Journal of Applied Sciences

ISSN 1812-5654

ANSInet
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Journal of Applied Sciences 13 (18): 3742-3746, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.3742.3746

Risk Analysis and Assessment of the Intelligent Transmission System

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Abstract: With the high-speed construction of intelligent power grid, a large number of intelligent factors, including sensors, smart meter and renewable energy facilities, will change the structure of power network and increase power grid operation risk. Moreover, power grid structure will become increasingly complex and uncertain factors have an expansion influence under a growing scale of grid. So, transmission system will face greater potential risks. Six aspects of the risks in smart grid system, namely transmission equipment risk, the spare capacity risk, running environment risk, network structure risk, design standard risk and the access risk of renewable energy, are analyzed in this study. On this basis, the fuzzy comprehensive evaluation method is applied to build risk evaluation index system of smart transmission system and the expert's opinions and the Delphi method are combined to calculate the weight coefficient of various factors. Finally, the comments set are assigned and the fuzzy value of each factor is calculated and then evaluates each factor's influence degree to the risk of intelligence transmission system.

Key words: Intelligent power grid, risk of transmission, the fuzzy comprehensive evaluation

INTRODUCTION

A lot of intelligent factors-including electron technologies to control tidal current (e.g., flexible transmission equipments) and some facilities such as renewable energy-will be introduced into the development of smart power grid (Zhao *et al*., 2009). The access of new elements and facilities will change power grid structure and increase power grid operation risk. Furthermore, it raises higher requirements to the stability and reliability of grid. Nowadays, many issues highlights such as long lines and the shortage of reactive spare. The safety tolerance of transmission system relatively declines and transmission system will face not only greater potential risks but also new challenges like planning, operation and so on. Hence, making a research on the effective risk assessment method of transmission system has an important theoretical research significance to ensure the safety and stability of transmission system (Li and Gao, 2009).

The fuzzy comprehensive evaluation method can solve the problems which have no answers with accurate mathematical methods (Yu *et al*., 2009). The risks of intelligent transmission system are synthetically considered and evaluation indexes like the risks of transmission equipment selection, the spare capacity, running environment, grid structure, design standard and the access of renewable energy. Experts' opinions are widely solicited and Delphi method is applied to calculate the weight coefficient of various factors (Zhang and Li, 2002). On this basis, the risks of intelligent transmission system are assessed.

RISK ANALYSIS OF INTELLIGENT TRANSMISSION SYSTEM

Intelligent transmission system risks mainly include six aspects, namely transmission equipment, the spare capacity, running environment, grid structure, design standard and the access of renewable energy.

Risk of transmission equipment: Domestic equipments and early imported equipments part are limited by manufacturing standards and economic conditions, so the equipments' operation reliability is not high, causing problems to safety operation. According to the statistics, a large number of equipments of 500 and 220 kV and below cause many problems and hidden dangers for

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China's electric power system. In 2003, power grid corporation system experienced transformers totally trip-out 233 times, on which manufacturing quality and ontology reason account for 19.31%.

Risk of spare capacity: Grid spare capacity includes the summation of load spare capacity, accident spare capacity and repair spare capacity. As the parallel of renewable energy, the effect of load forecast deviation, outage rate of generator and power forecast deviation causing by the uncertainties of renewable energy should also be considered to ensure spare capacity of electric power system. Grid spare capacity risks mainly include the shortage of total power supply, safety tolerance of power grid, reactive power grid and the risk of reactive power compensation equipment capacity lack (Liang *et al*., 2011). The randomness and intermittency of renewable energy increases power system operation risk while it increases the auxiliary services demand (Li *et al*., 2008). In view of the existing operation mode of power grid, some spare capacity to response the random fluctuation of generated power like renewable energy has significant meaning to maintain the power balance of electric system and to stabilize and prompt the scale development of renewable energy power (Li and Xie, 2011).

Risk of running environment: The possibility of accident the severe weather occurs frequently, such as hurricane and earthquake, causes grid accidents. In 2007, "3.4-3.9" snowstorm's happening bring about tripping of many lines and electric power disconnecting with major network in Dalian district which threaten the steady and safety operation of power heavily.

Risk of grid structure: Our country constantly perfects receiving end network structure, creating conditions for region span consumption of large renewable energy foundation on millions kw levels. However, east China grid, central China grid and north China grid are independent and not fully formed "three China" unified synchronous power grid which is not conducive to interval complementary of the consumption of renewable energy. The renewable energy mainly distributed in "three norths". At present, the connection among north China grid, northwest and northeast power grid is weak. Due to insufficient capital investment, power grid construction can't meet the demand for power grid development. Lines, transformer equipments are in long-term overloaded in east and north China grid where experience a rapid growth of load. It is extremely easy to cause a grid collapse accident, once the equipments fail (Bai *et al*., 2009).

Risk of design standard: At present, our country has set up some relative technology standards on important smart grid fields and electric vehicle charging, etc. (Qiu and Zeng, 2011). The technology standards lay beneficial foundation for intelligent grid's construction but there are still some problems. First of all, technology standards are not perfect and partial standards are missing. Second, compatibility issues of the existing technology standards need to be solved urgently. Finally, formulating technical standards need enough power.

Risk of renewable energy's access: The development of renewable energy in China has an influence on power grid which cannot be ignored, mainly including voltage, frequency, harmonic and voltage sag, etc. The influence degree depends on the type of wind generator, the method of control, design of wind farms, short-circuit capacity of access system and circuit parameters, etc. On February 24, 2011, wind power base in Jiuquan, Gansu, there happened an accident that 598 Wind Turbines unit on 840000 kW level taking off the nets outbreak, further exposed bugs in wind power grid integration and wind power operation. The accident also revealed the risk of renewable energy integration. State Electricity Regulatory Commission points out that reasons, mainly in four aspects: the wind power equipment, wind field management, power grid access and operation safety supervision, lead to the problem of accidents. So far, the problem of access risk of renewable energy arouse people's great attention

RISK ASSESSMENT FOR INTELLIGENT TRANSMISSION SYSTEM

Fuzzy comprehensive evaluation method:

- **Establish the total factor domain:** $U = \{U_1, U_2,..., U_L\}$, meet the conditions:

$$U = \bigcup_{m=1}^{L} U_m$$

$U_m \cap U_n = \varnothing$, m, n$\in$[1, L], when $m \neq n$. For any m, if $U_m \neq \varnothing$ exist, then call $U_m = \{u_{m1}, u_{m2},..., u_{mp_m}\}$ as subset of U. U is the total factor domain, in which p_m is the number of single factors contained in the factor "m".

- **Establish comments set and the weight coefficient:** $V = \{v_1, v_2,..., v_l\}$ is the comments set and $W_m = \{w_{m1}, w_{m2},..., w_{mp_m}\}$ is weight coefficient vector that all factors relative to v in subset factor U_m. Using Delphi method to calculate w_m, as shown in Eq. 1:

$$w_{mn} = \frac{\sum W_{mn} - \sum W_{min}}{d} + 0.1(n = 1, 2, ..., p_m) \quad (1)$$

Equation 1 gives the weight coefficient matrixin $W = (W_1, W_2,..., W_L)$ that each child factor sets U_m relative to v. U_m come from U

- **Make primary comprehensive evaluation for subset of factors:** First, do single factor evaluation for every child factor w_{mp_m} that selected from $U_m = \{u_{m1}, u_{m2},..., u_{mp_m}\}$. With the factor w_{mp_m}, we can ensure the membership x_{mp_m} which is calculated from the relationship between the factor and the comment v_r (r = 1, 2,..., l). So, the single factor evaluation set of u_{mp_m} is:

$$x_{mp_m} = \{x_{mp_m1}, x_{mp_m2},..., x_{mp_ml}\} \quad (2)$$

So the comprehensive evaluation matrix follows:

$$X_m = \begin{Bmatrix} x_{m11}\ x_{m11} \cdots x_{m11} \\ x_{m21}\ x_{m21} \cdots x_{m21} \\ \cdots \\ x_{mpl}\ x_{mpl} \cdots x_{mpl} \end{Bmatrix} \quad (3)$$

Make a fuzzy comprehensive evaluation to U_m by using the weighted average model, we get the fuzzy comprehensive evaluation set for U_m is:

$$Y_m = W_m X_m = (y_{i1}, y_{i2},..., y_{il}) \quad (4)$$

The second level fuzzy comprehensive evaluation matrix of factor U is:

$$X = \begin{bmatrix} Y_1 \\ Y_1 \\ \cdots \\ Y_L \end{bmatrix} = \begin{bmatrix} W_1X_1 \\ W_2X_2 \\ \cdots \\ W_LX_L \end{bmatrix} \quad (5)$$

The final evaluation result is:

$$Y = WX = (y_1, y_2,..., y_l) \quad (6)$$

RISK ASSESSMENT OF INTELLIGENT TRANSMISSION SYSTEM THAT BASED ON THE FUZZY COMPREHENSIVE EVALUATION METHOD

Full consideration about the influence that all kinds of risk factors to intelligent transmission system, we use the fuzzy comprehensive evaluation method to evaluate the effect of various factors.

Suppose the factor set of intelligent transmission system as $U = \{U_1, U_2, U_3, U_4, U_5, U_6\}$, where U_1 represent risk of transmission equipment; U_2 is risk of spare capacity; U_3 is running environment; U_4 is grid structure; U_5 is risk of design standard and U_6 is access risk of renewable energy. The fuzzy comprehensive evaluation index system is shown in Table 1.

Invite 10 experts, adopting the grade 5 mechanism to evaluate risk factors of transmission system. V = {v1, v2, v3, v4, v5, v6} = {very important, more important, important, general important, not too important}, Using the Delphi method to determine the weight coefficient factors. Each factor sets, all levels of the weight coefficient and fuzzy evaluation matrix, as shown in Table 2.

Table 1: Fuzzy comprehensive evaluation index of intelligent transmission system risk assessment

Target	Primary index	Second level index
Risk assessment of intelligent transmission system	Risk of transmission equipment U_1	Quality risk of old equipment U_{11}, equipment operation and maintenance management risk U_{12}
	Risk of spare capacity U_2	Lack of power supply U_{21}, risk of grid safety tolerance U_{22}, lack of power grid compensation capacityU_{23}
	Running environment risk U_3	Electric power facilities running environment U_{31}, electric power facilities outside factors U_{32}
	Risk of grid structure U_4	Inter-district grid safety risk U_{41}, the main structure risk on regional network U_{42}, electromagnetic loop network risk U_{43}
	Design standard risk U_5	Imperfect standard risk U_{51}, standard compatibility risk U_{52}
	Access risk of renewable energy U_6	Voltage risk U_{61}, power quality risk U_{62}

Table 2: Each factor sets, all levels of the weight coefficient and second level evaluation matrix

			Fuzzy evaluation matrix				
Factors set of level 1	Factors set of level 2	Level 2 weight coefficient	V_1	V_2	V_3	V_4	V_5
U_1	U_{11}	0.34	0.0	0.0	0.1	0.4	0.5
	U_{12}	0.66	0.0	0.1	0.1	0.3	0.5
U_2	U_{21}	0.37	0.4	0.3	0.2	0.1	0.0
	U_{22}	0.35	0.3	0.4	0.1	0.1	0.1
	U_{23}	0.28	0.2	0.3	0.2	0.2	0.1
U_3	U_{31}	0.58	0.1	0.2	0.4	0.2	0.1
	U_{32}	0.42	0.1	0.2	0.3	0.2	0.2
U_4	U_{41}	0.35	0.3	0.3	0.2	0.1	0.1
	U_{42}	0.31	0.2	0.4	0.2	0.2	0.0
	U_{43}	0.34	0.1	0.1	0.4	0.3	0.1
U_5	U_{51}	0.49	0.0	0.1	0.1	0.3	0.5
	U_{52}	0.51	0.0	0.1	0.1	0.4	0.4
U_6	U_{61}	0.53	0.3	0.3	0.2	0.1	0.1
	U_{62}	0.47	0.2	0.4	0.1	0.2	0.1

We can calculate the comprehensive evaluation vector of U_1 with Table 2:

$$Y_1 = W_1X_1 = (0.34, 0.66) \circ \begin{pmatrix} 0 & 0 & 0.1 & 0.4 & 0.5 \\ 0 & 0.1 & 0.1 & 0.3 & 0.5 \end{pmatrix}$$
$$= (0, 0.066, 0.1, 0.334, 0.5)$$

$$Y_2 = W_2X_2 = (0.37, 0.35, 0.28) \circ \begin{pmatrix} 0.4 & 0.3 & 0.2 & 0.1 & 0 \\ 0.3 & 0.4 & 0.1 & 0.1 & 0.1 \\ 0.2 & 0.3 & 0.2 & 0.2 & 0.1 \end{pmatrix}$$
$$= (0.309, 0.335, 0.165, 0.128, 0.063)$$

$$Y_3 = W_3X_3 = (0.58, 0.42) \circ \begin{pmatrix} 0.1 & 0.2 & 0.4 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.3 & 0.2 & 0.2 \end{pmatrix}$$
$$= (0.1, 0.2, 0.358, 0.2, 0.142)$$

$$Y_4 = W_4X_4 = (0.35, 0.31, 0.34) \circ \begin{pmatrix} 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.4 & 0.2 & 0.2 & 0 \\ 0.1 & 0.1 & 0.4 & 0.3 & 0.1 \end{pmatrix}$$
$$= (0.201, 0.263, 0.268, 0.199, 0.069)$$

$$Y_5 = W_5X_5 = (0.49, 0.51) \circ \begin{pmatrix} 0 & 0.1 & 0.1 & 0.3 & 0.5 \\ 0 & 0.1 & 0.1 & 0.4 & 0.4 \end{pmatrix}$$
$$= (0, 0.1, 0.1, 0.351, 0.449)$$

$$Y_6 = W_6X_6 = (0.53, 0.47) \circ \begin{pmatrix} 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.4 & 0.1 & 0.2 & 0.1 \end{pmatrix}$$
$$= (0.253, 0.347, 0.153, 0.147, 0.1)$$

Suppose the comments set = {very important, more important, important, general important, not too important} = {100, 80, 60, 40, 20}. The calculation of the importance of various factors follows:

$$u_1 = (0\ 0.066\ 0.1\ 0.334\ 0.5) \circ (100\ 80\ 60\ 4\ 20)^T = 34.64$$

$$u_2 = (0.309, 0.335, 0.165, 0.128, 0.063) \circ (100\ 80\ 60\ 40\ 20)^T = 37.98$$

$$u_3 = (0.1\ 0.2\ 0.358\ 0.2\ 0.142) \circ (100\ 80\ 60\ 40\ 20)^T = 58.32$$

$$u_4 = (0.201, 0.263, 0.268, 0.199, 0.069) \circ (100\ 80\ 60\ 40\ 20) = 66.56$$

$$u_5 = (0, 0.1, 0.1, 0.351, 0.449) \circ (100\ 80\ 60\ 40\ 20)^T = 70.12$$

$$u^6 = (0.253, 0.347, 0.153, 0.147, 0.1) \circ (100\ 80\ 60\ 470\ 20)^T = 70.12$$

Therefore 6 risk factors of the intelligent transmission system ranking by importance are:

$$u_2 > u_6 > u_4 > u_3 > u_5 > u_1$$

That is to say, according to the importance of 6 factors, affecting degree from high to low, respectively are: risk of spare capacity, access risk of renewable energy, risk of network structure, risk of running environmental, risk of design standard and risk of transmission equipment.

CONCLUSION

This study adopts the fuzzy comprehensive evaluation method to evaluate risk factors of intelligent transmission system. To begin with, six aspects of the risks in smart grid system are analyzed. On this basis, from total factor domain, comments set and the weight coefficient, the comprehensive evaluation of subset factors, this study introduces the basic process of fuzzy comprehensive evaluation. To establish fuzzy comprehensive evaluation index system of the risk of smart transmission system and combine the expert's opinions and the Delphi method to calculate the weight coefficient of various factors. Finally, the comments set are assigned and the fuzzy value of each factor, then evaluate each factor's influence on the risk of intelligence transmission system.

ACKNOWLEDGMENT

The study described in this study was Supported by the National Science Foundation of China (NSFC) (71271082).

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