Fuzzy Expert System for Electric Energy Consumed Prediction in Arab Gulf Countries

Abstract

This research gives an overview of using fuzzy logic with traditional expert system to design a fuzzy expert system for the determination of electric energy consumed prediction in Arab Gulf countries according to some economic indicators.

The purpose of this paper is to design a fuzzy expert system for modeling the system behavior of electric energy consumed prediction and to indicate the factors which effect the consumed electric energy such as the population and the electric energy generators. This paper explained the Mamdani model which is used in the purposed system.

The proposed fuzzy expert system is used for computing the future demand of the electric energy consumed in Arab Gulf countries . To show the effectiveness of the proposed fuzzy expert system it is compared with another traditional mathematical method. The proposed method gives a close result compared with the normal mathematical method.

استخدام نظام خبير مضبب لتحديد توقعات الطلب على الطاقة الكهربائية في دول الخليج العربي

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الملخص :

يقدم البحث دراسة حول استخدام المنطق المضبب مع الأنظمة الخبيرة التقليدية لتصميم نظام خبير مضبب لتحديد توقعات الطلب على الطاقة الكهربائية في دول الخليج العربي وفق بعض المؤشرات الاقتصادية مثل إنتاج الطاقة الكهربائية وعدد السكان .

تستعرض هذه الدراسة مفهوم نظرية المنطق المضبب واستخداماتها في الأنظمة الخبيرة ، كما تستعرض نموذج (Mamdani) الذي استخدم في النظام المقترح . وقد تم مقارنة النظام مع نتائج الطريقة الرياضية التقليدية التي يستخدمها الاقتصاديون عادة " وقد أعطت نتائج دقيقة ومتقاربة مما يعني أن النظام طريقة جديدة وكفوءة يمكن اعتمادها في الأنظمة الخبيرة الاقتصادية.

The purpose of the research:

The aim of this paper is to design a fuzzy expert system to determine the predication of electric energy consumed in Arab Gulf countries. The proposed fuzzy expert system is composed of two levels, on the first level the system reads the selected economic factors which effected the electric energy consumed. One of these factors is the population and the second factor is the electric energy generators, and then the electric energy consumed prediction is computed by using fuzzy logic theory which is power full to have a good result from ambiguity and uncertainty data. On the second level , the system gives special reports for the electric energy consumed which are computed by the program. The suggested system was designed by the use of Prolog language because of the flexibility in dealing with the symbolic data and back tracking, to facilitate the search in the data base. To show the effectiveness of the proposed system the performance of the fuzzy expert system model is compared to another traditional mathematical method.

Introduction

The term Artificial Intelligence and Expert system are sometimes used synonymously. Artificial Intelligence (AI) is a generic term which covers a very broad range of computer

applications that mimic human intelligence and/or behavior. One of the major elements in any AI system is the ability to reason. [1]

Expert system and other areas of AI were introduced to solve power system operation planning and control problems. Expert systems are typically based on utilizing domain expert's knowledge. It is frequently difficult to make expert systems work efficiently because crisp representation of human empirical knowledge is usually expressed in natural languages and contain inherently uncertain flexibility [2].Fuzzy methods represent cases with any combination of words and numbers and thus enable us to "compute with words".The general idea with fuzzy logic systems is to create a framework where computer programs can use that kind of knowledge to reason and act intelligently. [3]. Fuzzy logic is an established methodology that is widely used in thousands of applications in areas such as: transportation, automobiles, consumer, agriculture, medicine, management, and education[4] .

2- Fuzzy Logic

In 1965, Lotfi Zadeh suggested his theory of sets [5]. Fuzzy logic is an application area of fuzzy set theory. It utilizes concepts, principles, and methods developed within fuzzy set theory for formulating various forms of sound approximate reasoning. In order to utilize the apparatus of fuzzy set theory for approximate reasoning , it is necessary to establish a connection between the degree of membership in fuzzy sets and the degree of truth of fuzzy propositions.[6]

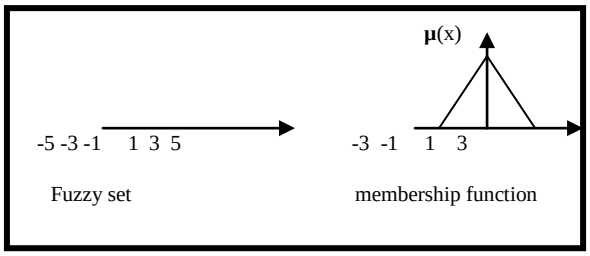
Zadeh proposed a set membership which was defined not on the finite two-value set {0,1} but rather over the real interval [0,1]. Set elements can still take old characteristic values or membership values of 0 and 1 but they can also now take 0.7 or 0.34 indicating partial set membership or a degree of membership. This fuzzy set can be described by different denoted **μ**A(x) and taking values in [0,1].[7]

A fuzzy set A in the universal set U is a set of ordered pairs of generic element u and its membership degree **μA(u) as:**

A= { (u. **μA(u))/u** ∈ **U}** ……..(1)

A fuzzy set definition is similar to crisp set one .To determine crisp set we name all the elements of the universe which belong to the set A. In a fuzzy set we name all the elements of the defined fuzzy set.

Actually, a fuzzy set is given by its membership function. The value of this function determines if the element belongs to the fuzzy set and in what degree. As shown in fig (1):[8]



Fig(1) Definition of fuzzy set

Under this correspondence, operations of negation, conjunction and disjunction on fuzzy propositions are defined in exactly the same

way as the operation of complementation, intersection, and union of fuzzy sets, respectively. [9].

The benefits of fuzzy set theory over traditional methods are as following [10]:

- Provides alternatives for the many attributes of objectives selected.
- Resolves conflicting objectives by designing weights appropriate to a selected objective.
- Provides the capability for handling ambiguity expressed in diagnostic process.

Fuzzy logic is an established methodology that is widely used to model systems in which variables are continuous , imprecise, or ambiguous. Fuzzy logic is used in thousands of applications, in areas such as : transpiration, automobiles, consumer electronics, robotics, computers, telecommunications, agriculture, medicine, management, and education. [11].

3-Fuzzy Expert System

An expert system is a computer program that simulates the judgment and behavior of a human and organization that has expert knowledge and experience in a particular field.[12]The expert system comprises three major modules as follows, (1) Knowledge base (2) Inference engine and ((3) User Inference.[13]

One of the first scientists who created such system was E. Mamdani who was constructing a controller for steam engine. [14] A FLS of Mamdani type is sketched in fig. (2):

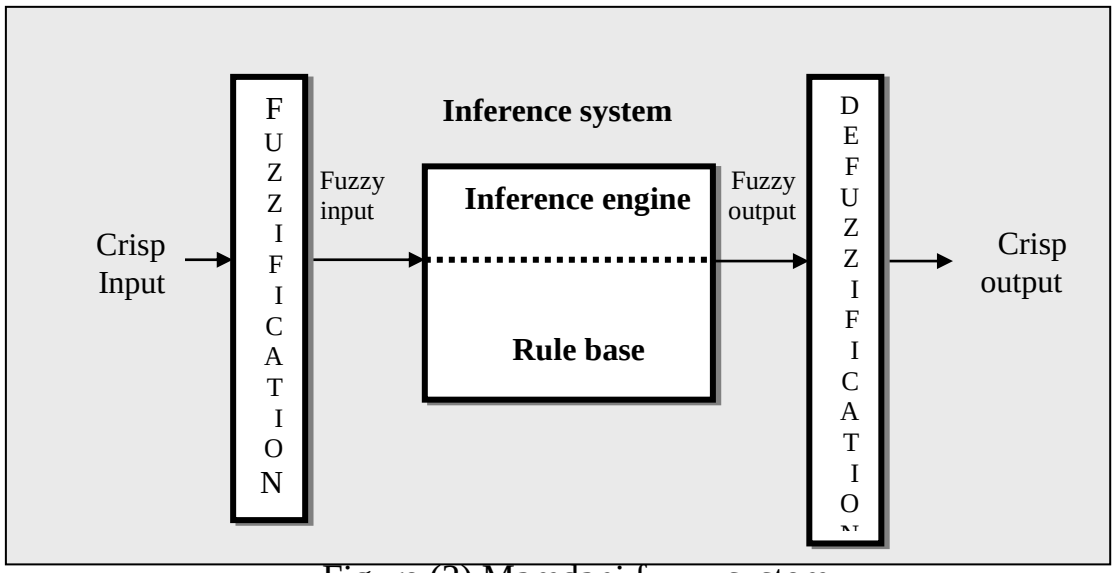


Figure (2) Mamdani fuzzy system

In fig (2) the three basic component of Mamdani fuzzy system are shown:

- The fuzzifier
- Inference system
- The defuzzifier

A mamdani fuzzy system is constructed in order to work with crisp inputs. It takes one or more real valued inputs and transform them into fuzzy sets that are then propagated to the inference system where the actual computation is performed. The rule base, where expert knowledge is contained , is combined with the input and an output for each rule in rule base and produced by the inference engine. These outputs from a fuzzy set which is

transformed into a crisp value by the defuzzifier part. This crisp value is the output of the FLS. [15]

4- Fuzzy Expert System for Electric Energy Consumed Prediction

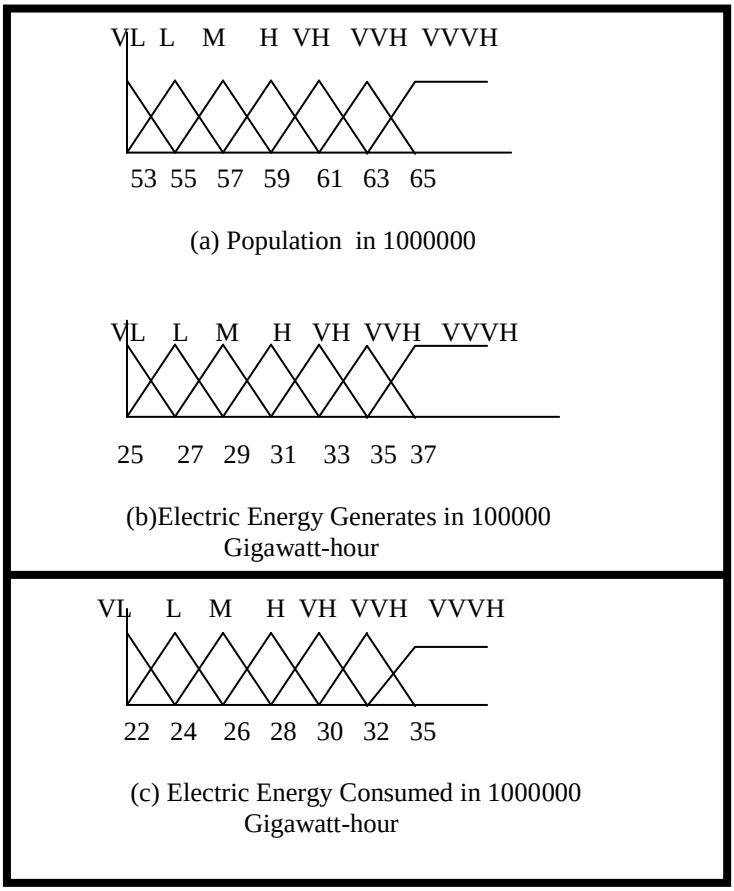
4-1 Approximate reasoning

Electricity plays a critical role as an "energy carrier," meaning that its main function is to deliver energy to users in a more usable form than the primary energy resources used to produce it. Because of its convenience and versatility, electricity use is growing at a faster rate than any other form of energy.

There are, however, issues related to electricity consumption that has important implications on energy planning. Electricity is generated from other fuels, including coal, oil, natural gas etc., and is delivered to consumers through an extensive transmission and distribution system. Converting fuels into electricity involves large losses of energy at power plants. On average, about 70% of the energy in the fuels used to generate electricity is lost. Much smaller amounts of energy are lost in transmission and distribution to customers. The sum of these losses is an important factor in developing recommendations to improve the efficiency of electrical appliances and equipment. [16]

There are many factors which affected the increment of Electric Energy Consumed in Arab Gulf Countries such as the increment in the population growth average, the low cost of

Electricity unit for the consumers, and the expansion in economic fields. The aim of this study is to develop an expert system for modeling the system behavior of electric energy consumed prediction and determining the factors which affected the electric energy consumed by the population and electric energy generates. The system made its decisions by using linguistic variables (very low (vlow), low, medium, high, very high ,vveryhigh)for naming the fuzzy sets, this process is called approximate reasoning. This process mimics the human expert's reasoning process much more than the conventional expert systems. Using The Triangle function to build a fuzzy set is shown in fig (3a-b). First fuzzy sets are for the population in ARAB GULF COUNTRIES and second fuzzy sets for Electric Energy Generated in ARAB GULF COUNTRIES. We try to build a system that can help us in making a recommendation on Electric Energy Consumed in ARAB GULF COUNTRIES as shown in fig (3-c) .



Fig(3) Fuzzy sets

The length of the set was discrete by depending on the tables [1], [2], and [3] which are based on the expert's experience in economics [17].

Table No. (1)
Population in ARAB GULF Countries
In Thousand

Year / *Countries*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
UAE	3247	3488	3754	4036	4368	4712
Bahrain	638	655	672	690	708	727
S.Arabia	20474	20976	21491	21983	22529	23067
Iraq	24086	24813	25565	26340	27138	27960
Qatar	571	579	618	636	667	693
Kuwait	2228	2243	2363	2484	2645	2798
Oman	2402	2478	2538	2341	2416	2493
(Summation) Arab Gulf Countries	53646	55232	57001	58570	60471	62450

Ref: www.oapecorg.org., p.p 134

Table No. (2)
Electric Energy Generated in Arab Gulf Countries
Giga watt-hour

Year / *Countries*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
UAE	39944	43172	46856	49450	52417	60698
Bahrain	6297	6779	7278	7715	8178	8698
S.Arabia	126191	133647	144702	149767	156506	176124
Iraq	31900	32251	33863	34000	34000	34000
Qatar	9735	10222	10733	11160	11718	13238
Kuwait	30617	31536	33112	34105	35639	39500
Oman	8915	9450	9912	10320	10836	11485
(Summation) Arab Gulf Countries	253599	267084	286456	296456	309294	343743

Ref: www.oapecorg.org. ,p.p 135

Table No. (3)
Electric Energy Consumed in Arab Gulf Countries
Gigawatt-hour

Year / *Countries*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
UAE	37866	38406	42104	44419	47084	53874
Bahrain	5515	5931	6455	6810	7185	7897
S.Arabia	114161	122944	128629	132488	138450	153284
Iraq	29160	30035	31537	32000	32000	32000
Qatar	8765	9116	9571	9954	10452	10700
Kuwait	27374	28195	29605	30937	32174	35000
Oman	6698	69166	7314	7607	7949	8800
(Summation) Arab Gulf Countries	229539	241593	255215	264215	275294	301555

Ref: www.oapecorg.org., p.p 136

4-3 Scaling factors

To choose membership functions, first of all one needs to consider the universe of discourse for all linguistic variables, applied to the rules formulation. To specify the universe of discourse, one must firstly determine the applicable range for a characteristic variable in a context of the system designed. The range is too large and necessary to scale, or normalized . Normalization means applying the standard range of {-1,+1} for the universe of discourse both for the input and the output. [18]

A scalar factor is used to normalize the input and output universe discourse, for example when population =53646 and Electric energy generate= 253599 then:

X1 = scalar factor * (X – set point) ……..(2)

Population1= 0.00005 * (53646-53000)

= 0.0323

Electric generates1= 0.000005 * (253599-250000)

= 0.017995

4-3 Fuzzy rules

The approximate reasoning is implemented through fuzzy rules. Since the proposed fuzzy system is comprised of two variables each one consist seven fuzzy sets, it is a 2 x i (a "two-by-one") .That means there are two input variables and one output variable. The system as such is a matrix of solutions in an M*N array which include 49 fuzzy rules called Fuzzy Associative Memory (FAM). Table (4) shows FAM for the proposed fuzzy system The terms(vlow, low,medium,high,vhigh,vvhigh,vvhigh) are the names of fuzzy sets which are indicated in fig.(3), these sets were divided according to table (1),(2) and (3), from the summation of population , the electric energy generated , and the electric energy consumed in Arab Gulf countries.The matrix of the rules is arranged according to the results of summation as a range of the distributed fuzzy sets indicated in fig(3).

Population / E-generated	Vlow	Low	mediu m	High	Vhihg	vvhigh	VVVhig h
Vlow	Vlow	VLow	Mediu m	Low	High	High	VVhigh
Low	Vlow	Vlow	Mediu m	Mediu m	Vhigh	vhigh	Vvvhigh
Medium	Vlow	Vlow	Mediu m	Mediu m	Vvhigh	vvhigh	Vvvhigh
High	Low	Mediu m	High	High	Vvhigh	Vvvhigh	Vvvhigh
Vhigh	Medui m	Vhigh	Vhigh	Vhigh	Vvhigh	Vvvhigh	Vvvhigh
Vvhigh	High	Vvhigh	Vvhig h	vvhigh	Vvvhigh	Vvvhigh	Vvvhigh
VVVhigh	Vhigh	Vvhigh	VvVhi gh	Vvvhi gh	Vvvhigh	Vvvhigh	Vvvhigh

Table (4) Fuzzy Associative Memory (FAM)

Table (4) indicates that the rules are used in the system to get the output (Electric Energy Consumed) from two inputs (population) and (Electric Energy Generated). The fuzzy rules of rule base are implemented according to the following form:

Rule (population, Electric Generated, Electric Consumed),

For example, the rules are as follows:

R1: if population is Vlow and E-Generated is Vlow then E-Consumed isVlow

R2: if population is Vlow and E-Generated is Vlow then E-Consumed isVlow

R3: if population is Vlow and E-Generated is Vlow then E-Consumed isVlow

R4: if population is Vlow and E-Generated is Vlow then E-Consumed isVlow

As one can conclude from the above explanation, the number of rules in a fuzzy system increases dramatically with the addition of new variables.

4-3 The Fuzzification

The fuzzification procedure continuously fuzzified the numerical inputs of fuzzy system, population and electric energy generated into fuzzy sets. The numerical inputs of the fuzzy system which normalized were fuzzified by using the triangle function as shown in fig (4) which is expressed functionally as :[19,20]

$$A(x) = \begin{cases} b\left(1 - \left|\dfrac{x-a}{s}\right|\right) & \text{when } a - s \le x \le a + s \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots \quad \textbf{(3)}$$

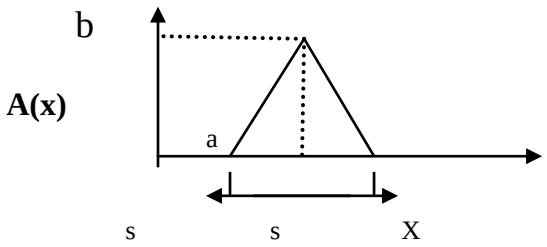


Figure (4) triangle function

In a proposed fuzzy system we make a reading of population and electric energy generates and find membership grade for them in the corresponding fuzzy regions which lie in knowledge base.

For example, for the population and electric energy generated which are normalized in the example above ,the fuzzification procedure was finding corresponding fuzzy sets and membership degree **μA(x)** by using the formula (3) . As shown below:

Variable	Fuzzy sets	memberships**μA(x)**
Population (0.0323)	Vlow, Low	(0.677, 0.323)
population and Electric Energy generate (0.01799)	Vlow, Low	(0.17995, 0.82005)

Table (5) membership degree

Then the fuzzified inputs are sent to the inference engine to compute the fuzzified output.

4-2 Fuzzy Inference

A complete fuzzy system includes a fuzzy inference engine. The fuzzy inference helps us build fuzzy relations based on the fuzzy rules that have been defined. Firing a fuzzy inference process, several fuzzy rules will be fired in parallel. The parallel rule firing, unlike the sequential evaluation of the rules in the conventional expert system, is much closer to the human reasoning process . The proposed fuzzy system is implementing the parallel firing; therefore all rules which are fire able by data will be fired simultaneously. Unlike that in a

sequential process some information contained in the variables may be overlooked. There are many different fuzzy inference methods. We will use a popular method called mamdani inference method. [21]Under inference, the truth value for premise of each rule is computed, and applied to the conclusion part of rule. This results in one fuzzy subset to be assigned to each output variable for each rule. We used MIN as inference rules. In MIN inference, the output membership functions clipped off height corresponding to the rule premise's computed degree of truth. As show in the example:

To the input variable which fuzzified in the example above, the inference procedure proceeds in two steps:

1- firing the rules in rule base which they are :

[R1] if population is Vlow and Electric is Vlow then Consumed = Vlow

[R2] if population is Vlow and Electric is Low then Consumed =Vlow

[R3] if population is Low and Electric is Vlow then Consumed = Vlow

[R4] if population is Low and Electric is Low then Consumed =Low

2- For all the predicate expressions connected by an AND., we take the minimum of their collective membership truth. This final truth is truth of rule premise:

Ptruth=min (E1, E2, E3, En) …… (4)

For the preview input s population =0.46424 and Electric= 0.49443 the MIN process results are shown in table (5):

Rule	Memberships	MIN
[R1]	0.677 & 0.82005	0.677
[R2]	0.677 & 0.17995	0.17995
[R3]	0.323 & 0.82005	0.323
[R4]	0.323 & 0.17995	0.17995

Table (5) MIN operation

2- The fuzzy set on the right-hand side of the firing rules is then reduced height by this amount as shown in table (6):

Fuzzy sets	Starting point	Ending point	Height
Vlow	0.0	0.1	0.0
Low	0.0	0.2	0.1
Vlow	0.0	0.1	0.0
Low	0.0	0.2	0.1

Table (6) Height of firing rules

The minimum memberships of premises of rules are clipped off at height of consequence of the rules as below: [22]

$$U = \sum_{i=1}^{k} ui.\mu(ui) \qquad \text{..... (5).}$$

U=(0.677*0.0)+(0.17995*0.1)+(0.323*0.0+(0.17995*0.1)

=0.017995

This result is sent to the defuzzification procedure.

4-3 Defuzzification

Defuzzification is used to convert the fuzzy output set to crisp number, there are more defuzzication methods at least 30. [23]. In a proposed fuzzy system we used the more common technique which is the center of gravity method as shown below: [24, 25]

$$U^* = \frac{\sum_{i=1}^{k} ui.\mu(ui)}{\sum_{i=1}^{k} \mu(ui)} \qquad \text{…….. (6)}$$

For the above example the fuzzification result is:

U = 0.017995/ 1.359

= 0.013232

4-4 Renormalized

We used renormalized method to convert the scaled value to the real output of the electric energy consumed as shown:

Real value = (output/scalar factor) + set point …… (7)

= (0.0132325/ 0.00005) + 22

electric energy consumed = 222646.51813

4-5 Results

It should be noted that the intelligent systems approach for this application was modified as a result of its application of electric energy in Arab Gulf countries. The fuzzy expert system was the most recent addition to the process. The proposed

system was able to capture the expert's knowledge and use it in a programming process for all the electric energy consumed in Arab Gulf countries as shown in figure (5). The interface design principles were implemented by the means of logical programming language Prolog , to give the specifications of a solution and allow the computer to derive the execution sequence for the solution, rather than specifying an algorithm for the solution of a problem .[26]

Table (7) shows the results of restimulation on electric energy in Arab Gulf countries depend on two factors: population and electric energy generates.

Table (7)

Year	Population (In thousand)	Electric Energy Generates(Gigawatt-hour)	Electric Energy Consumed (Gigawatt-hour)
2000	53646	253599	222619.3815
2001	55232	267084	237633.11688
2002	57001	286456	256459.54046
2003	58570	296456	264557.34266
2004	60471	309294	279340.5567
2005	62450	343743	300000

These results are compared to the real data in table (3) as shown in figure (6) And fig (7). We used the proposed fuzzy system for computing the expected electric energy consumed in Arab Gulf countries for years (2006-2015) as shown in table (8).

In the normal mathematical method the following equation is used to compute the compound growth average as:

$$R = \sqrt[n]{Q_t / Q_0} - 1 \quad \ldots\ldots (8)$$

Q0 is the base year
Qt is the compared year

n is the number of years

Increment Average INC = R* Q0 …….. (9)

Predict value (Qt) = Q0 + Increment Average …….. (10)

Then the electric energy consumed with reference to the data in table (3) was computed as follows:

From Eq.

$R = \sqrt[6]{300000/222619.3815} - 1$

R=5.1 % then the Increment Average will be INC =15292.917 then the predict value will be according to Eq. (10) as follows:

Qt (2006)=315292.92

Where

Qo (2005)= 300000

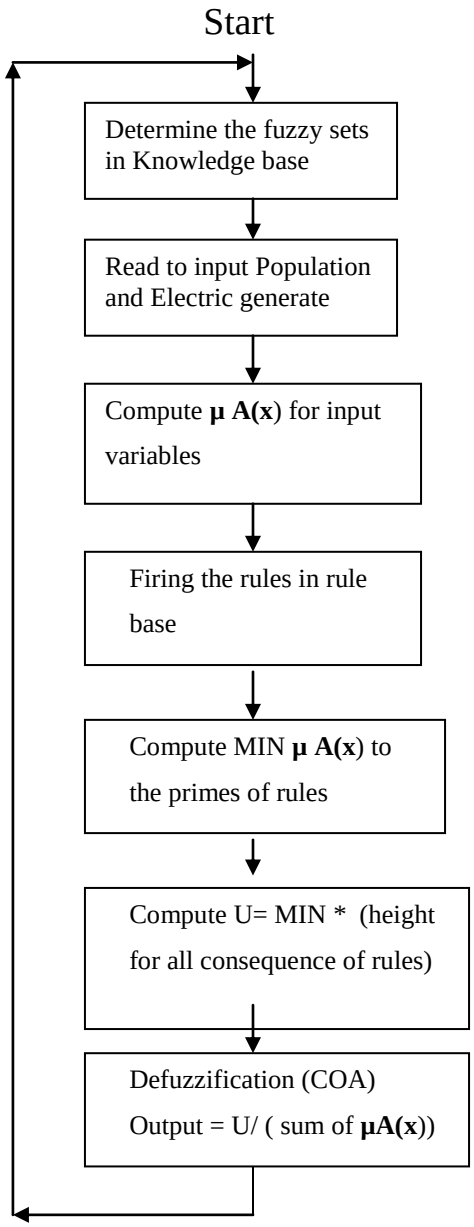


Figure (5) The flow chart of the suggested fuzzy system

The increments in the electric energy generated and the populations were computed for years (2005,2006) in the same way then :

Population compound growth average = 2.56%

electric energy generated compound growth average = 5.2%

Depending on these results we have new values for the years 2006,2015 as shown in table (8).

Table (8)

The predicted values calculated by mathematical and suggested methods

Year	Population (In thousand)	Electric Energy Generates (Gigawatt-hour)	Electric Energy Consumed (mathematical method) (Gigawatt-hour)	Electric Energy Consumed (computed by fuzzy system) (Gigawatt-hour)
2006	64429	378192	327186	320000
2007	66408	412641	354077	332535.40068
2008	68387	416090	380338	356623.37662
2009	70366	419539	406599	392514.03412
2010	72345	422988	432860	425096.80171
2011	74324	426457	459121	439535.55342
2012	76303	429886	485382	469212.97212
2013	78282	433335	511643	511346.08174
2014	80261	436784	537904	524617.42592
2015	82240	440233	564165	560000

In this table we compute the electric energy consumed by the proposed fuzzy system. We exchanged the fuzzy set discourse with new values and we can see the results as shown in fig. (8) and fig .(9) .There are many factors which effected the increase of electric energy consumed in Arab Gulf countries such as the increment in the population growth average and the continuous expansion in Economic fields and the low cost of electricity unit for the consumers from table No.8 . We found that the growth average of electric energy consumed is equal to 5.1% for the period 2000-2005 and the electric energy generated

is 5.2 % for the same period for Arab Gulf countries. These results refer to the decrement in the gap between the generated and consumed energy when a maximum electric load may occur before the electric power is failed. The results in both methods the normal mathematical method and the suggested fuzzy expert method as shown in fig.8 and fig.9 seemed close and the suggested system is working efficiently in predicting the electric energy consumed in Arab Gulf countries, so, it is a good method added to the normal mathematical methods and it proved that it gives accurate results. The results in the paper for both methods are viewed to the economics experts and they indicated that the results are acceptable.

4-6 Discussion

The Fuzzy Expert System can solve many problems in everyday life.

This study deals with the problem of prediction of the electric energy consumed in Arab Gulf countries by suggesting a new method to get the prediction which consists of fuzzy logic and an expert system as Artificial Intelligent technique.

In this paper a fuzzy expert system is built to specify the prediction demand on electric energy consumed in Arab Gulf countries and used the proposed fuzzy system to compute the expected electric energy consumed in Arab Gulf countries for the years (2006-2015) . The study indicates the large usage of the

electric energy consumed in these countries and shows the increase in the growth average for the electric energy consumed in the Arab Gulf countries . It indicates some of the factors that effect it such as population and the amount of electric energy generated. The proposed system is used to get the electric energy consumed predication and gives the necessary information to the planners of the real needs of new electric energy projects.

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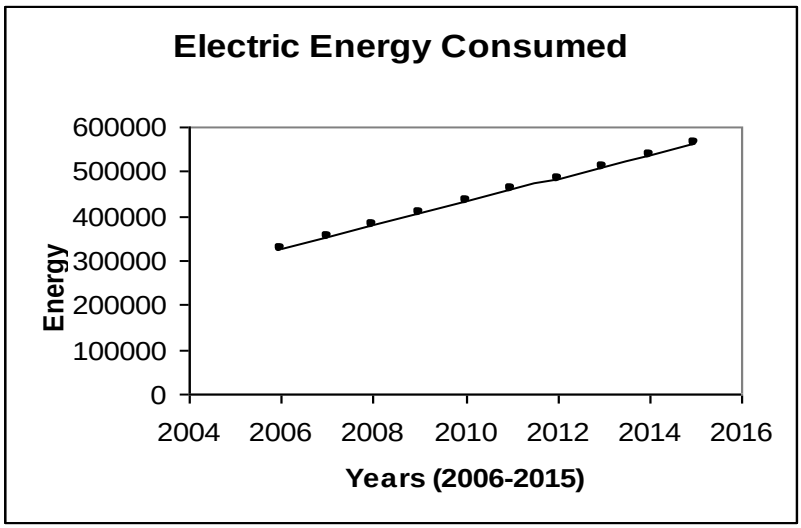


Figure(6) : Fuzzy System results

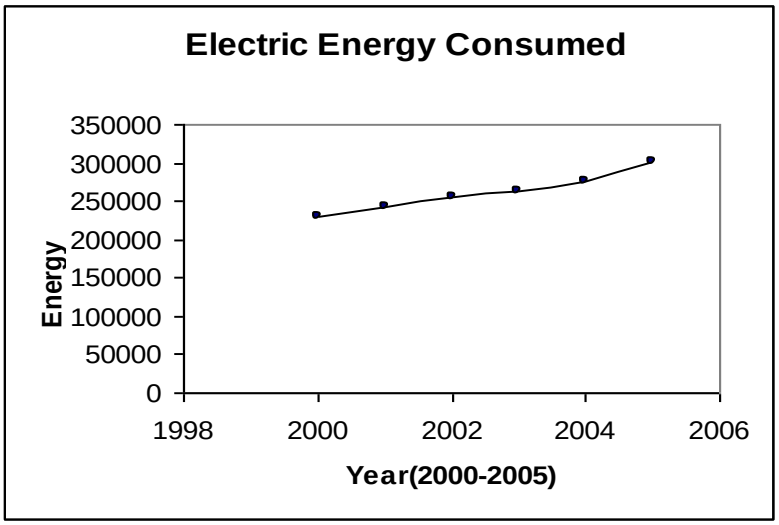
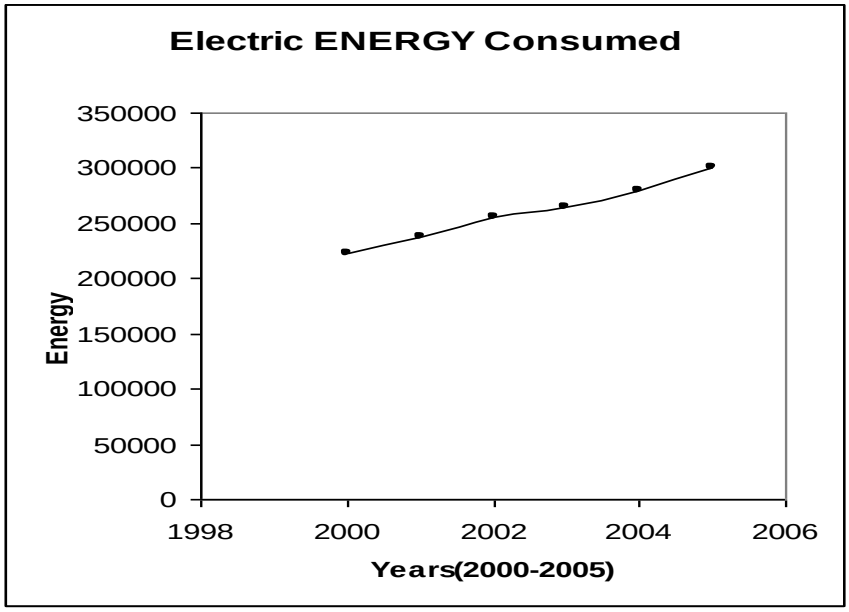
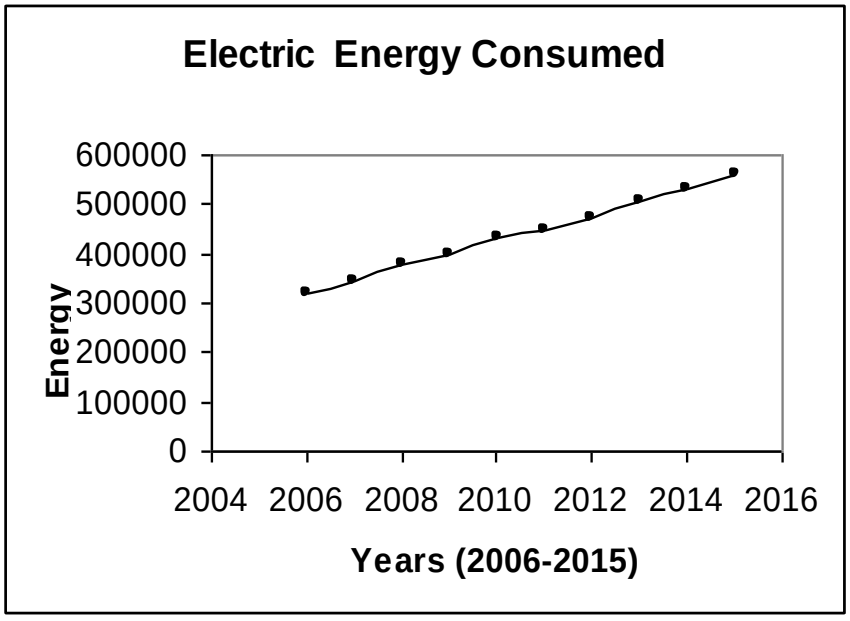


Figure (7): Real data results



Fig(8)The mathematical method results



Fig(9) The fuzzy system results