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Selection of Load Node Model in Power Systems: Fuzzy Logic Approach

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Abstract: The performance of a power system during transient operating conditions is highly dependent on the type of loads connected to its nodes. The latter can be constant impedance, constant current, constant power, or any combination of these three types. Hence, in order to properly simulate transient conditions in a power system, it is important to select appropriate load models that accurately describe the actual node loads. Different mathematical models are commonly used to describe node loads. However, the selection and application of mathematical node models is a time consuming process and may not be appropriate when the assessment of the likelihood of transient and stability problems in a power system is required on-line during the operation of the system. This paper presents a new method for selection and implementation of load node models based on the application of indistinct (Fuzzy Logic) approach, whereby the required calculation is made faster than using conventional mathematical approach.

Key words: Power system, indistinct set, fuzzy logic, load model, synchronous motor, static load, transient, logic statement

Introduction

It is a well-known fact that one of the main factors that affect the performance of a power system during both steady-state and transient conditions is the type of loads connected to the different nodes in the system. Hence, the importance of accurate load models in power system transient and stability studies has been well recognized (IEEE, 1994; Task force and William *et al.,* 1993). In order to obtain reliable system simulation results, it is crucial to accurately describe node load. Several dynamic load models have been proposed and used in studying small-disturbance, transient stability and voltage stability conditions (Shackshaft and Hadwick, 1977; Wilsun and Yakout, 1994; Hill, 1993 and Liang, 1993). These models are commonly based on mathematical equation implementation however, the selection of an appropriate node-load model is a time consuming processes and requires long computational processes. Which may not be convenient when the assessment of transient and stability problems in a power system is required on-line during the operation of the system.

In this paper a new method for selection and implementation of load node models based on the application of indistinct (Fuzzy Logic) approach is presented. Using the proposed model makes the selection and implementation of dynamic node loads in transient and stability studies simpler and faster than using any conventional mathematical approach. The theory behind the proposed algorithm and its design is also presented.

Theoretical background

The simulation of a transient state in a power system should be based on mathematical models that simulate the different system components as accurately as possible. However, a degree of approximation can be justified depending on the type, depth and duration of the problem under investigation (Zadeh, 1965). One of the factors that highly affect the reliability of the results obtained from the transient analysis of a power system is the accuracy of the mathematical models used to simulate system's node loads. Accordingly, the selection of an appropriate load model should take into consideration the following factors:

The model should be sufficiently representative from the point of view of providing reliable transient analysis results.

The load model should be as simple as possible to minimize computational time and effort and takes into consideration the availability of sufficient load data, for example type and structure of load, the parameters of individual load elements and the accuracy of the available data.

One of the methods of investigating the performance of a power system under transient operating conditions is to divide the system into several subsystems that are simulated using individual models. Based on such a method, a complete mathematical model of a power system can be given as a function of the system operating conditions and the degree and duration of disturbances as follows:

$$(\forall_Z \;, Z^i \subseteq Z, \forall \;\Delta t \;, t^i \subseteq T) \Rightarrow M^{i(s)} : \sum_{i=1}^{k} G^{i(s)} \;\; G^i, \qquad (1)$$

where z is a disturbance element, Z^i is a group of similar disturbances included in Z and t^i is the corresponding duration for each Z^i, Δt is time interval, T is a set of t^i, $G^{i(s)}$ is a group of sub-system models and G^i is the set of the complete model of the system.

Four different types of load models are commonly used in calculating transients in power systems (Gurevich, Libova and Hachatrjan, 1981; Syromjatnikov, 1984). Each of these types can be described by a set of mathematical node-load model as follows:

First type (M_1): Constant power, S_L, model or constant impedance, Y_L, model (i.e. S_L= const., or Y_L = const,)

Second type (M_2): Polynomial model (known also as ZIP model) represented by the static characteristics of the load as shown in Equation (2). It is composed of constant impedance (Z), constant (I) and constant power (P) components and their values depend on the aggregate characteristic of load component (Gurevich, Libova and Hachatrjan, 1981; Syromjatnikov, 1984):

$$P_L=1 ! a_p ! b_p + a_p U + b_p U^2$$
$$Q_L=1 ! a_Q ! b_Q + a_Q U + b_Q U^2 \quad (2)$$

Where: P_L and Q_L are power injected to the load a_P, a_Q, b_P and b_Q are load indices

Third type (M_3): Complex load model that consists of equivalent asynchronous motor and constant impedance. This model is described by the following equation (Syromjatnikov, 1984):

$$\frac{de'_q}{dt} ! \frac{1}{T'_d} e'_q \;\; s e'_d \quad \frac{N}{T_d x'_s} U_q$$

$$\frac{de'_q}{dt} ! \frac{1}{T'_d} e'_d \;\; s e'_q \quad \frac{N}{T_d x'_s} U_d$$

$$\frac{ds}{dt} ! \frac{1}{T_j} \left[m_0 \;\; k(1 \;\; s)^2 \right] ! \frac{1}{T'_j x'_s} e'_d U_q \quad \frac{1}{T_j x'_s} e'_q U_d \quad (3)$$

$$Q \;\; \frac{1}{x'_s} (U_q^2 \; ! \; U_q e'_q \; ! \; U_d e'_d \quad U_d^2)$$

Where:

e'_q, e'_d -Transient emf on d and q -axes;

U_q, U_d -d and q- axes voltage components,

T_d -d- axis time constant of rotor winding;

T_j -Inertia constant;

x'_s -Transient reactance of the motor;

$N=x_s ! x'_s$,

X_S -Synchronous-motor reactance;

T'_d -d-axis transient time constant;

m_0, k -The initial moment and coefficient.

Forth type (M_4): A complex load model consisting of an equivalent representing asynchronous motor, an equivalent representing synchronous motor and constant static load (admittance).

Node-load model selection using fuzzy logic theory

The selection of the appropriate load model (i.e. M_1, M_2, M_3, or M_4) depends on the level of voltage reduction,)U, the duration of disturbance)t and the structure of the load in terms of the percentage share of the following load types: S_A- asynchronous motors, S_C- Synchronous motors, S_A- static loads.

The above named parameters are described by a set of attributes:

$y = \{)U,\ )t,\ S_A,\ S_C,\ S_A\}$

The terms load structure, degree of penetration and duration of disturbance are all relative parameters, which are difficult to identify and describe using crisp values, which could lead to the implementation of conventional mathematical models. On the other hand, using indistinct algorithms to select a proper load node model based on the above parameters could serve as a more appropriate method.

To generalize the characteristic and degree of disturbance in a load node, a disturbance index (R) is considered as:

$R =)U.\ )t$

According to Zadeh L. (1965) each of the above mentioned parameters (i.e. R, S_A, S_C, S_A) is divided into the following linguistic variables termed as: - L - <low>; M - <medium>; H - <High>.
A membership function is then assumed for each term:

μ_{Ai} (Yi) , [0, 1],

This membership function characterizes the degree to which the crisp input value applies to the membership function of the parameter under consideration.
The fuzzy membership function is represented in a triangular form as shown in Fig.1:

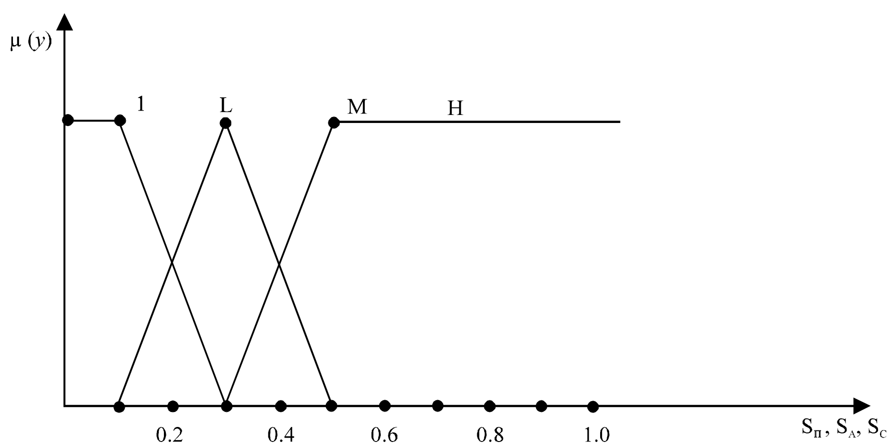

Fig. 1: Fuzzy membership function

Table 1: Logic statements

If the variables				
R	S_n	S_A	S_C	Then the Selected Model
L	L or M or B	L or M or B	L or M or B	M_1
M	M or B	L	L	M_2
M	L	M or B	M or B	M_2
M	B	L or M	L	M_2
M	L	B	L	M_3
B	L	M or B	M or B	M_4
B	L	M or B	L	M_3
B	B	L	L	M_2

Based on operational experience, statistical data and preliminary calculations, it is possible to formulate a table of logical statements that illustrate fuzzy decisions, as shown in Table 1.

The specified logical statements given in Table 1 allow defining the type of node-load model, which shall be considered as standard model reference (M_{is}).
Accordingly, an algorithm for the formation of specific node-load models comprises the following steps:

(1) The actual values of the attributes describing the status of node-loads (i.e. R, S_A, S_A and S_C) are defined.

(2) The specific values of membership functions are determined using the membership function diagrams

$$\mu Ai\ (Yi)/Yi$$

(3) Logic statements that correspond to each specific value of the membership functions are formulated

$$G^{(i)}\ \ \mu L(y1)/y1\ \ \mu M(y1)\ \ \mu B(y1)/y1\ \ \mu L(y2)/y1\ \ ....$$

(4) Each logical statement, $G^{(i)}$, is compared with its corresponding standard reference model:

$$M_{in}\ '\ G^{(i)} \min\ M_{is}$$

(5) Calculate a comparison index, I_i, which describes the vicinity of M_{in} to M_{is} using the following equation

$$I_i\ \ \frac{\mathbf{j}\ \ \mu_{Min}\ (y)}{\mathbf{j}\ \ \mu_{Mis}\ (y)}$$

(6) Finally select the most suitable model of the node-load according to the following equation:

$$M_{in} \quad \Sigma M_{is}/max I_i$$

In conclusion, in this paper a new method for the selection of node-load models is presented based on the application of indistinct (Fuzzy logic) approach. Compared to the conventional methods, the fuzzy logic based approach for node-load model selection accounts for the level of disturbance during transient conditions and takes into consideration that commonly the available information about the structure of node-loads are not completely clear. Accordingly, the proposed method allows a more sufficient selection of node-load models.

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