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Mathematics

FUZZY TIME SERIES METHOD FOR FORECASTING POWER GENERATION DATA

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ABSTRACT Electricity consumption forecasting is important for effective operation, planning and facility expansion of power system. Accurate forecasts can save operating and maintenance costs, increased the reliability of power supply and delivery system, and correct decisions for future development. The power generation development will be accompanied with the increasing demand of electricity. Hence, there is a need to forecast the power consumption for future decisions on generating electric power, load switching, and infrastructure development. Therefore, in this study, the Fuzzy time series (FTS) with membership function was implemented on the yearly electricity consumption from January 1971 to December 2019 to forecast January to December in five year electricity consumption. The procedure of the FTS and membership function was described together with January data. FTS is able to forecast the power generation consumption quite well..

KEYWORDS : Fuzzy Time Series; Membership Function; Linguistic Variable; MAPE; MSE

INTRODUCTION

The idea of fuzzy was born in 1965 when Lofti A. Zadeh, a well-respected professor in the department of electrical engineering and computer science at University of California, Berkeley, believed that all real world problems could be solved with efficient and analytical methods. In his words, "We need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not described in terms of probability distributions". Initially, the concept of fuzzy sets encountered sharp criticism from the academic community. Owing to this, fuzzy logic grew in both wide and comprehensive way and established the foundation of fuzzy logic technology and led to the development of application of this technology in the following years. In addition to maintain the usage legacy of fuzzy logic, fuzzy time series was used for forecasting low dimensional numerical data. Till date

Figure1: Different type of Power Generation

the research is flourishing in order to achieve a more flexible and more powerful methods and structures to solve real world problems that deal with high amount of uncertainty that grow due to the dynamics of the environment. This paper addresses the forecasting of coal source power generation.

Fuzzy Time Series Model

Let Y(t), (t =0, 1, 2, …) a sub set of R be the universe of discourse on which fuzzy set $f_i(t)$, (i =1, 2, …) are defined. F(t) is a collection of $f_1(t)$, $f_2(t)$, … then F(t) is called a fuzzy time series defined on Y(t). Here F(t) can be viewed as a linguistic variable. The conventional time series models fail to work when its values are linguistic ones.

First order model of Fuzzy Time Series:

Suppose F(t) is affected by F(t-1) only, then the fuzzy relation can be expressed by $F(t) = F(t-1)\circ R(t, t-1)$, where R(t, t-1) is a fuzzy relationship between F(t-1) and F(t). And the model $F(t) = F(t-1)\circ R(t, t-1)$ is called the first order model of F(t), where '$\circ$' is the max-min composition operator. The fuzzy relationship defined by R(t, t-1) is independent of time t then F(t) is a time invariant fuzzy time series; otherwise it is time variant fuzzy time series.

Membership Function

Let X be a nonempty set. A fuzzy set A in X is characterized by its membership function $A: X \to [0, 1]$ and A(x) is interpreted as the degree of membership of element x in fuzzy set A for each x in X. The value zero is used to represent complete non-membership; the value one is used to represent complete membership and values in between are used to represent intermediate degrees of membership. The mapping A is also called the membership function of fuzzy set A.

METHODOLOGIES

In Shyi-Ming Chen (1996) applied the fuzzy times series model to propose a step-by-step procedure for forecasting the coal source of the electricity of power generation. This method presented in the following steps for forecasting to coal sources:

Step 1:

To compute the appropriate length of interval using Shyi-Ming Chen method.

Step 2:

The number of intervals I as is computed in step 1

Step 3:

Let V_{max} and V_{min} be the maximum and minimum coal source of known power generation data. Based on V_{min} and V_{max}, we define the universe of discourse U as $[V_{max}+V_2, V_{min}-V_1]$. Where V_1 and V_2 are two proper positive numbers.Now, partition U into equal length intervals.

Step 4:

Let $A_1, A_2, \ldots, A_k$ be fuzzy sets which are linguistic values of the linguistic variable "coal source". Define fuzzy sets $A_1, A_2, \ldots, A_k$ on the universe of discourse U as follows:

$A_1 = a_{11}/u_1 + a_{12}/u_2 + \ldots + a_{1m}/u_m,$

$A_2 = a_{21}/u_1 + a_{22}/u_2 + \ldots + a_{2m}/u_m,$

$A_k = a_{k1}/u_1 + a_{k2}/u_2 + \ldots + a_{km}/u_m,$

Where $a_{ij} \in [0, 1]$, $1 \le i \le k$, and $1 \le j \le m$. The value of a_{ij} indicates the grade of membership of u_j in the fuzzy set A_i, where $a_{ij} \in [0, 1]$, $1 \le i \le k$, and $1 \le j \le m$.

Step 5:
Fuzzy logical relationships are being determined.

Step 6:
Fuzzy logical relationships are grouped according to coal source relationship with each fuzzy set and find fuzzy relation matrix Ri.

Step 7:
Defuzzify the group using fuzzy relation matrix and fuzzy sets.

Step 8:
Calculated the forecasted outputs. The calculations are carried out by the following principles:

I). If the fuzzified coal source of year i is A_j, and there is only one fuzzy logical relationship in the fuzzy logical relationship groups derived in step 6 in which the current state of the coal source is A_j

Step 9:
Two evaluation indices the Mean Absolute Percent Error (MAPE) and the Mean Square Error (MSE) are selected to evaluate the forecasting accuracy. The formulas of both indices are provided below:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right|$$

$$MSE = \frac{\sum_{i=1}^{n}(A_i - F_i)^2}{n}$$

Coal Source Data using Chen's Method

Step 1:
First the appropriate length of interval L is computed using Shyi-Ming Chen length procedure as follows. Finally the length of interval L=10.

Step 2:
Calculated number of intervals,

$$I = \frac{80 - 40}{10} = 4$$

Step 3:
The calculated number of intervals, n = 4 is applied for the actual coal source data and fuzzified variation.

Step 4:
The universe of discourse, U is defined as follows: The minimum(Vmin) and the maximum(Vmax)value in the coal source data are taken, and is subtracted and added respectively with two positive integers taken to be v_1 and v_2.This is shown in table 4.1. As a result U = [40, 80]. In this data, we partition U = [40, 80] into four intervals u_1, u_2, u_3, u_4. Where u_1=[40, 50], u_2=[50, 60], u_3=[60, 70], u_4=[70, 80].

Step 5:
It is assumed that the linguistic variable coal source data can take fuzzy values as A_1(not many), A_2 (not too many), A_3 (many), A_4 (many many).

Step 6:
The fuzzy set for each year's coal source data is found as follows:

TABLE-1
FUZZY LOGICAL RELATIONSHIPS OF THE COAL SOURCE

A1 → A2	A4 → A2
A2 → A1	A2 → A4
A1 → A2	A4 → A3
A2 → A2	A3 → A4
A2 → A1	A4 → A2
A1 → A1	A2 → A2
A1 → A2	A2 → A4
A2 → A2	A4 → A4
A2 → A3	A4 → A3
A3 → A3	A3 → A3
A3 → A4	

Divide the derived fuzzy logical relationships into groups based on the current states of the coal source of fuzzy logical relationships. Thus, based on Table 1, we can obtain four fuzzy logical relationship groups shown in Table 1.

TABLE-2
FUZZY LOGICAL RELATIONSHIPS GROUPS

Group1: A1 → A1, A2
Group2: A2 → A1, A2, A3
Group3: A3 → A3, A4
Group4: A4 → A3, A4

Step 8:
Thus, based on Tables 1 and 2, we can forecast the coal source of the electricity production from 1971 to 2019 by the proposed method. In the following, we only illustrate the forecasting process of the years 1972, 1973, and 1986. Thus, the forecasted value of 1986 is equal to 1/2 (65+75) = 70.In summary, the forecasted coal source value by the proposed method is shown in Table 4.

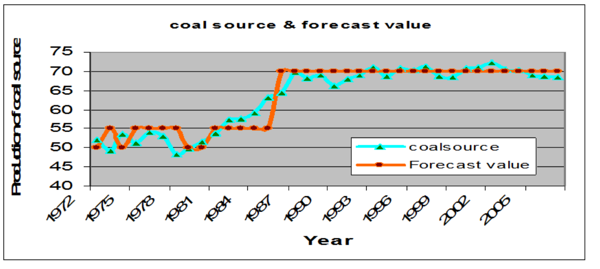

Figure 2: Curves of forecasted coal source and actual coal source

An Improved Method for Coal Source data Using Sturges' Rule
The aim of the present research is to develop an improved fuzzy time series method that can both provide the forecasting values in terms of Sturges' Rule and generate more accurate forecasting results at the same time. To obtain the number of intervals based on Sturges' Rule and further steps follow Chen's method. The formula of Sturges' Rule as follows:
The appropriate number of interval is computed as,
I≈1+3.32210logn, Where I is the number of classes in the data.We use 6 (six) fuzzy sets, i.e.U are partitioned into six equal intervals u_i (i=1, 2, …, 6), namely:
u_1=[48.322,52.295],u_2=[52.295,56.267]
u_3=[56.267,60.239],u_4=[60.239,64.211]
u_5=[64.211,68.184],u_6=[68.184,72.156]

TABLE-3

FUZZY LOGICAL RELATIONSHIP OF COAL SOURCE FOR STURGES' RULE

A1 → A1	A2 → A3	A5 → A6
A1 → A2	A3 → A3	A6 → A6
A2 → A1	A3 → A4	A6 → A5
A2 → A2	A4 → A5	A5 → A5

TABLE-4
ACTUAL AND FUZZIFY VALUE OF COAL SOURCE DATA FOR STURGES' RULE

Year	Coal source	Fuzzified value	Year	Coal source	Fuzzified value
1971	49.093	A1	1996	70.245	A6
1972	52.017	A1	1997	71.153	A6
1973	49.395	A1	1998	68.669	A6
1974	53.521	A2	1999	68.554	A6
1975	51.336	A1	2000	70.692	A6
1976	54.149	A2	2001	71.044	A6
1977	52.995	A2	2002	72.156	A6
1978	48.322	A1	2003	70.360	A6
1979	49.876	A1	2004	70.144	A6
1980	51.536	A1	2005	68.908	A6

1981	53.952	A2	2006	68.787	A6
1982	57.298	A3	2007	68.351	A6
1983	57.638	A3	2008	68.917	A6
1984	59.040	A3	2009	70.682	A6
1985	63.274	A4	2010	71.054	A6
1986	64.538	A5	2011	72.156	A6
1987	69.776	A6	2012	70.360	A6
1988	68.241	A6	2013	70.144	A6
1989	68.848	A6	2014	68.908	A6
1990	66.198	A5	2015	68.787	A6
1991	67.825	A5	2016	68.251	A6
1992	68.926	A6	2017	68.917	A6
1993	70.914	A6	2018	72.155	A6
1994	68.602	A6	2019	70.460	A6
1995	70.831	A6	2020	-	-

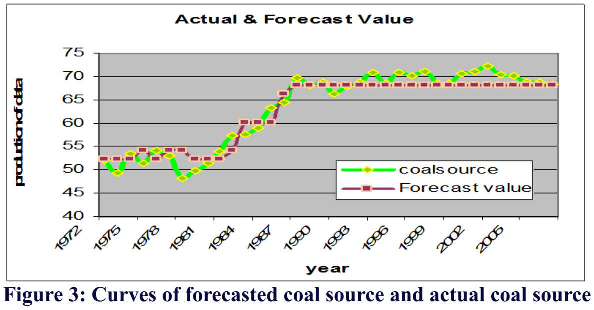

Figure 3: Curves of forecasted coal source and actual coal source For Sturges' Rule

CONCLUSIONS

In this Paper two different methods are discussed to forecast the historical data in fuzzy time series. A novel time-invariant method for forecasting Coal Source data is designed. The advantage of the proposed method is given higher accuracy comparing with Chen's (1996) time-invariant model. The proposed method gives the Mean Square Error value is 4.80929, Mean Absolute Percentage error value is 2.9671. It supports numerical and graphical representations.

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