Contingency analysis of 6 bus system by using Power system performance indices

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Abstract—**Now a days power system protection is an important role for an operating engineer, which can be done by doing online security assessment. Contingency analysis is one of the best methods to forecast the condition of power system if any unwanted event occurs in the power system. To do contingency analysis first the operator has to know the parameters like voltage, power and voltage angle at each and every bus by doing load flow analysis on the system. Newton Raphson method is the best load flow method as it gives accurate results in less time. In this paper all line outage contingencies in a standard 6 bus and 5 bus power system has been done in MATLAB environment. For each line outage contingency, load flow analysis has been done on the system and the active power and voltage performance indices have been calculated. These two performance indices will give the idea about the change in active power flow through the lines and voltages at the buses for a particular line outage. Summation of these two indices will give the performance index value through which ranking of severity will be given to the lines. And from the load flow results comparison has been done between low rank and high rank line outage contingencies. This contingency analysis helps the operational engineer to know which line outage is dangerous to the system and what prior action has to take to minimize the effect of that particular line outage.**

Keywords-contingency, contingency selection, newton raphson method, line outage, performance indices, overload.

I. INTRODUCTION

Contingency is expressed as an unwanted event occurring in the power system for a short duration of time, which actually specify the loss or outage of one or more components of power system [1]. At the time of outage of any component or equipment in the power system, contingency analysis shows the operators an indication, of what might be the position of power system [2]. It is fundamentally a software application run in power management system, simulating a speculative test on a list of notional cases, which would create power flow, voltage or reactive power violations in the sytem. These cases are recognized and ranked in order of their severity using contingency ranking approach [3].

Generally contingency analysis is separated into three parts, contingency creation, selection, and evaluation [4], but now a days the selection and the evaluation both are doing in same section. From so many years many work has been done on contingency selection mainly, whose aim is to reduce the indigenous long list of contingencies by selecting only the outages with severe limit violations [5]. This selection is seasoned by mainly two methods, i.e. contingency ranking and contingency screening. The screening methods are local solution based study, which primarily gives importance to the most dangerous cases for complete ac analysis, simultaneously the non-severe cases are deleted from the list [6]. Alternative method is ranking method, which uses performance index as a scalar value to narrate the effects of an outage on the whole system [7].

In this work, the effort has been given on contingency ranking. At starting the contingency list is formed, which contents those cases whose probability of occurrence is found to be high. The list, which is generally large, is translated into electrical network changes, mostly generator and/or line outages. Contingency evaluation using load flow is then carrying out on the following individual outages in decreasing order of severity. The activity will be remained up to the point where no post contingency violations are undergone.

II. CONTINGENCY ANALYSIS

A. Contingency creation:

It is the initial step of contingency analysis. It is made up of all set of viable contingencies that may happen in a power system. This process consists of making contingency lists.

B. Contingency selection:

It is the second step in contingency analysis; it is the process which includes finding of severe contingencies from all that may cause to violate bus voltages and power through lines. Here in this procedure contingency list is reduced by rejection of least severe contingency and taking into consideration of most severe outages. In this process the performance index has been used to find the most severe ones.

C. Contingency evaluation:

It is the third step and the most significant step as it includes necessary control and security actions which are required in order to reduce the effects of most severe contingencies in a power system.

III. NEWTON RAPHSON LOAD FLOW METHOD

The Newton-Raphson method is the most useful method for load flow solutions because of its different advantages. It has dominant convergence characteristics compared to remaining load flow methods. And has less calculation. The Newton-Raphson method is benefit for large power system networks as because computer storage requirements are less and increases almost linearly with size of problem.

The following equations are used in N-R method to measure voltage, current, active power and reactive power at different buses.

The current injected at the bus m is

$$I_m = \sum_{l=1}^{n} Y_{ml} V_l$$

In polar form we can write it as

$$I_m = \sum_{l=1}^{n} |Y_{ml}||V_l| \angle \theta_{ml} + \delta_l$$

We can write current in terms of active and reactive power

$$I_m = \frac{P_m - jQ_m}{V_m^*}$$

After substitution of I_m value in above equation we can get

$$P_m - JQ_m = |V_m| \angle - \delta_m \sum_{l=1}^{n} |Y_{ml}||V_l| \angle \theta_{ml} + \delta_l$$

By separating real and imaginary terms, we get

$$P_m = \sum_{l=1}^{n} |Y_{ml}||V_l||V_m| \cos(\theta_{ml} - \delta_m + \delta_l)$$

$$Q_m = \sum_{l=1}^{n} |Y_{ml}||V_l||V_m| \sin(\theta_{ml} - \delta_m + \delta_l)$$

By neglecting higher order terms if we expand the above equations by using Taylor's series we will get

$$\begin{bmatrix} \Delta P_2^K \\ \vdots \\ \Delta P_n^K \\ \Delta Q_2^K \\ \vdots \\ \Delta Q_n^k \end{bmatrix} = \begin{bmatrix} \begin{pmatrix} \frac{\partial P_2^K}{\partial \delta_2^K} & \cdots & \frac{\partial P_2^K}{\partial \delta_n^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^K}{\partial \delta_2^K} & \cdots & \frac{\partial P_n^K}{\partial \delta_n^K} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^K}{\partial |V_2|^K} & \cdots & \frac{\partial P_2^K}{\partial |V_n|^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^K}{\partial |V_2|^K} & \cdots & \frac{\partial P_n^K}{\partial |V_n|^K} \end{pmatrix} \\ \begin{pmatrix} \frac{\partial Q_2^K}{\partial \delta_2^K} & \cdots & \frac{\partial Q_2^K}{\partial \delta_n^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^K}{\partial \delta_2^K} & \cdots & \frac{\partial Q_n^K}{\partial \delta_n^K} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^K}{\partial |V_2|^K} & \cdots & \frac{\partial Q_2^K}{\partial |V_n|^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^K}{\partial |V_2|^K} & \cdots & \frac{\partial Q_n^K}{\partial |V_n|^K} \end{pmatrix} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^K \\ \vdots \\ \Delta \delta_n^K \\ \Delta |V_2|^K \\ \vdots \\ \Delta |V_n|^k \end{bmatrix}$$

The jacobian matrix will give the linear relationship between small changes in the angle $\Delta\delta_i^k$ and change in bus voltage ΔV_i^k with small variations in real power and reactive power ΔP_i^k and ΔQ_i^k

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J_1 & J_2 \\ j_3 & J_4 \end{pmatrix} \begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix}$$

The diagonal and off diagonal elements of J_1 are

$$\frac{\partial P_m}{\partial \delta_m} = \sum_{l \neq m} |V_m||V_l||Y_{lm}| \sin(\theta_{ml} - \delta_m + \delta_l)$$

$$\frac{\partial P_m}{\partial \delta_m} = -|V_m||V_l||Y_{ml}|\sin(\theta_{ml} - \delta_m + \delta_l), l \neq m$$

The power residuals ΔP_i^k, ΔQ_i^k can be written as

$$\Delta P_m^{\ K} = P_m^{\ sch} - P_m^{\ K}$$

$$\Delta Q_m^{\ K} = Q_m^{\ sch} - Q_m^{\ K}$$

From the power residuals and jacobian matrix we can get the voltage magnitude $|V_m^k|$ and voltage angle $\delta_m^{\ k}$.
The new values of voltages and angles are

$$|V_m^{\ (K+1)}| = |V_m^{\ K}| + \Delta|V_m^{\ K}|$$

$$\delta_m^{\ (K+1)} = \delta_m^{\ K} + \Delta\delta_m^{\ K}$$

IV. SYSTEM PERFORMANCE INDEX

The deviation of power system variables like bus voltages, power flows, from its rated value is measured by the system performance index. It is also used to evaluate the relative stability of a contingency [8].

A. Voltage performance index (*PI_V*)
B. Active power performance index(*PI_{MW}*)

A. **Voltage performance index (*PI_V*):**

The power system deficiency because of out of limit bus voltages is described by the voltage performance index [2].

$$PI_V = \sum_{i=1}^{N_B}\left(\frac{W}{2n}\right)\left\{\frac{\left(|V_i| - |V_i^{sp}|\right)}{\Delta V_i^{\lim}}\right\}^{2n}$$

Where $|V_i|$ is the i[th] bus voltage magnitude.
$|V_i^{sp}|$ is the i[th] bus specified voltage magnitude.
ΔV_i^{lim} is the voltage deviation limit which we can measure by taking average value of minimum and maximum allowable voltages at bus i.
n Is exponent of the penalty function and value is (=1)
N_B is the number of buses in the given power system.
W is the real non negative weighting facto and value is (=1)

Here to calculate ΔV_i^{iim} I have taken maximum voltage limit is 1.05P.U and minimum voltage limit is 0.95 P.U since we can accept ±5% deviation in voltage. This voltage performance index will give the information about the change in voltage at each and every bus.

B. Active power performance index (*PI_{MW}*):

This is the index through which we can identify the extent of power over flows through the transmission lines [9].

$$\mathbf{PI_p} = \sum_{l=1}^{N_L}\left(\frac{W}{2n}\right)\left(\frac{P_l}{P_l^{\max}}\right)^{2n}$$

Where,
P_l is the power flow (MW) through the line l
P_l^{max} is the maximum capacity of power flow through the line l
N_L is the number of the transmission lines of the power system
W is the real non-negative weighting facto and value is (=1)
n is exponent of penalty function and value is (=1)

$$P_l^{\max} = \frac{V_i * V_j}{X}$$

Where V_i is the voltage at bus i.
V_J is the voltage at bus j.
X is the reactance of the line between bus I and bus j.

V. RESULTS AND DISCUSSION

6 BUS SYSTEM:

Table 1 SYSTEM DATA

FROM BUS	TO BUS	R(P.U)	X(p.u)	B/2(P.U)	CAPACITY (MW)
1	2	0.1	0.2	0.02	30
1	4	0.05	0.2	0.02	50
1	5	0.08	0.3	0.03	40
2	3	0.05	0.25	0.03	20
2	4	0.05	0.1	0.01	40
2	5	0.1	0.3	0.02	20
2	6	0.07	0.2	0.025	30
3	5	0.12	0.26	0.025	20
3	6	0.02	0.1	0.01	60
4	5	0.2	0.4	0.04	20
5	6	0.1	0.3	0.03	20

The 6 bus data is taken from IEEE standard 6 bus system [10] Bus 1 is slack bus, 2, 3 buses are generator buses and 4, 5, and 6 buses are load buses. At healthy condition all transmission lines are carrying the power with in limits as shown below.

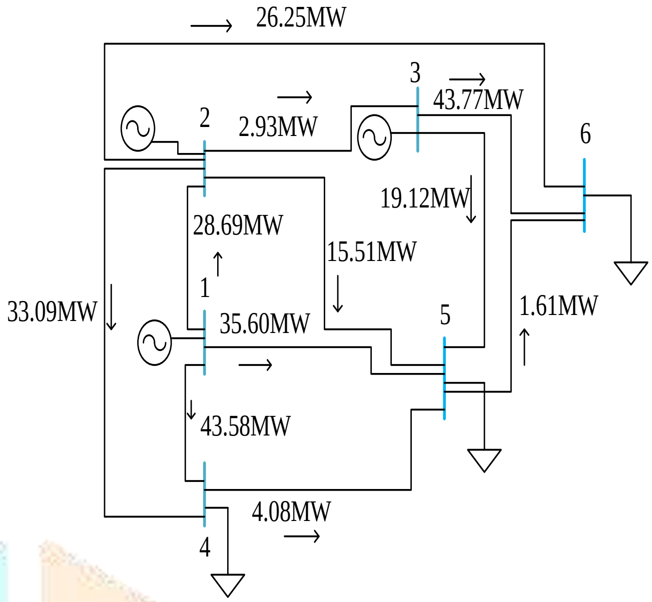

Figure 1 Six-bus network base case AC power flow

Now for each line outage the Newton Raphson load flow method has been done and the active power performance index and voltage performance index has been calculated by using the above formulaus. And then the ranking has been given based on the Performance Index (P.I) which can be calculated by adding the above two indices.

Table 2 Ranking of the lines

Tripped line	PI_V	PI_{MW}	PI	Rank
1-2	0.9490	0.0455	0.9865	10
1-4	1.1745	0.0561	1.2306	3
1-5	1.0833	0.0511	1.1344	5
2-3	0.9440	0.0338	0.9778	11
2-4	2.0635	0.05	2.1135	2
2-5	1.0592	0.0384	1.0976	6
2-6	0.9814	0.0396	1.021	7
3-5	1.1322	0.0421	1.1743	4
3-6	2.2195	0.0811	2.3006	1
4-5	0.9593	0.0344	0.9937	9
5-6	0.9756	0.0335	1.0091	8

From the above table we can conclude that the outage of line 3-6 is dangerous compare to remaining line outages. Now by doing outage of line 3-5, 3-6 individually, the observation has been done how line 3-6 is very danger than outage of line 3-5.

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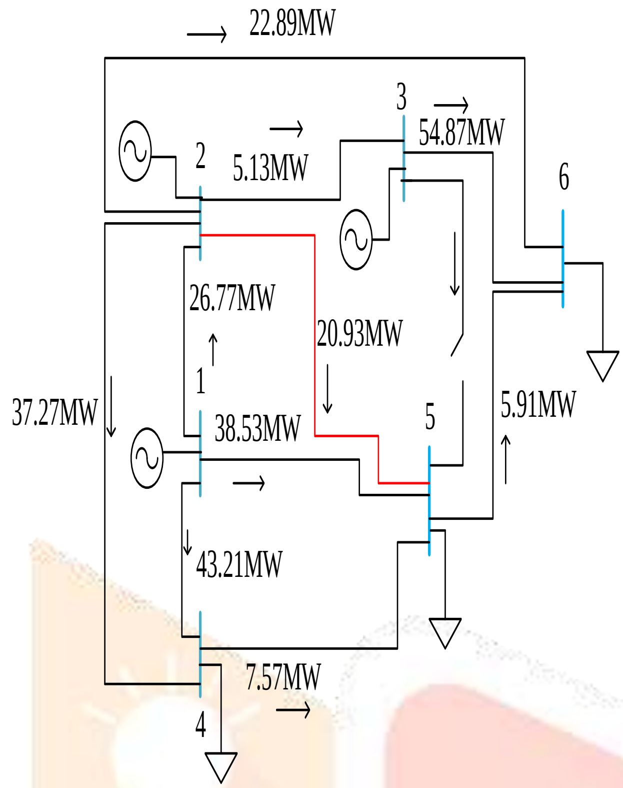

Figure 2 Six bus network power flows after line 3-5 gets tripped

by observing above figure we can conclude that, because of line 3-5 gets opened, the only one line 2-5 is overloaded (red line) and remaining all lines are in healthy condition.

Table 3 Percentage of overload of power through the lines after line 3-5 gets tripped.

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Tripped line		Overloaded line		
From	**To**	**From**	**To**	**Percentage**
3	5	2	5	5%

Instead of carrying 15.51 MW, the line 2-5 is carrying 20.93 MW which is 5% more than its maximum capacity 20 MW.

Now coming to voltages at all the buses, before contingency all the bus voltages are within the limits that is between 0.95 and 1.05P.U. after outage of line 3-5 we can observe that the voltage at bus 5 becomes 0.9537P.U which is 0.9854p.u at pre contingency state, remaining all buses have nearly the same voltage at both pre and post contingency which is shown below. But 0.9537 P.U is also acceptable voltage level because it is between voltage levels 0.95 to 1.05.

Table 4 pre contingency and post contingency state bus voltages for the line outage (3-5)

Bus no	Pre Contingency Voltage (P.U)	Post Contingency Voltage(P.U)

1	**1.05**	**1.05**
2	**1.05**	**1.05**
3	**1.07**	**1.07**
4	**0.9894**	**0.9845**
5	**0.9854**	**0.9537**
6	**1.0044**	**0.9991**

Now the line 3-6 which is having first rank from the performance index has been taken out to see the effect of outage of that line on other system.

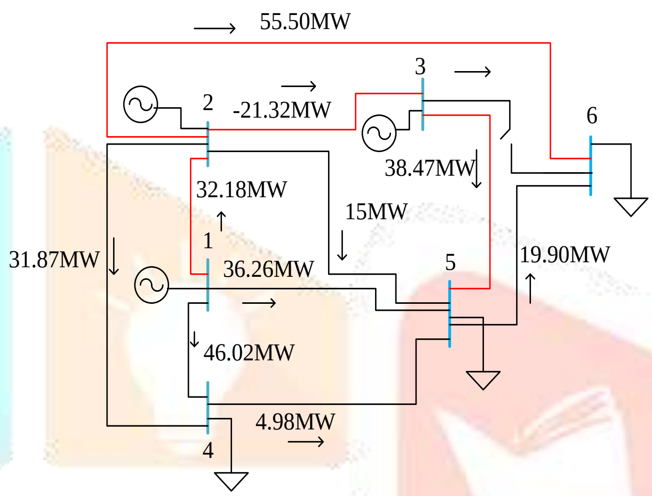

Figure 3 Six bus network power flows after line 3-6 gets tripped

Here because of outage of line 3-6 which got first rank from the indices 4 lines are getting overloaded (red lines) which leads to cascade failures of lines and total system blackout.

Table 5 Percentage of overload of power through the lines after the line 3-6 gets tripped

Tripped line	Over loaded lines	Percentage of overload
3-6	**1-2**	**7.26**
	2-3	**6.6**
	2-6	**85**
	3-5	**92.35**

Here from the above table we can tell that the line 3-5 is carrying 92.35% more than its rated capacity. Because of this huge overload this line also will be tripped which is same as open circuit fault of on the power system. Then the remaining lines have to take responsibility to carry the power which is very higher than their rated capacity. So all lines will get tripped and it leads to total power system block out. The following table shows the pre and post contingency voltages at the buses.

Table 6 pre contingency and post contingency state bus voltages for the line outage (3-6)

Bus no	Pre-contingency voltage(P.U)	Post-contingency voltage(P.U)
1	**1.05**	**1.05**
2	**1.05**	**1.05**
3	**1.07**	**1.07**
4	**0.9845**	**0.9854**

5	**0.9537**	**0.9574**
6	**0.9991**	**0.8898**

From the above table we can observe that all the buses have voltages within the limits i.e. from 0.95 to 1.05 except bus 6. Because of outage of line 3-6 the bus 6 is getting very low voltage 0.8898P.U. This situation is not there when the line 3-5 gets outage from the system because after the line 3-5 gets tripped from system also all the buses have the voltages with in the limits. So the performance index method is the reliable method in finding the severe line outages in the power system.

5BUS SYSTEM:

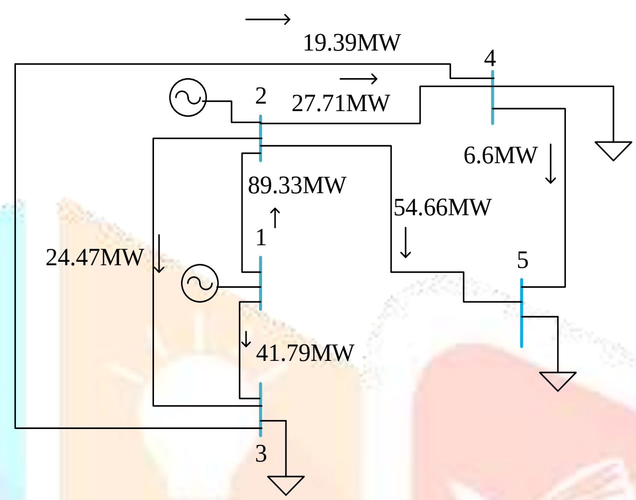

Figure 4 Five bus network base case AC power flow

The 5 bus data is taken from IEEE standard 5 bus system[11]. Bus 1 is slack bus, 2 is generator bus, remaining all buses are load buses.

Table 7 Ranking of the lines

Tripped line	PI_V	PI_{MW}	PI	Rank
1-2	2.4588	0.1386	2.5974	2
1-3	3.2521	0.0276	3.2797	1
2-3	2.2540	0.0295	2.2835	5
2-4	2.3784	0.0293	2.4077	3
2-5	2.0784	0.0811	2.1595	7
3-4	2.2836	0.0235	2.3071	4
4-5	2.1436	0.023	2.1666	6

From the results it is showing that the tripping of line 1-3 is severe compare to other trippings. But after doing contingency analysis of all line outages we can observe that the line 1-2 tripping which is having second rank is making the line 2-3 heavy loaded because that line is connected to slackbus and it is carrying 89.33 MW which is huge power transfer in that system. So the tripping of the line which is connected to slack bus with high power transfer is very dangerous outage in the system.

Table 8 Pre and Post contingency powerflows

LINE			Outage(1-2)	Outage(1-3)	
From	To	Pre Contingency power(MW)	Post contingency power(MW)	Post contingency Power(MW)	Maximum power (MW)
1	2	89.33	0	132.87	155
1	3	41.79	141.63	0	110
2	3	24.47	15.2	43.4	95
2	4	27.71	3.94	42.99	95
2	5	54.66	39.14	62.58	95
3	4	19.39	66.61	2.79	95
4	5	6.6	21.99	0.96	95

In the normal state, transmission line connecting bus 1 to 2 was the busiest line with carrying load of 89.33MW. Outage of such a line usually forces adjacent lines to reach their maximum capacity limits. This is wht happen in this case. The generator at bus 1 has to ramp down by 141.63-110=31.63MW. Because the emergency power carrying capacity of the only line 1-3 connected to generator 1 is 110MW.

VI. CONCLUSION

To give the contingency ranking, performance index has been used as a measuring tool. Newton Raphson power flow method is found most appropriate method in the approach of contingency selection, as it played a vital role in rejecting the large number of contingency cases and concentrated on the most severe contingency case. From the results, we can come to know that the calculation of performance indices gives a good measure of the cases, which has the highest potential to form the system parameters to go beyond their limits, calculation of PI are also obtained for the sake of increase in the accuracy of the sorting and ranking technique of the contingency analysis process.

VII. FUTURE SCOPE

From the above results we can know the state of power system if any equipment gets outage from the system. So by forecasting the effect of any outage, the engineer who is operating the system has to know the prior action what should be done for the particular outage. Especially at this condition “FACT” devices will help to control the power flow and to maintain good voltage profile at each and every bus. TCSC will be used to control the power flow through the lines which is getting overloaded and STATCOM, SVC will be used to maintain good voltage profile by giving reactive power or by taking reactive power from the bus. So we can extend this work by placing “FACT” devices in our system.

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