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Risk-Based Assessment and Decision Making of Power System Security in Power Market

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Abstract--**In new power market environment, the traditional security index will not meet economical requirement. Currently system operators are available of no well-designed tool and do decisions according their intuition or experience that doesn't meet market requirement too. But research work is seldom about it and market operation of system security is limited to ancillary service. Combining with the research on China power market trends and based on risk, the paper will specially discuss transient security assessment, decision making on security.**

Firstly, based on risk assessment theory, it will mainly analyze a new transient security index and give out detailed assessment progress. The index consist transient insecurity probability and outcome to obtain balance between technology and economy. Based on Conditional Probability theory, it deduces the probability in response to probability distribution of system operation condition and fault in some system operation condition. Facility Method is introduced to evaluate the risk assessment.

Secondly, risk decision theory about dynamic security is put forward. An utility function decision process-a stochastic optimization method is formulated to compute the optimal initial operation state. Aiming at the deficient current decision level of system operator in Jiangsu Province Electrical Company, the decision-making strategy well balanced technical security and economy.

Index Terms—**Power market; security; regional power market; risk; decision; insurance;security**

I.INTRODUCTION

MANY countries are introducing competition to power industry in order to developing power market, which is a historical reform in the industry. Although power market could promote efficiency and decrease cost through competition, it certainly impacts on system security. It is assuring that the contradiction between economy and security will not be fundamentally resolved in any market. In order to solve the problem, risk theory is introduced to power industry.

According to the present situation of China power market, this paper first analyzes a new transient security index based on risk and gives out detailed assessment progress, then formulates a Markov decision process to compute the optimal initial operation state. Finally, this method is applied in the project of Jiangsu Province Electrical Company. And it is proved as a decision-making strategy well balanced technical security and economy.

II NEW TRANSIENT SECURITY INDEX

This paper introduces a new transient security index, the risk of transient insecurity, to evaluate the system security. The calculate process is listed as follows.

A. Transient insecurity probability

There are two basic methods to evaluate transient insecurity probability, Monte-Carlo simulation method and enumeration method. Considering the purpose of this paper, enumeration method is better..

In analysis processes, it is supposed that relaying protection system and breakers work normally. Since the probability of events like those is tiny, this hypothesis is rational. It is supposed that the structure of system is known and that line j, the location of the line j Lj, and types of faults F, which are independent to each other, can describe faults. There is the deduction of transient insecurity probability as followed.

1) The probability of fault

Proposition 1: the probability of fault of each line obeys Poisson distribution. Fault rate is expressed by λ_j.

Proposition 1 is proved in [1].Supposing that the line will be switched off several hours after a fault happen, there is only one fault that can happen in next period of time. So, the fault probability of Line L can be formulated as:

$$\Pr(L=j)=\Pr(N=1|\lambda_j)=\left.\frac{e^{-\lambda}\cdot\lambda_j^N}{N!}\right|_{N=1}=e^{-\lambda_j}\cdot\lambda_j \qquad (1)$$

2) The location of fault

Proposition 2: The location of fault obeys discrete uniform distribution.

Proposition 2 is proved in [2].

Supposing that a fault happened in Line j, the fault probability of the location of Line j L_j can be formulated as:

$$\Pr(L_j=l|N_j)=\frac{1}{N_j} \qquad (2)$$

where N_j is the number of the parts of line.

3) Types of faults

Event space consists of four independent type of faults. According to damage to system, from severity to mildness, four types of faults are listed in Table I.

TABLE I IMPEDANCE vs. FAULT TYPE

n	Type of faults	Impedance
1	Three-phase ground fault	0
2	Two-phase ground fault	$\frac{Z^0\cdot Z^-}{Z^0+Z^-}$
3	Interphase short-circuit	Z^-
4	Monophase ground fault	Z^-+Z^0

Other types of faults are not considered here, because that the probability of those faults is tiny. Fault impedance is expressed by negative sequence impedance and zero sequence impedance.

Considering given line, the frequency of fault type F=n is expressed as f_n, which can be gotten from historical data. So the probability of fault type F=n can be formulated as:

$$Pr(F=n)=\frac{f_n}{\sum_1^4 f_j} \qquad n=1\cdots 4 \qquad (3)$$

Generally, a event is called a instable event, if it can make some units out of synchronism or cut-off, expressed with K_S.

Proposition 3:the probability of K_S is complete probability.

Proposition 3 is proved in [2].

The probability of certain fault F_u can be confirmed by three independent random variables (j ,L_j and F).

So, the probability of K_S can be formulated as follows:

$$\Pr(K_S|\overline{x})=\sum_{j=1}^{N}\sum_{l=1}^{N_j}\sum_{n=1}^{4}\underbrace{P(K_S|L=j,L_j=l,F=n,\overline{x})}_{I}\cdot\underbrace{\Pr(L=j)\cdot\Pr(L_j=l)\cdot\Pr(F=n)}_{II} \qquad (4)$$

where part I is the condition probability of K_S. if only fault rate, fault type and fault location are modeled by probability theory, this part is equal to 1 or 0, which is decided by whether K_S can happen under those states or not. Part II is the combined probability of the fault state: the product of the probability of Line j faulting, the fault probability of location L_j of line j faulting and the probability of fault of type n happening. Equation (4) includes the relationship between K_S and fault line, fault location, fault type.

B. Evaluation of outcome of transient insecurity

Generally, the outcome model of transient insecurity is difficult to definite. This paper adopts a Facility Method to definite the outcome.

With the development of power industry and the introduction of power market, so many changes have happened in power system operation. The outcome of transient insecurity is different too. Simply, this paper divides the outcomes of transient insecurity into four parts: (1) the cost of repair and start, (2) the opportunity cost of generators, (3) the loss of customers, (4) the outcomes of linkage events.

1) Cost of repair and start——ImS

When the units are out of out of synchronism, they should be repaired off-line. And so does fault line. The cost of this is expressed by C_{rep}. The other part of cost is the start cost, because the repaired unit has to start again in order to enter the generating market, so:

$$\mathrm{Im}_{start}=C_{rep}+C_{start} \qquad (5)$$

2) Opportunity cost of generators——ImO

When the units are cut-off, the contracts that were made with these units will be token on by other units usually less efficient, or the contracts will be canceled, which will interrupt the supply to customers. The former is called as generating opportunity cost, and the latter is called as load-broken cost.

So, ImO can be formulated as follow:

$$Im_O = (C_{new} - C_{old}) \cdot h \cdot P_{lost} \tag{6}$$

where C_{new} is generating unit cost during fault, C_{old} is generating unit cost before fault, h is fault duration, P_{lost} is the power that should be supplied by the outage units.

3) Loss of customers——ImD

Fault will make the power supply reduced, so some customers may be cut off. ImD is defined as the product of penalty factor C_{pen}, duration time h and broken load P_{shed}.

$$Im_D = C_{pen} \cdot h \cdot P_{shed} \tag{7}$$

4) Outcomes of linkage events——ImC

The outcomes of linkage events are difficult to weigh by money, but the amount of the loss will be huge.

So, the sum of the costs of four types of outcomes is approximately equal to the total outcome of outcome of transient insecurity.

$$\begin{aligned} \mathrm{Im}(K_S|\overline{x}) &= \mathrm{Im}_S(K_S|\overline{x}) + \mathrm{Im}_O(K_S|\overline{x}) \\ &+ \mathrm{Im}_D(K_S|\overline{x}) + + \mathrm{Im}_C(K_S|\overline{x}) \end{aligned} \tag{8}$$

C. The risk of transient insecurity[3]

The risk of event is defined as the product of the probability of event and the outcome of event. The risk is the Bernoulli distribution function of the event. Supposing that probability of transient insecurity is expressed by p.

$$\mathrm{Im} \sim \mathrm{Bernoulli}(p) \qquad \mathrm{Im} = \begin{cases} I & p \\ 0 & 1-p \end{cases} \tag{9}$$

The entire process of algorithm to compute the transient insecurity risk of certain line is listed as follows:

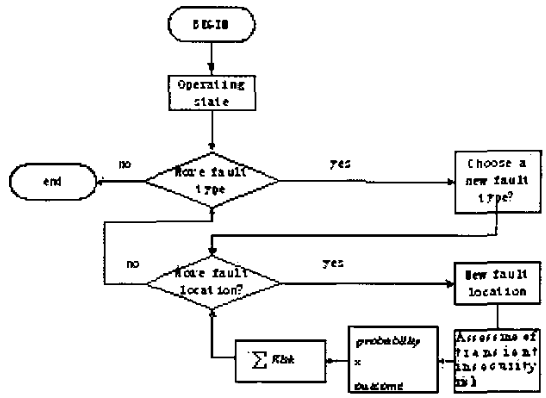

Fig. 1 Risk calculation of dynamic security of single line

III Risk DECISION THEORY

Facing the same value of the risk of transient insecurity, different system operators will have different attitudes. So, before decisions are made, it is necessary to adopt utility evaluation method[4] to help system operators make decision.

The utility function can be approximated as:

$$u(x) = a\ln(x+b) + c \tag{10}$$

In this formula, there are three unknown parameters. In order to make certain the utility formula, three points of the formula are wanted. Because it is convenient to get the points where utility values get the max, the min and the medium value, the formula is easy to get. Then the utility function can be well expressed.

Making decisions on dynamic security can reflect the attitude of system operator to the risk of transient insecurity, so it is more helpful to operators. The process of making decisions is narrated by the example followed.

Supposing that the operator is confronted to several measures, S_1, $S2 \ldots, S_m$, which correspond separately to original states, $\theta_1, \theta_2 \ldots \theta_n$. The probabilities of those original states, $\theta_1, \theta_2 \ldots \theta_n$, are Pr_1、Pr_2、…、Pr_n, $\sum_{i=1}^{n}(\mathrm{Pr}_i) = 1$. Supposing that S_i under state θ_j can bring the profit or loss a_{ij}. u（a_{ij}）render the utility value of a_{ij}（i=1,2…m;j=1,2…n）. So the expected value of the utility value of S_i:

$$u(S_i) = \sum_{j=1}^{n} Pr_j \cdot u(a_{ij}) \tag{11}$$

if $u(S^*) = \max(u(S_i))$, S^* is the best measure.

IV ANALYSIS IN JIANGSU POWER SYSTEM

In JiangSu power system, the yangcheng power plant is very important to transient insecurity. So this paper analyses the risk of the main transmitting line, jiangdou line, under the two typical output of yangcheng power plant. Supposing that the price of power is 530RMB/MWhr, the profit of the system only takes the profit of transmitting more power. When the output of the yangcheng power plant is 2100MW and 1750MW, the profit or loss and the probabilities of increasing the power of jiangdou line are listed in TABLE II, III.

TABLE II TRANSIENT INSECURITY LOSS & ADDITIONAL INOME AND PROBABILITY OF JIANGSU LINE (P_{output}=2100MW)

Measure	Power Increase (MW)	Probable Loss (RMB)	Probability of Loss	Probable Profit (RMB)	Probability of Profit	Expected Val of Profit or Loss (RMB)
1	0	0	0	0	1	0
2	110	7734320	0.0075	165000	0.9925	0.1058×10^6
3	170	7873040	0.0221	255000	0.9779	0.0754×10^6
4	250	8011760	0.0331	375000	0.9669	0.0974×10^6
5	420	8335440	0.3569	630000	0.6431	-2.5698×10^6
6	500	8520400	0.3569	750000	0.6431	-2.5586×10^6

TABLE III TRANSIENT INSECURITY LOSS & ADDITIONAL INOME AND PROBABILITY OF JIANGSU LINE (P_{output}=1750MW)

Measure	Power Increase (MW)	Probable Loss (RMB)	Probability of Loss	Probable Profit (RMB)	Probability of Profit	Expected Val of Profit or Loss (RMB)
1	0	0	0	0	1	0
2	130	7734320	0.0043	195000	0.9957	0.1609×10^6
3	250	7965520	0.0155	375000	0.9845	0.2457×10^6
4	330	8150480	0.0948	495000	0.9052	-0.3246×10^6
5	430	8381680	0.2716	645000	0.7284	-1.8066×10^6
6	520	8520400	0.3569	780000	0.6431	-2.5393×10^6
7	570	8659120	0.3569	855000	0.6431	-2.5406×10^6

According to the above-mentioned decision-making strategy, it is obvious that measure 2 is the best measure when the output of yangcheng power plant is 2100MW and measure 3 is the best when 1750MW.

V CONCLUSIONS

In power market, based on the economical theory, the members of power market will make the most of the mechanism and the resource to make the max profit or the min loss. It is assuring that the contradiction between economy and security will not be fundamentally resolved in any market.

This paper introduces the concept of risk and develop the risk decision theory to help the operators make decisions. And the method was applied to Jiangsu Province Electrical Company. It is proved efficient and well balancing the technical security and economy.

REFERENCES

[1] R.Billinton and R.N.Allan. Reliability Evaluation of Power Systems. New York (Second Edition). Plenum Press,1996

[2] Liu Fu-bin. Risk-based assessment, decision and operation of power system security in power market. Ph.D dissertation, Southeast University, 2003

[3] Vijay Vittal, etc. An Overview of Risk Based Security Assessment. IEEE Trans. on Power System,1999

[4] PAN Jie-rn. Utility Theory in Decision Analysis,

Shanghai Jiao Tong Press,2000

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