Reliability importance measure of energy producers from energy consumers' perspective

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There is an increasing trend in consideration of the electricity-supply quality in modern power systems. One of the quality-related aspects is the desired level of reliability at the points of electrical-energy consumption or load points. In this regard, the system operator needs to evaluate the impact of system components on the reliability at the considered load points. "Reliability importance" is a quantitative index in order to measure this impact. The reliability importance measure in most of the conventional methods is on the basis of the risk sensitivity analysis. Such an analysis imposes prohibitive computational burden in large power systems. Considering these points, this paper proposes an approach to evaluate the reliability importance, which is not suffered from the immense computational burden. The proposed method determines the reliability importance of the electrical-energy producers or generators from the consumers or load points perspective in a selected area of the power system. In order to do so, generators are ranked according to their impact on the mentioned area. This impact is measured on the basis of the effect of generators on power-flows in the lines which cross-boundary of the selected area. Capacity and unavailability of the generators are also considered in the ranking calculations. Applicability and computational efficiency of the proposed method is validated through studies conducted on two test systems.

keywords: *Reliability importance, Generator, Load point.*

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NOMENCLATURE

Abbreviations

GenBus Bus which has generator(s).
GSF Generation shift factor.
EA External area.
SA Study area (area of interest).
i, j, k Index of buses.
g Index of buses which have generators.
i-j Index of line between buses *i* and *j*.
gen_{unit} Index of generating units which are connected to bus g.
A_{gen_unit} Availability of a generating unit.
$GSF_{i-j,g}$ GSF between line *i-j* and bus g.
$GSF^{*}_{i-j,g}$ Modified GSF between line *i-j* and bus g.
N_{SA} Number of buses of the study-area
P_k^{max} Maximum capacity of MW generation at bus k.
P_g^{max} Maximum capacity of MW generation at bus g.
$P_{gen\_unit}^{\max}$ Maximum MW capacity of a generating unit.
$P_{tot}^{\max}$ Total maximum MW capacity of all generators.
ΔP_{i-j} Change of power flow in line *i-j*.
ΔP_g Change of power injection due to the power generation change (outage) at bus g.
$\overline{RE}$ Average change of the reliability index among the buses in the study area.
RF_g Ranking (importance) factor of generator bus g.
RI_i^{base} Reliability index at bus i of the study area in the base case or when the external-area generator buses are not fully reliable.
RI_i^{new} Reliability index at bus i of the study area when a generator bus in the external area is assumed to be fully reliable.
S_{base} Base of power in the per unit calculations.
U_g Unavailability of generator bus g.
$U_{EA}^{\min}$ Minimum unavailability of generator buses in the external area.
x_{i-j} Reactance of the line between buses i and j.
$X'(r,c)$ Element in row r and column c of the DC load-flow reactance matrix.

1. INTRODUCTION

Modernization of power systems requires more attention to issues such as new technologies, distributed generation, efficiency, asset management and more active roles of the electricity consumers. These issues, on the one hand, necessitate to measure the importance or role of the system components as well as to improve asset management methods. On the other hand, the expectation level for the quality of the electricity supply has increased. One of the important criteria for the quality of electricity supply is reliability.

Reliability can be defined as the ability of the power system to keep the electricity-supply risk below a certain level. Reliability and risk are interchangeably used to measure this ability. Lower risk of the electricity supply is equivalent to higher reliability. At high voltage levels of the power grid, generators and transmission lines are the main considered components in the reliability evaluation problem. This problem is usually designated as the composite-power-system reliability evaluation [1, 2]. Traditional methods of the reliability evaluation in composite power systems usually include determining contingencies or outage events of the system components, examining violations of the power-grid constraints and applying remedial actions to eliminate the mentioned violations. In these methods, usually, an optimization problem is solved with the objective of minimizing load loss or load interruption. Because of large numbers of the contingencies, numerous network constraints and needing to solve an optimization problem for each contingency, reliability evaluation in large power systems are faced with a prohibitive computational burden. So, there is still research space to find methods that have less computation.

In modern power systems, it is important to enhance the monitoring and management of the system components from various aspects. One aspect is the planning problem, where identifying points with higher priority for system expansion could save the planning investment [3]. The prioritized points include the system's weak points from the perspective of reliability. Another aspect is the power-system maintenance problem. Since there are limited investment and maintenance personnel, it is useful to identify more important components that should be prioritized for maintenance. An important sub-problem of the maintenance is the reliability-centered maintenance. In this sub-problem, in order to improve the maintenance efficiency, important elements from the perspective of the reliability are given more priority to be included in the maintenance [1, 4, 5]. The next aspect is the greater involvement of electricity consumers in the operation of the power system. For instance, consumers in an electricity market may prefer to have an option to select a supplier that can provide electricity in accordance with their desired reliability level at a reasonable price [6–8]. This obliges the system operator to pay more attention to reliability at load-points or areas where loads with particular reliability concerns are gathered. The above-mentioned aspects indicate that it is valuable to determine the role, importance, or influence of the system components from the reliability perspective.

Determining the importance of system components from the reliability viewpoint is the subject of studies known as reliability importance or component criticality measure. In these studies, reliability-related indices are usually applied to assess the importance or the extent of influence of system components on the system reliability and to rank the components accordingly [9]. For example, one of the well-known indices in this regard is the Birnbaum criteria. This is the ratio of change in the system reliability at a time to change in the reliability of one component at the same time [10]. Many of the methods used to calculate such a criterion or similar indices are on the basis of the risk sensitivity analysis. In the risk sensitivity analysis, a reliability-related index is calculated in an initial or a base-case condition. Then the system state or a parameter of the considered component(s) is changed and the reliability-related index is recalculated afterward. The relative change of the calculated index in initial and new conditions indicates the reliability importance of the considered component(s). Such methods are more practical in small and uncomplicated power systems. These methods face difficulty in the composite power system due to the required massive computational burden.

Another point regarding the conventional methods for the important measure is that their formulation may need to be changed or modified when used in the power system. This is due to some of their considered assumptions that are not suitable for the power system. For example, the assumption of a definite time period or a limited-mission time for the system components does not give real results in the power system. Components in a power system are usually subject to maintenance programs and hence, have a long service or lifetime, which is not a limited-mission time. Another point is the time-dependency of formulas used in the conventional methods, which are not consistent with the long-term model of the power system. Because of these limitations, new indices or methods for the reliability importance measure in power systems still are welcomed.

Various methods have been reported in the literature to measure the reliability importance in the power system which can be divided into two broad categories;

The first category includes methods that are on the basis of probability concepts. In these methods, the importance indices are introduced and concepts such as fault-tree and cut-set are used to calculate the indices. The fault-tree based methods seek a hierarchical relation between the system components that lead to operation failure. The cut-set based methods determine system failures due to the disconnection of its input and output. For example, in order to calculate the importance indices, a reliability block diagram of a simple system in [11], cut-sets of a transmission substation in [12], fault-tree of a marine power plant in [13], fault-tree of a nuclear power plant in [14] and cut-sets of a transmission substation in [15] have been applied. Such fault-tree or cut-set based methods are not suitable for large composite power systems where consideration of numerous related combinations is impractical.

The second category includes methods that are based on the sensitivity analysis. In these methods, different scenarios or contingencies are created by changing the system state or a parameter of its components and then estimating the corresponding change of the risk-related indices in different scenarios. For example, in [16] and [17], the importance measure and ranking of lines connected to a transmission substation have been analyzed with AREP software in different loading conditions. Paper [18] has studied the effect of distributed generation on the reliability of the distribution system for different faults and restoration scenarios. In [19], Monte-Carlo simulation and Bayesian network have been used to estimate the reliability importance of the power-system components. In this paper, an optimization problem from the perspective of the load-loss is solved in different scenarios. In [20], a method has been presented to rank the power-grid components from the reliability viewpoint under different system loading conditions. The method examines the effect of the different contingencies on reliability in which the ac power-flow equations are taken into account. Paper [21] has applied the concept of shadow-price through an optimization problem to rank system components from the reliability perspective. The objective function of the optimization problem is minimizing the load interruption. In [22], a method has been proposed to rank the system components for a reliability-centered-maintenance program. The method examines different contingencies and minimizes the cost of an electricity outage. Paper [23] has investigated different capacities and locations of the distributed generation and its effect on the distribution system reliability with ETAP software. In [24], co-ordination of the generation and transmission expansion planning for different scenarios of the wind-power sources with reliability constraint has been studied. Paper [25] considers the problem of transmission planning with the effect of wind-power sources on system reliability. In this work, an optimization problem is solved for different network-configurations. In [26], an important measure in terms of the weighted indices has been defined in the presence of the wind-power sources. Weights of the indices and rankings of the system components depend on the different system states. Using Monte Carlo simulation, paper [27] determines states of transmission lines after a storm and calculates the importance of indices for the lines. In this paper, the criterion for evaluating the system's functionality after the storm is the ability to supply power in accordance with the dc load-flow model. The common point between the above-reviewed methods is the need to calculate reliability or importance-measure indices in different states or scenarios of the system, which is similar to the risk sensitivity analysis. In these methods, reliability evaluation is performed many times, which is time-consuming and is impractical to cope with a large power system that has numerous components.

The points mentioned in the previous paragraphs indicate that it is useful to increase computational efficiency in estimating reliability importance. This issue is addressed in the present paper. This paper estimates the reliability importance of buses that have electricity producers or generators (GenBuses) from the perspective of the consumers or load points in a composite power system. The proposed method determines the ranking of the GenBuses in accordance with their impacts on a group of loads in a considered area. This is performed on the basis of the GenBus impacts on power-flow through the transmission lines, which cross the area boundaries. In the proposed method, reliability calculations are not used in order to increase computational efficiency.

Contributions of this paper can be mentioned as follows:

- The main contribution is the formulation presented to measure the importance of the GenBuses. Unlike conventional methods, this formulation does not require complex and deterrent calculations. Also, the computation time is not significantly sensitive to the size of the power system;
- The proposed formulation is based on the maximum possible impact of the generators and therefore the obtained results do not need to be recalculated for a variety of the system loading conditions;
- In the proposed formulation, known technical features of the power grid, such as generators' capacity and network reactance matrix, are included.

The rest of this paper is organized in three sections; The proposed method is illustrated in Section 2. Evaluation results of the proposed method are reported on the basis of the studies conducted on two test systems in Section 3. Concluding remarks terminate the paper in Section 4.

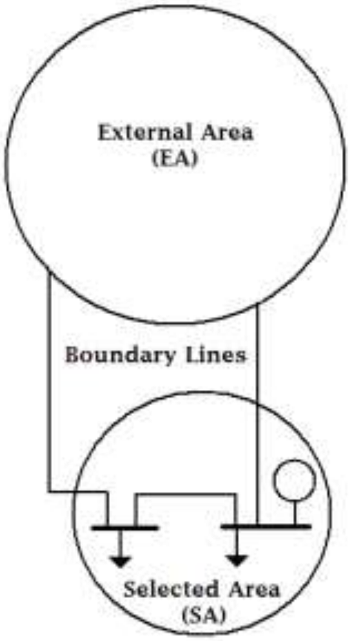

Fig. 1. The assumed selected area (SA) and external area (EA) in the proposed method.

2. DESCRIPTION OF THE PROPOSED METHOD

As shown in Fig. 1, it is assumed in the proposed method that a power system is partitioned into two areas, which are named by the "selected area" (SA) and the "external area" (EA). The SA indicates the area that includes the considered load points (load buses) where reliability is of interest. The remaining part of the power system, where reliability importance of GenBuses should be determined, is designated by the EA. The impact of the EA GenBuses on the reliability of the SA load points is of concern in this paper.

The proposed method tries to rank the EA GenBuses based on their effect on the reliability of the SA load points. This effect is indirectly tracked through the boundary lines between the SA and EA. This is in accordance with two facts; Firstly, reliability is mainly related to active-power generation and its flow in the system. Secondly, the boundary lines are the only ways for the active-power interchange between the SA and EA. The mentioned facts support the main idea of this paper that, in order to estimate impacts of the EA GenBuses on the reliability of the SA load points, impacts of the GenBuses on the active power-flows in the boundary-lines could be measured. The EA GenBuses with higher ranks has more reliability importance from the perspective of the SA load points.

Considering the above-mentioned facts, this paper employs Generation Shift Factor (GSF), which is a well-known factor, to rank the EA GenBuses. This factor indicates that how a change in the power produced by a generator at a bus affects the power flow in a line. The GSF is defined as follows [28]:

$$GSF_{i-j,g} = \frac{\Delta P_{i-j}}{\Delta P_g} = \frac{X'(i,g) - X'(j,g)}{x_{i-j}} \quad (1)$$

Where:
ΔP_{i-j}: Change of power flow in line *i*-*j*,
ΔP_g: Change of power injection due to power generation change

(outage) at bus g,
$GSF_{i-j,g}$: GSF between line i-j and bus g,
x_{i-j}: Series reactance of the line which connects buses i and j,
$X'(r,c)$: Element in row r and column c of the DC load-flow reactance matrix.

The word power in the above formulation means active or MW power. In the case of the generator outage, ΔP_g in (1) is equal to $-P_g^0$ or minus of the power generation at the bus g before the outage.

The conventional definition of the GSF depends on the presence of a slack bus in the system. This means that only one bus is responsible for retaining power balance in the system by compensating for power-injection changes in other buses. It is more realistic to ignore the limiting assumption of one slack bus. There is an approach in this regard, which is to apply the modified formulation presented in [28]. In the formulation, it is assumed that power injection change at a bus is allocated to all remaining generators in proportion to their maximum MW capacity. So, the modified GSF is formulated as follows [28]:

$$GSF^*_{i-j,g} = GSF_{i-j,g} - \sum_{k\neq g} \frac{GSF_{i-j,k} \times P_k^{\max}}{P_{\text{tot}}^{\max} - P_g^{\max}} \tag{2}$$

Where,
$GSF^*_{i-j,g}$: Modified GSF between line i-j and bus g,
P_k^{max}: Maximum capacity of MW generation at bus k,
P_g^{max}: Maximum capacity of MW generation at bus g,
P_{tot}^{max}: Total (Sum of) maximum MW capacity of all generators.

Equation (2) can be applied to determine the outage impact of the EA GenBuses on the boundary lines between the SA and EA.

Other points are also considered to determine the proposed rankings. These points are the effects of MW-capacity and the unavailability of the EA generators. Higher unavailability is equivalent to more failure probability of generator. It is anticipated that a generator with higher capacity and higher unavailability will cause more outage impact on the considered lines. The following equation can be applied to consider these points:

$$\begin{gathered} \Delta P_{i-j}^{\max} = -P_g^{\max} \times U_g \times GSF^*_{i-j,g} \\ \Rightarrow \left|\Delta P_{i-j}^{\max}\right| = P_g^{\max} \times U_g \times \left|GSF^*_{i-j,g}\right| \end{gathered} \tag{3}$$

Where, P_g^{max} and U_g represent the maximum capacity and unavailability of GenBus g, respectively. Equation (3) includes the influence of the MW capacity and the unavailability of a GenBus in its impact on a line.

It is necessary to introduce an equation that integrates all the above-mentioned points. This equation defines the ranking factor, which is applied in the present paper and formulated as follows:

$$RF_g = \frac{P_g^{\max}}{S_{base}} \times \frac{U_g}{U_{EA}^{\min}} \times \sum_{\substack{i-j\in Boundary\\ Lines}} \left|GSF^*_{i-j,g}\right| \tag{4}$$

Where:
P_g^{max}: Maximum MW capacity of GenBus g in the EA,
U_g: Unavailability of GenBus g in the EA,
U_{EA}^{min}: Minimum unavailability of GenBuses in the EA,
$GSF^*_{i-j,g}$: Modified GSF between GenBus in the EA and boundary-line
S_{base}: Base of power in the per unit calculations.

By the above factor, the EA GenBuses are ranked based on their cumulative and maximum impacts on the boundary lines. This is the proposed reliability importance measure in this paper. It estimates the EA GenBus impacts on the reliability of the SA load points.

Since GSFs with opposite signs could cancel each other in the summation process, their absolute value has been used in (4). This is equivalent to consider the cumulative impacts of the generators on the boundary lines.

It is possible that more than one generator be connected to a GenBus in a power system. In this case, the GSF in (4) is determined for each GenBus instead of each generating unit connected to that bus. So index g in (4) indicates a GenBus and not a generating unit. In the same manner, average unavailability is assigned to a GenBus whish is in proportional to the generating units' availability and capacity, as follows:

$$U_g = 1 - \frac{\sum\limits_{gen\_unit \in\ Bus\ g} P_{gen\_unit}^{\max} A_{gen\_unit}}{P_g^{\max}} \tag{5}$$

Where, A_{gen_unit} and $P_{gen\_unit}^{\max}$ are availability and maximum MW capacity of a generating unit connected to the bus g, respectively.

Finally, it is necessary to mention that the $U_g/U_{EA}^{\min}$ acts as a scaling factor for unavailability in (4). Depending on $U_{EA}^{\min}$, this factor could have values that are greater than 1.0. When $U_{EA}^{\min}$ approaches zero, the mentioned fraction becomes indefinite and in this case, $U_g/U_{EA}^{\min}$ in (4) is replaced by 1.0. This means ignoring the $U_g/U_{EA}^{\min}$ in case of $U_{EA}^{\min} \simeq 0$.

3. SIMULATION RESULTS

In this section, the applicability of the proposed method is validated by illustrating the study results on two power systems.

A. The first case study

Applying the simple 7-bus system of Fig. 2, this study shows how equations in the proposed method are employed to determine the ranking of the EA GenBuses from the reliability-perspective of the SA load points. Data of the system components are presented in Tables 1 and 2. The base power is considered as 100 MVA. As shown in Fig. 2, the SA includes buses 6 and 7 and the EA includes the remaining buses. Bus 3 has been considered as the slack bus.

The DC load-flow reactance matrix has been obtained from the line data of Table 2. The GSF matrix is calculated by elements of the reactance matrix. Table 3 shows the GSF matrix among the EA GenBuses and the boundary lines.

Capacity and unavailability of GenBuses no. 1 and 3 are calculated on the basis of (5), as follows:

$$P_1^{\max} = 2 \times 75 = 150 \quad (MW)$$

$$U_1 = 1.0 - \frac{2\times 75 \times (1-0.03)}{150} = 0.03$$

$$P_3^{\max} = 150 + 75 = 225 \quad (MW)$$

$$U_3 = 1.0 - \frac{\begin{pmatrix} 150 \times (1-0.06) + \\ 75 \times (1-0.03) \end{pmatrix}}{225} = 0.05$$

From Table 2, the minimum value of unavailability for GenBuses in the EA is 0.03. Maximum MW capacity in the system is:

$$P_{\text{tot}}^{\max} = 150 + 225 + 150 + 75 = 600 \quad (\text{MW})$$

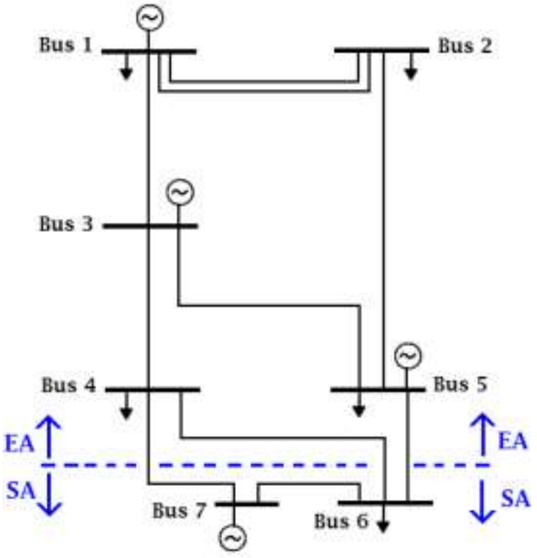

Fig. 2. Single line diagram of the system considered in the first case study.

The modified GSF is calculated by (2) for each of the EA GenBuses, as shown in Table 4. For example, the modified GSF is determined as follows for bus no. 3:

$$GSF^*_{4-6,3} = GSF_{4-6,3} - \frac{1}{P^{max}_{tot} - P^{max}_{3}} \left(\begin{array}{l} GSF_{4-6,1} \times P^{max}_{1} + \\ GSF_{4-6,5} \times P^{max}_{5} + \\ GSF_{4-6,7} \times P^{max}_{7} \end{array} \right)$$

$$GSF^*_{4-6,3} = 0 - \frac{1}{600-225} \left[\begin{array}{l} -0.046 \times 150 + \\ (-0.162 \times 150) + \\ (-0.108) \times 75 \end{array} \right] = 0.105$$

$$GSF^*_{4-7,3} = GSF_{4-7,3} - \frac{1}{P^{max}_{tot} - P^{max}_{3}} \left(\begin{array}{l} GSF_{4-7,1} \times P^{max}_{1} + \\ GSF_{4-7,5} \times P^{max}_{5} + \\ GSF_{4-7,7} \times P^{max}_{7} \end{array} \right)$$

$$GSF^*_{4-7,3} = 0 - \frac{1}{600-225} \left[\begin{array}{l} -0.039 \times 150 + \\ (-0.135 \times 150) + \\ (-0.423) \times 75 \end{array} \right] = 0.154$$

$$GSF^*_{5-6,3} = GSF_{5-6,3} - \frac{1}{P^{max}_{tot} - P^{max}_{3}} \left(\begin{array}{l} GSF_{5-6,1} \times P^{max}_{1} + \\ GSF_{5-6,5} \times P^{max}_{5} + \\ GSF_{5-6,7} \times P^{max}_{7} \end{array} \right)$$

$$GSF^*_{5-6,3} = 0 - \frac{1}{600-225} \left[\begin{array}{l} 0.085 \times 150 + \\ 0.297 \times 150 + \\ (-0.469) \times 75 \end{array} \right] = -0.059$$

In the final stage of calculation, the ranking of the EA GenBuses based on their cumulative and maximum impacts on the boundary lines are determined by (4), as illustrated in Table 5. The following example shows the calculation procedure for the EA bus no. 3:

Table 1. Data of generators and loads for the system in the first case study

Bus	Generating Units (MW)	Load (MW)
1	75 + 75	90
2	0	120
3	150 + 75	0
4	0	45
5	150	90
6	0	135
7	75	0
	Generating Unit (MW)	Unavailability
	75	0.03
	150	0.06

Table 2. Data of lines for the system in the first case study

From Bus	To Bus	Name	Reactance (p.u.)	Maximum Capacity (MW)
1	2	1-2	0.1 (Each Line)	100 (Each Line)
1	3	1-3	0.1	100
2	5	2-5	0.2	100
3	4	3-4	0.1	100
3	5	3-5	0.125	100
4	6	4-6	0.125	100
4	7	4-7	0.1	100
5	6	5-6	0.05	100
6	7	6-7	0.05	100

$$RF_3 = \frac{P^{max}_{3}}{S_{base}} \times \frac{U_3}{U^{min}_{EA}} \times \sum_{\substack{i-j \in Boundary \\ Lines}} \left| GSF^*_{i-j,3} \right|$$

$$RF_3 = \frac{225}{100} \times \frac{0.05}{0.03} \times \left(\begin{array}{c} |0.105| \ + \\ |0.154| \ + \\ |-0.059| \end{array} \right) = 1.192 \quad (pu)$$

In Table 5, the row before the last one represents the cumulative f outage-effect of the EA GenBuses on the boundary lines. Values in this row are indirectly dependent on electrical distances among the considered buses and the boundary lines. These values are then scaled by capacity and unavailability multipliers to give the ranking in the last line of the Table.

It is pertinent to note in Table 5 that rankings in the proposed method are consistent with the observable facts in the system. Although the MW capacity of bus 5 is lower than the MW capacity of bus 3, the ranking of the former bus is higher. The reason is that bus 5 is closer to the boundary lines. Buses 1 and 5 have the same MW capacity; however, bus 1 is farther from the boundary lines and hence has lower rank compared to the rank of bus 5.

B. The second case study

This study is conducted on the IEEE Reliability Test System (IEEE-RTS), which is shown in Fig. 3. Power Generation and network data of the system has been given in [29]. According to Eqs. (4) and (5), the proposed method requires supplementary data for the GenBuses, which is presented in Table 6.

In this study, buses 116, 119 and 120 constitute the SA. Large generators are around the SA and it is interesting to discover which of these generators has more reliability impact on the SA

Table 3. The GSF matrix in the first case study

		Generator Buses			
EA-SA Boundary Lines		1	3	5	7
4	6	-0.046	0	-0.162	-0.108
4	7	-0.039	0	-0.135	-0.423
5	6	0.085	0	0.297	-0.469

Table 4. The modified GSF matrix in the first case study

		EA Generator Buses		
EA-SA Boundary Lines		1	3	5
4	6	0.026	0.105	-0.129
4	7	0.077	0.154	-0.052
5	6	0.064	-0.059	0.347

load points. Boundary lines between the EA and SA are 114-116, 115-116, 116-117 and 120-123.

Applying Eq. (4), the ranking of the EA GenBuses from the perspective of the SA load points' reliability is estimated and shown by the solid red line in Fig. 4.

In this case study, it is not straightforward to check the correctness of the rankings by visual inspection of the system. Instead, a computational tool is required to justify the rankings.

In order to validate the obtained rankings, risk sensitivity analysis has been performed. In the sensitivity analysis, it is assumed that the EA GenBuses (according to their order in the obtained ranking list) to be fully reliable one at a time. Fully reliable here means zero unavailability. For each case of a fully reliable GenBus, a reliability index is calculated at the SA load points. Then, the average relative change of that index for all of the SA buses is determined as follows:

It is worth mentioning that the application of the sensitivity analysis or the $\overline{RE}$ is not mandatory and not a part of the proposed method. It is only used to validate the EA-bus rankings obtained by the proposed method. The $\overline{RE}$ is only a computational tool to show the relative change of the reliability index in the SA buses due to zero unavailability in each of the EA GenBuses. So, it does not indicate concepts such as index error forecast or error due to uncertainty and so on.

Expected Energy Not Supplied (EENS) is the reliability index that has been applied in this study. The reliability evaluation has been performed by the NEPLAN software version 5.4 [30].

The dotted blue curve in Fig. 4 illustrates the obtained curve by (6) in the second case study. This curve shows the average change of the EENS at the SA load points (relative to the base case) when GenBuses in the sequence of 118, 121, 123, 113, 122, 115, 107, 102, 101 are assumed to be fully reliable.

$$\overline{RE} = \frac{100}{N_{SA}} \times \sum_{i \in \{SA\}} \left| \frac{RI_i^{new} - RI_i^{base}}{RI_i^{base}} \right| \tag{6}$$

Where:
RI_i^{new}: Reliability index at bus i of the SA when a GenBus in the EA is assumed to be fully reliable,
RI_i^{base}: Reliability index at bus i of the SA in the base case or when the EA GenBuses are not fully reliable,
N_{SA}: Number of the SA buses.

Both curves in Fig. 4 show a similar descending trend and hence the proposed ranking for the EA GenBuses is almost in accordance with the results of the sensitivity analysis. It is therefore concluded that the ranking obtained by the proposed method is acceptable.

Table 5. Ranking of the EA generator buses in the first case study

		EA Generator Buses		
EA-SA Boundary Lines		5	3	1
4	6	-0.129	0.105	0.026
4	7	-0.052	0.154	0.077
5	6	0.347	-0.059	0.064
$\sum \left\| GSF^*_{i-j,g} \right\|$		0.527	0.318	0.167
RF_g		1.58	1.192	0.25

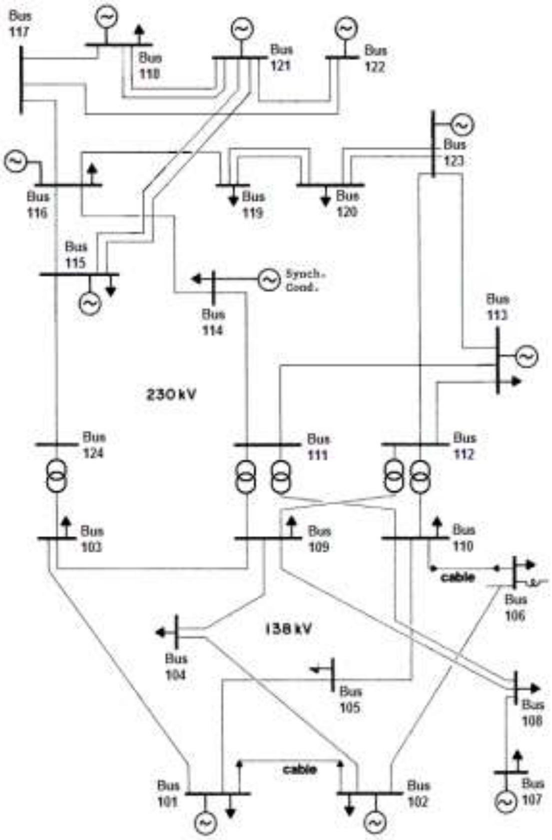

Fig. 3. Single line diagram of the system considered in the second case study.

To demonstrate the computational efficiency of the proposed method, it is worth mentioning that execution time for determining the ranking of GenBuses in Fig. 4 is about 5 seconds by a PC with ordinary software. If this ranking were based on the risk sensitivity analysis, it would take about 1385 seconds to compute it by the same computer.

4. CONCLUSION

A method for estimating the reliability importance of the generators from the perspective of the selected load points in a power system was proposed in this paper.

The proposed method does not need the risk sensitivity analysis and hence does not impose an immense computational

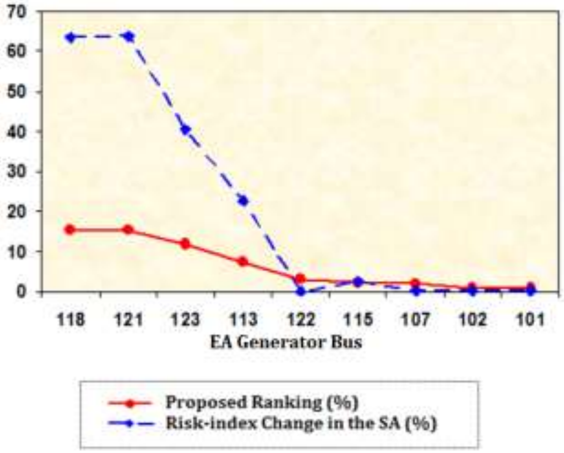

Fig. 4. Proposed ranking for the EA GenBuses and its validation through sensitivity analysis in the second case study.

Table 6. Supplementary data for generator buses in the second case study

Generator Bus	Maximum MW Capacity	Unavailability
101	192	0.037
102	192	0.037
107	300	0.04
113	591	0.05
115	215	0.034
116	155	0.04
118	400	0.12
121	400	0.12
122	300	∼0
123	660	0.061

burden. This is an advantage over the conventional methods, which are based on the risk sensitivity analysis and suffer from the massive computational burden. Also, ranking-results determined for generators in the proposed method have an acceptable degree of accuracy.

The capability to cope with the load-point reliability is a feature of the presented method, which is useful in studies of deregulated or restructured power systems. For instance, the SA may be a distribution company and the proposed method enables it to specify preferable generation companies from the perspective of its reliability requirements.

It is expected that the proposed method could be applied as a decision-making tool for planning, operation and maintenance applications in the power system. For example, depending on the GenBus rankings, a designer can decide which bus in the EA should be given more priority to increase MW capacity in order to improve the SA reliability. Also, it is possible to schedule a maintenance program in which more important generators in the EA are more carefully maintained causing to less failure and less negative impact on the SA reliability.

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