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POWER FLOW ANALYSIS WITH VOLTAGE DEPENDENT LOAD

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ABSTRACT

Conventional load flow strategies display the heap at the transports as steady dynamic and responsive forces. In fact these can be consistent present, steady impedance, steady power or any mix of these sorts of burdens. In this paper endeavor has been rolled out to improvement the heap stream scientific definition with a specific end goal to fuse the models of steady impedance and consistent current kind of load notwithstanding customary consistent power each one in turn. The changed load stream definition is tried on standard 5-transport framework and the outcomes are exhibited here.

Keywords: Constant current loads, Constant impedance loads, Constant power loads, Voltage sensitive loads.

INTRODUCTION

The load flow studies are performed for power framework arranging, operation, and control. Stack stream thinks about information are likewise utilized for possibility investigation, blackout security evaluation, and in addition for ideal dispatching and strength. The heap stream issue has gotten more consideration than the various power framework issues consolidated. [1]

Stack stream estimations give control stream and voltage to a predefined control framework subjected to the managing ability of generators, condensers and tap changing under load transformers and additionally determined net exchange between individual working framework [2].

In ordinary load flow considers, it is assumed that the dynamic and receptive power requests are indicated consistent esteem, autonomous of the voltage esteem. Despite the fact that in reality, the different sort of private, business and Industrial load request dynamic and responsive power which are elements of framework voltage and recurrence. This impacts, if considered can bring about significant changes in the consequences of load stream and ideal power stream ponders. Additionally the voltage reliance of framework load generally influences the dynamic conduct of a power framework, and the impedance of its legitimate representation in power framework steadiness considers has likewise been perceived [5].

The impacts of voltage and recurrence on dynamic and receptive power loads have been contemplated by a few scientists for quite a while [3-19]. The writing on the fuse of load models in load flow studies is constrained to just a couple studies [4-6, 10, 20-22]. It has been demonstrated that heap displaying has noteworthy impacts for a few frameworks [21].

frequency deviation is viewed as unimportant if there should arise an occurrence of static investigation like, load stream thinks about. The impacts of voltage deviations are primarily considered for getting quicker and precise outcomes. In late year, much exertion has been given to load demonstrating and the assessment of model parameters through field estimations [6].

Few reviews have been done on consolidating load demonstrating in load-stream calculations. The writing is restricted to two reviews done by El-Hawary [23] and Murty [24]. The main review proposes a summed up nonlinear model for which P = I *jVbJ yet does not examine the reasonable points of interest required in the assessment of the proposed parameters. Murty considers an exponential model with applications to a 5-bus system, which proposed the change of the power conditions to join the impact of Varing burden models. This thus changed the Jacobian Matrix of the N-R Algorithm.

In a few reviews done on load displaying by Ontario Hydro [5, 6] a few parts of load stream have additionally been considered quickly. Some other writing accessible on web depends on the comparable idea as 1 and 2 and the recreation is done utilizing programming like ETAP and others. In any case, the client characterized control stream programming don't permit clients to specifically alter the Jacobian grid and just give the offices to the cycle between the fundamental program and the client characterized show. This emphasis infrequently separates, particularly when the framework is vigorously stacked or badly molded.

The goal here is to concentrate the conduct of the heap stream arrangement when load models are fused utilizing MATLAB programming. The code created is summed up to such an extent that it can settle any number of transport frameworks at once. It additionally gives the adaptability to change the kind of the heaps at the transports and to contrast comes about and the routine load-stream comes about. Accessible load-stream information and some accessible model parameters of a specific model are utilized as a part of this review.

Power Flow Formulation With Voltage Sensitive Loads

The exponential model for representating the dependence of active power (P) and reactive power (Q), on the bus voltage magnitude at a load bus in an electric power network takes the following form,

$$P_i^* = \left(Q_i^{SP} - Q_i\right)\left(V_i\right)^b = 0 \tag{1}$$

$$Q_i^* = Q_{i(n)}\left(\frac{V_i}{V_{i(n)}}\right)^b \tag{2}$$

The coefficient $P_{i(n)}$ and $Q_{i(n)}$ represents the active and reactive powers at nominal voltage $V_{i(n)}$. An alternate form of equation (1) and (2) can be written as

$$P_i^* = P_i\left(v_i\right)^a \tag{3}$$

$$Q_i^* = Q_i\left(v_i\right)^b \tag{4}$$

Where V_i is the voltage in per unit base voltage taken as $V_{i(n)}$

In conventional load flow studies the 2n-1 equations normally solved are:

$$P_i = P_i - P_i^{sp} = 0 \quad \text{for } i = 2,\ldots\ldots,n \qquad (5)$$

$$Q_i = Q_i - Q_i^{sp} = 0 \quad \text{for } i = m+1,\ldots\ldots,n \qquad (6)$$

Where;

$$P_i = V_i \sum_{i=1}^{n} V_j Y_{ij} \operatorname{Cos}(\theta_i - \theta_j) \qquad (7)$$

$$Q_i = V_i \sum_{i=1}^{n} V_j Y_{ij} \operatorname{Sin}(\theta_i - \theta_j) \qquad (8)$$

m= number of generator buses including the swing bus n= total number of buses

The set of load equation (7) & (8) are non-linear and solved by Newton Raphson iterative method which requires finding a jacobian matrix to update the current estimates of improved solutions. Since instead of constant specified powers, model of the form as in equations (3) and (4) are used, then equation (5) & (6) change to

$$P_i = \left(P_i - P_i^{SP}\right)\left(V_i\right)^a = 0 \quad \text{for } i = 2,\ldots, n \qquad (9)$$

$$Q_i = \left(Q_i - Q_i^{SP}\right)\left(V_i\right)^b = 0 \quad \text{for } i = m+1,.., n \qquad (10)$$

Let the equations (9) & (10) be denoted as P_i^* and Q_i^*. In conventional Newton Raphson algorithm the matrix vector relationship between the changes in real and reactive powers and the bus voltages and angle are represented as,

$$P_i = \partial P_i / \partial \theta_i \,.\, \Delta\theta_i + \partial P_i / \partial V_i \,.\, V_i$$

$$Q_i = \partial Q_i / \partial \theta_i \,.\, \Delta\theta_i + \partial Q_i / \partial V_i \,.\, V_i$$

Where,

$$P_i = \left[P_2 \ldots P_n\right]^T$$

$$Q_i = \left[Q_2 \ldots Q_n\right]^T$$

$$\Delta\theta_i = \left[\Delta\theta_2 \ldots \Delta\theta_n\right]^T$$

$$V_i = \left[V_2 \ldots V_n\right]^T$$

$$\partial P_i / \partial\theta_i = \left[\partial P_2 / \partial\theta_2 \ldots \partial P_n / \partial\theta_n\right]^T$$

$$\partial P_i / \partial V_i = \left[\partial P_2 / \partial V_2 \ldots \partial P_n / \partial V_n\right]^T$$

$$\partial Q_i / \partial\theta_i = \left[\partial Q_2 / \partial V_2 \ldots \partial Q_n / \partial V_n\right]^T$$

Where bus 1 is the slack bus and the jacobian sub matrix are:

$$J_1 = \partial P_i / \partial \theta_i \quad , \quad J_2 = \partial P_i / \partial V_i$$
$$J_3 = \partial Q_i / \partial \theta_i \quad , \quad J_4 = \partial Q_i / \partial V_i$$

When voltage dependent loads are considered, the powers P_i and Q_i will change to P_i^* and Q_i^* as in equation (3) and (4). This change the jacobian elements of the jacobian with voltage dependent loads are derived from the bus power equation (3) and (4).

Differentiating (3) the diagonal elements of $J2$ are

$$\frac{\partial P_i^*}{\partial V_i} = P_{i(n)} .a.V_i^{a-1} + \frac{\partial P_{i(n)}}{\partial V_i} V_i^a$$

but

$$\frac{\partial P_{i(n)}}{\partial V_i} = 2V_i Y_{ii} \cos\theta_{ii} - \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i Y_{ik} \cos(\theta_i - \theta_k)$$

hence

$$\frac{\partial P_i^*}{\partial V_i} = a.P_{i(n)} .V_i^{a-1} + \left(2V_i Y_{ii} \cos\theta_{ii} - \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i Y_{ik} \cos(\theta_i - \theta_k)\right) V_i^a \tag{11}$$

The off- diagonal element of $J2$ will be

$$\frac{\partial P_i^*}{\partial V_j} = \frac{\partial P_{i(n)}}{\partial V_j} V_i^a$$

Similarly differentiating equation (4) the diagonal elements of $J4$ are

$$\frac{\partial Q_i^*}{\partial V_i} = Q_{i(n)} .b.V_i^{b-1} + \frac{\partial Q_{i(n)}}{\partial V_i} V_i^b$$ but

$$\frac{\partial Q_{i(n)}}{\partial V_i} = -2V_i Y_{ii} \sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i Y_{ik} \sin(\theta_i - \theta_k)$$

So,

$$\frac{\partial Q_i^*}{\partial V_i} = b.P_{i(n)} .V_i^{b-1} - 2V_i Y_{iiii} \sin\theta + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i Y_{ik} \sin(\theta_i - \theta_k) V_i^b \tag{12}$$

And the off-diagonal element of $J4$ are

$$\frac{\partial Q_i^*}{\partial V_j} = \frac{\partial Q_{i(n)}}{\partial V_j} V_i^b$$

The diagonal and off diagonal terms of J1 are

$$\frac{\partial P_i^*}{\partial \theta_i} = \frac{\partial P_{i(n)}}{\partial \theta_i} V_i^a \text{ and } \frac{\partial P_i^*}{\partial \theta_j} = \frac{\partial P_{i(n)}}{\partial \theta_j} V_i^a \text{ respectively.}$$

Similarly the diagonal and off diagonal term of J3 are

$$\frac{\partial Q_i^*}{\partial \theta_i} = \frac{\partial Q_{i(n)}}{\partial \theta_i} V_i^b \text{ and } \frac{\partial Q_i^*}{\partial \theta_j} = \frac{\partial Q_{i(n)}}{\partial \theta_j} V_i^b \text{ respectively.}$$

The estimated bus voltages and powers are used to evaluate the elements of jacobian, and then the new estimates for the bus voltage are

$$\theta_i^{k+1} = \theta_i^k + \Delta\theta_i^k$$

$$V_i^{k+1} = V_i^k + V_i^k$$

The process is repeated until P_i^* and Q_i^* for all buses are within a specified tolerance. The line flows can be calculated with the final bus voltages, the given values of line charging and line admittances.

TEST CASE AND SIMULATION

Standard 14 bus test network is used to analyze the different types of load models at the buses. The codes are developed in MATLAB. The value of exponential parameters a and b for the active and reactive powers, that represents the constant current, constant power loads , constant impedance loads are give in table 1.

Table 1 Load type and exponent values

S.NO	Type of Load	Range of Exponent	
		Active power (a)	Reactive Power (b)
1	Constant Power Loads	0	0
2	Constant Current Loads	1	1
3	Constant Impedance Loads	2	2

Newton Raphson Power flow algorithm:
It consists of following steps.

1. Form the bus admittance matrix.
2. Assume bus voltages.
3. Set Iteration count C=0
   Calculate Bus Powers and Power mismatch P, Q f g

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If the mismatch is less than the given tolerance, output the result else go to 5.

4. Calculate the Bus Currents and the elements of Jacobian matrix and find the Voltage corrections Vector
5. Update the Voltage, increment the counter.
6. Go to step 4.

Test Data of 14-bus system is given in table 2, 3.

Table 2 Bus Data

Bus No	**BUS VOLTAGE**		**GENERATOR**		**LOAD**	
	Voltage magnitude(pu)	Phase angle (deg)	(MW, MVAR)	Qmin, Qmax	P(MW)	Q(MVAR)
1	1.06	0	0.4,0	-0.4,0.5	0.21	0.0
2	1.045	0	0,0	0,0.4	0.94	0.127
3	1.010	0	0,0	-0.06,0.24	0.47	0.19
4	1	0	0,0	-0.06,0.24	0.076	0.039
5	1	0	0,0	0,0	0.11	0.075
6	1	0	0,0	0,0	0.0	0.0
7	1	0	0,0	0,0	0.0	0.0
8	1	0	0,0	0,0	0.295	0.166
9	1	0	0,0	0,0	0.09	0.058
10	1	0	0,0	0,0	0.035	0.018
11	1	0	0,0	0,0	0.061	0.016
12	1	0	0,0	0,0	0.135	0.058
13	1	0	0,0	0,0	0.149	0.05
14	1	0	0,0	0,0	0.0	0.0

Table 3 Line data

Transmission Line	**Sending Bus**	**Receiving Bus**	**Line resistance (pu)**	**Line reactance (pu)**	**Line suseptance (pu)**
1	1	2	0.01938	0.05917	0.0528
2	2	3	0.08	0.24	0.0438
3	2	4	0.06	0.18	0.0492
4	1	5	0.06	0.18	0.034
5	2	5	0.04	0.12	0.0346
6	3	4	0.01	0.03	0.0128
7	4	5	0.08	0.24	0.0
8	5	6	0.02	0.06	0.0
9	4	7	0.08	0.24	0.0
10	7	8	0.06	0.18	0.0
11	4	9	0.06	0.18	0.0
12	7	9	0.04	0.12	0.0
13	9	10	0.01	0.03	0.0
14	6	11	0.08	0.24	0.0
15	6	12	0.02	0.06	0.0

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16	6	13	0.08	0.24	0.0
17	9	14	0.06	0.18	0.0
18	10	11	0.06	0.18	0.0
19	12	13	0.04	0.12	0.0
20	13	14	0.01	0.03	0.0

RESULTS OF LOAD FLOW CALCULATION WITH VOLTAGE SENSITIVE LOADS

The test network is tested first with Conventional load flow. Then it is analyzed with voltage sensitive loads at each of the bus.

For constant power load the convergence is achieved in 6 iteration while for constant current types of loads the convergence is in 9 iteration and for constant impedance type of loads it is 10 iteration with standard 14-bus system. The simulation yield the Bus Active and Reactive power flow with constant power, constant current and constant impedance loads as shown in Fig.1-2 respectively.

Voltages at the buses with different types of loads are given in table 4, 5, 6.

Line active and reactive power flow with constant power, constant current and constant impedance loads as shown in Fig. 3-4 respectively.

The simultaneous yield Active and Reactive power losses in the transmission line with constant power, constant current and constant impedance loads as shown in Fig. 5-6 respectively.

Active power at bus is minimum for constant impedance type of load and maximum for constant power type of load. But at bus 4 active power for constant power type of load is less as compared to the constant impedance type of load.

Also Reactive power at bus is minimum for constant power type of load and maximum for constant impedance type of load.

Active and reactive power at line is maximum for constant power type of load and minimum for constant impedance type of load.

Active and reactive power losses at line are maximum for constant power type of load and minimum for constant impedance type of load.

Table 4 Voltage at the buses with constant power Loads

Bus No	Bus Voltage	
	|V|	θ
1	1.06	0
2	1.045	-4.9403
3	1.01	-12.9616
4	1.0150	-11.8381
5	1.0427	-7.6192
6	1.07	-8.9013
7	1.0525	-11.4871
8	1.09	-12.1690
9	1.0464	-10.8432
10	1.0479	-10.7110
11	1.0572	-9.9262
12	1.0674	-9.1099
13	1.0621	-9.5302
14	1.0598	-9.7154

Table 5 Voltage at the buses with constant current Loads

Bus No	Bus Voltage	
	|V|	θ
1	1.06	0
2	1.045	-4.8521
3	1.01	-12.744
4	1.0154	-11.636
5	1.0455	-7.4861
6	1.07	-8.7104
7	1.0527	-11.285
8	1.09	-11.964
9	1.0466	-10.645
10	1.0481	-10.513
11	1.0574	-9.7313
12	1.0674	-8.9182
13	1.0622	-9.3368
14	1.0599	-9.5213

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Table 6 Voltage at the buses with constant impedance Loads

Bus No	Bus Voltage	
	|V|	θ
1	1.06	0
2	10.45	-4.7682
3	1.01	-12.537
4	1.0156	-11.442
5	1.046	-7.3257
6	1.07	-8.5349
7	1.0528	-11.095
8	1.09	-11.772
9	1.0467	-10.458
10	1.0482	-10.327
11	1.0574	-9.5498
12	1.0674	-8.7415
13	1.0622	-9.1577
14	1.06	-9.3411

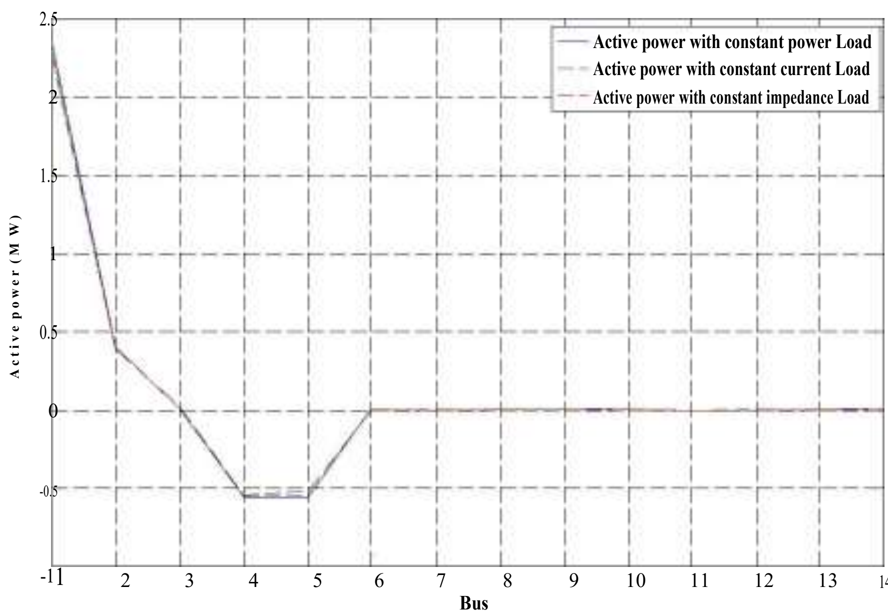

Figure.1. Active Power at Buses

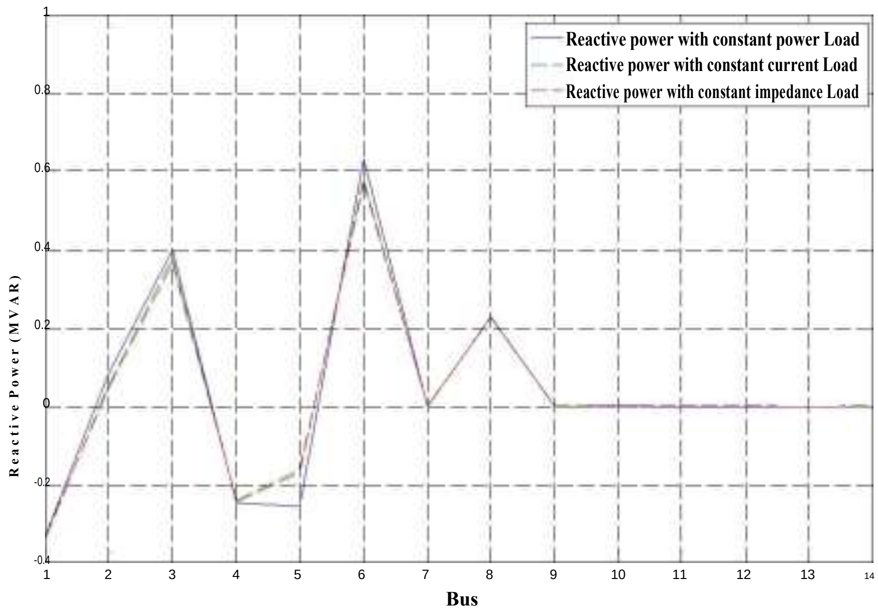

Figure 2. Reactive power at Buses

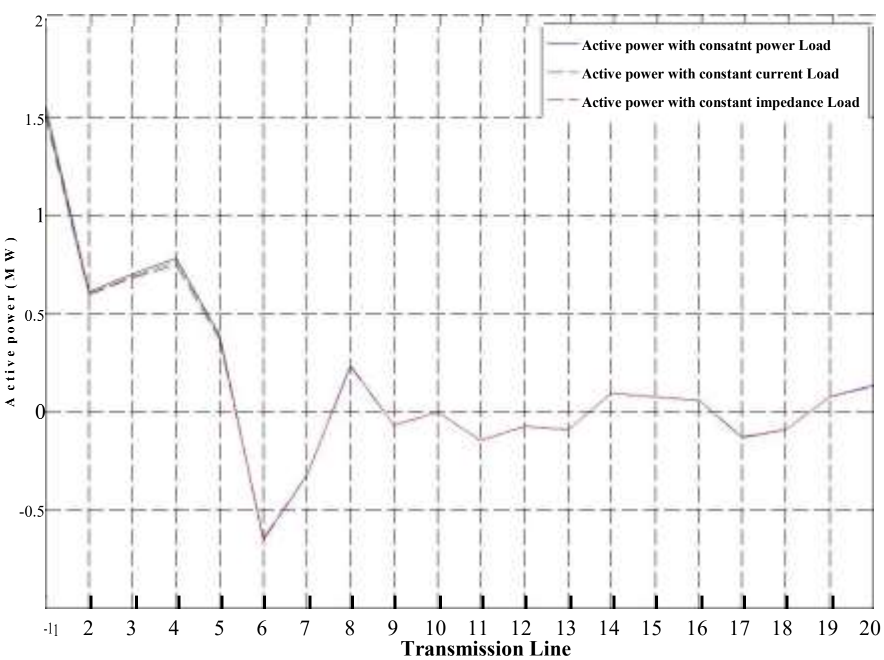

Figure 3. Active power at Line

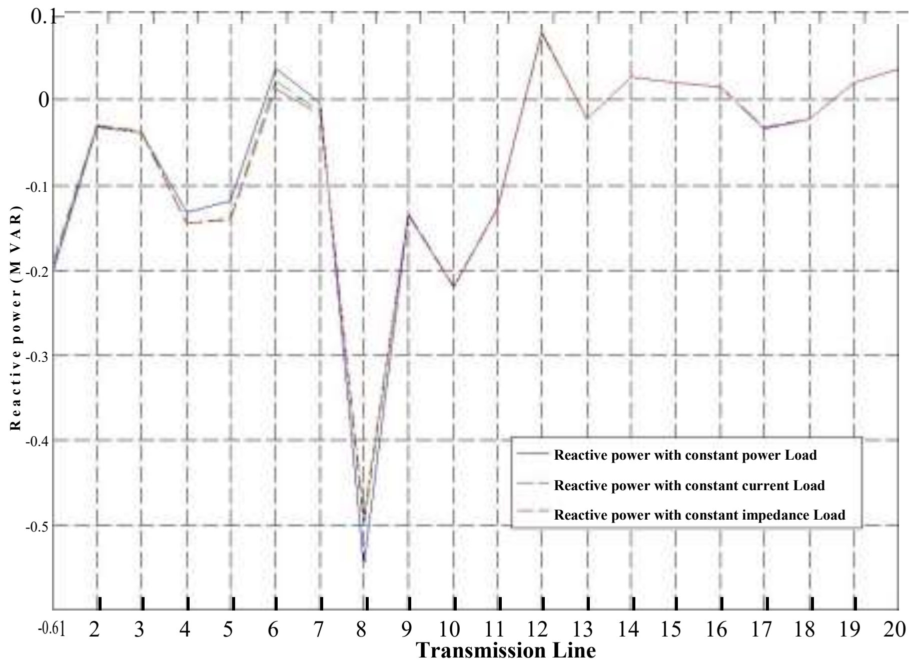

Figure 4. Reactive power at Line

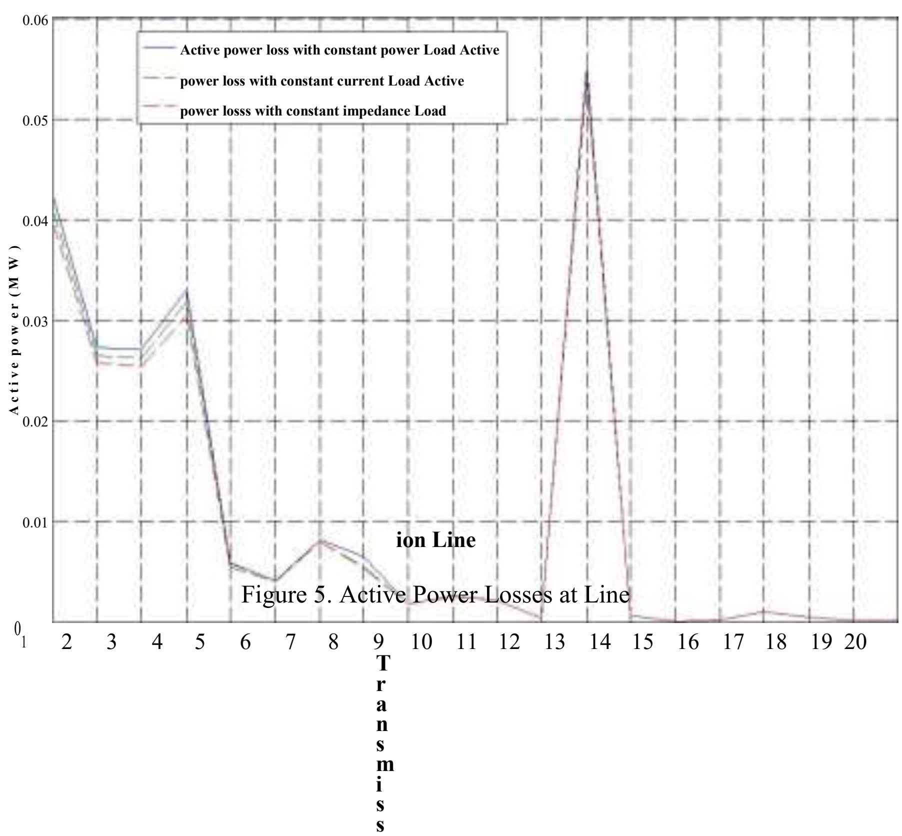

Figure 5. Active Power Losses at Line

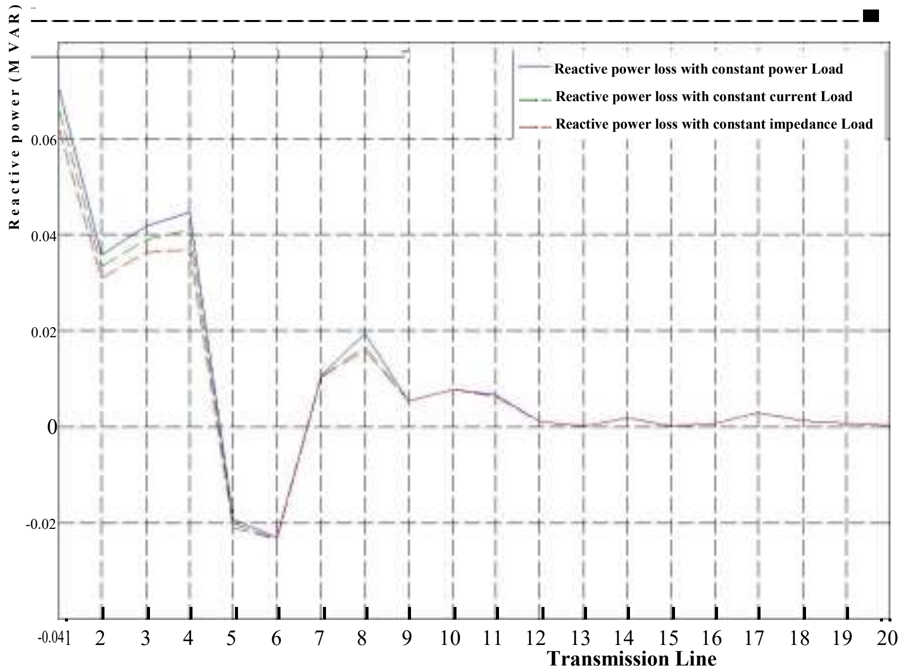

Figure 6. Reactive Power Losses at Line

CONCLUSIONS

In this paper, load flow analysis has been performed for voltage sensitive loads for a standard 14-bus system. The Numerical result for the standard 14 bus network has been presented. As compared with the constant current load, constant impedance loads require additional iteration to obtain the solution. So the load flow analysis with the voltage sensitive loads is more accurate than those for the constant power load.

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