Assessment and classification of line overload risk in power systems considering different types of severity functions

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Abstract: - Power system security assessment based on the concept of risk is required in the current power environment. In risk based security assessment, the likelihood and severity of security violation are the two main factors that determine the security level of a power system. To evaluate likelihood of security violation, the probability technique based on Poisson probability distribution function is adopted. Severity function signifies the extent of security violation. Two types of severity functions, namely the continuous and percentage of violation severity functions are considered in this study. This paper presents the assessment of risk of line overload at various loading condition using a risk index. A risk classification technique is also proposed so as to provide a qualitative interpretation of the risk index value by classifying the risk as low, medium and high degree of risk. This paper presents the implementation of line overload security assessment on the IEEE 24 bus test system and practical interconnection power system so as to investigate the effect of severity functions on risk classification in risk assessment. Results are presented in terms of risk index curves.

Key-Words: - Line overload, Probability, Risk, Severity, Security, Uncertainty.

1 Introduction

Nowadays, power system operation has transformed from deterministically regulated system to more competitive and uncertain market environment. The operation of bulk electric power system has also become more complicated, thus increasing the complexity in monitoring power systems. In addition, transmission loading pattern also differs from what has been originally planned. Therefore, the ability to monitor and handle power systems has greatly increased in complexity. High uncertainty is a characterizing feature of this complexity. The ability to obtain, manage and use large data amounts of information has become the primary means of handling uncertainty [1].Therefore, planning and decision making process in this diverse market requirement has become increasingly important.

Present power system's interconnections are more complex and its operation has also become complicated. This condition makes it more difficult to monitor and handle power system since the actual power system operating conditions are difficult to predict. In addition, the unprecedented changes in the world's technology have also changed customers' expectation towards availability in the electricity supplies. For example, momentary events that have gone unnoticed a few years ago are now of utmost importance and cannot be neglected. A few seconds of interruption may cause millions of profit loss due to the increased level of dependency on electricity supply in our daily activities.

The increase in today's world density population has also forced power systems to operate under increasingly stressed condition and close to their limits. As a consequence, power systems become more heavily loaded and vulnerable to disturbances, hence putting the security of power systems at risk. This scenario has in some way deteriorated the reliability of power system operation. Starting up a new power plant could be an option to prevent such problem, but the initial cost is not always affordable. Changes in this current electric power industry have brought a need in assessing and integrating reliability into decision making process.

Power systems have evolved over decades. Their primary emphasis has been on providing a reliable and economic supply of electrical energy to their customers [2]. Power system reliability and security have the same implication. For example, an operating system whose security level is low is said to be unreliable and vice versa. Power system security refers to the degree of risk in its ability to survive imminent contingencies without interruption of customer service [3]. Among the factors that can affect security of power systems is system operating condition and probability of contingency. In a power network, an individual disturbance resulting in line overload, low voltage or voltage collapse may occur for a number of reasons at any time. Hence, the occurrence of disturbance that leads to security violation is unpredictable and unavoidable.

2 Literature Review

Risk based security assessment (RBSA) is a relatively new approach that takes into consideration the uncertainty introduced by an actual power system operating condition as well as the severity of security violation should a contingency occur. The risk index developed through RBSA can quantitatively capture the probability of occurrence of each possible contingency that may cause security violation and the impact of the event. In general, the study of RBSA can be categorized as risk based static security assessment and risk based dynamic security assessment. Risk based static security assessment (RBSSA) considers risk of equipment overload and voltage limit violation whereas risk based dynamic security assessment (RBDSA) considers risk of voltage instability and early swing transient instability. This paper focuses on RBSSA that considers line overload violation (LO) as security limits.

In power system operation and planning, assessment needs to be performed in order to assist system operators in maintaining system security level within an acceptable range. However, this task becomes more difficult since power system is operated closer to its limits. In the traditional deterministic assessment practice, power system must be operated with significant security margin considering only the most credible contingencies [4] – [6]. This result in highly conservative decisions requiring high cost solutions in order to satisfy loading and outage conditions [7]. For example in [8], security classifier using Classification and Regression Tree (CART) only classifies a given operating point under a single disturbance is secure or insecure.

To allow power system to operate closer to its limits or even beyond them, a more refined security assessment method is required at the planning and operating stage. RBSA method is one kind of refined security method that is able to take into account probability nature of many uncertainty variables and the extent of security violation subjected to uncertainty variables.

Risk index obtained through RBSA method is able to quantify the degree of risk of a given operating condition. Nonetheless, classifying the risk index value into an easily interpretable result is also crucial. Risk classification provides qualitative information on the security level of any given operating condition. Through risk classification, the operating limit of power systems can be clearly observed.

A considerable amount research has been done in determining the risk of line overload in power systems in which the first work began in 1994 [9]. In reference [9], a predefined list of transmission line outages in the order of 'N-1' is considered when calculating the risk index value. A comparison was made between risk based and deterministic security assessments of power systems based on single criterion contingency [6]. For simplicity, the values of probability of line outage are assumed in [6] and [9].

A more comprehensive study on RBSSA of power systems can be seen in [10]- [12]. In [10], the risk index contour plotted was obtained with a limited set of "N-1' contingency. Online RBSSA was developed in [13] and [14] to provide rapid online quantification of a security level with an existing or forecasted operating condition considering generator, transformer and transmission line outages. In [10]- [12], the contingencies are assumed to be Poisson distributed, and hence Poisson probability distribution function (pdf) is used to calculate the probability of contingency occurrence with a given failure rate.

A condition-based risk index for line overload and low bus voltage based on the credibility theory employed to model fuzziness of component outages with a given probability of failure is developed [15]. Another probabilistic technique that is applied in risk assessment to determine the probability of voltage collapse is by using the Monte Carlo simulation [16]. In the same reference, a comparison is made between the Monte Carlo simulation and the radial basis function neural network for RBDSA of power systems.

The application of risk assessment in identifying high risk event can be seen in [17] and [18]. Both references consider transient stability as security limits.

In this paper, a more thorough line overload risk assessment is performed on a practical interconnected power system by incorporating a new risk classification technique and investigating the effect of different severity functions.

3 Risk Based Security Assessment

Risk based technique has given a paradigm shift towards security assessment. Risk based security assessment (RBSA) is a relatively new approach that takes into consideration the uncertainty introduced by an actual power system operating condition as well as the severity of security violation should a contingency occur. The risk index developed through RBSA can quantitatively capture the probability of occurrence of each possible contingency that may cause security violation and the impact of the event. There are two important attributes in risk assessment, namely likelihood and impact. It is defined as the product of event likelihood (PROB(E)) and its severity (SEV(E)) and is given by,

$$\mathrm{RISK(E)} = \mathrm{PROB(E)} \times \mathrm{SEV(E)} \qquad (1)$$

where E is event.

3.1 Uncertainty

Generally in risk assessment, uncertainties are grouped into uncertainty in the occurrence of contingency and uncertainty in operating conditions. Each contingency in a power system is caused by the failure of transmission line, transformer or generator. Uncertainty in operating conditions includes variation in system parameter or the forecasted load.

In this study, only uncertainty in transmission line outage is considered. The probability of transmission line outage that can cause security violation is termed as event likelihood. In a given operating condition, the risk of line overload (LO) is equal to the sum of line overload risk of individual's contingency and it is given by,

$$\mathrm{RISK(LO)} = \sum_{i=1}^{N} \mathrm{RISK_{LO}(E_i)}$$

$$\mathrm{RISK(LO)} = \sum_{i=1}^{N} [\mathrm{PROB(E_i)} \times \mathrm{SEV_{LO}(E_i)}] \qquad (2)$$

where,

E_i : i^{th} line outage

N : total number of contingency

The probability distribution function of transmission line outage is assumed as follows [19];

$$\mathrm{PROB(F_k)} = 1 - e^{-\lambda_k} \qquad (3)$$

where λ_k is failure rate of transmission line.

Using joint probability distribution and assuming all events are independent, the probability of 'N-1' contingency in a power system is derived as follows;

$$\mathrm{PROB(E_i)} = \mathrm{PROB}(\overline{F_1} \cap \overline{F_2} \cap \cdots \cap \overline{F_N})$$

$$= \mathrm{PROB(F_i)} \prod_{j \neq i}^{N} \mathrm{PROB}(\overline{F_j}) \qquad (4)$$

Assuming a transmission line outage is an event that is collectively exhaustive [19]; hence the following relationship is valid;

$$\mathrm{PROB}(\overline{F_k}) = 1 - \mathrm{PROB(F_k)} \qquad (5)$$

Substituting (3) and (5) into (4) yields,

$$\mathrm{PROB(E_i)} = \left(1 - e^{-\lambda_i}\right) * e^{-\sum_{j \neq i} \lambda_j} \qquad (6)$$

3.2 Severity Functions

Severity functions are used to uniformly quantify the severity of network performance line overload. Severity function for line overload is defined specific to each lines. The power flow of each bus determines the line overload severity of that line. In general, there are three types of severity functions, namely; discrete severity function, continuous severity function and percentage of violation severity function [20]. This paper only consider continuous and percentage of violation severity function in view of the fact that discrete severity function only evaluates the number of line overload violation but not the extent of violation [1].

Continuous severity function for line overload is illustrated in Fig.1. The near violation for line overload is assumed to take place when line flow exceeds 90% of its rating and increase linearly as line flow exceeds the limit. For each circuit, its severity function evaluates to 1 at the deterministic limits which is at 100% of line flow rating.

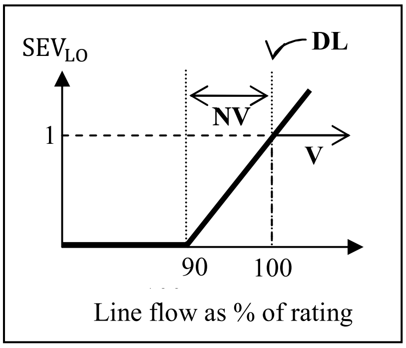

Fig.1 Continuous severity function

where,

NV : Near Violation region
V : Violation region
DL : Deterministic Limit

Mathematically, continuous severity function can be written as,

$$SEV_{LO}(S_k) = \begin{cases} 10(P_k - 0.9) & , PR_k \geq 0.9 \\ 0 & , PR_k < 0.9 \end{cases} \quad (7)$$

where,

S_k : k^{th} line
PR_k : percent of line flow of the k^{th} line

Severity of a given contingency evaluated from percentage of violation severity function only assesses the percentage of the extent of line overload violation. Percentage of violation severity function of line overload for each circuit is given by,

$$SEV_{LO}(S_k) = \begin{cases} PR_k - 1.0 & , PR_k \geq 1.0 \\ 0 & , PR_k < 1.0 \end{cases} \quad (8)$$

Severity of line outage for each contingency can then be calculated as,

$$SEV_{LO}(C) = \sum_{S=1}^{M} SEV_{LO}(S_k) \quad (9)$$

where,

C : contingency
M : total number of lines

Flowchart in Fig.2 shows the procedure in calculating the severity function employed in the proposed RBSA.

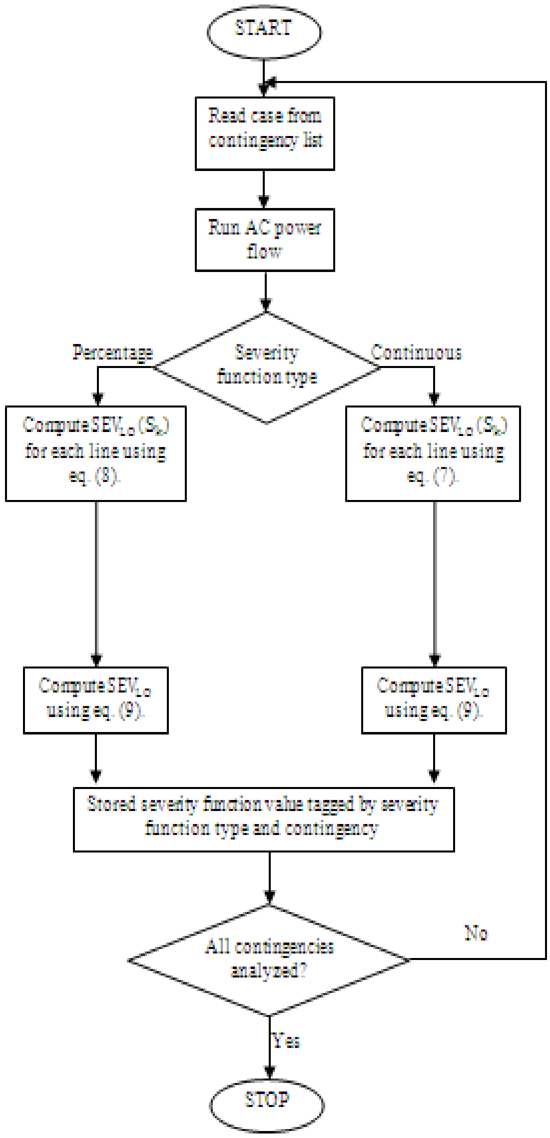

Fig. 2 Flowchart of calculation of severity function

4 Risk Classification Technique

The value of risk index quantifies the degree of risk of the current operating condition. However, further interpretation on whether the risk index value is deemed to be high, medium or low has yet to be made. This paper explores on how risk classification can be made in RBSA and the proposed risk classification is shown in Fig. 3.

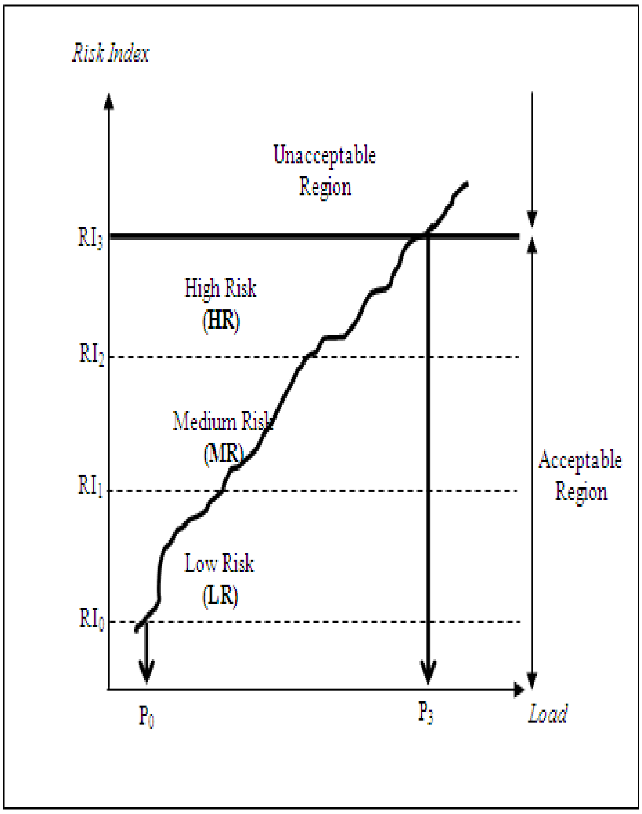

Fig. 3 Risk classification

Fig. 3 shows the plot of risk index values with respect to the operating points. Points P_0 and P_3 indicate the range of possible loading conditions in the acceptable region. This acceptable region refers to the feasible operating condition before a power system becomes insecure. From Fig. 3, the operating point, P_0 refers to the load at base case condition whilst the operating point, P_3 refers to the maximum permissible load before the operating point becomes unacceptable. Unacceptable in this context means that a power system becomes insecure even when all transmission lines are in service. The lower and upper bound risk index values are associated with load P_0 and P_3, respectively. The acceptable operating point region is then divided into three equally spaced risks. Power system risk is classified as low, medium and high if the risk index values are between RI_0 and RI_1, RI_1 and RI_2 and RI_2 and RI_3, respectively. The implementation of the proposed risk classification is described by referring to the flowchart shown in Fig.4.

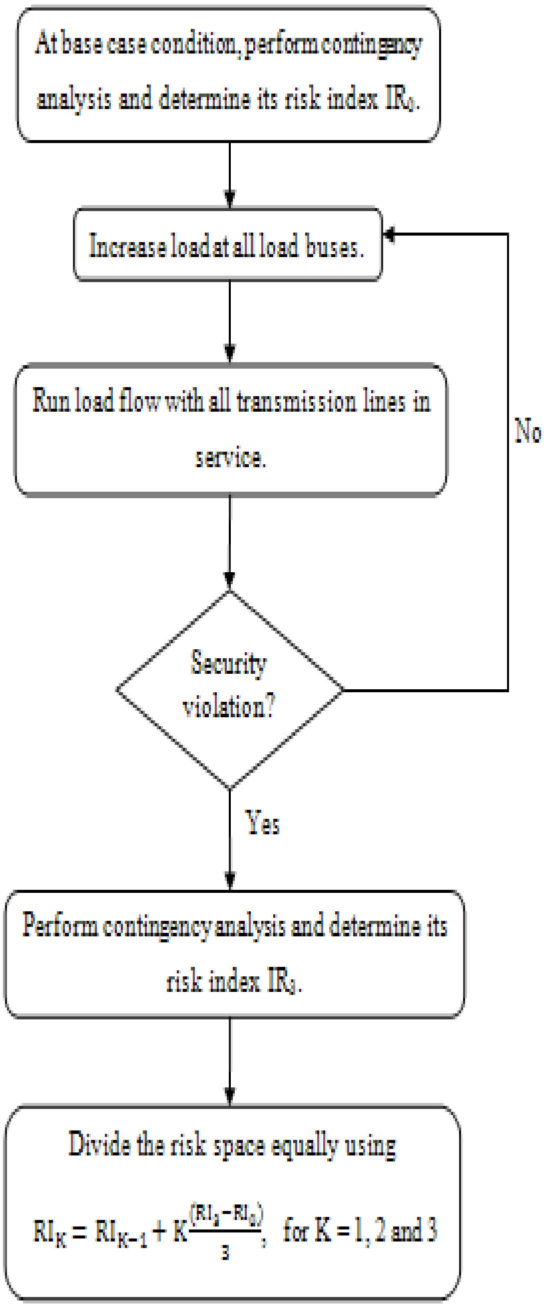

Fig. 4 Flowchart for risk classification

5 Results and Discussion

The proposed RBSA method is implemented on IEEE RTS-96 and practical power system. IEEE RTS-96 consists of 24 buses, 35 transmission lines including 2 parallel lines and 5 transformers with total real and reactive power load at base case condition equal to 2850 MW + j580 Mvar. The practical power system interconnection is comprises of 87 buses, 177 transmission lines including 59 single, 53 double and 3 quadruple lines at voltage level of 275kV. The total real and reactive power load at base case condition is 10920 MW + j2420 MVar.

Only uncertainty in the transmission line outages are considered in the study. A two-state single repairable Markov model is assumed for all the transmission lines [1], in which each transmission line is assumed to exist only up or down states.

In this section, the line overload risk index considering line outage and load increase are calculated by using two different severity functions. The reliability data of IEEE RTS-96 is as given in [21]. Failure rate of the transmission line in the practical interconnected power system is assumed to be 0.02 failure/year. In the event of transmission line outages, line flow of all transmission lines need to be examined. To assist this, a database consisting of line flow at different loading conditions, is developed. For power flow simulations, the Power System Analysis Toolbox (PSAT) is used [13].

In this study, the risk index is calculated at every 5% and 2% increase in load from base case until it reaches its maximum permissible load for IEEE RTS-96 and practical interconnected power system respectively. The risk index curves with respect to total loads are plotted by interpolating points between the calculated risk index values. Total line overload risk indices of both test systems utilizing continuous and percentage of violation severity function are shown in Fig. 5 and 6 respectively. 0% increase in load from base case indicates the load condition at base case.

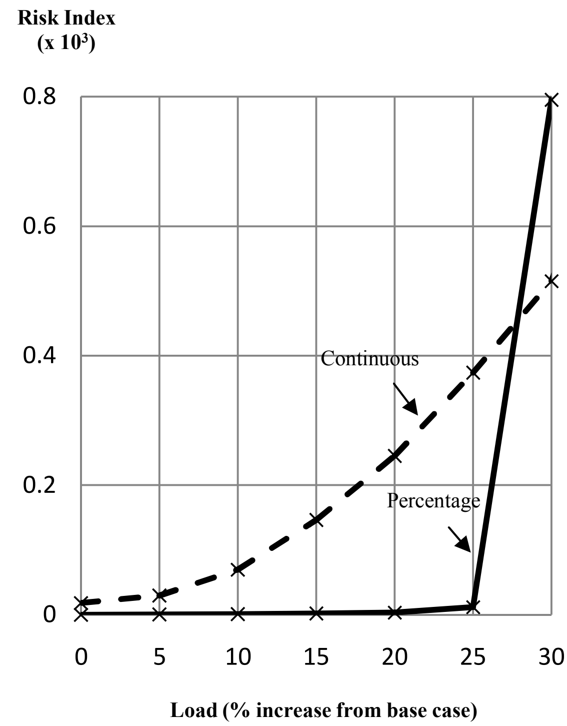

Fig. 5 Risk of line overload in IEEE RTS-96 test system.

Fig. 5 shows the total line overload risk considering continuous and percentage of violation severity function in IEEE RTS-96 test system. The curves in Fig. 5 show that similar pattern of risk index curves are obtained for two different severity functions. Line overload risk increases as load is increased from base case to maximum allowable load. When load is increased from base case to 25%, risk index computed by considering continuous severity function shows prominent risk index value. This is due to the fact that at these load conditions the effect of near violating contingency is more significant when compared to the impact of violating contingency. An exponential increase in the risk index value can be seen when continuous severity function is adopted. When load is raised from 25% to 30% increase from the base case load, risk index computed using percentage of violation severity function shows a sharp increase in risk index value.

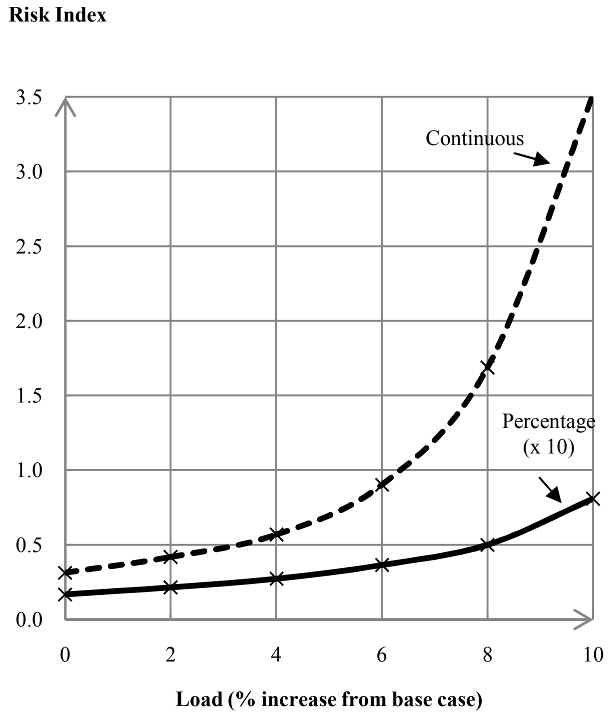

Fig. 6 Risk of line overload in a practical interconnected power system.

From Fig. 6, risk of line overload in practical interconnected power system computed from continuous severity function shows risk index value increase exponentially as load is increased from base to 10% increase in load from base case. At 6% to 10% increase in load from base case, risk index value computed using continuous severity function increase significantly. This is due to the fact that continuous severity function considers both the near violating and violating impact of security violation which is not included in the percentage violation severity function. Risk index value obtained from utilization of percentage of violation severity function indicates linear increase in risk as load is raised from base case to 6% increase in load from base case. Risk index started to increase exponentially at 6% to 10% increase in load from base case and a sharp increase in risk can be seen when load is increased from 8% to 10% from base case load.

The curves in Fig. 5 and 6 depict similar pattern of risk index curves obtained from utilization of two different severity functions. The results obtained from using two different severity functions are consistent in the sense that the line overload risk index value increases as loads are increased from base load to maximum permissible load.

Risk classification of line overload is performed independently with respect to severity function type. Figs. 7, 8, 9 and 10 show risk classification done on risk obtained from using the continuous and percentage violation severity functions, respectively.

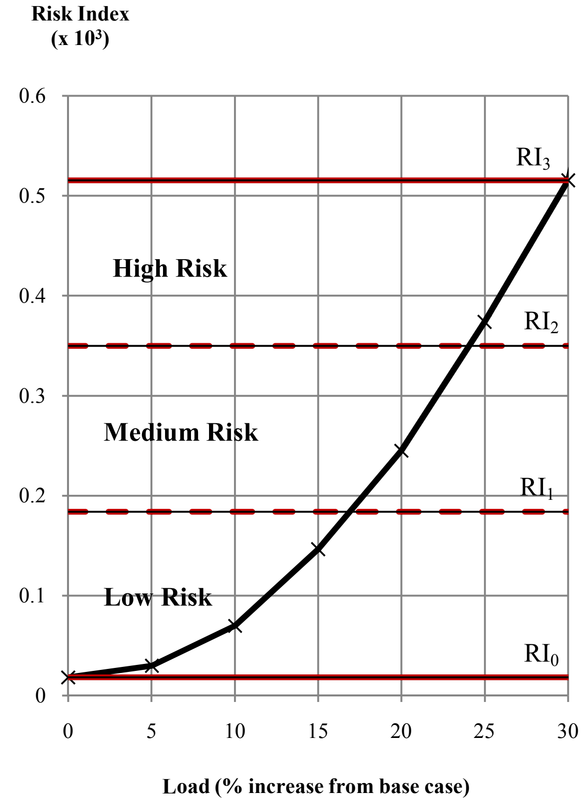

Fig. 7 Risk classification of the IEEE RTS-96 using continuous severity function.

From Fig. 7, it is noted that the test system should not be operated at loads greater than 15% increase from base case load in order to remain in the low risk region. At 20% increase in load from base case, the power system is said to operate in the medium risk region. When load is increased to 25% from base case, the operating point is classified as high risk because the load margin between the current operating and maximum permissible load becomes very small. The maximum permissible load for line overload is 30% increase from base case load.

In contrast to what shown in Fig. 7, Fig. 8 shows that the limit of load to ensure low risk operating point is extended until 25% increase in load from base case. Risk index computed by considering percentage of violation severity function underestimate the severity of security violation.

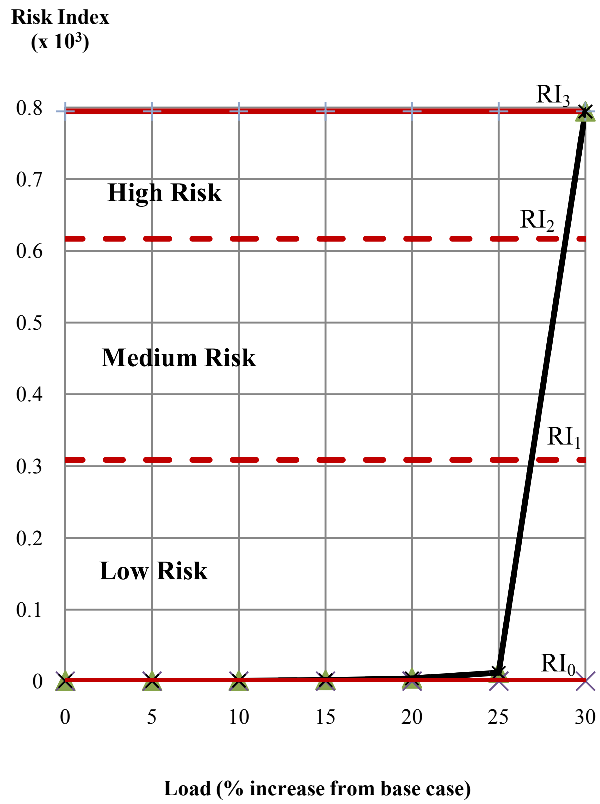

Fig. 8 Risk classification of the IEEE RTS-96 using percentage of violation severity function.

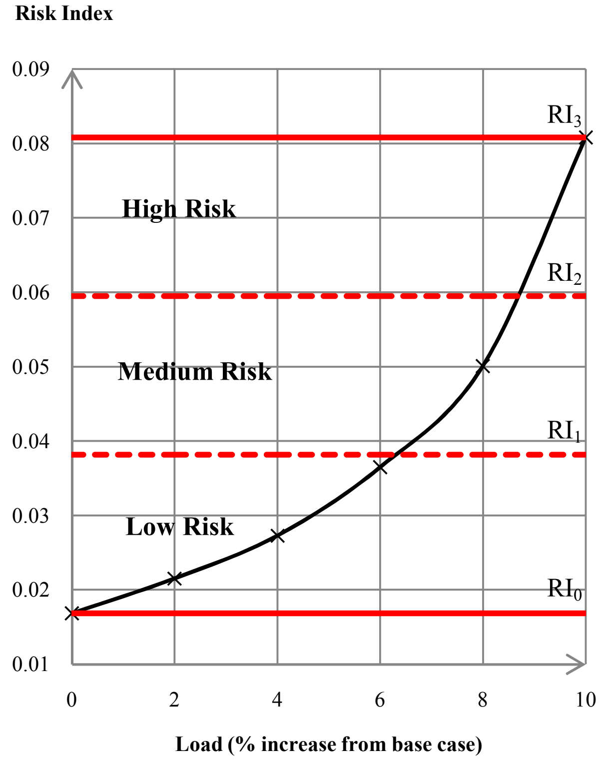

Fig. 10 Risk classification of the practical power system interconnection using percentage of violation severity function.

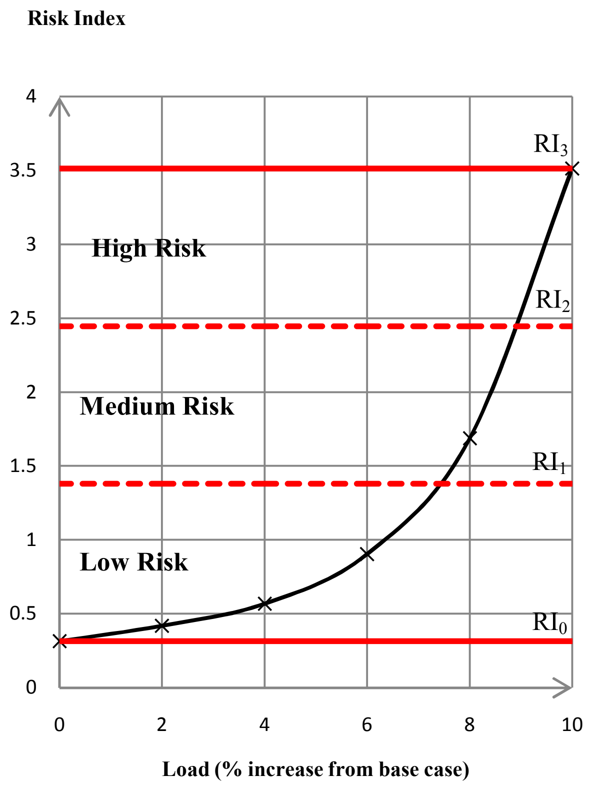

Fig. 9 Risk classification of the practical power system interconnection using continuous severity function.

From Figs.9 and 10 it is noted that power system should not be operated at a load greater than 10% increase from base case in order for the practical power system interconnection to remain in the acceptable region. From both risk classification results shown, the operating condition between base case load to 6% increase from base case load is classified as low risk operating point. At 8% increase in load from base case, risk of line overload calculated through continuous and percentage of violation severity functions conclude that the power system is operated at the medium risk region. As can be seen from Figs. 9 and 10, the possible operating point in the high risk region become very stringent, therefore small load fluctuation may result in an unacceptable operating condition. Classification made through risk index computed using continuous severity function give a more practical result since the near violating consequences are taken into account.

6 Conclusion

The value of risk index indicates the secure level of the current power system operating condition. Numerically, the risk index value at the same operating point obtained from using different severity functions will be different. However, risk index values determined by each severity function conclude that maximum load demand will result from highest risk index value. It implies that security of a power system deteriorates as load increases. In all cases considered in this study, the least risky operating condition is the base case condition while at maximum permissible load is the most risky condition

Effects of likelihood of security violating contingency and its impact are considered in risk measurement using percentage violation of severity function. Risk index computed by using the continuous severity function considers both the near violating and violating impact of security violation as well as its likelihood. From the result presented in this paper, the continuous severity function gives the advantage of being able to zoom in into the consequence of near violating contingency.

The proposed risk classification technique has the ability to qualitatively interpret the numerical values of the risk index. Through risk classification, the operating limit of power systems can be clearly seen. From the risk classification results, the maximum permissible load in line overload can be identified. In addition, visualization of risk level through risk classification technique discussed in this paper provides additional information on the current operating condition of power system so that timely corrective or protective action can be initiated.

References:

[1] James McCalley, Vijay Vittal, Nicholas Abi-Samra, An overview of Risk Based Security Assessment, *IEEE Power Engineering Society Summer Meeting,* Vol. 1, 1999.

[2] H. Haroonabadi, M. R. Haghifam, Generation Reliability Assessment in Power pool Market Using MCS and Intelligent Systems, *WSEAS Transaction on Power System*, Issue 6, Vol. 3, June 2008.

[3] IEEE/CIGRE Joint Task Force on Stability and Definitions, Definition and Classification of Power System Stability, *IEEE Transactions On Power Systems*, vol. 19, No.2, May 2004.

[4] Hua Wan, James McCalley, Vijay Vittal, Risk Based Voltage Security Assessment, *IEEE Transaction on Power System*, Vol. 15, No.4, November 2000.

[5] C. Ning, C. A. Hsieh, T. Y. Hsiao, C. N. Lu, Two application examples of probabilistic risk assessment in power system operations, *9th International Conference on Probabilistic Methods Applied to Power Systems KTH*, Stockholm, Sweden, June 2006.

[6] D. S. Kirschen, D. Jayaweera, Comparison of risk-based and deterministic security assessments, *IET Generation Transmission Distribution*, 2007, 1, (4):527-533.

[7] Youjie Dai, James McCalley, Nicholas Abi-Samra, Vijay Vittal, Annual Risk Assessment for Overload Security, *IEEE Transactions On Power Systems*, vol. 16, No.4, November 2001.

[8] Anil Swarnkar, K. R. Niazi, CART for Online Security Evaluation and Preventive Control of Power System, *Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines*, Tenerife, Spain, December 16-18, 2005

[9] J. D. McCalley, V. Vittal and N. Abi-Samra," An Overview of Risk Based Security Assessment", *IEEE-PES Summer Meeting*, 1999.

[10] Task Force on probabilistic Aspects of Reliability Criteria of the IEEE PES Reliability, Risk and Probability Applications Subcommittee," Probabilistic Security Assessment for Power System Operations", *IEEE-PES Society General Meeting*, June 2004.

[11] M. Ni, J. D. McCalley, V. Vittal and T. Tayyib,"Online Risk-Based Security Assessment", *IEEE TRANSACTIONS ON POWER SYSTEMS*, vol. 18, No.1, February 2003.

[12] M. Ni, J. D. McCalley, V. Vittal and T. Tayyib,"Software Implementation of Online Risk-Based Security Assessment", *IEEE TRANSACTIONS ON POWER SYSTEMS*, vol. 18, No.3, August 2003.

[13] Federico Milano, Power System Analysis Toolbox (PSAT) [Online] **http://thunderbox.uwaterloo.ca/~fmilano**

[14] Marayati Marsadek, Azah Mohamed, Zulkifli Mohd. Norpiah, Risk based static security assessment of power systems considering the effects of severity functions, *The 3rd*

International Power Engineering and Optimization Conference, 2009.

[15] Y. Feng, W. Wu, B. Zhang and W. Li,"Power System Operation Risk Assessment Using Credibility Theory", *IEEE TRANSACTIONS ON POWER SYSTEMS*, vol. 18, No.1.

[16] L. D. Arya, L. S. Titare and D. P. Kothari, " Determination of Probabilistic Risk of Voltage Collapse Using Radial Basis Function (RBF) Network", *Electric Power Systems Research*, November 2005.

[17] Tetsushi Miki, Consideration of Uncertainty Factors in Search for High Risk Events of Power Systems Caused by Natural Disasters, *WSEAS Transaction on Power System,* Issue 3, Vol. 3, March 2008.

[18] Tetsushi Miki, The Efficient Offline Search System for High Risk Events of Power Systems Caused by Natural Disasters, *WSEAS Transaction on Power System,* Issue 5, Vol. 3 , May 2008.

[19] R. Y. Yates and D. J. Goodman, *Probability and Stochastic Process*, John Wiley & Sons, 2005

[20] M. Ni, J. D. McCalley, V. Vittal and T. Tayyib, Online Risk-Based Security Assessment, *IEEE Transactions On Power Systems*, vol. 18, No.1, February 2003.

[21] The IEEE Reliability Test System,Reliability Test System Task Force, *IEEE TRANSACTIONS ON POWER SYSTEMS*, 1999.