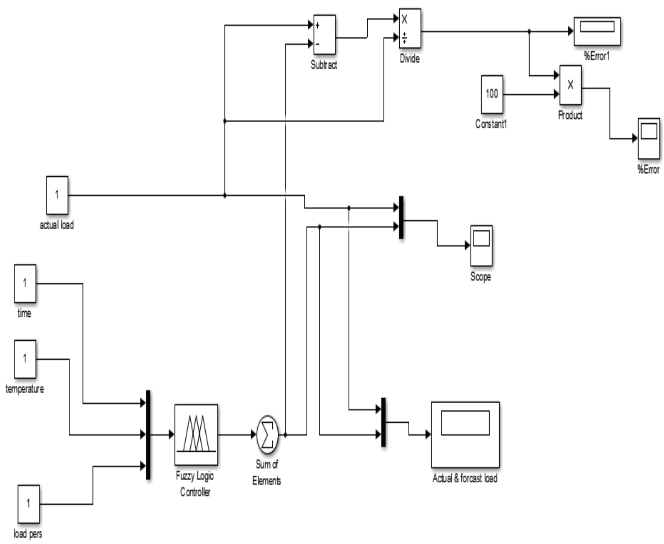

Figure 9: Simulink Model Design

This system works with temperature, time, and previous load, which affect the forecasted load. There are other parameters such as humidity and wind speed that affect the forecasted load but in Sudan, they can be neglected. This is because Sudan is in the hot region, and as such there were not any irregular values of the aforementioned parameters in previous years. The error ratio in the proposed forecast model was calculated by using Equation (2):

$$\%Error = [\ (AL - FL)/AL] \times 100 \quad (2)$$

where: AL = Actual load

FL = Forecasted load

The load forecast was performed for the day 3rd of February 2020. The obtained data of the actual load, that is, the previous similar day load and fuzzy forecast load for February 3rd, 2020, were presented as shown in Figure 10.

The load forecast was performed for the day 4th of February 2020. The obtained data of the actual load, previous similar day load, and fuzzy forecast load for February 4th were presented as shown in Figure 11.

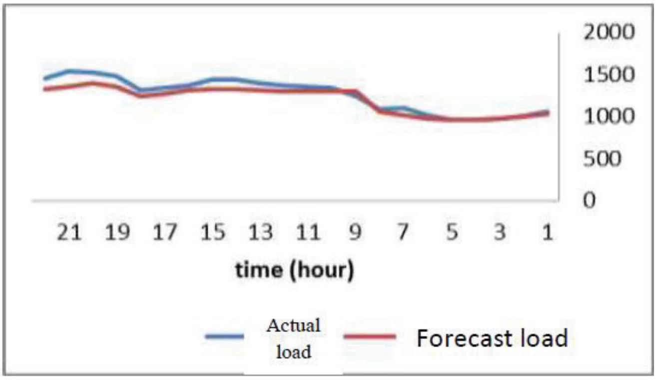

Figure 10: Load Curve of February 3rd, 2020

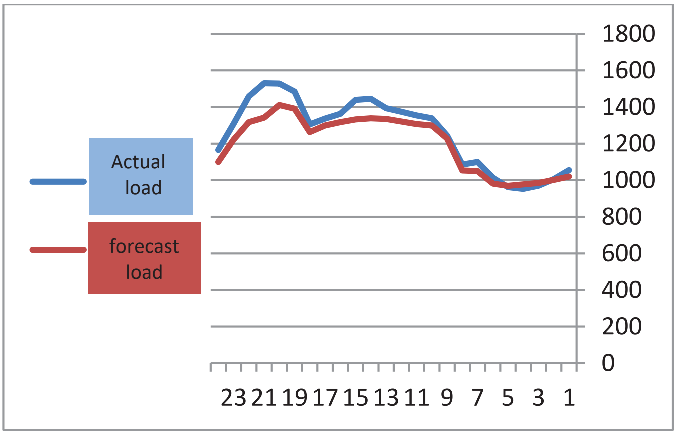

Figure 11: Load Curve of February 4th, 2020

The results obtained from the fuzzy logic were compared with the actual load forecasting and it gives an error ratio in the range of 12% and 0.0948%. Figure 11 and Figure 12 present the load curve for 3rd February 2020 and 4th February 2020 respectively. From the curve, it was observed that the fuzzy forecasted load curve is very close to the actual load curve.

The paper takes samples results from the day of 3rd

February 2020. The results show that at the time 03:00, the temperature was 30 ºC, and the load forecasting was low because there was no loading on the network, because of that reason the error ratio was relatively high 7.49%. At 12:00, the temperature was 38 ºC, and the load forecasting was high because this considered the rush time of the day, and the error ratio was low -0.76%. At 23:00, the temperature was 34 ºC, and the load forecasting is relatively high, and the calculating of the error ratio was 5.6%.

Similarly, the paper takes samples of results from the day of 4th February 2020. The results give that at the time 02:00, the temperature was 31 ºC, and the actual and fuzzy load forecasting is near to each other because of that reason the percentage error is relatively high 1%. At the time 13:00, the temperature was 40 ºC, and the actual and fuzzy load forecasting is not near to each other, and the percentage error is 5.56%. At 22:00, the temperature was 36 ºC, and the actual and fuzzy load forecasting was also not close to each other, and the error ratio was 9.39%.

The overall results show that the actual and fuzzy forecasted loads at the rush time between 12:00 to 13:00 provide a low error ratio. Also, in the day-night, the obtained results show that the comparison of actual and fuzzy forecasted had a relatively high error ratio.

IV. Conclusion

The study presents Mamdani based fuzzy logic control system for forecasting the electric load demand in power systems. This is because an accurate forecasted model is an essential tool in the management and planning of generation, transmission, and distribution of the electric load demand in each electric grid network. To that effect, this study used Mamdani-based fuzzy logic control to predict the futuristic load demand. Input parameters were collected and fed to the developed fuzzy logic control to forecast the load. The Simulink model was used to forecast the load and calculates the error ratio of the system. The overall results show that the proposed system gives highly accurate results.

V. Acknowledgment

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