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Electrical Load Estimation Based on Fuzzy Logic

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Abstract: The daily electrical load estimation is an essential mission of any power system. This procedure is necessary for system obligation, economical distribution of generation and maintenance time of electrical networks. In this study, we propose an electrical load estimation method using fuzzy inference system that gives more accurate results for the estimated loads. Also, it can serve the electrical power system generation that depend on some important parameters. These electrical loads parameters including temperature, humidity and speed of the wind are applied as inputs to the fuzzy logic system to obtain eventually the estimated load as output by utilizing suitable membership functions.

Key words: Fuzzy logic, membership function, Fuzzy Inference System (FIS), parameters, temperature, humidity

INTRODUCTION

Estimating the electrical load of power networks is very essential parameter to planning the generation, transmission and distribution of any electrical power system. The load estimation is an essential part of integrated process in the designing and operating of electric energy management systems in any country (Hammid *et al*., 2016; Moghram and Rahman, 1989). Any power generation scheduling needs information about loads connected to the electric power generator. These estimated information helps to avoid overloading, equipment failure occurrence and continuously assessing the power system security. There are many algorithms used to estimate electrical load, however, fuzzy logic is not used for the task of load prediction in similar approach of this study (Abboud *et al*., 2009). In this study, fuzzy logic is used to estimate electrical load because it is a solution to complicated problems in all life fields as it is similar to reasoning of human and making of decision (Abboud and Jassim, 2012; Abboud and Seleh, 2014). Fuzzy logic also, replies suspicions and mysterious points produced by language of human where everything cannot be labelled in accurate and separated expressions. In addition, fuzzy algorithms are often strong meaning that they are not very ticklish to changing which happen in environments rules and often have a briefer development time than traditional procedures (Abboud, 2011). With three inputs relying upon the climate information, first input is a temperature, second input is a humidity-percentage and the third input is wind-speed. All inputs have three Gaussian shape membership functions to obtain the estimated electrical load with three triangular membership functions and the output is suggested to be normalized in order to be used at any size of load and at any time for the estimated of load (Abboud and Jassim, 2012a, b). The time can be classified day by day, week by week, month by month, season after season or yearly.

Literature review: The following are the attempts of using fuzzy logic outcomes for electrical load estimating. The first attempt is decreasing the error of forecasted and the time of processing. The process includes function of Gaussian membership, if then rules and the operation of Fuzzy logic. Fuzzy focused on method of Short Term Load Forecasting (STLF) is used to a study of real case and shows the result that the STLF of the fuzzy influence has more accuracy and better results. Besides, the model of current Fuzzy STLF helps the economical case by decreasing error the prediction of load (Mamlook *et al*., 2009). In the second attempt researchers approach they tries to use fuzzy logic for short-term load prediction using Mamdani implication. The base of fuzzy rule is prepared depend on temperature, time and similar load in past day. So, for analysis we use the MATLAB Simulink Software. To predict of load, load data is token from the center of send the load in the region. This study summarizes that by using approach of fuzzy logic it is easy for the predictors to understand because it works on the easy “IF-THEN” statements. Functions of rectangular membership are used for both the input and output variables as well as It helps in decisions of unit commitment and maintenance of schedule device (Manoj and Shah, 2014; Abboud and Saleh, 2014). In third attempt, there’s a certain general algorithm explained

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using data gathered from residential sectors. It is summarized that this algorithm is able of predicting electrical load with so high accuracy even with predication is done on a larger data size. The outcomes gained by the suggested fuzzy technique proved to be excellent to traditional techniques in forecasting long-term load accurately (Hammid, 2013; Pujar, 2010; Abboud, 2015a).

By Pujar (2010) and Abboud (2015a, b) capital Gross Domestic Product (GDP) and population are taken as input variables and the expected electricity consuming is taken as an output variable. To foretell the annual electricity requirement in India, fuzzy decision tree is applied. Past 30 years of historical data has been used for exercise and 4 years of data is used for testing the fuzzy decision tree. The outcomes case suggested that decision tree model has given high performance and less error rate than the artificial neural network model (Hammid *et al*., 2017a, b; Tale *et al*., 2017). The researchers proposed to adopt a methodology for short-term load forecasting over the network and intermittent neural network of the time series, the high-energy consumption load was the steel factory, to implement the load forecasting related to the factory of their own production within the 12 days. The results obtained effectively solve the problem of decreased forecasting accuracy due to some factors caused by high power consumption companies (Hammid *et al*., 2013; Li *et al*., 2015). A work discussed on short-term load forecasting for the holidays. The purpose is to present different models using fuzzy logic without weather information. The data between 2009 and 2011 are used to design this work. This work was done by the MATLAB program by developing and checking two models for each holiday, each model has 3 inputs and one output with historical data from past years, inputs were the consuming data from last week and the type of holidays. The results were clear that the second model was better than the first In terms of accuracy of prediction and Absolute Percentage Error (MAPE) values (Cevik and Cunkas, 2016; Hammid, 2016). After 18 years study, starting from (1997-2014) for the purpose of reaching the pre-load forecast for the long term with the least linear technology, data were taken from the Amritsar substation, mathematical equations along with fuzzy logic methodology was used. The interpolation techniques have been taken into account. It is found that minimum percentage error happens in S-curve equation and maximum percentage error happen in parabola equation. It is also observed that S-curve method is best suited for conducting accurate load forecasting using fuzzy logic (Hammid *et al*., 2017a, b).

Fuzzy logic system: Fuzzy logic is similar to the way human being interpret ideas. It has the possibility of gathering heuristics of human into computer-assisted making of decision because it is a multi-valued logic (Al-Assam *et al*., 2011a). Fuzzy logic system suitable for additional tasks compared to classical form of logic. They were first developed in set theory. The “Fuzzy set” has been utilized to expand classical sets. This addition allows a level of flexibility for representation (Al-Assam *et al*., 2011b). This quality is realized by membership functions which give fuzzy sets the ability of modeling in linguistic form. Fuzzy logic can be a novel route for realizing and making a decision by considering imprecise information in which verity can have a value between 0 and 1 (Zadeh *et al*., 1996). This process is called as fuzziness: so, fuzziness comes from the uncertain and imprecise nature of conceptual criteria and aspects. Fuzzy logic deals with a form of thinking using specific mathematical formulas which provides results based on a group of IF-THEN rules. It is best way to describing the behavior of systems which are ambiguous to be matching with precise mathematical analysis in contrast to the traditional systems that cannot deal with inaccuracy or lack in information (Al-Assam *et al*., 2012). Fuzzy logic system is basically based on IF-THEN rules according to the following terms: fuzzification, rule base, fuzzy inference and fuzzification. A general fuzzy system is shows in (Fig. 1) (Rai *et al*., 2012).

Fuzzy logic is considered fuzzy inference system which helps in making decision depending on input parameters. Approximate reasoning is also, another name of fuzzy reasoning which is the results conclusion process from Fuzzy sets and their basics (Hammid Sulaiman, 2017). Fuzzy Inference System (FIS) is a framework founded on fuzzy basics, fuzzy sets and fuzzy logic (Albu-Rghaif *et al*., 2018). In this study, fuzzy logic system is employed to making decisions to estimate

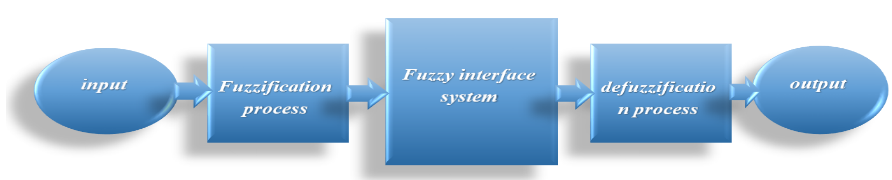

Fig. 1: Fuzzy logic system

electrical loads. These predicted loads are mostly vague and constantly changing with three important parameters including temperature, humidity degree and wind speed. The usage of these parameters give better performance of error free delivery of data to electrical networks.

MATERIALS AND METHODS

The proposed fuzzy logic based system to estimate electrical load is described in Fig. 2. This system is controlled by fuzzy logic system to decide the type of estimated load (under average, average and over average) depending on the values of the input parameters temperature, humidity-percentage and wind-speed.

In the proposed system the incoming inputs pass through the fuzzy inference system as shows in Fig. 3 to decide the estimated load by using rules in Fuzzy Inference System (FIS) in aim to obtain the best estimation. Table 1 and 2 are used to describe fuzzified input parameters of Iraq and Egypt countries as a universe of discourse which are considered in this study after applying fuzzy inference system of type Mamdani. Table 1 shows the range of input parameters temperature (0-55°C), humidity percentage (0-75%) and wind-speed (0-75 km/h) of Iraq country while Table 2 shows the range of input parameter of temperature (-10-50°C), humidity percentage (0-100%) and wind-speed (0-90 km/h) of Egypt country.

Table 1: Iraq inputs and their range values

Input	Range
Temperature	0-55°C
Humidity percentage	0-75%
Wind speed	0-75 km/h

Table 2: Egypt inputs and their range values

Input	Range
Temperature	-10-50°C
Humidity percentage	0-100%
Wind speed	0-90 km/h

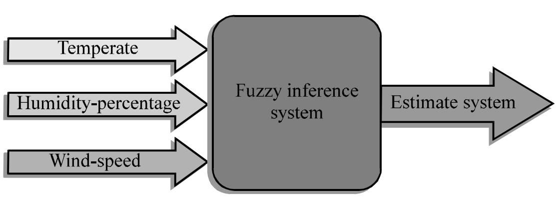

Fig. 2: Load estimation based on fuzzy system

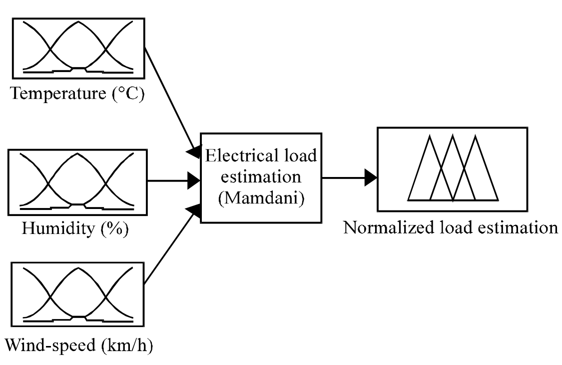

Fig. 3: Fuzzy inference system

RESULTS AND DISCUSSION

Experimental results of the proposed fuzzy system are modeled with three input fuzzy parameters and one normalized output fuzzy parameter as shows in the Fig. 4-7. The vertical axis in all these figures represents the degree of membership in the input or output parameter fuzzy functions in the range [0-1] while the horizontal axis represents only the input or output fuzzy parameter. The first input represents temperature with range (-10-60°C) as shows in Fig. 4. The second input represents the

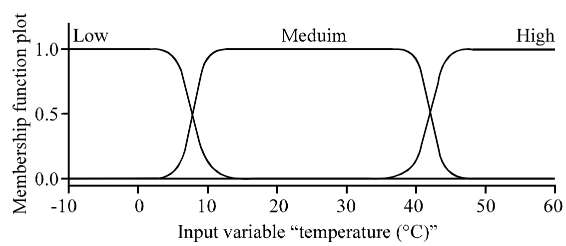

Fig. 4: Membership functions of temperature (Plots points: 400)

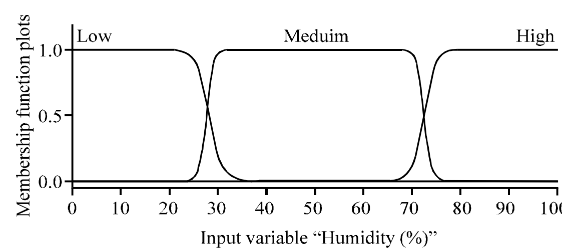

Fig. 5: Membership functions of humidity (Plots points: 400)

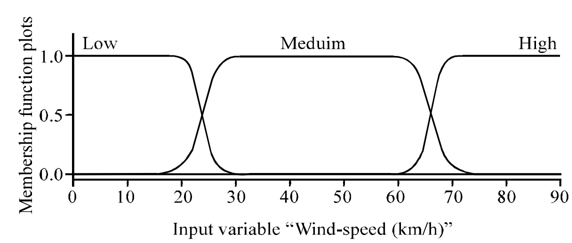

Fig. 6: Membership functions of wind-speed (Plots points: 400)

humidity percentage with range (0-100%) as shows in Fig. 5. The third input represents the wind speed with range (0-90 km/h) as shows in Fig. 6. The estimated load as shows in Fig. 7 is obtained from combination of these three input parameters. Each one of these three inputs and normalized output is represented in a three bell shape membership functions. These functions are named low, medium and high, respectively. The low membership function is used for low input range values of input parameter while medium membership function is used for medium values of input parameter. Lastly, high membership function is used for high values of input parameter. Furthermore, we have to mention that MATLAB Software gives different background colors for

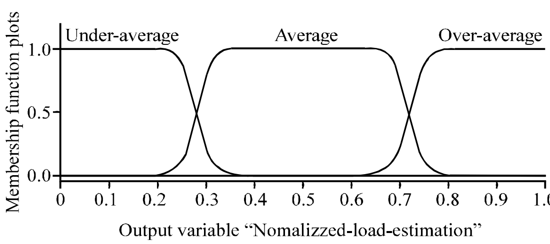

Fig.7: Membership functions of normalized output (Plots points: 400)

input and output fuzzy parameters and also it sets the number of points for plot resolution as shown in the top right corner of the plot with the number (400).

The range values of input parameters already exist in the global universe while the estimated electrical load output is normalized to make fuzzy inference system flexible to use as shows in Fig. 7. The output fuzzy parameter also has three bell shape membership functions. These functions are named under-average, average and over-average respectively. The under-average membership function, represents the lowest estimated consumed electrical load while average membership function indicates that the modest serviced electricity to the consumers in terms of consumed power. However, over-average membership function refers to the highest consumed amount of electricity (or load).

Figure 8-10 shows the rules, rule viewer and surface viewer of FIS for Iraq country. An example of IF-THEN fuzzy rules to predict the electrical load is shows in Fig. 8. The maximum number of fuzzy rules that can be deployed at any time in the FIS is 36 rules. Another representation of these rules is illustrated in Fig. 9. Also, the surface view of the FIS that includes the input and output parameters is shows in the Fig. 10. These figures assert that the FIS can estimate the real electrical load accurately based on

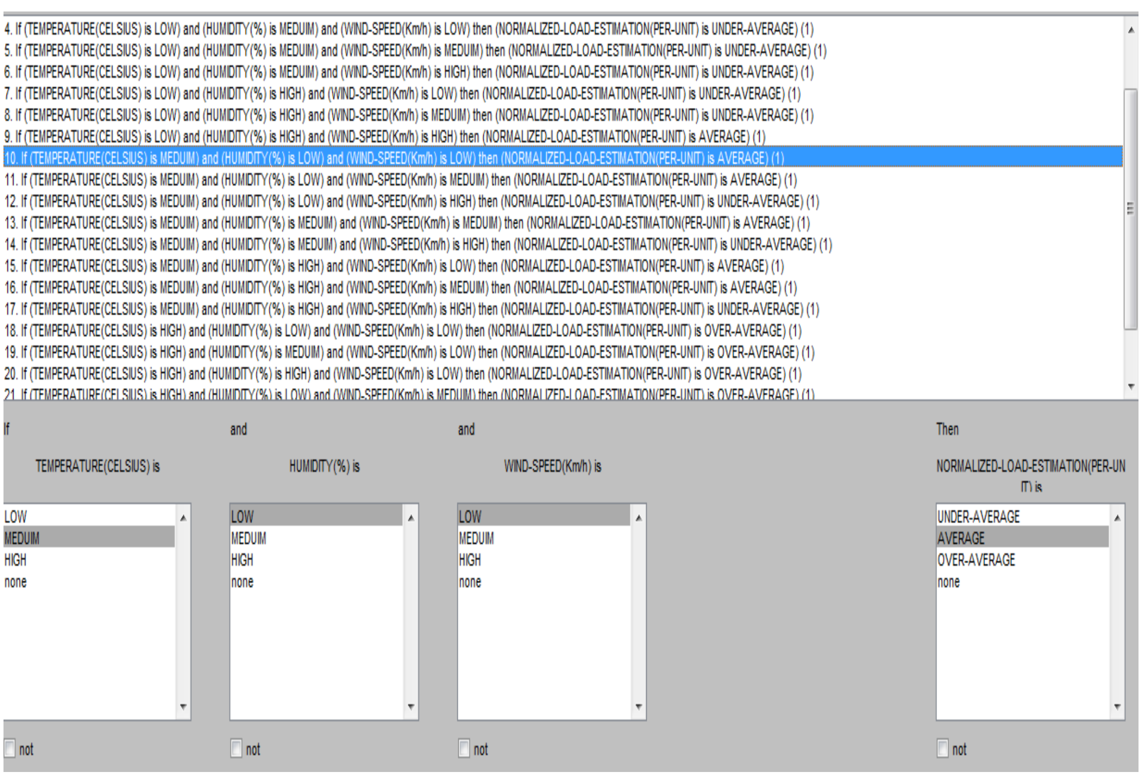

Fig. 8: Rules of fuzzy inference system (Iraq)

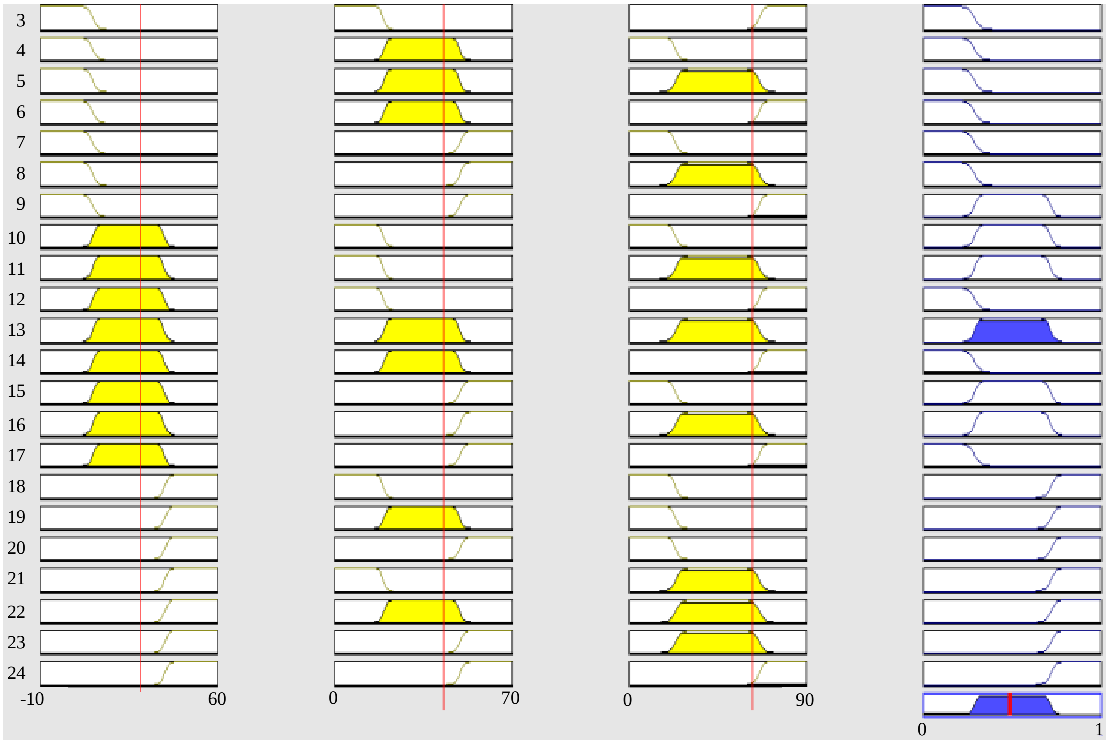

Fig. 9: Rule viewer of fuzzy inference system (Iraq)

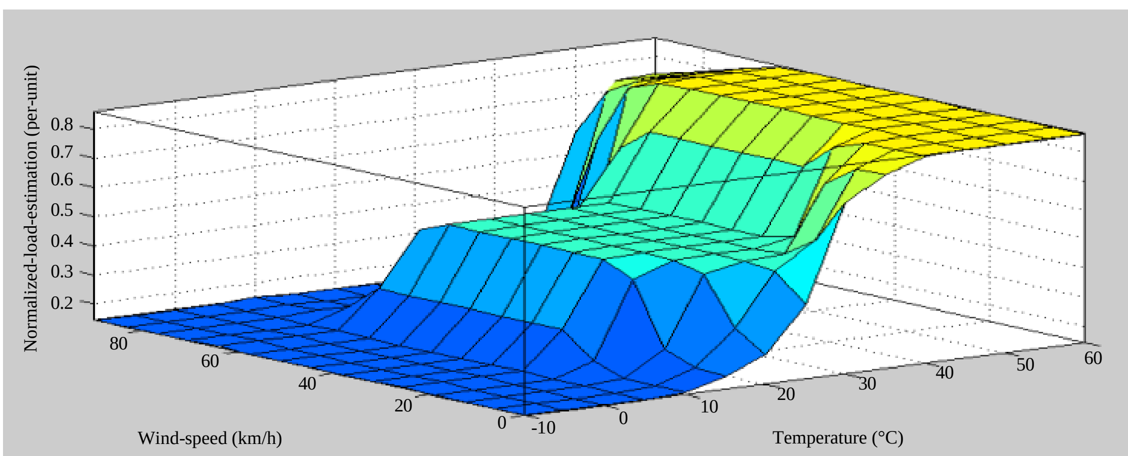

Fig. 10: surface viewer of fuzzy inference system (Iraq)

the precise values of input parameters to the fuzzy system. For example, in Fig. 8 the rule number 13 estimate that the load is average based on the temperature value is medium and humidity is medium and wind speed is medium. We can clarify this rule that if environmental conditions are almost good then the consumed power is almost average.

Figure 9 shows the fuzzy rules in the row form where each row represents a group of fuzzy inputs and single fuzzy output. There are 3 key colors in this figure which are the yellow, blue and red colors. The yellow color is used to represent the input parameters of temperature, humidity and wind speed while the normalized estimated electrical load is represented by blue color. Finally, the red line that cross each input column (yellow color) represents a certain value within these fuzzy input parameters while the red line that cross the output (blue color) gives the specific value of estimated electrical

3. If (Temperature(Celsius) is Low) and (Humidity(%) is Medium) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Under-Average) (1)
4. If (Temperature(Celsius) is Low) and (Humidity(%) is Medium) and (Wind-Speed(km/h) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Under-Average) (1)
5. If (Temperature(Celsius) is Meduim) and (Humidity(%) is Low) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
6. If (Temperature(Celsius) is Meduim) and (Humidity(%) is Low) and (Wind-Speed(km/h) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
7. If (Temperature(Celsius) is Meduim) and (Humidity(%) is Low) and (Wind-Speed(km/h) is High) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
8. If (Temperature(Celsius) is Meduim) and (Humidity(%) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
9. If (Temperature(Celsius) is Meduim) and (Humidity(%) is High) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
10. If (Temperature(Celsius) is Meduim) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
11. If (Temperature(Celsius) is Meduim) and (Wind-Speed(km/h) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Average) (1)
12. If (Temperature(Celsius) is High) and (Humidity(%) is Low) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
13. If (Temperature(Celsius) is High) and (Humidity(%) is Low) and (Wind-Speed(km/h) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
14. If (Temperature(Celsius) is High) and (Humidity(%) is Low) and (Wind-Speed(km/h) is High) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
15. If (Temperature(Celsius) is High) and (Humidity(%) is Medium) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
16. If (Temperature(Celsius) is High) and (Humidity(%) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
17. If (Temperature(Celsius) is High) and (Humidity(%) is High) and (Wind-Speed(km/h) is Low) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
18. If (Temperature(Celsius) is High) and (Humidity(%) is High) and (Wind-Speed(km/h) is Medium) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
19. If (Temperature(Celsius) is High) and (Humidity(%) is High) and (Wind-Speed(km/h) is High) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)
20. If (Temperature(Celsius) is High) then (Normalized-Load-Estimation(Per-Unit) is Over-Average) (1)

Fig. 11: Rule viewer of fuzzy inference system (Egypt)

load within fuzzy output parameter. There is also another 3D surface color graph generated by MATLAB Software that show the relationship among input parameters (on X and Y axes) and normalized output (on Z axis) as shown in the Fig. 10. There are 5 key colors in this figure which are the blue, light blue, aqua, lime and yellow colors. We can notice that gradual change in the color (i.e., light blue) from blue to aqua represents the interference between the two region of fuzzy membership functions of output (under-average and average) while the gradual change in the color (i.e., lime) from aqua to yellow represents the interference between the two region of fuzzy membership functions of output (average and over-average). The choice of one of them will depend on the highest value of membership functions at certain values of inputs. Also, we can notice form this figure that the consumed power increase gradually with the increase of the input parameters especially the temperature. Also, the temperature and wind speed represents the most important input fuzzy parameters in Iraq country. Where the blue color in the surface graph indicates that if temperature and wind speed values in the low range then the amount of consumed power in the under-average range however yellow color in this surface graph refers to the highest amount of consumed power in the over-average range with the highest values of input parameters. In addition, the green color in this surface graph refers to the average consumed amount of power whenever input fuzzy parameters have medium range values.

Figure 11-13 shows the rules, rule viewer and surface viewer of FIS for Egypt country. An example of IF-THEN fuzzy rules to predict the electrical load is shows in Fig. 11. The maximum number of fuzzy rules that can be deployed at any time in the FIS is 36 rules. Another representation of these rules is illustrated in Fig. 12. Also, the surface view of the FIS that includes the input (on X and Y axes) and output (on Z axis) parameters is shown in the Fig. 13. These figures assert that the FIS can estimate the real electrical load accurately based on the precise values of input parameters to the fuzzy system. For example, in Fig. 11 the rule number 16 estimate that the load is over average based on the temperature value is high and humidity is medium. We can clarify this rule that if environmental conditions are bad then the consumed power is very high.

Figure 12 shows the same fuzzy rules (same rule 16) in the row form where each row is group of fuzzy inputs and single output. There are three key colors in this figure which are the yellow, blue and red colors. The yellow color is used to represents the input parameters of temperature, humidity and wind speed while the normalized estimated electrical load is represented by blue color. Finally, the red line that cross each input column

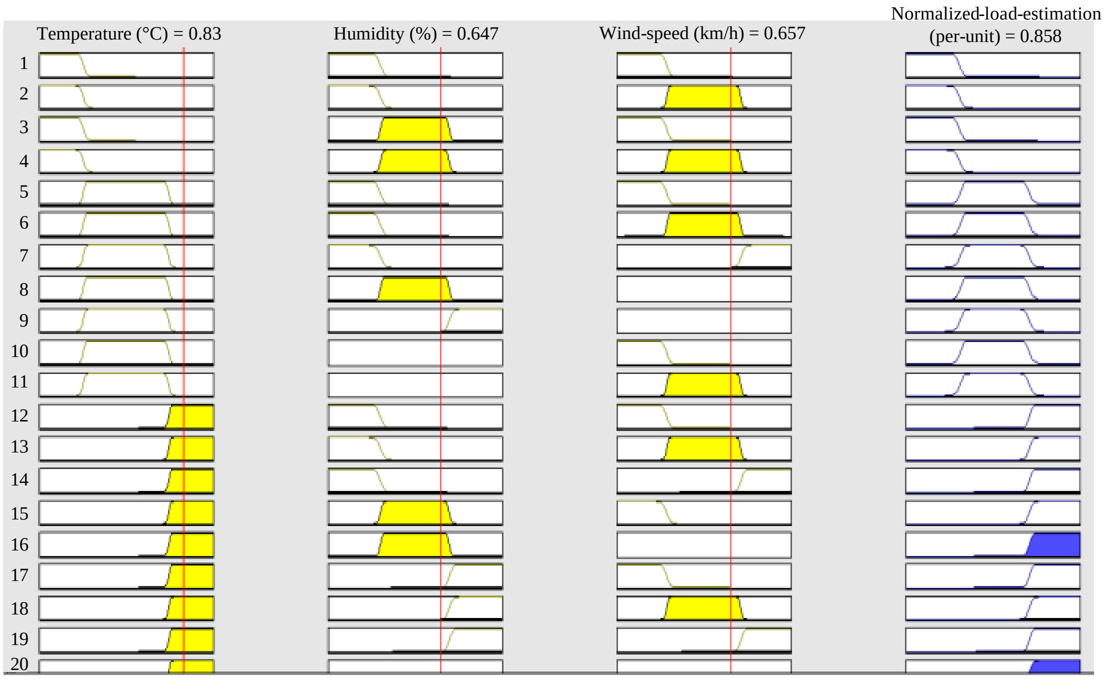

Fig. 12: Rule viewer of fuzzy inference system (Egypt)

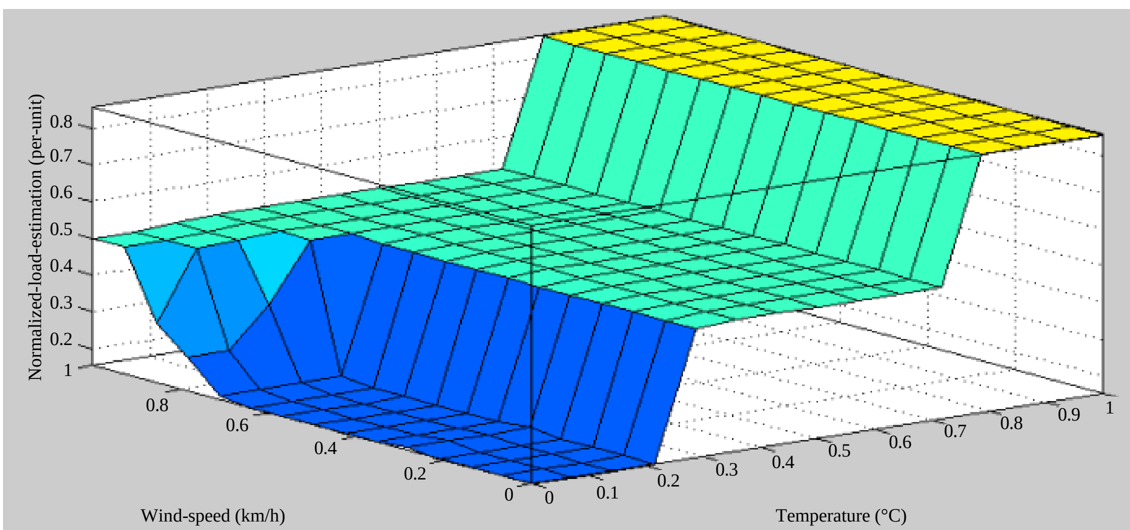

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Fig. 13: Surface viewer of fuzzy inference system (Egypt)

(yellow color) represents a certain value within these fuzzy input parameters while the red line that cross the output (blue color) gives the specific value of estimated electrical load within fuzzy output parameter.

There is also, another 3D surface graph that show the relationship among input parameters and normalized output as shown in the Fig. 13. There are three key colors in this figure which are the blue, aqua and yellow colors. We can notice that gradual change in the color from blue to aqua represents the interference between the two region of fuzzy membership functions of output (under-average and average) while the gradual change in the color from aqua to yellow represents the interference between the two region of fuzzy membership functions of output (average and over-average). The choice of one of them will depend on the highest value of membership

Table 3: Comparison between real and estimated load of Diyala Governorate in Iraq

Months	Real load	Estimated load
January	Under average	Under average
February	Under average	Under average
March	Under average	Average
April	Average	Average
May	Over average	Average
June	Over average	Over average
July	Over average	Over average
August	Over average	Over average
September	Over average	Over average
October	Over average	Over average
November	Average	Average
December	Under average	Under average

functions at certain values of inputs. Also, we can notice from this figure that the consumed power increase gradually with the increase of the input parameters especially two more effective inputs temperature and wind-speed. Also, the temperature and wind speed represents the most important input fuzzy parameters in Egypt country. Where the blue color in the graph indicates that if temperature value in low range (0-0.2) and wind speed high range (0-0.7) then the amount of consumed power is in average range however aqua color in this surface graph refers to the highest amount of consumed power in the over-average with the highest values of input parameters. In addition, the yellow color in this surface graph refers to the average consumed amount of power whenever input fuzzy parameters have medium range values.

We noticed from the results presented in the earlier figures that there is a linear relationship between input parameters (temperature, humidity, wind speed) and normalized output (estimated electrical load). In other words, if the input parameters have low values then the electrical load in under average. Also, if these parameters have medium values then the consumed electrical power is almost average. Lastly, if these parameters have high values then the amount of consumed power is over average. Hence, the fuzzy system will try to obtain best suitable performance of the electrical power system. To verify the efficiency of our work, we got a real electrical load of Diyala governorate in Iraq for the year (2017) and we compared it with the estimated load predicted by our algorithm. The results of this comparison is shown in Table 3.

As shown from the results in Table 3 that the accuracy of electrical load estimation is 83.33%. in addition, we have another practical case study by recording the daily consumed currents in the sector of Diyala governorate of Iraq in the range of [150 A (as minimum) to 250 A (as maximum)]. These readings are compared with estimated current by applying our fuzzy algorithm taking into account the three input parameters

Table 4: Comparison between real and estimated load for a selected sector in Diyala Governorate in Iraq

Time (h)	Real current (A)	Estimated current (A)
0-1	200	190
1-2	190	185
2-3	175	180
3-4	150	160
4-5	150	155
5-6	170	165
6-7	190	180
7-8	200	190
8-9	200	200
9-10	200	195
10-11	190	195
11-12	190	185
12-13	190	190
13-14	210	205
14-15	220	215
15-16	240	230
16-17	250	260
17-18	250	255
18-19	240	250
19-20	230	240
20-21	220	220
21-22	210	210
22-23	210	200
23-24	200	205

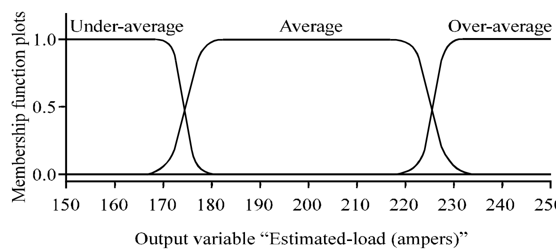

Fig. 14: Membership functions of estimated electrical load output

after modifying the normalized output to the values of real consumed currents starting with minimum current of (150 A) and ending with maximum current of (250 A) as shown in Fig. 14.

From the results Table 4 that comparing the real and estimated load for a selected sector in Diyala Governorate in Iraq, we concluded that the maximum error between the real and estimated values is about 5%. These results mean that the accuracy of estimation increased when applying the algorithm for shorter period of time.

CONCLUSION

The electrical load estimation is extremely helpful tool to manage any electrical power system. The management means that the estimation system should take in account all the parameters specially in countries face problems in power system organization like the cases studied in simulation to offer additional parameter to reach to optimum performance trying to solve the electrical power suppling issue.

RECOMMENDATION

As a future research will use another artificial intelligence training algorithm like back propagation algorithm mixed with fuzzy logic system to design intelligent controller to obtain adaptive system for electrical load estimation.

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