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Power System Contingency Ranking Using Fast Decoupled Load Flow Method

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Abstract: **Voltage instability is the phenomena associated with heavily loaded power systems. It is normally aggravated due to large disturbance. The Power system security is one of the significant aspects, where the proper action needs to be taken for the unseen contingency. In the event of contingency, the most serious threat to operation and control of power system is insecurity. Therefore, the contingency analysis is a key for the power system security. The contingency ranking using the performance index is a method for the line outages in a power system, which ranks the highest performance index line first and proceeds in a descending manner based on the calculated PI for all the line outages. This helps to take the prior action to keep the system secure. In this paper Fast Decoupled power flow method is used for the power system contingency ranking for the line outage based on the Active power and Voltage performance index. The ranking is given by considering the overall performance index, which is the summation of Active power and voltage performance index. The proposed method is implemented on a IEEE-14 bus system.**

Keywords: **Contingency; Line outage; Load flow; Performance index; Voltage stability.**

1. INTRODUCTION

The load flow, or power flow, computation is the most important network computation in power systems. Load flow computations bring insight in the steady-state behavior of a power system. This is needed in many control and planning applications. The study of contingency analysis is an important aspect of power system security. The major task in power system planning is to examine the performance of a power system and the need for new transmission expansion due to load growth or generation expansion [1, 2]. Security assessment provides information to the system operators about the secure and insecure nature of the operating states in the event of an unforeseen contingency, so that proper control/corrective action can be initiated within the safe time limit. Static security analysis identifies violations of the operational constraints by solving an AC load flow, described by a set of nonlinear equations for each post-contingency case. Therefore, contingency analysis plays an important role in real-time power system security evaluation. Contingency analysis comprises the simulation of a set of contingencies in which the system behavior is observed. Each post-contingent scenario is evaluated in order to detect operational problems and the severity of violations. The majority of methods are based on the evaluation by means of some Performance Index (PI). Ranking methods rank the contingencies in approximate order of severity, based on the value of a scalar performance index, which is the measure of system stress expressed in terms of network variables and are directly evaluated [3, 4]. Many PI based analytical methods suffer from the problem of misclassification or/and false alarm. The conventional methods are found to be unsuitable for on-line applications because of high computational time requirement. Hence there is a pressing need to develop fast, reliable and accurate on-line security assessment tools to ensure secure operation of the power system. Over the years, a lot of effort has been put into solving load flow problems efficiently. For a concise overview of earlier methods see [5]. In modern applications, the most widely used techniques are the Newton-Raphson method with a direct linear solver [6], and the Fast Decoupled Load Flow (FDLF) method [7]. For an overview of the derivation of the load flow problem formulation used in this paper, and the application of the two above mentioned solution methods on this problem formulation, we also refer

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to [8]. The Newton-Raphson method is a very powerful tool. The FDLF method is a very fast load flow method, but lacks some of the convergence properties of the Newton process. When applied to critical systems, or systems with strongly varying R/X ratios, the FDLF method may well fail to converge In this paper we focus on the Newton-Raphson method. But where traditionally a direct linear solver is used in each Newton iteration, we use iterative linear solution methods. The proposed model for contingency analysis is found to be suitable as a decision making tool for online applications at the energy management systems.

2. CONTINGENCY ANALYSIS

Since contingency analysis involves the simulation of each contingency on the base case model of the power system, three major difficulties are involved in this analysis. First is the difficulty to develop the appropriate power system model. Second is the choice of which contingency case to consider and third is the difficulty in computing the power flow and bus voltages which leads to enormous time consumption in the Energy Management System.

It is therefore apt to separate the on-line contingency analysis into three different stages namely contingency definition, selection and evaluation. Contingency definition comprises of the set of possible contingencies that might occur in a power system, it involves the process of creating the contingency list. Contingency selection is a process of identifying the most severe contingencies from the contingency list that leads to limit violations in the power flow and bus voltage magnitude, thus this process eliminates the least severe contingencies and shortens the contingency list. It uses some sort of index calculations, which indicates the severity of contingencies. On the basis of the results of these index calculations the contingency cases are ranked. Contingency evaluation is then done which involves the necessary security actions or necessary control to function in order to mitigate the effect of contingency.

Contingency Analysis using Sensitivity Factors The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. One of the easiest ways to provide a quick calculation of possible overloads is to use sensitivity factors [1]. These factors show the approximate change in line flows for changes in generation on the network configuration and are derived from the DC load flow**.** These factors can be derived in a variety of ways and basically come down to two types: **Generation Shift Factors** and **Line Outage Distribution Factors** [8]

The **generation shift factors** are designated *ali* and have the following definition:

$$a_{li} = \frac{\Delta f_i}{\Delta P_i} \qquad (1)$$

Where *l*= line index, *i*=bus index, Δf_l = change in megawatt power flow on line *l* when a change in generation ΔPi occurs at bus i, ΔP_i = change in generation at bus *i.*

It is assumed that the change in generation ΔP_i is exactly compensated by an opposite change in generation at the reference bus, and that all other generators remain fixed. The a_{li} factor then represents the sensitivity of the flow on line *l* due to a change in generation at bus *i.* If the generator was generating Pio MW and it was lost, it is represented by ΔP_i, as the new

$$\Delta P_i = -P_i^0 \qquad (2)$$

Power flow on each line in the network could be calculated using a pre calculated set of ***"a"*** factors as follows:

$$f_i = f_l^0 + a_{li}\Delta P_i, \text{ for } l = 1,2, \dots L \qquad (3)$$

Where, f_i = flow on line *l* after the generator on bus *i* fails, f_l^0 = flow before the failure

The outage flow f_i on each line can be compared to its limit and those exceeding their limit are flagged for alarming. This would tell the operations personal that the loss of the generator on bus *i* would result in an overload on line *l.* The generation shift sensitivity factors are linear estimates of the change in flow with a change in power at a bus. Therefore, the effects of simultaneous changes on several generating buses can be calculated using superposition. The **line outage distribution factors** are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{l,k} = \frac{\Delta f_l}{f_k^0} \qquad (4)$$

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Where,

dl,k = line outage distribution factor when monitoring line *l* after an outage on line *k*, Δf_l = change in MW flow on line *l*, f_k^0 = original flow on line *k* before it was outaged i.e., opened , If one knows the power on line *l* and line ***k*****,** the flow on line *l* with line *k* out can be determined using ***"d"*** factors.

$$f_l = f_l^0 + d_{l,k} f_k^0 \tag{5}$$

Where f_l^0 and f_k^0 = pre outage flows on lines *l* and *k*, respectively, f_l = flow on line *l* with line *k* out

By pre calculating the line outage distribution factors, a very fast procedure can be set up to test all lines in the network for overload for the outage of a particular line. Furthermore, this procedure can be repeated for the outage of each line in turn, with overloads reported to the operations personnel in the form of alarm messages. The generator and line outage procedures can be used to program a digital computer to execute a contingency analysis study of the power system. It is to be noted that a line flow can be positive or negative so that we must check *fl* against $-f_{lmax}$ as well as f_{lmax}. It is assumed that the generator output for each of the generators in the system is available and that the line flow for each transmission line in the network is also available and the sensitivity factors have been calculated and stored.

Contingency Selection:

Since contingency analysis process involves the prediction of the effect of individual contingency cases, the above process becomes very tedious and time consuming when the power system network is large. In order to alleviate the above problem contingency screening or contingency selection process is used. Practically it is found that all the possible outages does not cause the overloads or under voltage in the other power system equipments. The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection. The contingencies are selected by calculating a kind of severity indices known as Performance Indices (PI) [1]. These indices are calculated using the conventional power flow algorithms for individual contingencies in an off line mode. Based on the values obtained the contingencies are ranked in a manner where the highest value of PI is ranked first. The analysis is then done starting from the contingency that is ranked one and is continued till no severe contingencies are found. There are two kind of performance index which are of great use, these are **active** power performance index (PI_P) and reactive power performance index (PI_V). PI_P reflects the violation of line active power flow and is given by eq.6.

$$PI_p = \sum_{i=1}^{L} \left(\frac{P_i}{P_{imax}}\right)^{2n} \tag{6}$$

Where,

P_i = Active Power flow in line *i*, P_{imax} = Maximum active power flow in line *i*, n is the specified exponent, L is the total number of transmission lines in the system.

If *n* is a large number, the PI will be a small number if all flows are within limit, and it will be large if one or more lines are overloaded. Here the value of n has been kept unity. The value of maximum power flow in each line is calculated using the formula

$$P_i^{max} = \frac{V_i - V_j}{X} \tag{7}$$

Where,

V_i = Voltage at bus i obtained from FDLF solution, V_j = Voltage at bus j obtained from FDLF solution

X = Reactance of the line connecting bus „i" and bus „j"

Another performance index parameter which is used is reactive power performance index corresponding to bus voltage magnitude violations. It mathematically given by eq. 8

$$PI_V = \sum_{i=1}^{npq} \left[\frac{V_i - V_{inom}}{V_{imax} - V_{imin}}\right)^2 \tag{8}$$

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Where,

Vi= Voltage of bus I, Vimax and Vimin are maximum and minimum voltage limits, V_{inom} is average of V_{imax} and V_{imin} , N_{pq} is total number of load buses in the system

For calculation of PI_V it is required to know the maximum and minimum voltage limits, generally a margin of + 5% is kept for assigning the limits i.e, 1.05 P.U. for maximum and 0.95 P.U. for minimum. It is to be noted that the above performance indices is useful for performing the contingency selection for line contingencies only. To obtain the value of PI for each contingency the lines in the bus system are being numbered as per convenience, then a particular transmission line at a time is simulated for outage condition and the individual power flows and the bus voltages are being calculated with the help of fast decoupled load flow solution.

3. ALGORITHM FOR CONTINGENCY ANALYSIS USING FAST DECOUPLED LOAD FLOW

The algorithm steps for contingency analysis using fast-decoupled load flow solution are given as follows:

***Step 1*:** Read the given system line data and bus data.

***Step 2*:** Set the counter to zero before simulating a line contingency.

***Step 3*:** Simulate a line contingency.

***Step 4*:** Calculate the active power flow for in the remaining lines and the maximum power flow P_{Max} using eq. 7.

***Step 5*:** Calculate the active power performance index PI_P which give the indication of active power limit violation using eq. 6.

***Step 6*:** Calculate the voltages at all the load buses following the line contingency.

***Step 7*:** Calculate the reactive power performance index PI_V that gives the voltage limit violation at all the load buses due to a line contingency using eq. 8.

***Step 8*:** Check if this is the last line outage to be simulated; if not the step (3) to (7) is computed till last line of the bus system is reached.

***Step 9*:** The contingencies are ranked once the whole above process is computed as per the values of the performance indices obtained.

***Step 10*:** Do the power flow analysis of the most severe contingency case and print the results.

4. RESULTS AND DISCUSSION

The main focus here is to perform the contingency selection process, by calculating the active and reactive power performance indices i.e. PI_P and PI_V respectively. The contingencies are then ranked where the most severe contingency is the one which is having the highest performance index value. The computation of these indices has been done based on load flow analysis carried out using fast decoupled load flow (FDLF) under MATLAB environment. The most severe contingency is then chosen from the contingency list and the corresponding power flows and bus voltages are analyzed for the entire system. The study has been carried out for the following standard systems:

14-Bus System:

The system consists of 1 slack bus, 9 load buses and 4 generator buses. There are three synchronous compensators used only for reactive power support. The active power flow in each transmission lines that has been obtained using FDLF. This state of the system corresponds to the pre contingency state. The system has a total 20 number of transmission lines, hence we evaluate for 20 line contingency scenarios by considering the one line outage contingency at a time. The performance indices are summarized in the Table 1. From Table 1 it can be inferred that outage in line number 16 is the most vulnerable one and its outage will result a great impact on the whole system. The high value of PI_V for this outage

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also suggests that the highest attention be given for this line during the operation. Fig. 1 and Fig. 2 shows the graphical representation of the performance indices for all the line contingencies with the value of PI on the y-axis and the outage line number labeled on the x-axis.

Table 1 Performance Indices & Contingency Ranking using FDLF for 14-Bus System

Contingency number	**PI_P**	**PI_V**	**Ranking**
1	1.1893	7.3232	10
2	0.9817	7.6996	11
3	1.1654	10.0014	7
4	0.9999	7.3213	12
5	0.9820	8.8759	9
6	0.9640	13.2572	2
7	0.9915	0.3566	19
8	1.0747	1.1753	17
9	0.9807	10.5776	4
10	1.2296	1.6047	16
11	1.0142	9.5907	8
12	1.0127	1.8089	15
13	1.0569	1.3669	18
14	1.0072	10.4518	6
15	1.0759	0.0844	20
16	**1.0118**	**13.3503**	**1**
17	1.0164	2.3482	13
18	1.0030	10.5217	5
19	1.0000	12.5538	3
20	1.0080	2.2896	14

The contingencies have been ordered by their ranking where the most severe contingency is being ranked 1 and the least has been ranked 20. The variation of reactive performance index with their ranking has been shown in the Fig. 3. It is clear from the result of different PI_V that the contingency number 16 which the line outage contingency corresponding to the **line connected between buses (9-10)** is the most severe contingency. Hence the post contingency analysis corresponding to this line outage has been performed. The voltage of the system corresponding to the pre contingency state and the post contingency state has been detailed in Table 2. The MW flows corresponding to the pre contingency state and the post contingency state has been detailed in Table 3.

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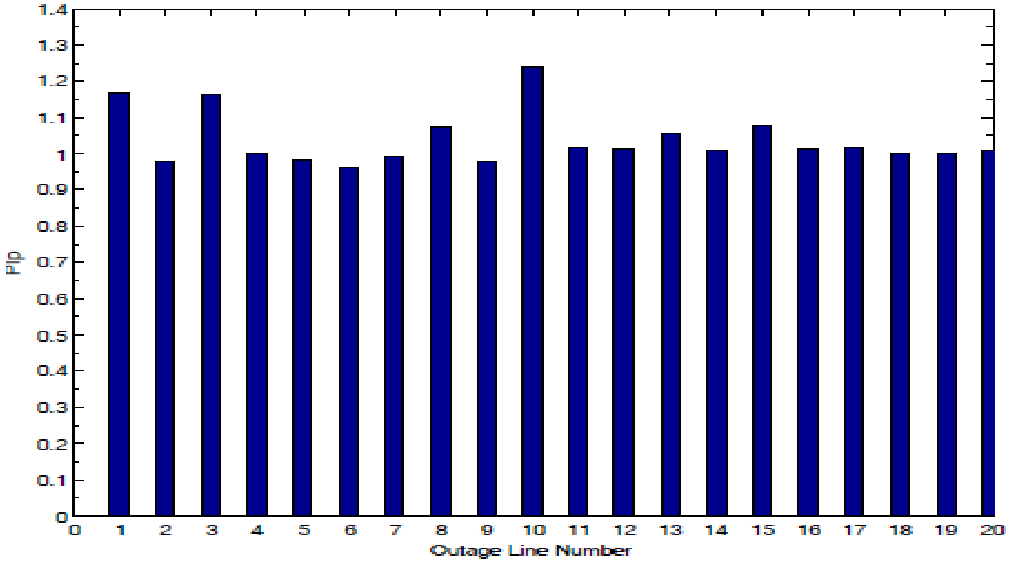

Fig. 1 Values of PI_P for 14-Bus system

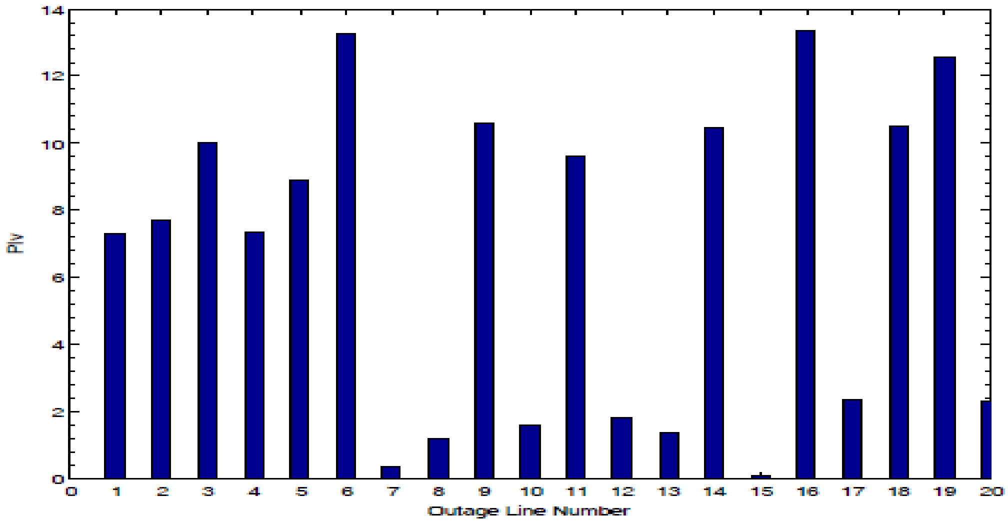

Fig. 2 Values of PIV for 14-Bus system

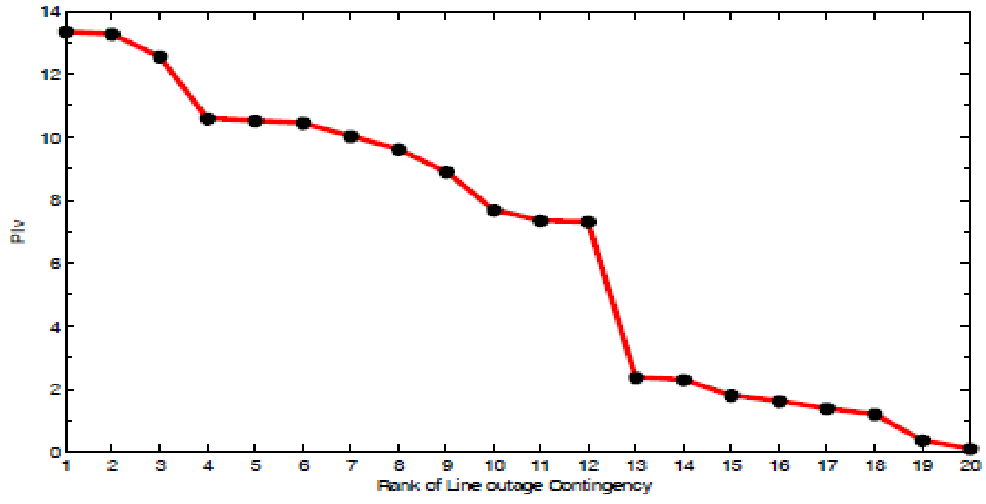

Fig. 3 Contingency Ranking and PIV of 14-Bus system

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Table 2 Bus Voltages in the Pre and Post Contingency State

Bus Number	Pre-contingency voltage (pu)	Post-contingency voltage (pu)
1	1.075	1.065
2	1.050	1.070
3	1.000	1.007
4	1.002	1.020
5	1.009	1.010
6	1.025	1.025
7	1.007	1.008
8	1.016	1.026
9	0.993	0.996
10	0.991	0.978
11	1.004	0.997
12	1.007	1.018
13	1.001	1.002
14	0.978	0.984

Table 3 Active Power Flow in the Pre and Post Contingency State

Line No	Start Bus	End Bus	Pre contingency MW flow
1	1	2	163.3 MW
2	1	5	75.7 MW
3	2	3	71.6 MW
4	2	4	56.3 MW
5	2	5	42.03 MW
6	3	4	24.17 MW
7	4	5	60.19 MW
8	4	7	27.38 MW
9	4	9	16.8 MW
10	5	6	43.74 MW
11	6	11	7.96 MW
12	6	12	7.93 MW
13	6	13	198.23 MW
14	7	8	0.0 MW
15	7	9	26.35 MW
16	**9**	**10**	**4.68 MW**
17	9	14	9.04 MW
18	10	11	4.52 MW

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5. CONCLUSION

The methods of contingency analysis using sensitivity factors and AC power flow have been presented, the analysis with AC power flow using FDLF is found most suitable. Since, the list of possible contingency cases is very large for a complex network like power system, hence the approach of contingency selection plays a very important role as it eliminates the large number of contingency cases and focuses on the most severe contingency case. It is highly demanding that the entire process of contingency analysis is done in least time. Hence, to speed up the contingency analysis process as a whole, the computing speed in the selection process must be enhanced. From the results obtained it can be concluded that the calculation of performance indices gives a good measure about the severity of all the possible line contingencies occurring in the system. The indices with highest value reflect a severe case which has the highest potential to make the system parameters to go beyond their limits. Hence, the most severe contingency case has been chosen from the list of various line contingencies and the post contingency analysis pertaining to this contingency has been done where the most important system parameters like bus voltages and the MW flows have been calculated. The list of severity of contingencies before the power system is put to operation acts as a useful guide to run a reliable system.

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