Research Article

Contingency Analysis and Ranking of Kurdistan Region Power System Using Voltage Performance Index

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Abstract

In this paper, analysis and ranking of single contingency due to the outage of transmission lines for a large scale power system of the Kurdistan Region (KR) are presented. Power System Simulator software (PSS®E33) is used to simulate the Kurdistan Region power system network and perform the contingency analysis for single line outage. This analysis is essential in order to predict and evaluate the voltage stability in case of contingency occurrence to know the most severe case and plan for managing it. All possible transmission line outages of the network are tested individually. After each branch disconnects, load flow analysis are applied by using Newton Raphson method then all bus voltages are recorded, and compared with them before the contingency. Voltage performance index is calculated for all possible contingencies to rank them according to their severity and determine the most severe contingency which is corresponding to the highest value of performance index. Also, the contingencies which cause load loss and amount of this load are observed.

Keywords: Voltage Stability, Contingency Analysis, PSS®E33, Voltage Performance Index (PIV), Kurdistan Region (KR) Network.

1. Introduction

Contingency can be expressed as an undesirable event happening in the power system network such as an outage of one or more components of the power system for example loss of a transmission line (Fischl, Halpin et al. 1982). During the outage of any equipment, contingency study displays an idea of what may be the situation of the power system after the contingency occurrence (Doshi, Salgar et al., 2015). In order to confirm the reliability of the system, contingency study is accomplished as part of the power system operation and planning. It could help utilities in identifying possible problems, arranging helpful measures beforehand, making right choices for maintenance purposes, and taking improved control arrangements (Ruiz & Sauer 2007). In this paper, analysis and variations in the voltage profile for the whole system after the occurrence of the transmission line outage are presented.

This analysis provides more confidence in the security of the power system beyond the contingency occurrence in a bulk power system to enhance voltage stability (Muhammad 2019). The outage of one branch of transmission line may lead to a line overloading in other branches and/or a system voltage rise or drop. Load flow analysis using Newton Raphson is the useful approach for study and analysis. Bus voltages after all possible line outages are calculated and recorded. Transmission line contingency severity is evaluated using voltage the Performance Index PIv. The highest value of this index means the highest severity of the contingency (Chowdhury, Mondal et al., 2015).

2. Study Description

A real 132 kV power system of KR network is shown in Figure 1 which consists of 280 buses, 123 loads and 284 branches with total power generation of 3535.0513 MW and 3455.6566 MW as peak load for the month of July 2020.

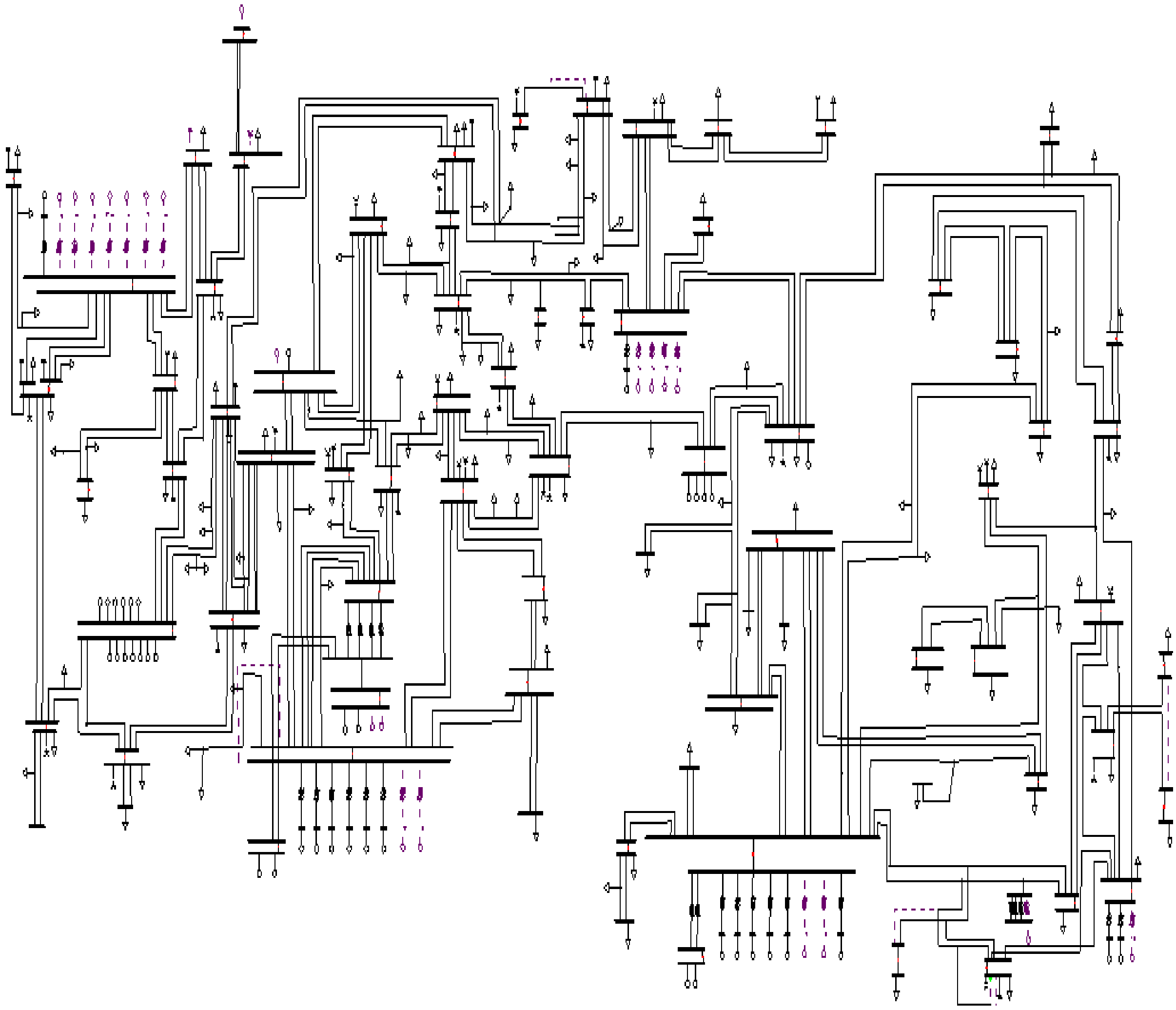

Figure 1. Kurdistan Region Network.

Figure 2 shows the voltage profile of the system buses without any contingency as it is clear some buses are under minimum permissible range (0.9 pu). The average bus voltages without contingency is 0.95455.

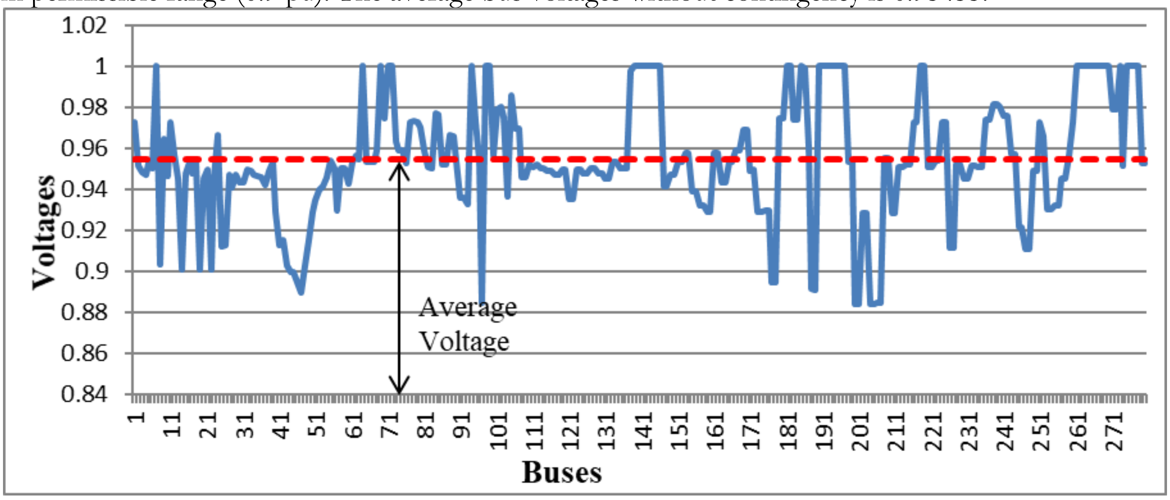

Figure 2. Voltage Profile for KR Network Buses without Contingency.

The contingency study includes single line outage only. All possible contingencies are simulated and the bus voltages are recoded under each contingency then the voltage performance index is calculated for each contingency. The permissible voltage range is 132 kV ± 10% according to the Iraqi Grid Code (Husein & AbdulFatah 2016). The voltage performance index is ranked to determine the most severe transmission line outage.

Many important files are needed to be used as input files for PSS®E which are:

1) Saved case file (*.sav): contains the information about the content of power system networks such as buses, branches, power plants and loads.

2) Subsystem file (*.sub): creates a subsystem for studying and analyzing in a given area.

3) Monitoring data file (*.mon): monitors the elements of the network to record the bus voltages less than or higher than permissible voltage, and it records the power flow rate with higher than 100% of the full capacity.

4) Contingency file (*.con): all contingencies with voltage and power flow rate violation are recorded.

The contingency report consists of four parts: general data, branches with power flow violation and the percent of violation, bus voltage with lower than or higher than permissible voltage change and the fourth part is the contingency legend.

3. Newton Raphson Method for Load Flow

The power flow analysis is one of the most important problems in power system studies (Milano 2008). The most useful method for load flow is Newton Raphson due to its advantages and accuracy (Roy & Jain 2013). Power flow solution is the fundamental duty of power system operation. The following equations illustrate the Newton Raphson load flow technique (Okakwu, Ogujor et al., 2017).

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{1}$$

Where I_i is the current injected into the bus i, writing the equation polar form

$$I_i = \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right| \angle\theta_{ij} + \delta_j \tag{2}$$

The current in terms of of active and reactive power at bus i:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{3}$$

From these two above equations we get:

$$P_i - jQ_i = |V_i|\angle - \delta_i \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right|\angle(\theta_{ij} + \delta_j) \tag{4}$$

By separating real and imaginary parts

$$P_i = \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right||V_i| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{5}$$

$$Q_i = \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right||V_i| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{6}$$

These two equations can be rewritten as:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ --- \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots\cdots\cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots\cdots\cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots\cdots\cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots\cdots\cdots & \frac{\partial P_2^{(k)}}{\partial \delta_2} \\ \hline \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots\cdots\cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots\cdots\cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots\cdots\cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots\cdots\cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ --- \\ \Delta \left|V_2^{(k)}\right| \\ \vdots \\ \Delta \left|V_n^{(k)}\right| \end{bmatrix} \tag{7}$$

This matrix can be written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \tag{8}$$

Where J_1, J_2, J_3 and J_4 are Jacobian sub matrices.

For J_1 diagonal element:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ j \neq i}}^{n} |V_i| \left|V_j\right|\left|Y_{ij}\right| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{9}$$

For J_1 off diagonal element:

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i|\left|V_j\right|\left|Y_{ij}\right| \sin\left(\theta_i - \delta_i + \delta_j\right), j \neq i \tag{10}$$

For J_2 diagonal element:

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i|\left|Y_{ij}\right| \cos\theta_{ij} + \sum_{\substack{j=1 \\ j \neq i}}^{n} \left|V_j\right|\left|Y_{ij}\right| \mathrm{Cos}\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{11}$$

For J_2 off diagonal element:

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j), j \neq i \tag{12}$$

For J_3 diagonal element:

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ j \neq i}}^{n} |V_i|\,|V_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{13}$$

For J_3 off diagonal element:

$$\frac{\partial Q_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right), j \neq i \tag{14}$$

For J_4 diagonal element:

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} - \sum_{\substack{j=1 \\ j \neq i}}^{n} |V_j||Y_{ij}|\sin\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{15}$$

For J_4 off diagonal element

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j), j \neq i \tag{16}$$

The difference between scheduled and calculated values are $\Delta P_1^{(k)}$ and $\Delta PQ_1^{(k)}$

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \tag{17}$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \tag{18}$$

The solution for the new values of the voltage and angle are:

$$|V_i|^{(k+1)} = |V_i|^{(k)} + \Delta|V_i|^{(k)} \tag{19}$$

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{20}$$

4. Voltage Performance Index

The usual way for checking the steady state contingency is by running the load flow for the system after each line outage. Some line outages could result in the constraint violations of the system such as bus under and over voltages and transmission line overload. The system performance regarding bus voltages can be evaluated by an index which identifies the severity limit of voltage values as a result of a given contingency (Swarup & Sudhakar 2006).

The ranking of the system is done by sorting the contingencies according to the values of performance index, below is the equation of this index (Semitekos & Avouris 2002).

$$PI_V = \sum_{i=1}^{N} \left[\frac{2(\mathrm{V_i} - \mathrm{V_{inom}})}{\mathrm{V_{imax}} - \mathrm{V_{imin}}}\right]^2 \tag{21}$$

Where Vi is the voltage of bus i

Vmax and Vmin are maximum and minimum voltage limits.

Vinorm is the avearge of maximum and minimum voltage.

N is the number of system buses.

5. Contingency Analysis and Ranking Algorithm

There is growing need to give the operators the essential information regarding security level of the system as a result of the contingencies in the power system and to know what measures should be chosen, or not chosen (Chen & McCalley 2005;,Donde, López et al., 2008). In light of this fact, it is important to rank the contingencies according to their severity. Figure 3 is the flow chart for the contingency analysis and ranking.

6. Results

The process of a single contingency for a large scale power system of KR is simulated using PSS©E software and all transmission line outages were tested individually. Newton Raphson load flow was conducted after each line outage then all bus voltages were recorded and the voltage profile for the whole system ws observed. Figure 4 shows the voltage profile for the most severe cases which are the outages of the lines (14001-14003) 1 and (14001-14003) 2 as it is clear the voltage profile is worse than that of the system without any contingency as shown in Figure 1 and the average bus voltages is less than that of normal case without contingency.

Figure 5 illustrates the amount of load loss during single contingencies. It is clear that the outage of line (341-13036) 1 causes the greatest load loss which is 52.4 MW. The remaining contingencies do not cause load loss in the network.

The voltage performance index was calculated for each contingency using equation (21) then these values were recorded and ranked in a descending manner. The highest value represents the severest transmission line outage. Due to the large number of contingencies only the first twenty contingencies are listed in Table 1. It is clear that the outage of lines (14001-14003) 1 and (14001-14003) 2 have the highest voltage performance index which is 114.305 so it is the most severe contingency. It was also observed that this line outage has the highest number of buses suffering from voltage violation (voltages below minimum permissible value 0.9 pu) which are 26 buses and also it has the lowest average bus voltage which is 0.94701.

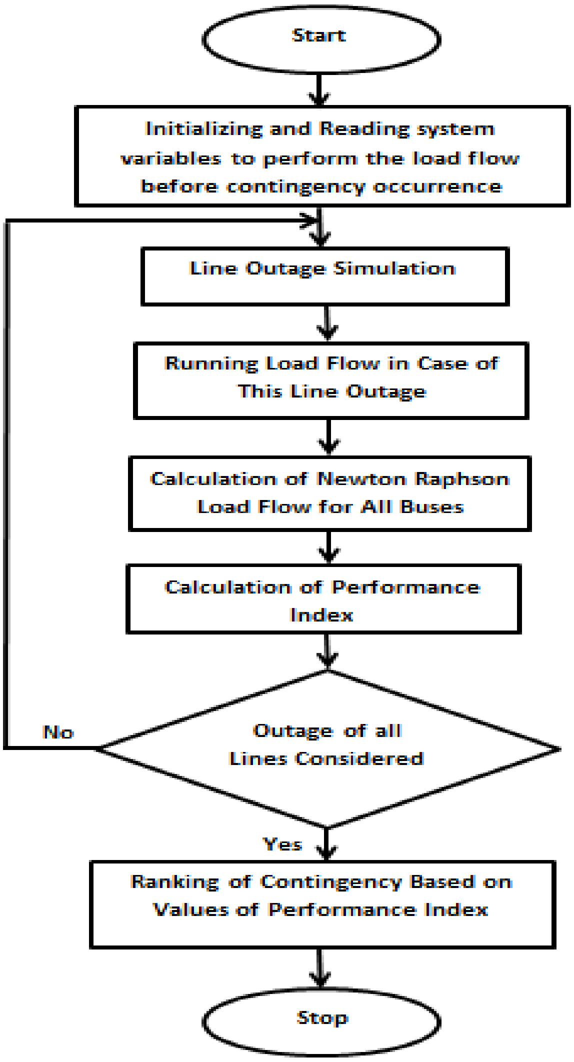

Figure 3. Flow Chart of Contingency Analysis and Ranking.

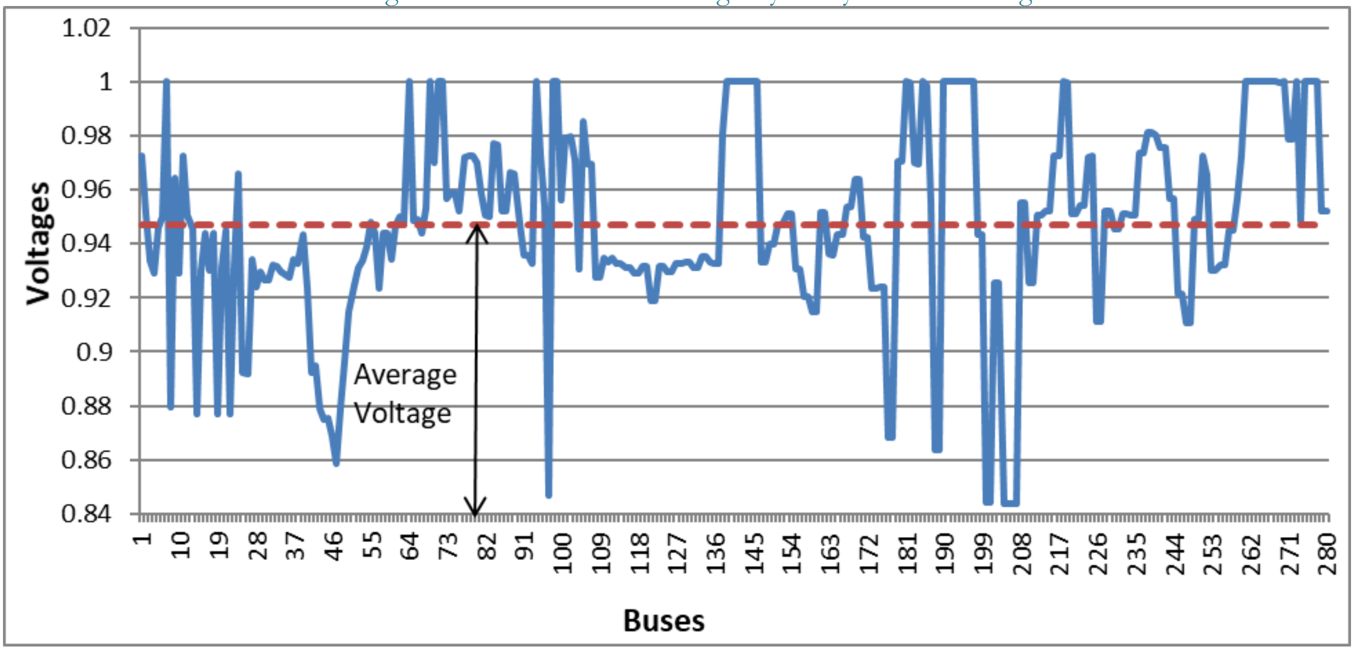

Figure 4. Voltage Profile for KR Network Buses with Severest Contingency.

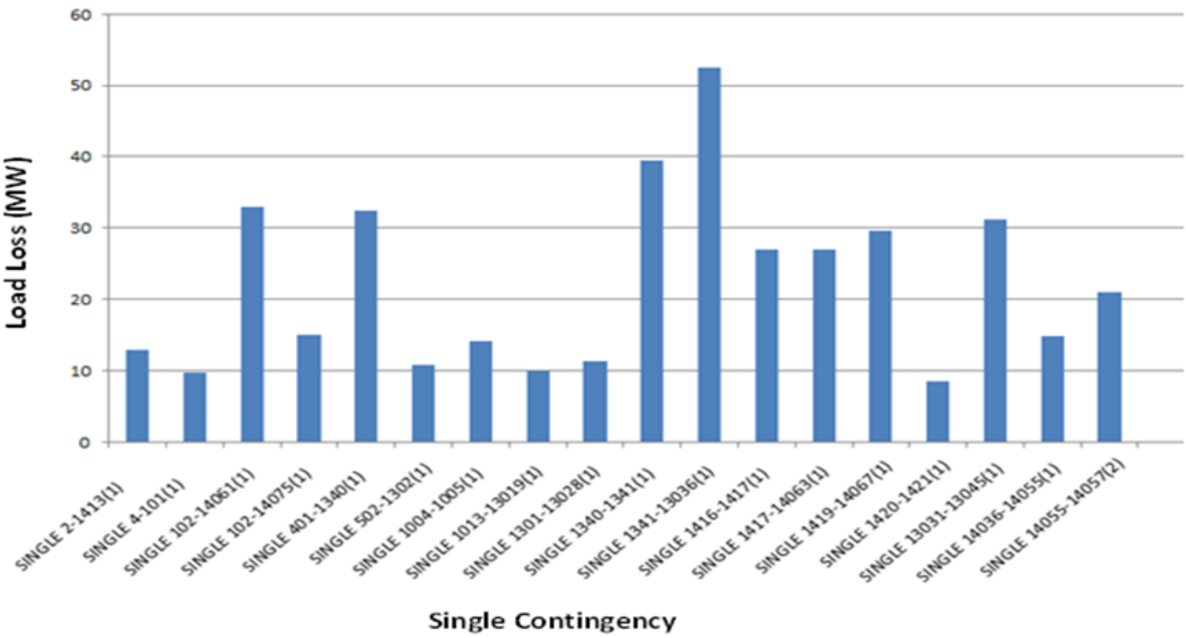

Figure 5. Amount of Load Loss at Single Contingencies.

Figure 6 shows the voltages of all these 26 buses for pre contingency and post contingency in case of the severest line outage. The figure shows the effect of the severest case of line outage on the bus voltages which proves that the highest voltage performance index values means the most severe line outage.

Table 1. Voltage Performance Index Ranking.

Contingency (Line Outage)	Voltage Performance Index	Contingency Ranking
14001-14003)1	114.305498	1
14001-14003)2	114.305498	
14003-14018)1	107.782158	2
14003-14018)2	107.782158	
601-1303	105.501761	3
1434-14020	99.60087	4
402-1302	99.268291	5
10-601	98.691466	6
13026-14020	98.57855	7
1345-13040	98.126742	8
1434-13026	97.330376	9
10-1305	97.087836	10
1354-13036	96.364338	11
103-1345	95.688988	12
103-13004	95.386994	13
13019-13036	95.371594	14
1312-13013	94.942615	15
402-1308	94.865219	16
1305-1306	94.591238	17
1354-13019	93.843274	18
(10012-10029)1	92.460509	19
(10012-10029)2	92.460509	
14018-14020	91.576225	20

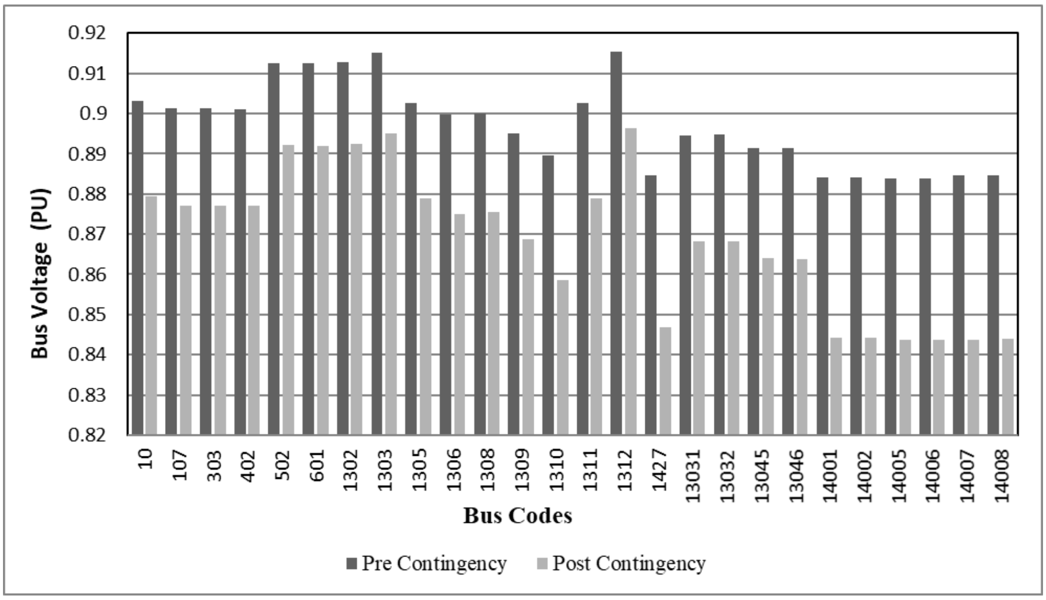

Figure 6. Minimum Bus Voltages Pre and Post (14001-14003) outages.

7. Conclusions

Single contingencies for the KR network are analyzed and ranked according to their severity by using PSS®E software. All possible single contingencies are simulated and Newton Raphson load flow is applied after each contingency then voltages of all buses are recorded to observe the voltage profile of the network for each case.

Contingency ranking is obtained by calculating the voltage performance index for each contingency and ranking them from the highest to lowest value. It was found that the outages of the lines (14001-14003) 1 and (14001-14003) 2 have the highest index value (114.305) which is the most severe contingency. This is validated also by observing the average and minimum bus voltages. It was found that the highest index value corresponds to the lowest average and minimum bus voltage. This evaluation of the most severe contingency is used in the operation and planning process to estimate the situation and prepare the required measures in advance.

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