CONTINGENCY RANKING IN A POWER TRANSMISSION SYSTEM USING ZIP LOAD MODELING

Seshapalli SAIRAM[1], Suresh Babu DARAM[2]

The Load models play vital role in the effect of particular situations. In this paper, the ZIP load modeling is considered and is incorporated in Newton-Raphson load flow technique. The contingencies are ranked for single line outage through constant impedance (Z), constant current (I), constant power (P) and ZIP load models respectively. A voltage stability measure, Condition Number of the Jacobian matrix in N-R load flow technique is computed for every Single line outage condition. The line contingencies are ranked based on the largest value condition number. The results were investigated on IEEE-14 and IEEE-30 bus system using MATLAB Software.

Keywords: Load modeling, Load flow Control, Power system analysis computing, MATLAB.

Nomenclature:

P_0	Initial values of real power
Q_0	Initial values reactive power and respectively
V_0	Initial values voltage at a load bus
a, b	Load parameters, value is 0 to 2
P_i	Nominal values of the load active power
Q_i	Nominal values of the load reactive power
Z	Constant impedance
I	Constant current
P	Constant power
$\|J\|$	Norm of a Jacobian matrix
$\|J^{-1}\|$	Norm of an inverse Jacobian matrix

1. Introduction

Power system engineers conduct studies to determine the security of the system under various conditions. The reliability of a particular power system is dependent on the monitoring, operations and planning studies conducted for the network. The static load model can use in load flow, optimization, voltage

[1] Research scholar, Department of Instrumentation and Control Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India. e-mail: seshapallisairam@gmail.com
[2] Associate Professor, Department of Electrical and Electronics Engineering, Sree Vidyanikethan Engineering College, Tirupati (A.P), India, e-mail: sureshbabudaram@gmail.com

stability, and dynamic load models are more appropriate for dynamic stability studies [1]. Two approaches have used as tools to develop load model [2]. The first one is the measurement-based approach, involves direct measurements at different substations and feeders to determine the voltage and frequency characteristics of the active and reactive loads at the point. The second one is the component-based approach, involves the development of load model from the mix of different load classes and the characteristic to each of them.

Load modeling has been conducted since a long time to improve the accuracy of power system analysis. The advantages of load modeling are as follows:

- Enhanced control capacity with variation of power demand.
- Enhanced calculation of active and reactive power demand at respective buses.
- Control of over voltage and under voltage at load bus.

The static and dynamic load models are classified according to the effect of voltage on the load. The load variation depends only on the instantaneous voltage input and related to the preceding voltage input. The static load model is a polynomial-based model composed of constant impedance characteristics, constant current characteristics, and constant power characteristics. This static model is also known as ZIP load model and is often expanded to static load model with frequency characteristics using a proportion coefficient. Using ZIP and exponential load models, critical points in the system were considered in [4]. Steady state operating conditions of a power system were obtained by calculating the magnitudes, angles of the voltage at different nodes and active, reactive power flow in the power network [5]. Power system analysis benefits from a flexible and detailed representation of load behaviour, specifying load models to capture physical behaviour. Static system results are very helpful to the system operator to secure the system during any transmission line outage in the system [6-7].

Contingency screening and ranking is the process to determine the possibility of specific contingencies which may cause power system instability based on their severity. Suitable preventive control actions can be implemented considering contingencies that are likely to affect the power system performance [8]. Condition number computed for Newton-Raphson (N-R) Jacobian matrix provides the system severity of a line outage from the system stability point of view. The formulation of a problem is defined to be ill-conditioned if computed values are very sensitive to small changes in input values [9].

This paper is organized as follows. The static load models are described in section-2. The polynomial load models incorporated in Newton-Raphson method is described in section-3. The contingency ranking based on the condition number is given in section-4. The proposed algorithm is explained in section-5. Finally, the case study simulations results and discussions performed are discussed in section-6.

2. Static Load Model

Dissimilar load models would prominently affect voltage stability analysis. Static load models do not vary with time. In these models, active and reactive power loads are expressed as exponentials and polynomials of voltage and frequency. The following are various static load models used.

Exponential load model:
The exponential load model for real and reactive power at load bus is represented as a below.

$$P = P_0\left(\frac{V}{V_0}\right)^a \tag{1}$$

$$Q = Q_0\left(\frac{V}{V_0}\right)^b \tag{2}$$

Polynomial load model:
The polynomial load model is also called ZIP load model. Z stands for constant impedance, I represent constant current and P refers to constant power. The polynomial model for active and reactive power is given as in equation (3) and (4).

$$P = P_i\left[P_1\overline{V}^2 + P_2\overline{V} + P_3\right] \tag{3}$$

$$Q = Q_i\left[Q_1\overline{V}^2 + Q_2\overline{V} + Q_3\right] \tag{4}$$

Here $\overline{V} = \frac{V}{V_0}$

a). Constant impedance load model
The active and reactive powers are proportional to squared voltage. In this model, the values of active and reactive powers are given as $P_1 = Q_1 = 1$, $P_2 = Q_2 = P_3 = Q_3 = 0$. The constraints for power equations are $P_1 + P_2 + P_3 = 1$, $Q_1 + Q_2 + Q_3 = 1$. By substituting the above constraints in equation (3) and (4), we obtain equation (5) and (6).

$$P = P_i V^2 \tag{5}$$

$$Q = Q_i V^2 \tag{6}$$

b). Constant current load model
The active and reactive powers are proportional to voltage. In this model, the values of active and reactive powers are given as $P_2 = Q_2 = 1$,

$P_1 = Q_1 = P_3 = Q_3 = 0$. The constraints for power equations are $P_1 + P_2 + P_3 = 1$, $Q_1 + Q_2 + Q_3 = 1$. By substituting the above constraints in equation (3) and (4), we obtain equation (7) and (8).

$$P = P_i V \tag{7}$$

$$Q = Q_i V \tag{8}$$

c). Constant power load model

The active and reactive powers are proportional to voltage. In this model, the values of active and reactive powers are given as $P_3 = Q_3 = 1$, $P_1 = Q_1 = P_2 = Q_2 = 0$. The constraints for power equations are $P_1 + P_2 + P_3 = 1$, $Q_1 + Q_2 + Q_3 = 1$. By substituting the above constraints in equation (3) and (4), we obtain equation (9) and (10).

$$P = P_i \tag{9}$$

$$Q = Q_i \tag{10}$$

Most of the loads can be represented as selected combination of the ZIP model, with different parameters reflecting the composition. Constant power loads lead to stability problems because there is a tendency for the current to increase to keep the power a constant, when the voltage drops. This can lead to a further drop in the voltage. Constant impedance loads, on the other hand, tend to damp voltage oscillations.

3. Polynomial load models in Newton-Raphson Load Flow Method:

In this section, the mathematical representation of polynomial model in load flow analysis is explained.

a). Constant Impedance (Z) in Newton-Raphson Load Flow Method:

The active and reactive power equations in N-R load flow method considered from [10]. In this model, the values of active and reactive powers are represented using the constant impedance only i.e., Z alone. By constraints the constant impedance value in active and reactive power, we obtain equation (11) and (12).

$$P_Z = \left[\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] V_i^2 \tag{11}$$

$$Q_Z = \left[-\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \right] V_i^2 \tag{12}$$

b). Constant Current (I) Incorporated With Newton-Raphson Method:

The active and reactive power equations in N-R load flow method considered from [10]. In this model, the values of active and reactive powers are represented using the constant current only i.e., I alone. By constraints the constant current value in active and reactive power, we obtain equation (13) and (14).

$$P_I = \left[\sum_{j=i}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] V_i \quad (13)$$

$$Q_I = \left[- \sum_{j=i}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \right] V_i \quad (14)$$

c). Constant Power (P) Incorporated With Newton-Raphson Method:

The active and reactive power equations in N-R load flow method considered from [10]. In this model, the values of active and reactive powers are represented using the constant power only i.e., I alone. By constraints the constant power value in active and reactive power, we obtain equation (15) and (16).

$$P_P = \left[\sum_{j=i}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] \quad (15)$$

$$Q_P = \left[- \sum_{j=i}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \right] \quad (16)$$

d). ZIP Incorporated With Newton-Raphson Method:

The active and reactive power equations in N-R load flow method considered from [10-11]. In this model, the values of active and reactive powers are represented using the all impedance, current and power i.e., Z, I, P. By constraints the all impedance, current and power value in active and reactive power, we obtain equation (17) and (18). In this load model, the main parameters are $P_1 = P_2 = P_3 = 0.333$, $Q_1 = Q_2 = Q_3 = 0.333$. Substitute these parameters in below equations.

$$P_{ZIP} = \left[\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] * \left[p_1 \bar{v}^2 + p_2 \bar{v} + p_3 \right]$$

$$P_{ZIP} = P_1 \left[\sum_{j=1}^{n} |V_i^3||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] + P_2 \left[\sum_{j=1}^{n} |V_i^2||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right] + \quad (17)$$

$$P_3 \left[\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \right]$$

$$Q_{ZIP} = \left[- \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \right] * \left[q_1 \bar{v}^2 + q_2 \bar{v} + q_3 \right] \quad (18)$$

$$Q_{ZIP} = P_1\left[-\sum_{j=1}^{n}\left|V_i^3\right|\left|V_j\right|\left|Y_{ij}\right|\sin(\theta_{ij}-\delta_i+\delta_j)\right] + P_2\left[-\sum_{j=1}^{n}\left|V_i^2\right|\left|V_j\right|\left|Y_{ij}\right|\sin(\theta_{ij}-\delta_i+\delta_j)\right] +$$
$$P_3\left[-\sum_{j=1}^{n}\left|V_i\right|\left|V_j\right|\left|Y_{ij}\right|\sin(\theta_{ij}-\delta_i+\delta_j)\right]$$

From the constant impedance (z), constant current (I), constant power (P), and ZIP load models, the active and reactive powers are incorporated in N-R load flow method. The Jacobian matrix gives the linearized relationship between small changes in voltage angle and voltage magnitude with the small changes in real and reactive power as given in equation (19).

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \quad (19)$$

The difference between the scheduled and calculated values are the power residual and are given in equation (20) and (21)

$$\Delta P_i^k = P_i^{sch} - P_i^k \quad (20)$$

$$\Delta Q_i^k = Q_i^{sch} - Q_i^k \quad (21)$$

The new estimated bus voltages are given in equation (22) and (23)

$$\delta_i^{(k+1)} = \delta_i^k + \Delta\delta_i^{(k)} \quad (22)$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^k\right| \quad (23)$$

4. Contingency ranking based on Condition number

The large variation in the power system leading to the collapse situation has to be identified by a measuring constraint. Condition Number of the Jacobian is used to quantify the measure of the system stability of the system. A large condition number is an indicator of the ill-conditioned matrix, i.e., the determinant will be closer to zero and hence the load flow will not converge, and the system will be insecure. A lower condition number indicates the system to be secure as the inverse of the Jacobian matrix exists.

The contingency ranking [12] is carried out based on the Condition Number (CN) of the Jacobian matrix computed in N-R load flow solution. The N-R load flow solution in a matrix form can be represented as (24).

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = J\begin{bmatrix}\Delta\delta\\ \Delta V/|V|\end{bmatrix} \quad (24)$$

Where J is the Jacobian matrix and is represented as (25)

$$J = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|}|V| \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|}|V| \end{bmatrix} \tag{25}$$

The correction values for the assumed unknown values are given by (26)

$$\begin{bmatrix} \Delta\delta \\ \Delta V / |V| \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{26}$$

Condition Number is a measure of the sensitivity of the matrix to a numerical operation. A Condition Number (CN) of a nonsingular Jacobian matrix can be given as (27)

$$CN(J) = \|J\|.\|J\|^{-1} \tag{27}$$

5. Proposed Algorithm

The computational methodology has been carried out through the following proposed algorithm.

Step 1: Read line and bus data of the given system and assumes that system angle, load (MW & MVAR) and generator (MW & MVAR, Q_{min} & Q_{max}) data are constant.

Step 2: Carry out the load flow study using constant impedance (Z) load model using equation (11) & (12).

Step 3: Carry out the load flow studies using constant current (I) load model using equation (13) & (14).

Step 4: Carry out the load flow studies using constant current (P) load model using equation (15) & (16).

Step 5: Carry out the load flow studies using ZIP load modeling equation (17) & (18).

Step 6: Run the load flow without line outage contingency and use results as the base case.

Step 7: Calculate Condition Number (CN) of Jacobian matrix of N-R load flow technique for each line outage condition having maximum CN.

Step 8: Rank the more sensitive line under each line outage condition having maximum CN.

6. Case Study

In this section, the numerical results are carried out on IEEE 14-bus system and IEEE 30-bus system [12] to understand the proposed algorithm.

A. IEEE 14-bus system

This system consists of 1-slack bus, 4-generator buses, 9-load buses and 20-transmission lines. The newton-Raphson method is used by involving Z, I, P and ZIP method for ranking the contingency.

Table 1

CONTINGENCY RANKING BASED ON CONDITION NUMBER FOR IEEE-14 BUS SYSTEM

Rank	Line	Z-Alone	Line	P-Alone	Line	I-Alone	Line	ZIP
1	1 to 2	435.4760	1 to 2	363.8830	1 to 2	388.5991	1 to 2	388.6190
2	5 to 6	237.6792	5 to 6	226.7807	5 to 6	232.2029	5 to 6	232.2692
3	7 to 9	169.4079	4 to7	158.7870	4 to7	158.2704	4 to7	159.0935
4	4 to7	155.5504	1 to 5	153.4951	1 to 5	152.8384	1 to 5	152.8304
5	1 to 5	153.4832	7 to 9	134.8018	7 to 9	146.4140	7 to 9	146.0394
6	6 to 13	140.8212	9 to 10	129.6106	6 to 13	130.7411	6 to 13	130.7083
7	9 to 14	130.6268	2 to 4	129.0135	2 to 4	128.8850	2 to 4	128.8746
8	2 to 4	129.4198	2 to 3	128.8875	2 to 3	128.8059	2 to 3	128.7901
9	6 to 11	129.0549	4 to 9	128.1635	4 to 9	128.4925	4 to 9	128.4849
10	4 to 9	129.0401	9 to 14	126.8759	9 to 10	128.2900	9 to 10	128.2659
11	2 to 3	128.9932	6 to 13	126.8386	9 to 14	127.8368	9 to 14	127.8048
12	9 to 10	127.2038	2 to 5	125.4633	6 to 11	125.1462	6 to 11	125.1391
13	2 to 5	124.7505	6 to 11	122.8587	2 to 5	124.8630	2 to 5	124.8524
14	6 to12	121.9962	6 to12	122.1477	6 to12	121.9148	6 to12	121.9116
15	13to 14	121.9806	13to 14	118.7092	13to 14	119.0495	13to 14	119.0089
16	10 to 11	117.6298	10 to 11	118.2719	10 to 11	117.2937	10 to 11	117.2610
17	12 to 13	115.5723	12 to 13	118.0723	12 to 13	116.6763	12 to 13	116.6459
18	3 to 4	115.1114	3 to 4	115.9262	3 to 4	115.3281	3 to 4	115.3141
19	4 to 5	75.2381	4 to 5	74.6127	4 to 5	74.9927	4 to 5	74.9839

The contingency ranking of the IEEE-14 bus system is given Table I. The most critical line is 1 to 2 and the condition number for Z, I, P and ZIP is 435.47, 388.59, 363.883 & 388.619 respectively. The largest condition number leads the system collapse. The top five contingency ranks of ZIP load models are considered. From Table 1, it can be observed the outages 1-2, 5-6, 7-9, 4-7, and 1-5 are more severe outages respectively in the ZIP load model. The voltage magnitude of ZIP load model is compared with Z, I & P under these outage conditions.

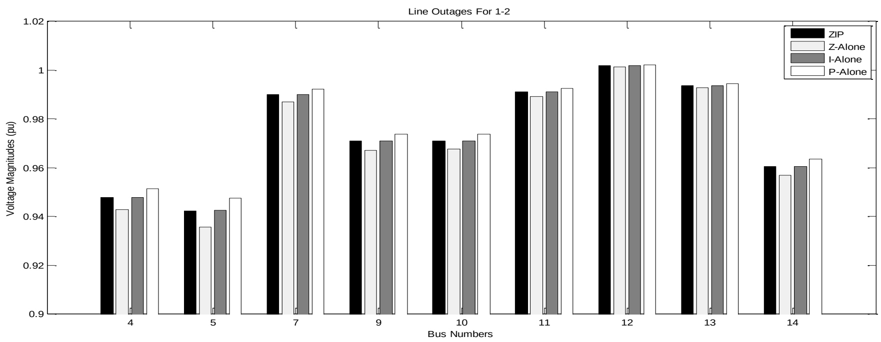

Fig. 1. Voltage Magnitudes for buses 4 to 14 at line 1-2 outage

The voltage magnitudes of all load buses at line outage 1-2 of ZIP, Z, I and P is shown in Fig 1. Compared to various load models constant power (P) affects the system more. Constant impedance (Z) has a very low effect on the power system. The voltage magnitudes of the load buses at line outage 5-6 of ZIP, Z, I, and P is shown in Fig 2. Compared to various load models constant power (P) affects the system more. ZIP load model, constant impedance (Z) and constant current (I) has a very low effect on the power system. Similarly, the voltage magnitudes of the load buses at 4-7 outage of ZIP, Z, I and P is shown in Fig 3. Compared to various load models constant power (P) affects the system more. ZIP load model has a very low effect on the power system.

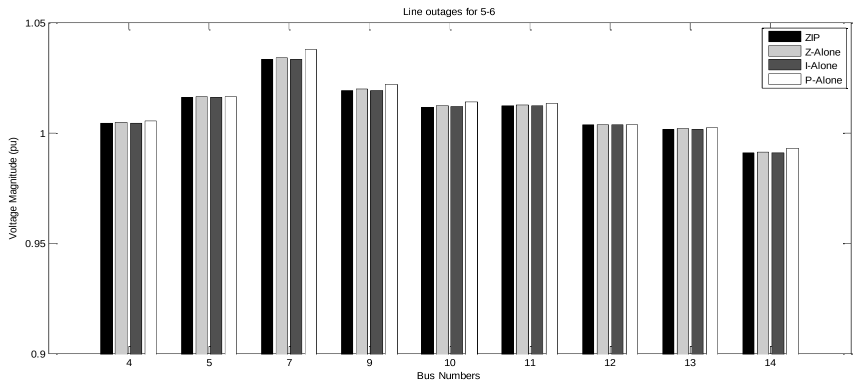

Fig. 2. Voltage Magnitudes for buses 4 to 14 at line 5-6 outage

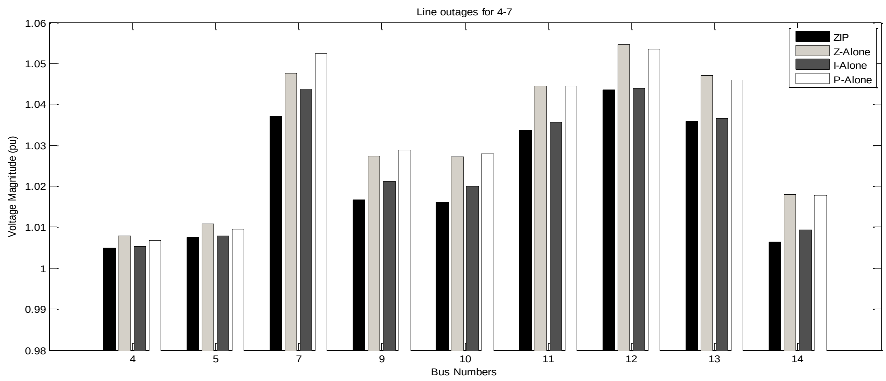

Fig. 3. Voltage Magnitudes for buses 4 to 14 at line 4-7 outage

Voltage magnitudes of the load buses at line outage 1-5 of ZIP, Z, I and P is shown in Fig 4. Compared to various load models ZIP, constant power (P) affects the system more. Constant impedance (Z) has a very low effect on the power system.

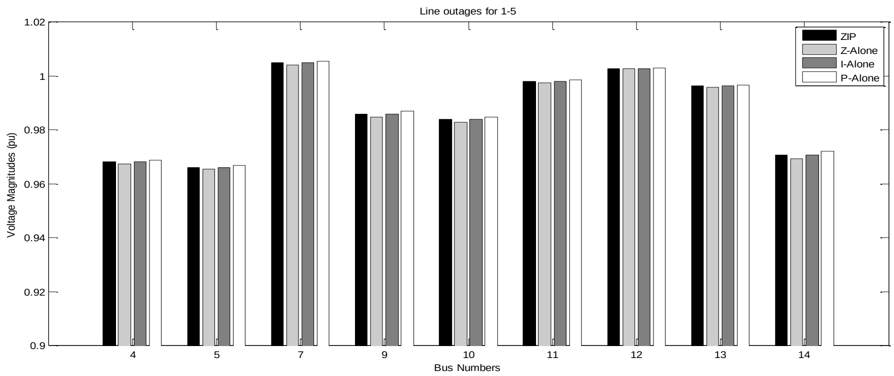

Fig. 4. Voltage Magnitudes for buses 4 to 14 at line 1-5 outage

Voltage magnitudes of the load buses at line outage 7-9 of ZIP, Z, I and P is shown in Fig 5. Compared to various load models constant power (P) affects the system more. Constant impedance (Z) has a very low effect on the power system.

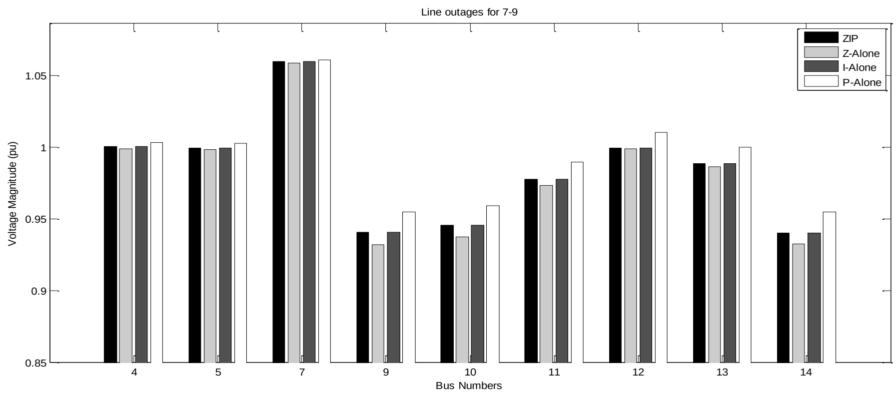

Fig. 5. Voltage Magnitudes for buses 4 to 14 at line 7-9 outage

B. IEEE 30-bus system

This system consists of 1-slack bus, 5-generator buses, 24-load buses and 41-transmission lines. The newton-Raphson method is used by involving Z, I, P and ZIP method for ranking the contingency. The contingency ranking of the IEEE-30 bus system is given in Table II. The most critical line using Z is 27 to 30, I is 3 to 4, P is 3 to 4 and ZIP is 3 to 4 and the condition number for individual Z, I, P and ZIP load models are 779.3269, 611.1744, 604.2886 & 611.1782 respectively. The largest condition number leads the system collapse. The top five contingency ranks of ZIP load models are considered. From Table II, it can be observed the outages 3-4, 9-10, 27-29, 27-30, and 2-6 are more severe outages using ZIP load model. The voltage magnitude of ZIP load model is compared with Z, I & P under these outage conditions are discussed below.

Table 2

CONTINGENCY RANKING BASED ON CONDITION NUMBER FOR IEEE-30 BUS SYSTEM

Rank	Line	Z-Alone	Line	P-Alone	Line	I-Alone	Line	ZIP
1	27 to 30	779.3269	3 to 4	604.2886	3 to 4	611.1744	3 to 4	611.1782
2	27 to 29	731.3016	9 to 10	543.3141	9 to 10	575.9380	9 to 10	576.1139
3	3 to 4	629.1448	2 to 6	540.7280	27 to 29	574.4791	27 to 29	572.8324
4	9 to 10	627.6854	2 to 4	523.6947	27 to 30	558.6636	27 to 30	556.1621
5	2 to 6	568.0342	2 to 5	523.0526	2 to 6	549.9820	2 to 6	550.0696
6	12 to 15	567.6276	27 to 29	516.8977	2 to 5	534.8135	2 to 5	534.7946
7	10 to 20	562.6103	10 to 20	508.2019	2 to 4	532.1868	2 to 4	532.2851
8	2 to 5	560.1416	12 to 15	507.8236	12 to 15	529.1791	12 to 15	529.2068
9	24 to 25	550.9898	27 to 30	503.6241	10 to 20	528.6453	10 to 20	528.7827
10	2 to 4	550.8099	25 to 27	502.6040	22 to 24	515.5708	22 to 24	515.6793
11	22 to 24	546.6852	5 to 7	501.5897	25 to 27	514.2336	25 to 27	514.4140
12	15 to 23	534.1013	22 to 24	497.5275	5 to 7	513.7606	5 to 7	513.9009

Rank	Line	Z-Alone	Line	P-Alone	Line	I-Alone	Line	ZIP
13	25 to 27	532.5687	24 to 25	493.2528	24 to 25	513.1440	24 to 25	513.1703
14	10 to 21	530.7135	15 to 23	492.3206	15 to 23	507.8009	15 to 23	507.9371
15	5 to 7	529.9668	10 to 21	489.8252	10 to 21	504.5724	10 to 21	504.7163
16	15 to 18	520.4999	15 to 18	489.2968	15 to 18	501.1807	15 to 18	501.3630
17	19 to 20	519.7134	12 to 14	487.6547	19 to 20	499.7584	19 to 20	499.9114
18	12 to 14	517.1404	19 to 20	487.5672	12 to 14	498.9509	12 to 14	499.1357
19	12 to 16	516.2618	12 to 16	486.9974	12 to 16	498.0710	12 to 16	498.2520
20	29 to 30	516.2192	10 to 22	483.9300	10 to 22	493.9239	10 to 22	494.0833
21	10 to 22	510.8437	10 to 17	483.7497	29 to 30	493.5467	29 to 30	493.5902
22	6 to 28	510.3369	21 to 22	482.9001	8 to 28	492.9245	8 to 28	493.0955
23	8 to 28	510.1018	8 to 28	482.7417	10 to 17	492.8415	10 to 17	493.0120
24	23 to 24	509.1301	29 to 30	482.1342	23 to 24	491.6712	23 to 24	491.8111
25	10 to 17	508.0076	23 to 24	481.8180	21 to 22	491.1631	21 to 22	491.3157
26	16 to 17	505.9031	14 to 15	481.4543	16 to 17	490.3200	16 to 17	490.4739
27	21 to 22	505.5393	16 to 17	481.2983	14 to 15	490.1150	14 to 15	490.2696
28	14 to 15	505.0516	18 to 19	481.0781	18 to 19	489.7452	18 to 19	489.8980
29	18 to 19	504.7420	6 to 28	459.9422	6 to 28	477.1707	6 to 28	477.0430
30	4 to 6	496.8055	6 to 7	458.7231	4 to 6	467.5256	4 to 6	467.6022
31	6 to 7	480.5662	4 to 6	448.0282	6 to 7	466.8088	6 to 7	466.9527
32	6 to 8	460.8627	6 to 8	412.9931	6 to 8	432.5377	6 to 8	432.8638

The voltage magnitudes for buses from 3 to 18 at line outage 3-4 using ZIP, Z, I and P is shown in Fig 6. Compared to the various load models constant impedance (Z) affects the system more. Constant power (P) has a very low effect on the power system.

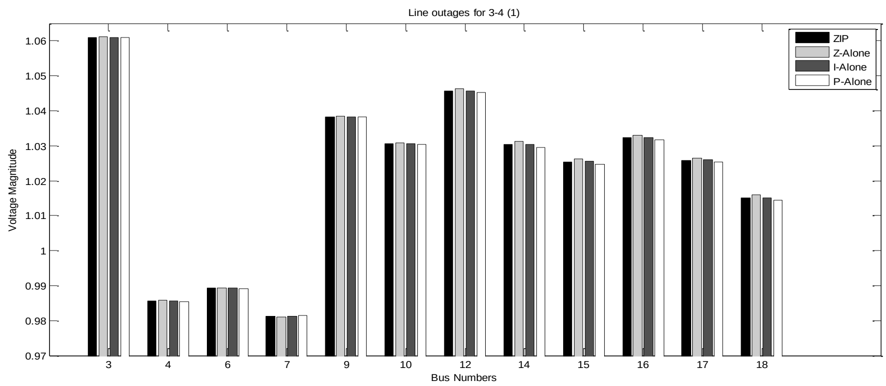

Fig. 6. Voltage Magnitudes for buses 3 to 18 at line 3-4 outage

The voltage magnitudes for buses from 19 to 30 at line outage 3-4 using ZIP, Z, I and P is shown in Fig 7. Compared to various load models constant impedance (Z) affects the system more. Constant power (P) has a very low effect on the power system.

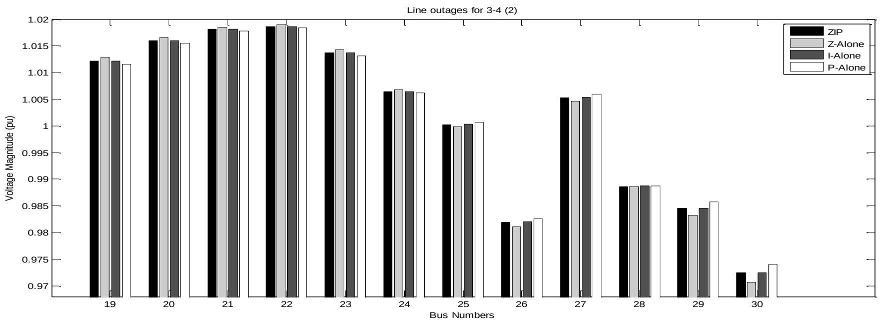

Fig. 7. Voltage Magnitudes for buses 19 to 30 at line 3-4 outage

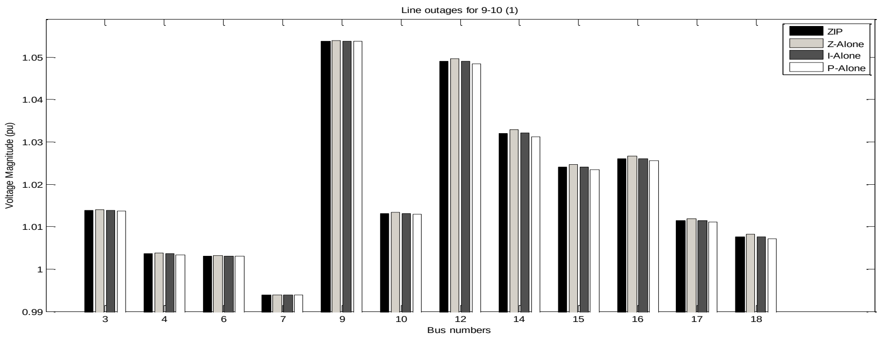

Fig. 8. Voltage Magnitudes for buses 3 to 18 at line 9-10 outage

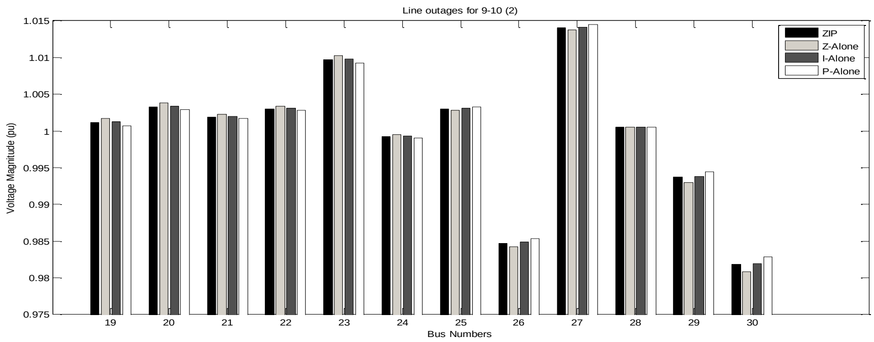

Fig. 9. Voltage Magnitudes for buses 19 to 30 at line 9-10 outage

The voltage magnitudes for buses from 3 to 18 and buses from 19 to 30 at line outage 9-10 of ZIP, Z, I and P are shown in Fig 8 and Fig 9 respectively. Compared to various load models ZIP, constant impedance (Z) and constant current (I) affects the system more. Constant power (P) has a very low effect on the power system. In Fig 9, constant impedance (Z) affects the system more and constant power (P) has a very low effect on the power system

Voltage magnitudes for buses from 3 to 18 and from 19 to 30 at line outage 27-29 using ZIP, Z, I and P is shown in Fig 10 and Fig 11 respectively. Compared to various load models constant current (I) affects the system more and constant impedance (Z) has a very low effect on the power system.

Voltage magnitudes for buses from 3 to18 and from 19 to 30 at line outage 27-30 of ZIP, Z, I and P is shown in Fig 12 and Fig 13 respectively. Compared to various load models ZIP, constant power (P) & constant current (I) affects the system more. constant impedance (Z) has a very low effect on the power system.

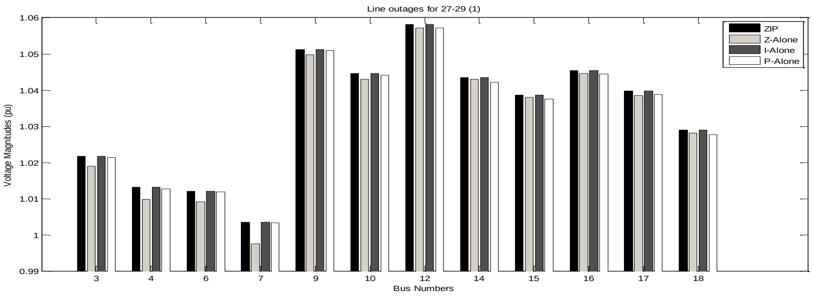

Fig. 10. Voltage Magnitudes for buses 3 to 18 at line 27-29 outage

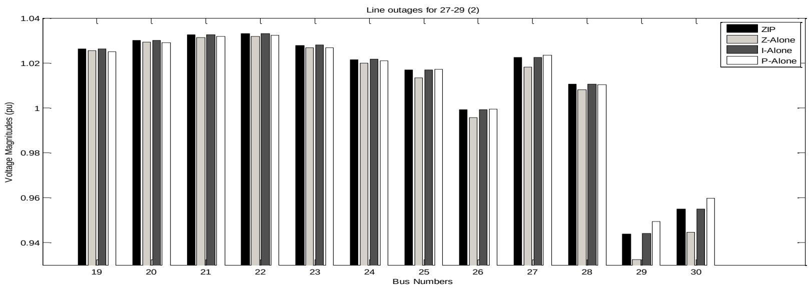

Fig. 11. Voltage Magnitudes for buses 19 to 30 at line 27-29 outage

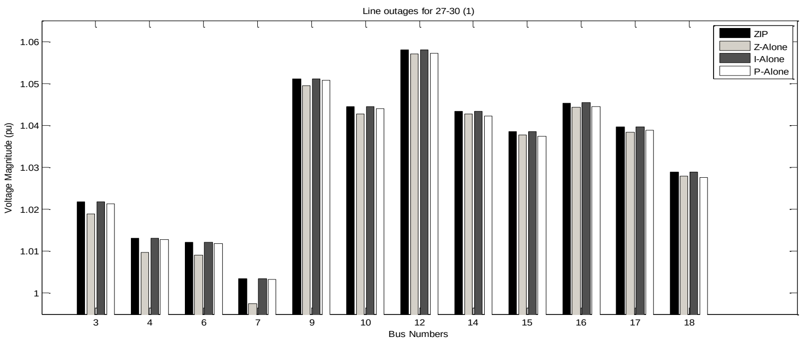

Fig. 12. Voltage Magnitudes for buses 3 to 18 at line 3-4 outage

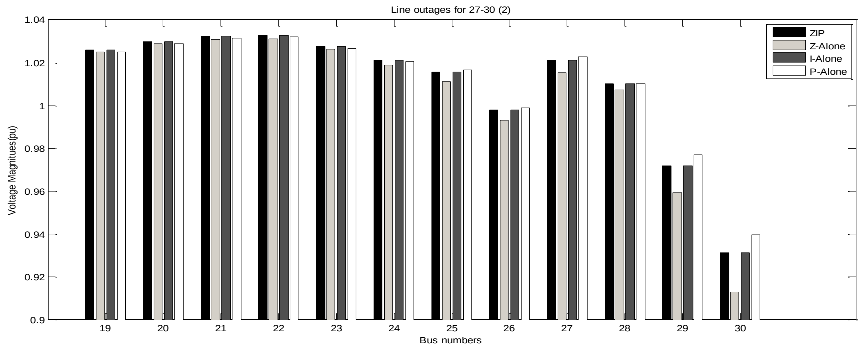

Fig. 13. Voltage Magnitudes of 27-30 line (2)

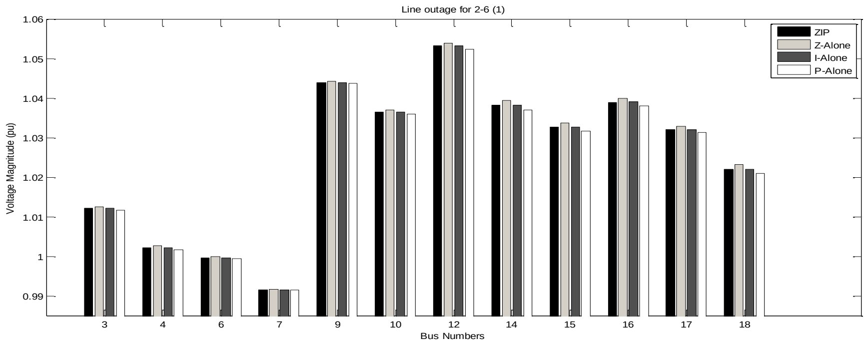

Fig. 14. Voltage Magnitudes for buses 3 to 18 at line 2-6 outage

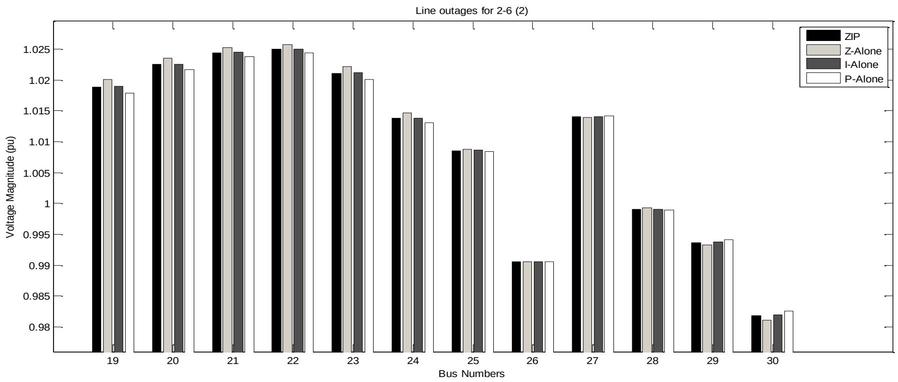

Fig. 15. Voltage Magnitudes for buses 18 to 30 at line 2-6 outage

Voltage magnitudes for buses from 3 to18 and from 19 to 30 at line outage 2-6 of ZIP, Z, I and P is shown in Fig 14 and Fig 15 respectively. Compared to various load models ZIP, constant impedance (Z) & constant current (I) affects the system more. In Fig 15, constant impedance (Z) affects the system more and constant power (P) has a very low effect on the power system in both the Figs.

7. Conclusions

An investigation for Constant Impedance (Z), Constant Current (I), Constant Power (P), & ZIP load model incorporated with N-R method under single line outage conditions is presented. The system stability based on the condition number using the individual load models like Z, I, P & ZIP is described. The most severe line is identified using various load models. The severe line is associated with the slack bus, as it has to carry the load which has been generated by a slack bus under a line which is connected to a load. The voltage magnitude for all the load buses in the individual systems using ZIP load model is compared with Z, I & P for top five outage conditions.

REFERENCES

1. Aurea S. Carneiro, Lais F. Araujo and Jose Luiz R. Pereira, "Static Load Modeling Based on Field Measurements", IEEE Transactions on Power Systems, vol. 21, no. 2, p. 688, 2008.
2. Dong-Hyun Chung, Daehak-gil, Gamgok-myeon, Eumseong-gun and Chungbuk, "A Study on the Measurement Based Approach Techniques for Static Load Modeling", International Journal of Computer and Information Technology (IJCIT), Vol.03, Issue-02, Mar. 2014.
3. Amit Patel, Kevin Wedeward, and Michael Smith, "Parameter Estimation for Inventory of Load Models in Electric Power Systems," World Congress on Engineering and Computer Science, Vol. 1, pp. 22-24, Oct. 2014.
4. Sandra Pérez-Londoño, Luis Rodríguez-García and Juan Mora-Flórez, "A comparative analysis of dynamic load models for voltage stability studies," IEEE Transactions on Power Syst., 2014.
5. Rakesh Singh Rathour, Deena L. Yadav, "Newton Raphson TCSC Model for Power System Stability Improvement", International Journal of Artificial Intelligence and Mechatronics, Volume-4, Issue-02, 2015.
6. Scott Greene, Ian Dobson, Fernando L. Alvarado, "Contingency Ranking for Voltage Collapse via Sensitivities from a single nose curve", IEEE Transactions on Power Systems, vol.14, no.1, pp.232-240, Feb 1999.
7. Zhihong Jia, B.Jeyasurya, "Contingency Ranking for On-Line Voltage Stability Assessment", IEEE Transactions on Power Systems, vol.15, no.3, pp.1093-1097, Aug 2000.

A. J. Wood and B. F. Wollenberg, "Power generation, operation and control", 2nd Edition, Jhon and Wiley & Sons Ltd, 2009.

8. Ram, S.S., Daram, S.B., Venkataramu, P.S. and Nagaraj, M.S., 2018. Analysis of Exponential and Polynomial Load models using Newton-Raphson Method with Hybrid Power Flow Controller. *International Journal of Control and Automation*, *11*(11), pp.43-56.
9. Hadi Saadat, "Power System Analysis", Third Reprint Tata Mcgraw-hill 2003.
10. Ram, S.S., Daram, S.B., Venkataramu, P.S. and Nagaraj, M.S., 2018. Analysis of ZIP Load Modeling in Power Transmission System. *International Journal of Control and Automation*, *11*(7), pp.11-24.
11. Suresh Babu Daram, P. S. Venkataramu, and M.S. Nagaraj,"Condition Number Based Contingency Ranking under Line Outage Condition Incorporating IPFC", International Conference on Renewable Energy Utilization (ICREU), 2016.