CONTINGENCY ANALYSIS OF TRANSMISSION LINE OUTAGE IN A 9-BUS POWER SYSTEM USING POWER WORLD SIMULATOR

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Abstract

Power system planning is an essential aspect in power system for quality power supply. Operating electrical equipment at the specified voltage limit is necessary for satisfactory performance, failure of which the life of the equipment will be at risk. Thus, the need for both load flow and contingency analysis for proper power system planning and operation. In this study, a contingency analysis of transmission line outage was carried out on a 9-bus power system using power world simulator. The load flow solution was achieved using Newton Raphson iterative technique after which a contingency analysis was carried out on the steady state power solution for both transmission line and transformer outages on the 9- bus power system network. The simulation results obtained for the power flow analysis converged and was found to have a high degree of accuracy with a tolerance power mismatch of 0.0001. The result suggests the applicability of the model for effective planning and operation in power system.

Keywords: *Power flow, Contingency analysis, Newton Raphson Iterating technique, model, Power world simulator.*

Introduction

Power flow analysis is the study of power system to determine the steady state operating characteristics/conditions of the system based on the given line data and bus data for planning, operation and control of power system. Power flow study is a very crucial analysis forming a major activity in power system needed for planning, operation and expansion of power system. Basically, it is used to determine operating conditions for a power system to be in a steady state or normal mode. The operating conditions are the voltage magnitude at each bus, voltage angle, real and reactive power absorbed/generated at each bus, line flow and line losses. However, there are possibilities of harmful disturbances that could arise in the power system known as contingency such as tripping of transmission line, loss of generator, large sudden change in load etc. which may impact negatively on the quality and reliability of the power supply. Failure of the power system to withstand such a disturbance will result to voltage instability, a violation of prescribed operating voltage limit which in turn hampered the system integrity to make power available for the user. Thus in addition to power flow analysis, for estimating state of the system after a disturbance, the need to further carried out contingency analysis is paramount with a view to having a well-designed system in order to minimize or eradicate consequences of the possible future contingencies in the power network for a quality, secured and reliable power supply.

Literature Review

Identifying possible system outages/fault, predicting the effect on the power system and taking necessary preventive/ corrective action to avoid system trouble before their occurrence is referred to as contingency analysis. According to (Fayez, 2016), voltage stability has attracted a significant attention as it is becoming a major threat in the power system. An outage of one transmission line or transformer will result to over load in other branches and or sudden rise or drop in system voltage. To obtain a power flow solution, there is need to develop the network model, obtain the power flow equations and solving the equations using a numeric method are the core requirements for the power flow analysis. The non-linear algebraic equation is solved using a numerical method (Khanabadi et al., 2015; Kotamarty et al., 2008; Mandloi & Jain, 2014; Mittal et al., 2011; Onah & Madueme, 2015; Patra, 2015) such as Gauss Siedel, Newton Raphson iterative technique etc. to obtain set of two unknown variables at each bus. There are basically four electrical parameters needed to be available at each bus out of which two are unknown. Electrical bus is classified into three groups namely load bus, generator bus and slack bus(Khanabadi et al., 2015). A load bus has both reactive power and real power specified/ known leaving two other parameters as unknown i.e. voltage magnitude and angle, while a generator bus has real power and voltage known with two unknowns of reactive power and voltage angle. A slack bus is regarded as reference bus with only voltage magnitude and angle known. Studies have shown that newton Raphson iterative technique and Gauss Siedel are the most popular technique used in solving power flow equations(Khardenvis, 2012). The load flow solution obtained is used for contingency analysis, as a step geared towards power system security. The process of detecting any serious voltage limit violation or potential over load in the event of contingency is called system security assessment. In a study carried out by (Patra, 2015), a single line and double line contingencies were considered and the performance index were estimated for each type of contingency. A measure of the effect of a contingency or an outage/system component failure on power system is called performance or severity index. According to (Khardenvis, 2012), transmission line are designed to withstand up to 125% of their apparent capacity. Basically, in contingency analysis power operator are provided with information on the number of violations for any given system element failure/outage and corresponding remedial action to remove the violation.

Methodology

The methodology adopted for this study involves three critical steps. The first step is collection of data for a given network power structure and analysing the data to put it in the required form for the development of a model. Formulation of power flow equation and solving it using newton Raphson technique will be carried by building a model of the power network using the processed data and simulating the model to obtaining the power flow solation for a steady state operation as the second step. The simulation results give the power flow solution on which a contingency analysis will be carried on to form the third step of obtaining the effect of transmission line outage on the power network in combination with failure of transformer one after the other.

Data Collection

A 9- bus power network system was considered for this study. The required data for the load flow analysis and contingency analysis are line data and bus data. The line data contains the impedance and susceptance parameter values of transmission lines in per unit, impedance and susceptance parameter values of transformers in per unit, transformer tap setting and MVA capacity of transformers. Transformer and transmission lines are the two most important branch elements whose data values are needed to be provided in line data. Bus data contains MW & MVAR values of loads connected to load bus, MW value and voltage magnitude of generators connected to generator bus with load magnitude on it if any, and voltage magnitude and angle of slack bus. The bus data and line data used for this study is IEEE standard test data as shown in table 1 and table 2 respectively. The 9-bus power network system is depicted by a single line diagram shown in fig 1.

Table 1: Bus Data

				Generation		LOAD	
Bus No.	**Bus Type**	**Voltage in per unit**	**Nominal voltage in kV**	**MW**	**MVAR**	**MW**	**MVAR**
1	SLACK	1.04	16.5	100	0	0	0
2	PV	1.025	18	163	6.7	0	0
3	PV	1.025	13.8	85	-10.9	0	0
4	PQ	1	230	0	0	0	0
5	PQ	1	230	0	0	125	50
6	PQ	1	230	0	0	90	30
7	PQ	1	230	0	0	0	0
8	PQ	1	230	0	0	100	35
9	PQ	1	230	0	0	0	0

Table 2: Line Data

Line From	Line To	R in per unit	X in per unit	B in per unit
1	4	0	0.0576	0
4	5	0.01	0.085	0.176
4	6	0.017	0.092	0.158

6	9	0.039	0.17	0.358
5	7	0.032	0.161	0.306
9	3	0	0.0586	0
7	2	0	0.0625	0
9	8	0.0119	0.1008	0.209
7	8	0.0085	0.072	0.149

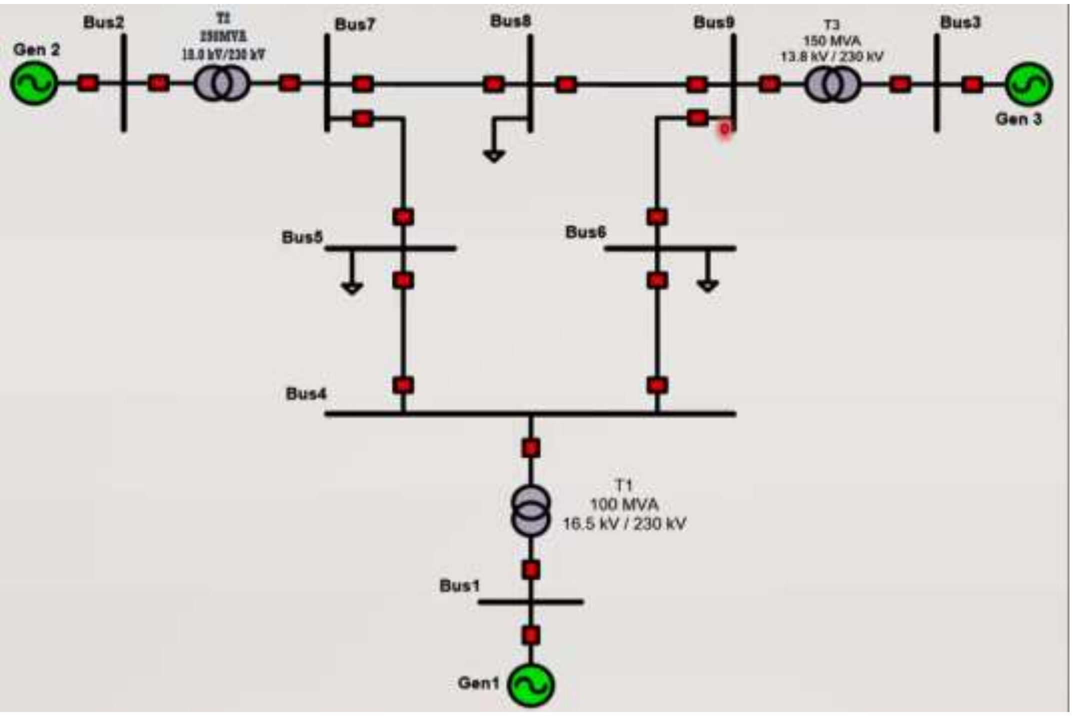

Figure 1: Line diagram of 9-bus network system used as case study

Development of power system network model

The bus and line data were used to build a 9- bus power system in power world simulator. The model developed in the power world simulator software was solved using newton Raphson iterative technique to obtain the power flow solution for the power system model. The model structure built in simulator is as shown in figure 2 using the available standard IEEE 9-bus data. The power flow equation for voltage at each bus is as given in equation (1).

$$V_i = \frac{\frac{P_i - jQ_i}{V_i} + \sum_{j=1}^{j=n} y_{ij} V_j}{\sum_{j=0}^{n} y_{ij}} \qquad j \neq i \qquad (1)$$

Where:

P, Q represent real power and reactive power respectively, n represents total number of buses,

V, y, represent voltage and admittance respectively

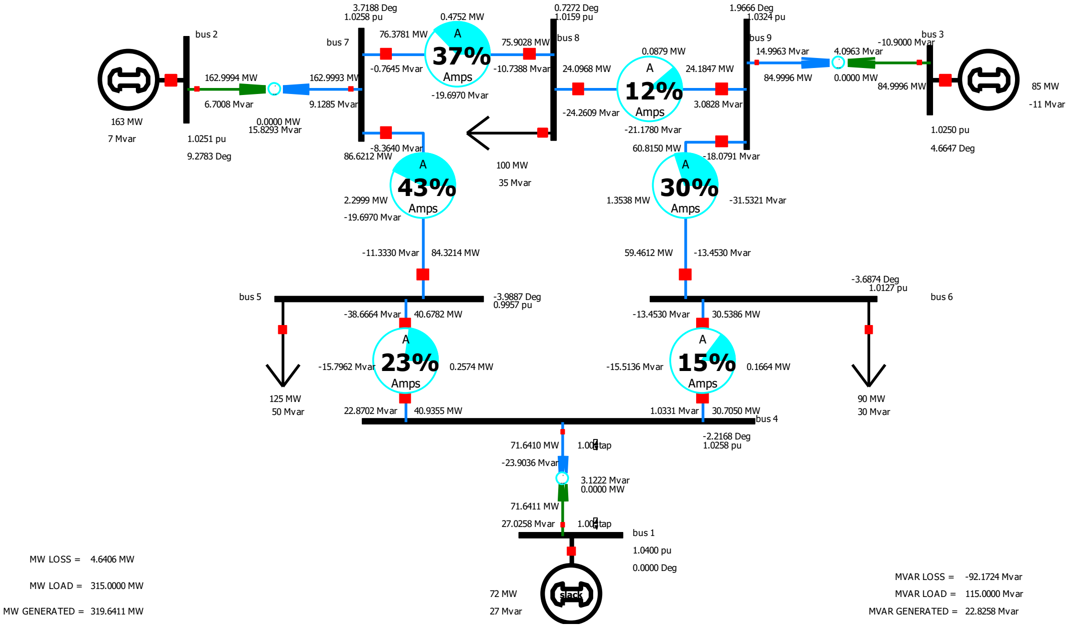

Fig. 2: Network Configuration in Power world simulator

The power flow solution obtained through simulation using newton Raphson iterative technique provides values of the voltage magnitude in per unit and angle at each bus, amount of real power and reactive power generated at each generator bus, magnitude of real power and reactive power absorbed at each load bus in MW and MVAR respectively, line flow for each branch, MW and MVAR line loss in each branch and the percentage load of each branch for a steady state power system is shown in fig. 2.

Contingency Analysis

The steady state power solution obtained is used for contingency analysis. The effect of transmission line outage one after the other with or without transformer in combination were considered for the contingency analysis. the two possible parameters that were used as basis for violation are the operating voltage limit of 0.95 to 1.05 per unit and the load on each branch line expressed as a percentage of its maximum capacity of $200MVA$ with a tolerance of +15%. For each of the contingency, power flow solution was obtained to predict possible violations in terms of either voltage or percent load.

Simulation Results

Case 1: Transformer TR1 outage

The network was simulated to obtain possible violations when TR1 between bus 1 and 4 is removed. The results obtained is shown in fig 3. Opening of transformer 1 resulted to six voltage violations as shown in table 3, at bus 3,4,5 6,8 and 9 with voltage value of 0.83,0.77,0.77,0.76,0.87 and 0.84 in per unit respectively, without over load at any of the transmission line.

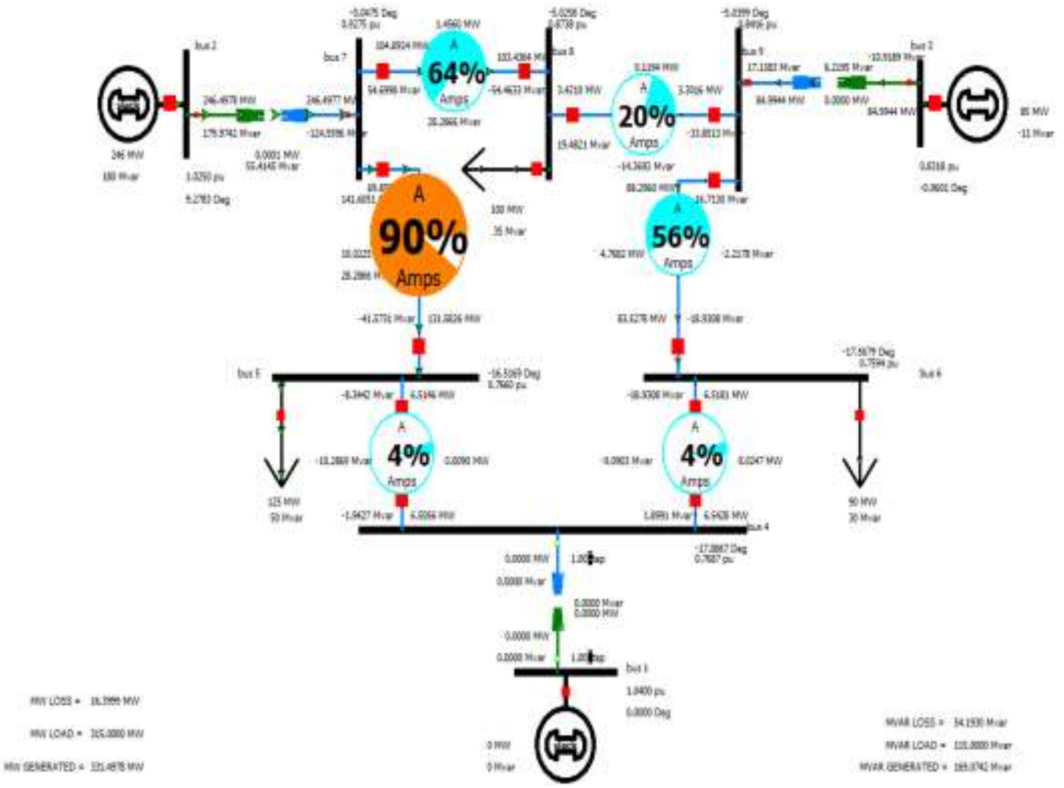

Fig 3: network simulation when TR1 is removed

Case 2: when TR1 and TL2 are both OPEN

Figure 4 shows a case of simultaneous opening of both transmission line TL 2(between bus 4 and 6) and transformer TR1 which resulted to only voltage violation at bus 3,4,5,6,7,8, and 9 as shown in table 3(a), without overload on any of the transmission line.

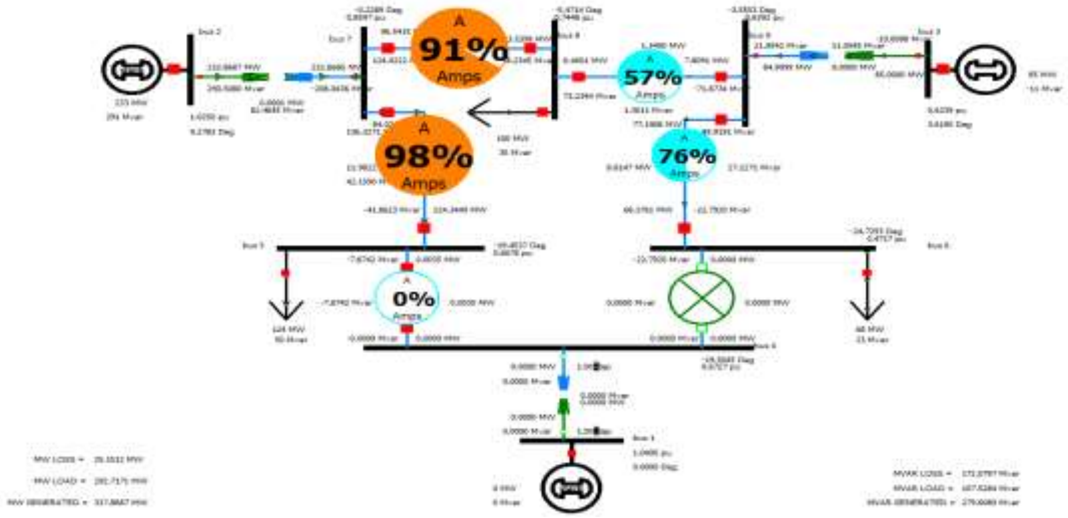

Fig. 4: simulation for contingency of when TR1 and TL2 are both open

Case 3: When TR2 and TL5 are both OPEN

Voltage violations were observed at five different buses with voltage value of 0.56, 0.89, 0.78,0.48 and 0.58 at bus 3,5,6,8 and 9 respectively. No over load at any of the transmission line during the contingency. The MW power loss and voltage values are as shown in table 3(b).

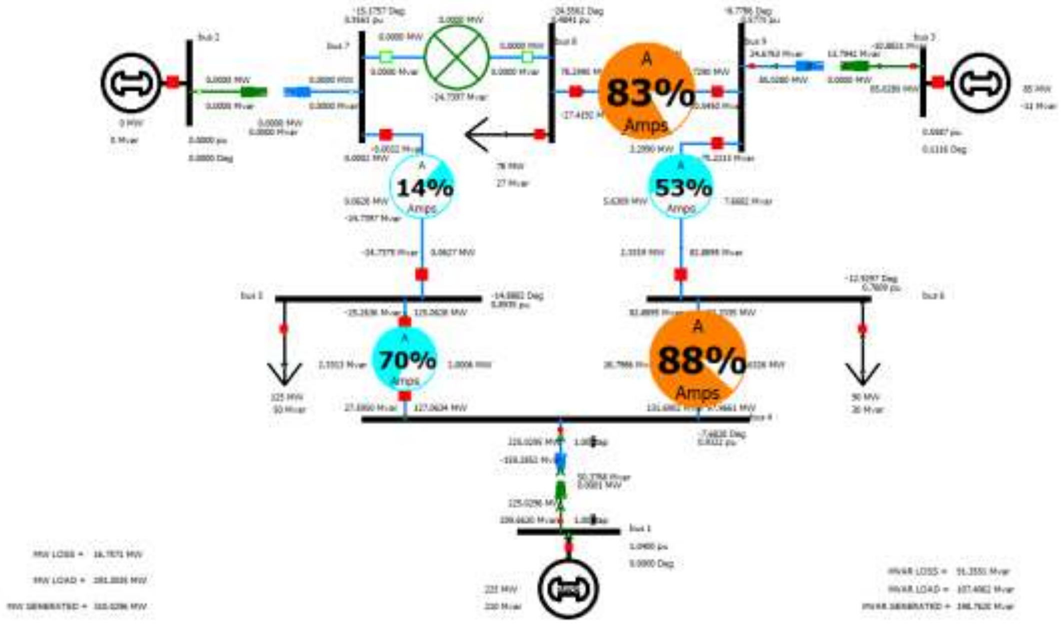

Fig. 5: network simulation for contingency when TR2 & TL5 are both open

Table 3(a): Per unit bus voltage simulation results for contingency analysis

		Contingency				Contingency		
Bus number	**Per unit voltage at steady state**	**Per unit voltage when transformer (TR1) is open**	**Per unit voltage when transformer TR1 and transmission line TL2 are both open**	**Per unit voltage when transformer TR2 and TL5 are both open**	**Voltage angle at steady state**	**Voltage angle when transformer (TR1) is open**	**Voltage angle when transformer TR1 and transmission line TL2 are both open**	**Voltage angle when transformer TR2 and TL5 are both open**
1	1.04	1.04	1.04	1.04	0	0	0	0
2	1.0251	1.025	1.025	0	9.2783	9.2783	9.2783	0
3	1.025	0.8318	0.6239	0.5587	4.6647	-0.9601	3.6195	0.1116
4	1.0258	0.7687	0.6727	0.9322	-2.2168	-17.0867	-19.5045	-7.6828
5	0.9957	0.766	0.6676	0.8935	-3.9887	-16.5169	-19.4537	-14.8882
6	1.0127	0.7594	0.4717	0.7809	-3.6874	-17.5679	-24.7293	-12.9297
7	1.0258	0.9275	0.8597	0.9161	3.7188	-0.0475	-0.2289	-15.1757
8	1.0159	0.8738	0.7448	0.4841	0.7272	-5.0258	-5.4714	-24.5562
9	1.0324	0.8416	0.6392	0.5771	1.9666	-5.0399	-3.5553	-8.7786

Table 3(b): MW Loss and percent load simulation results for three cases of contingency

				CONTINGENCY ANALYSIS				**Contingency**		
BUS From	BUS To	Line Number	MW Loss at steady state	MW LOSS when T1 is open	MW Loss when T1 and TL2 are both open	MW Loss when T2 and TL5 are both open	Percent load at steady sate (%)	percent Load when T1 is open (%)	Percent load when T1 and TL2 are both open	Percent of full load capacity when T2 and TL5 are both open
4	5	TL1	0.2574	0.009	0	2.0006	23	4	0	70
4	6	TL2	0.1664	0.0247	0	5.6326	15	4	0	88
5	7	TL3	2.2999	10.0225	11.9822	0.0628	43	90	98	14
6	9	TL4	1.3538	4.7682	8.8147	5.6309	30	56	76	53
7	8	TL5	0.4752	1.456	3.0017	0	37	64	91	0

8	9	TL6	0.0879	0.1194	1.349	3.43	12	20	57	83

Graphical illustrations of total MW power loss, value of voltage violations and percent load for the three cases presented above are as shown in figure 6, 7 and 8 respectively. Among the three cases of contingency, case three has the lowest voltage value of 0.4841 per unit while case 2 has the highest MW loss at the lowest total MW load demand. However, case 1 has the highest total MW generation.

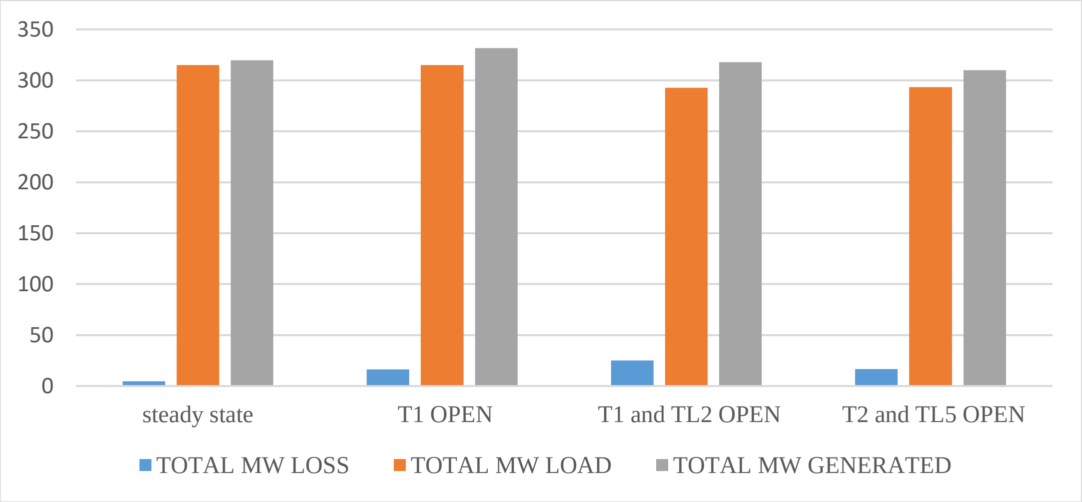

Fig 6: Total MW Loss for the various Contingency

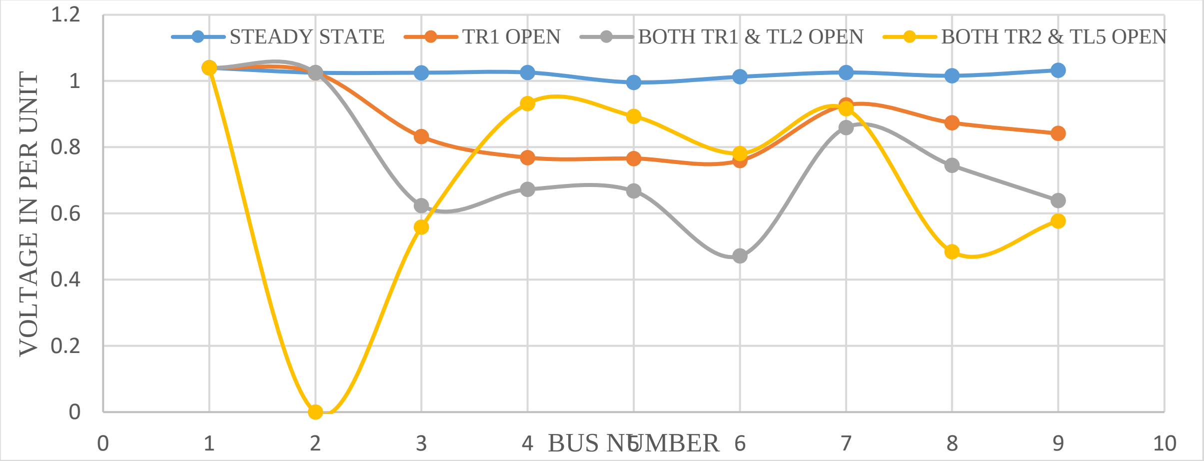

Fig 7: Graph of per unit voltage against bus number under various contingency

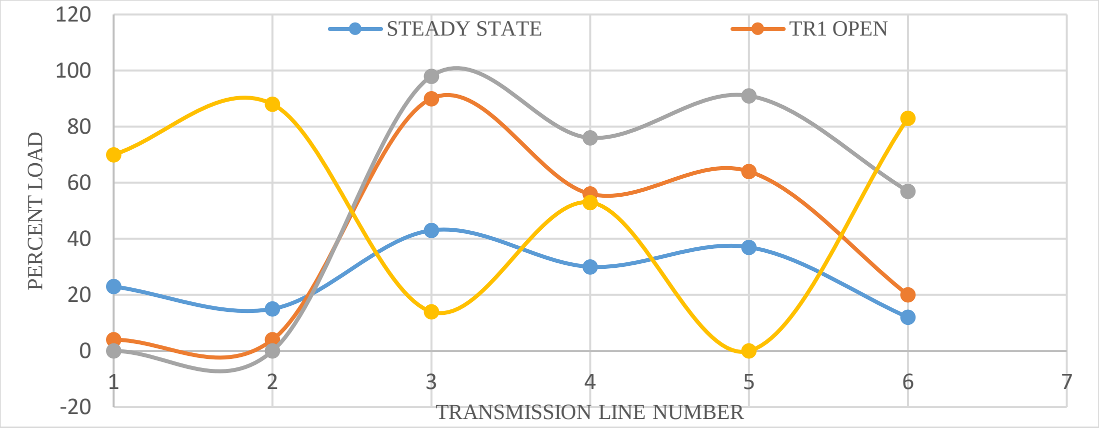

Fig 8: Graph of Percent Load against transmission line number for different contingency

The breakdown of the total MW loss in each of the transmission line for the three cases is as shown in fig 9.

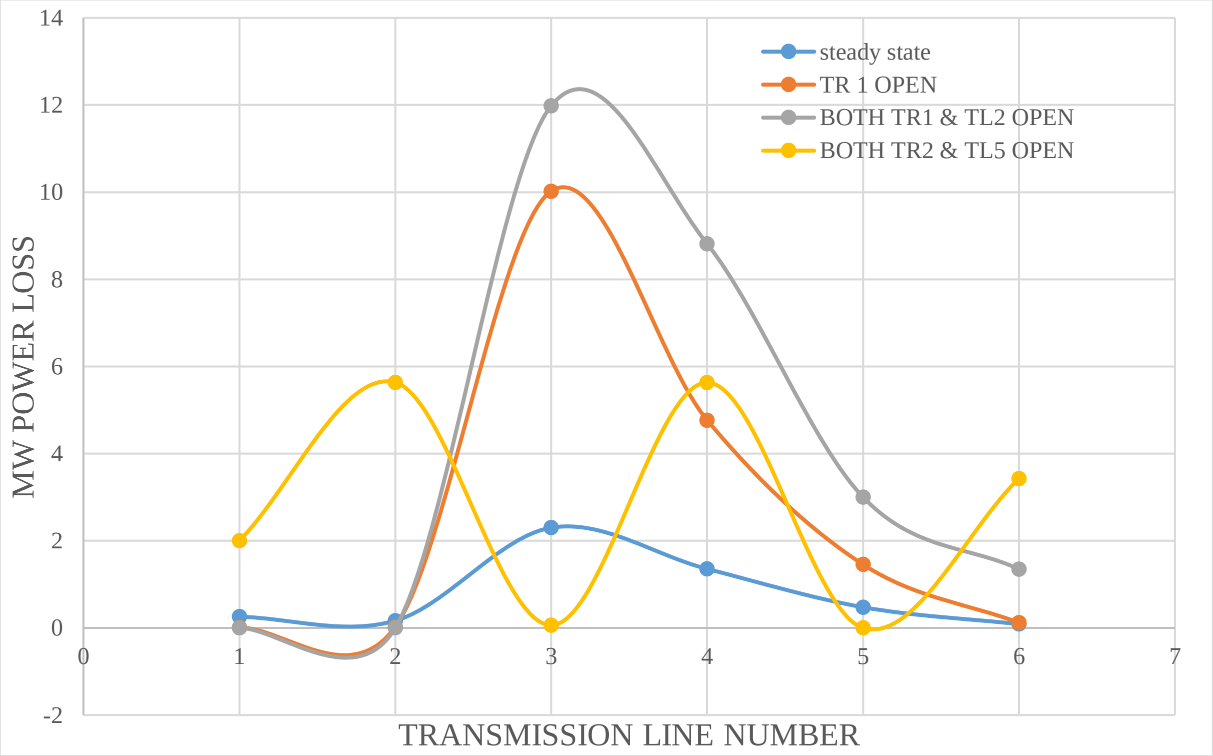

Fig 9: Graph of MW Loss against transmission line number for different contingency

Conclusion

Power flow analysis of the 9 bus power system was carried out using Newton Raphson iterating technique. The load flow solution obtained form the basis for the contingency analysis of the power system. Cases of transmission line outage and transformer failure were considered. The simulation was carried out in power world simulator. The simulation results obtained was found to be accurate. The analysis of the results obtained indicate the MW loss in the transmission line, percent load and number of voltage violation in the entire power system for each of the contingencies. This form of analysis will go a long way in planning to overcome hypothetical situation in power system for a reliable and quality power supply.

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