Risk assessment of line overload in a practical power system 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. This paper presents the assessment of risk of line overload on a practical interconnected power system at various loading condition using a risk index. Two types of severity functions, namely the continuous and percentage of violation severity functions are considered in this study. 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. Results are presented in terms of risk index curves.


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, planning and decision making process in this diverse market requirement has become increasingly important.

In many parts of the world, power system’s networks are forced to operate under increasingly stressed condition. 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 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 [1]. 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.

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 [2] – [4]. This result in highly conservative decisions requiring high cost solutions in order to satisfy loading and outage conditions [5]. 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. Risk based security assessment (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.

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.

### 2 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,

\[
\text{RISK(E)} = \text{PROB(E)} \times \text{SEV(E)}
\]  

where E is event.

#### 2.1 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,

\[
\text{RISK}(\text{LO}) = \sum_{i=1}^{N} \text{RISK}_{\text{LO}}(E_i) = \sum_{i=1}^{N} [\text{PROB}(E_i) \times \text{SEV}_{\text{LO}}(E_i)]
\]

where,

- \(E_i\) : ith line outage
- \(N\) : total number of contingency

The probability distribution function of transmission line outage is assumed as follows [6]:

\[
\text{PROB}(F_k) = 1 - e^{-\lambda_k}
\]

where \(\lambda_k\) 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;

\[
\text{PROB}(E_i) = \text{PROB}(F_i) \prod_{j=i}^{N} \text{PROB}(F_j)
\]

Assuming a transmission line outage is an event that is collectively exhaustive [6]; hence the following relationship is valid;

\[
\text{PROB}(F_k) = 1 - \text{PROB}(F_k)
\]

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

\[
\text{PROB}(E_i) = (1 - e^{-\lambda_k}) \times e^{-\lambda_k}
\]

#### 2.2 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 circuit/branch. 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 [7]. 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 [9].

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.

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

![Flowchart of calculation of severity function](image)

**3 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.

Mathematically, continuous severity function can be written as,

\[
SEV_{LO}(S_k) = \begin{cases} 
10(P_R - 0.9), & P_R \geq 0.9 \\
0, & P_R < 0.9
\end{cases}
\]  
(7)

where,

- \( NV \) : Near Violation region
- \( V \) : Violation region
- \( DL \) : Deterministic Limit

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,

\[
SEV_{LO}(S_k) = \begin{cases} 
PR_k, & PR_k \geq 0 \\
0, & PR_k < 0
\end{cases}
\]  
(8)

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

\[
SEV_{LO}(C) = \sum_{i=1}^{M} SEV_{LO}(S_k)
\]  
(9)

where,

- \( C \) : contingency
- \( M \) : total number of lines

Fig.1 Continuous severity function

where,

- \( NV \) : Near Violation region
- \( V \) : Violation region
- \( DL \) : Deterministic Limit

![Fig. 1 Continuous severity function](image)
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 \( R_{I0} \) and \( R_{I1} \), \( R_{I1} \) and \( R_{I2} \) and \( R_{I2} \) and \( R_{I3} \), respectively. The implementation of the proposed risk classification is described by referring to the flowchart shown in Fig. 4.

**4 Results and Discussion**

The proposed RBSA method is verified on a practical power system in which the system consists 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 \( 10920 \text{ MW} + j2420 \text{ MVar} \). 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 [9].

In this section, the line overload risk index considering line outage and load increase are calculated by using two different severity functions. The failure rate of the transmission line is assumed to be 0.02 failure/year. For power flow simulations, the Power System Analysis Toolbox (PSAT) is used [8]. Five transmission line outages are not listed in the contingency list since those line outages caused divergence in power flow solutions. In this study,
the risk index is calculated at every 2% increase in load from base case until it reaches its maximum permissible load. The risk index curves are plotted by interpolating points between the calculated risk index values. The total line overload risk indices of the test system are shown in Fig. 5. The 0% increase in load from base case indicates the load condition at base case.

![Risk of line overload (LO)](image)

**Fig. 5 Risk of Line overload**

The curves in Fig. 5 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 10% of base case load. The risk of line overload computed by using the continuous severity function shows a significant increase in the risk index. 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 classification of line overload is performed independently with respect to severity function type. Figs. 6 and 7 show risk classification done on risk obtained from using the continuous and percentage violation severity functions, respectively.

![Risk Index](image)

**Fig. 6 Risk classification for risk index computed by using the continuous severity function**

![Risk Index](image)

**Fig. 7 Risk classification for risk index computed by using the percentage violation severity function**

From Figs. 6 and 7 it is noted that power system should not be operated at a load greater than 10% increase from base case in order 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. 6 and 7, 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. 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. In addition risk classification also provides information on the current operating condition of power system so that timely corrective or protective action can be initiated.

References: