International Journal of Engineering & Technology, 7 (4.22) (2018) 211-214

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

N-2 Contingency Analysis of an IEEE 14 bus system using MI Power

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Abstract

Nowadays multiple outage contingencies are important for the way the transmission network is used in the deregulated environment. With the increasing load demand and to operate economically, the transmission network is heavily stressed. In this paper, N-2 contingency analysis of an IEEE 14 bus system has been done using MiPower software. Contingency analysis is done for all the possible combinations of N-2 outages of the system using Fast Decoupled load flow method. Real performance index and Voltage performance index are calculated and they are added to give performance index (PI) value to rank the severity of the line outages. Load flow analysis has been done for the severe contingency case.

Keywords: *Multiple contingencies, Performance indices, Fast Decoupled load flow method.*

1. Introduction

Power System Security is defined as the ability of the system to operate in normal operating state i.e. without violating any operating limits of the system, when any sudden disturbance or an unexpected event has occurred on the system. Power system security is any important aspect for system planning studies and also for the operation and control of the power system network [2]. DyLiacco has classified the power system network into 5 operating states as shown in figure below [3]

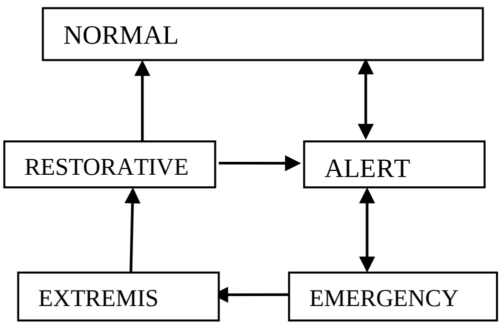

Fig 1: Operating states of a Power system

Table I: Operating states of Power System

STATE	CONDITION	COMMENT
Normal	‘E’, ‘I’ is satisfied.	Security constraints are satisfied, Secure state.
Alert	‘E’ is satisfied and ‘I’ is in danger of violation.	Decrease in Reserve margins, Preventive control action and Unsecure state.
Emergency	‘E’ is satisfied and ‘I’ is violated.	Severe disturbance, Heroic actions should be initiated.
Extremis	‘E’, ‘I’ is violated.	Emergency control action.
Restorative	‘I’ is satisfied.‘E’ is not satisfied	System transits to Normal or Alert state

Where ‘E’ is the Equality constraints which define the balance between generation and load demand and ‘I’ is the Inequality constraints which define the limitations of the physical equipment. Power system security is classified into Steady state security, Transient and Dynamic stability security. In this paper, steady state security of the system is considered [2].
The power system equipment are designed to operate at certain limits and are protected by using automatic devices [8]. In case of any disturbance, which results in violation of the limits, it will make the protective device to operate and if this disturbance causes any further switches to operate, other equipment will be out of service. If this process of cascading events continues, the complete system or parts of it may collapse, which is referred as system Blackout [4]. Contingency is defined as removal or outage of power system equipment from the system due to its failure. Outages are of two types one is power outage and the other one is branch outage. Power outage means the outage of generators, outage of compensating devices. Whether it is a real power outage or reactive power outage; both are power outage contingencies. In the branch outage, the outage of a transmission line and outage of a transformer are considered.

Multiple contingencies are given importance in a deregulated environment; these cascaded events are havoc to the system. In this paper, N-2 line outages of an IEEE 14 bus system are considered; no. of possible cases of N-2 is given below [5] ,

$$\binom{L}{2} = \frac{L(L-1)}{2} \tag{1}$$

Where, L is the no. of transmission lines.

In this paper, Fast Decoupled load flow method is employed for contingency analysis of the system as it has the following advantages of speed, storage when compared with other load flow methods and also this method avoids retriangulation of matrices [B'] and [B"] for at most three simultaneous outage branches because they contain only network admittances and they are constant and need to be triangulated only once at the starting of the base case [6]. Real and Voltage performance indices are used to rank the contingencies of the system [7] and to determine the performance index both the real and voltage performance indices are added and we can evaluate the most severe contingency cases from the higher values of performance index [1] .
The paper is structured as follows: In section II we will see Contingency analysis. In section III we will see Algorithm and Flowchart. In section IV we will see Test case and Results. In section V and VI we will see Conclusion and Future scope respectively.

2. Contingency analysis

Contingency analysis is any important aspect for both the planner and operator of the system. It helps the operator to evaluate the system for the severe contingency cases. Contingency analysis is of three steps:

2.1. Contingency list

This consists of list of all possible cases of contingencies.

2.2. Contingency selection

There are several methods for selection of credible contingencies like Sensitivity factors method, Performance indices, concentric relaxation, bounding methods []. In this paper performance indices are used for ranking the contingencies.

2.2.1. Real Performance Index (PI_{MW})

To measure the change in MW line flows of the system during a contingency is given by Real performance index

$$PI_{MW}=\sum_{i=1}^{L}\frac{W}{2n}\left(\frac{P_i}{P_{max}}\right)^{2n} \quad (2)$$

Where,
L is the number of transmission lines of the system
n is an exponent and value is between 1 to 5
W is a real non-negative weighting factor
P_i is the line flow through the line i
P_{max} is the maximum flow through the respective line

2.2.2. Voltage Performance Index (PI_v)

To measure the change in voltage magnitudes at the buses during a contingency is given by Voltage performance index PI_v =

$$\sum_{i=1}^{N}\left(\frac{W}{2n}\right)\left\{\frac{(|V|_i-|V|_i^{SP})}{(V_i^{max}-V_i^{min})}\right\}^{2n} \quad (3)$$

Where,
N is the no. of buses in the system
W is the real non-negative weighting factor
n is the exponent and value is between 1 to5
$|V_i|$ is the voltage magnitude at bus i
$|V_i^{sp}|$ is the specified voltage magnitude at bus i
V_i^{max} and V_i^{min} are the maximum and minimum allowable limits at bus i

2.3. Contingency evaluation

In this step, load flow analysis of the most severe contingencies is performed and precautionary measures to be taken are known.

3. Algorithm and flowchart

3.1. Algorithm of the N-2 contingency analysis using FDLF

1. Read the given load flow data of the system.
2. Run the load flow for the base case without any outages on the system.
3. Make a list of all possible case of N-2 contingencies.
4. Model a N-2 contingency from the list and run the load flow for the case.
5. Line flows for the above case are calculated and real performance index (PI_{MW}) is calculated.
6. Voltage magnitudes at the buses are calculated and voltage performance index (PI_v) is calculated.
7. Add the real and voltage performance indices for the above case and store the value.
8. Repeat the steps 4 to 7 for the remaining possible contingencies.
9. Rank the contingencies based on their values.
10. Load flow analysis has to be done for the most severe contingency.

3.2. Flowchart of Contingency Analysis using FDLF

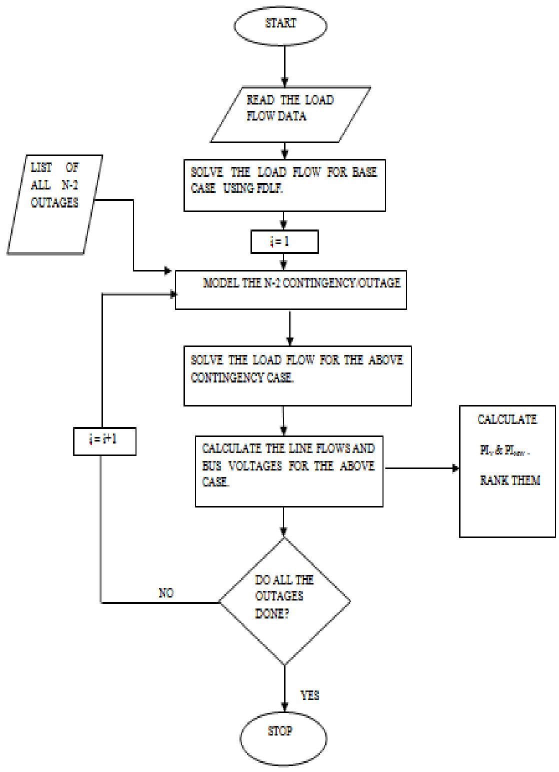

Fig.2: Flow chart of N-2 contingency

4. Test case and results

For the study of N-2 contingency, IEEE 14 bus system has been considered. Contingency Ranking analysis has been done using Fast Decoupled load flow method in MiPower software. In this 14 bus system, we have considered only transmission lines for our analysis; we have 17 transmission lines in this case. Therefore, number of possible N-2 contingencies is

$$\binom{17}{2} = \frac{17(16)}{2} = 136$$

Using real performance index and voltage performance index we have ranked all the possible contingency cases and load flow analysis for the credible/critical contingency case is done.

Table. II: system data

LINES	R (p.u)	X(p.u)	B(p.u)	MVA RATING
1 TO 2	0.02	0.06	0.03	130
1 T0 5	0.05	0.22	0.02	90
2 TO 3	0.05	0.2	0.02	65
2 TO 4	0.06	0.2	0.02	65
2 TO 5	0.06	0.2	0.017	50
3 TO 4	0.07	0.2	0.017	65
4 TO 5	0.01	0.04	0.006	65
6 TO 11	0.09	0.19	0	18
6 TO 12	0.12	0.25	0	32
6 TO 13	0.66	0.13	0	32
7 TO8	0	0.17	0	32
7 T0 9	0	0.11	0	32
9 TO 10	0.031	0.08	0	32
9 TO 14	0.127	0.27	0	32
10 TO 11	0.082	0.19	0	12
12 TO 13	0.22	0.19	0	12
13 TO 14	0.17	0.34	0	12

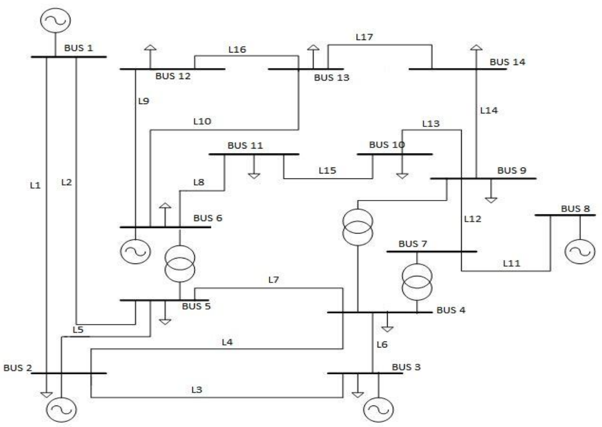

Fig.3: Single line diagram of IEEE 14 Bus system

Table. III: Ranking of contingencies

LINES	PIV	PIMW	PI	RANK
L8L13	8.05E+02	4.32E+00	8.10E+02	1
L9L16	4.11E+02	9.95E+00	4.21E+02	2
L8L15	4.07E+02	9.77E+00	4.17E+02	3
L13L15	4.05E+02	8.72E+00	4.14E+02	4
L14L17	4.03E+02	8.02E+00	4.11E+02	5
L14L16	8.15E+01	1.42E+01	9.57E+01	6
L9L10	6.59E+01	2.03E+01	8.62E+01	7
L10L14	5.38E+01	2.75E+01	8.13E+01	8
L1L14	2.15E+01	3.08E+01	5.23E+01	9
L1L9	2.17E+01	2.68E+01	4.84E+01	10
L9L14	3.05E+01	1.60E+01	4.65E+01	11
L3L14	2.16E+01	2.33E+01	4.49E+01	12
L2L14	2.14E+01	2.27E+01	4.41E+01	13
L7L9	2.79E+01	1.58E+01	4.37E+01	14
L9L12	2.95E+01	1.34E+01	4.29E+01	15
L2L9	2.65E+01	1.56E+01	4.21E+01	16
L9L11	2.99E+01	1.19E+01	4.18E+01	17
L9L17	3.05E+01	1.05E+01	4.10E+01	18
L8L9	2.73E+01	1.33E+01	4.06E+01	19
L4L14	2.15E+01	1.89E+01	4.05E+01	20
L13L14	2.22E+01	1.77E+01	3.99E+01	21
L7L14	2.16E+01	1.79E+01	3.94E+01	22
L5L14	2.14E+01	1.80E+01	3.94E+01	23
L8L14	2.37E+01	1.49E+01	3.86E+01	24
L4L9	2.33E+01	1.53E+01	3.85E+01	25
L6L14	2.15E+01	1.69E+01	3.85E+01	26
L12L14	2.19E+01	1.63E+01	3.82E+01	27
L11L14	2.26E+01	1.49E+01	3.75E+01	28
L9L15	2.44E+01	1.28E+01	3.72E+01	29
L14L15	2.23E+01	1.45E+01	3.68E+01	30
L1L7	6.26E+00	3.01E+01	3.64E+01	31
L1L11	1.28E+01	2.33E+01	3.61E+01	32
L6L9	2.28E+01	1.29E+01	3.57E+01	33
L2L3	9.77E+00	2.59E+01	3.57E+01	34
L5L9	2.19E+01	1.37E+01	3.56E+01	35
L10L16	1.98E+01	1.54E+01	3.52E+01	36
L9L13	2.15E+01	1.36E+01	3.51E+01	37
L1L3	5.29E+00	2.84E+01	3.36E+01	38
L1L16	8.32E+00	2.51E+01	3.35E+01	39
L1L6	5.27E+00	2.74E+01	3.27E+01	40
L1L10	6.49E+00	2.61E+01	3.26E+01	41
L1L8	7.33E+00	2.52E+01	3.25E+01	42
L1L12	7.17E+00	2.45E+01	3.16E+01	43
L3L9	2.50E+01	6.59E+00	3.16E+01	44
L7L11	1.46E+01	1.69E+01	3.14E+01	45
L1L5	5.23E+00	2.61E+01	3.13E+01	46
L3L4	6.22E+00	2.51E+01	3.13E+01	47
L1L13	5.24E+00	2.55E+01	3.07E+01	48
L1L4	5.27E+00	2.52E+01	3.05E+01	49
L1L15	5.65E+00	2.47E+01	3.03E+01	50
L1L17	4.85E+00	2.50E+01	2.99E+01	51
L2L4	8.38E+00	2.12E+01	2.96E+01	52
LINES	PIV	PIMW	PI	RANK
L4L7	8.00E+00	2.00E+01	2.80E+01	53
L3L16	9.37E+00	1.82E+01	2.76E+01	54
L3L11	9.85E+00	1.75E+01	2.74E+01	55
L3L12	7.73E+00	1.82E+01	2.59E+01	56
L8L16	1.55E+01	1.04E+01	2.59E+01	57
L3L5	5.55E+00	1.99E+01	2.55E+01	58
L7L16	1.13E+01	1.41E+01	2.54E+01	59
L2L5	7.43E+00	1.74E+01	2.48E+01	60
L7L8	1.00E+01	1.47E+01	2.47E+01	61
L2L16	8.07E+00	1.65E+01	2.45E+01	62
L3L13	5.70E+00	1.87E+01	2.44E+01	63
L3L15	6.30E+00	1.80E+01	2.43E+01	64
L2L8	1.01E+01	1.42E+01	2.43E+01	65
L12L16	1.23E+01	1.18E+01	2.41E+01	66
L2L7	8.59E+00	1.54E+01	2.40E+01	67
L8L12	1.19E+01	1.19E+01	2.38E+01	68
L2L10	8.33E+00	1.52E+01	2.35E+01	69
L7L12	8.80E+00	1.46E+01	2.34E+01	70
L11L16	1.30E+01	1.04E+01	2.34E+01	71
L3L17	5.21E+00	1.81E+01	2.33E+01	72
L7L10	7.79E+00	1.54E+01	2.32E+01	73
L2L12	6.92E+00	1.62E+01	2.31E+01	74
L4L11	9.67E+00	1.34E+01	2.31E+01	75
L4L16	9.14E+00	1.38E+01	2.29E+01	76
L8L11	1.24E+01	1.04E+01	2.29E+01	77
L2L11	8.39E+00	1.44E+01	2.27E+01	78
L15L16	1.28E+01	9.90E+00	2.27E+01	79
L2L13	5.14E+00	1.72E+01	2.23E+01	80

It has been found that 80 of the line outage combinations push the system to the unsecure state, they are given in the above table and rest of the line combinations do not have any serious impact on the system. When the lines between the buses (6 & 11) and (9 & 10) are opened.

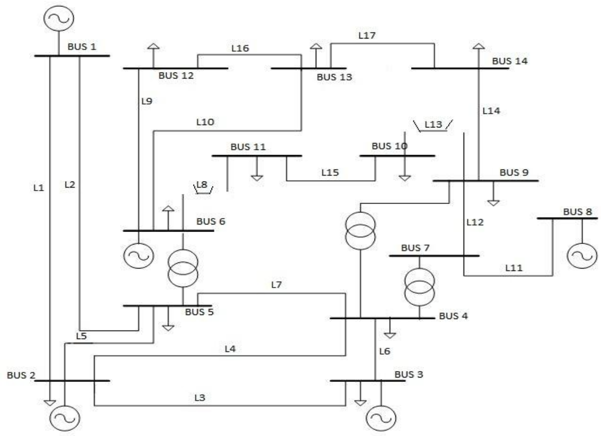

Fig.4: Lines between (6 & 11) and (9 & 10) are opened.

It has been observed that the buses 10 and 11 are isolated from the system and lines between the buses (1 & 2) and (2 & 3) are overloaded by 118.24 and 120.4 percentage respectively and the voltage at the buses 10,11,13,14 are violated against its limit.

Table. IV: Voltage Profile before and after contingency

BUS NO.	VOLTAGE BEFORE CONTINGENCY (p.u)	VOLTAGE AFTER CONTINGENCY (p.u)
10	0.9628	0
11	0.9778	0
13	0.9644	0.9319
14	0.9628	0.9310

5. Conclusion

For an IEEE 14 bus system, 136 possible N-2 contingencies are ranked using real performance index and voltage performance index and found that 80 of the line combinations are critical, i.e. these combinations make the system to transit from Normal to Unsecure state, which are shown in table 3. Lines between the buses (6 & 11) and (9 & 10) is ranked one, when these lines are outaged the system has been isolated, voltage profile at buses 10, 11, 13 and 14 are violated and lines L1 and L3 are overloaded. Credible/Critical contingencies of the system are determined with the studies

Future scope

For a large power system network, large number of N-2 contingencies are possible in which most of them will be Non-critical, by using algorithms like Impact tracking system(ITS) which uses Line outage distribution factors(LODF'S) and Overload tracking system (OTS) which uses line overload limits, the list of critical contingencies will be greatly reduced. FACTS devices can be used to improve the line flows and the voltage profile of the system.

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