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A Power Transfer Distribution Factor Model For Sensitivity Analysis Of Time Flows On Power System Bus Injections

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Abstract
Power transfer distribution factor, (PTDF) is a useful factor for sensitivity analysis of line flows. It shows the linear and impact of a transfer of power.
This research paper presents a PTDF model to evaluate the sensitivity of line flows using a 12-bus system as a case study. It is a polynomial model of order 6 whose order increases as more buses are injected into the system.
A source and a sink were specified for each transaction for the flows of active powers from source to sink in a direction. PTDF provides a linear and approximation of how the flow on the transmission lines and interface changes in response to the transaction between the seller and buyer. The PTDFs are operating point dependent.
Appropriate correction actions were taken to bring back the MW on the lines to within its operational limit to ensure that the MVA limit of the lines and all line flows are within operational limits.

When the generation at bus 10 was reduced to 130MW and shedding the load at busses 2 and 5 to 65MW, bus 7 to 60MW and at bus 8 to 10MW, at bus 3 and 8 to 40MW, the MW on the lines came back to within its operational limit. The MVA limit of the lines and all the line flows were within the operational limit.

The polynomial model developed will help the busy power system operators or engineers in formulating appropriate policies.

Keywords: LODFs, PTDF, Voltage Stability, Contingency, Source, Sink, Change in transactions, Disturbance.

I. INTRODUCTION

The security of a power system is its ability to withstand a set of severe but credible contingencies and to survive transition to an acceptable new steady state condition .This is assessed by detection of operating limit violation and contingency analysis [10].

Voltage stability is the ability of a power system to maintain steady and acceptable voltage at all busses in the system at normal operating conditions, after being subjected to a disturbance. It is desired that the power system remain in the equilibrium state under normal conditions and react to restore the status of the system to acceptable conditions after a disturbance i.e. the voltage after a disturbance is restored to a value close to the pre-disturbance situation. A power system network is said to enter a state of voltage instability when a disturbance causes a gradual and uncontrollable decline in voltage. The causes of voltage instability are contingencies, increasing load, external factors or improper operation of voltage control devices and load variations [14], [15].

a. *Contingency Analysis*

A contingency is a failure of any one piece of equipment (line or transformer), which can be caused by either external or internal disturbances. Power system is expected to withstand the failure of any one piece of equipment and still function normally. Contingency analysis in a power system area refers to the study of different situations where one or more of the system components including a transmission line, generator, transformer etc are out of service either intentionally or due to fault [2], [12].

Contingencies may result in severe violation of the operating constraints. The analysis allows the system to be operated defensively. Many of the problems which occur on the power system can cause serious troubles within a short line if the operator could not take fast corrective action [5], [7].

Contingency analysis which puts the whole system or a part of the system under stress occurs due to sudden opening of a transmission line, generator tripping, sudden change in generation or sudden change in load value [4], [6].

b. *Line Outage Distribution Factor*

The line outage distribution factor (LODF) is a linear resistivity factor for establishing the effect of the critical contingencies and hence suggest possible preventive and corrective actions to solve the system violations [1], [8].

Importance of** Line **Outage Distribution Factor

i. LODF are used to determine the change in the MW flow compared to the pre-contingency flow.
ii. They are independent of flows but depend on the assumed network topology.
iii. They are used to approximate the change in the flow on one line caused by the outage of a second line [3], [13].

c. *Power Transfer Distribution Factor*

A power transfer distribution factor (PTDF) is used for sensitivity assessment of line flows on power system bus injections.

PTDF is defined as [9], [11]:

$$\text{PTDF} = \frac{\Delta P_{ij}}{\Delta T_{mn}}$$

Where:

ΔP_{ij}= Change in real power flow of line i-j for transition between m-n.

ΔT_{mn}= Change in transactions between 'm' and 'n'.

II. MATERIALS AND METHOD

Development of a PTDF model

- Identification of the source and sink for the transactions.
- Determination of ΔP_{ij}.
- Determination of ΔT_{mn}
- Plot ΔP_{ij} versus ΔT_{mn} to obtain a graph.
- Obtain the model equation using curve fitting tools.

III. Results and Discussions

The results of the analysis are shown in Figures 1(a), (b) and (c). Observation shows that there were 3 violations along line 1 to 2 with a percentage MVA limit of 250.6. Four (4) violations were recorded along lines 1 to 5 with a percentage MVA limit of 275.4 which represent an additional percentage MVA limit of 24.8. There was only one (1) violation recorded along line 5 to 4 with a percentage MVA limit of 138.4. This line had the least violation during the study period. In addition, line 12 to 3 recorded the largest violation of 11 with a percentage MVA limit of 118.7. The number of violation varies throughout the lines for the 12 bus system.

Figures 2(a) and (b) shows the line outage distribution factor (LODF) of the 12 bus system used as case study in this paper. Line 1 to 2 recorded a percentage LODF of -180 from -156.8MW to 140.5MW. Line 5 to 4 had no percentage LODF, hence no MW range. Line 11 to 4 had the largest percentage LODF of 260 with a MW range from 102.6MW to 152.5MW.

Figure 3 shows the relationship between the PTDF and the line number after violation for the 12- bus system.

Lines 3 to 6, 8 to 2 and 11 to 4 recorded the least percentage PTDF while the remaining 10 lines recorded the highest percentage PTDF.

The percentage PTDFs decreased appreciably from 100 to −100 for line 1 to 2, line 1 to 5, line 2 to 4, and line 3 to 5. A sudden sharp increase from −100MW to 100MW is noticed on line 3 to 6.

Along line 5 to 4, 6 to 4, and 7 to 3, the %PTDF dropped appreciably from 100 to −100 in each case while on line 8 to 2 the % PTDF then increased from −100 to 100.

On lines 9 to 2, and 10 to 5, the percentage PTDF also decreased sharply from 100 to −100 in each case until another of percentage PTDF increased of −100 to 100 is observed on line 11 to 4. Finally on line 12 to 3, the percentage PTDF also decreased appreciably from 100 to – 100 thus indicating a pronounced level of fluctuations in the percentage PTDF after the bus violation..

Some of the lines carried the power exceeding the limit. However, there is the need to take appropriate actions to solve these MVA violations.

When the generation at bus 4 is reduced to 150MW and shedding the load at buses 2 and 4 to75Mw, bus -5 to 70MW and at bus 6 to 15MW), at bus 1 and 3 to 150MW, the MW on the lines will come back to within its operational limit.

Figures 4(a) and (b) shows that after the bus violations, the percentage LODF has increased from −180 to 180 on line 1 to 2 while the MW rating also increased from −86.5MW to 78.4MW.

On line 1 to 5, the percentage LODF remained the same at 180 before and after the bus violation even though, the MW increased from 73.6MW to 82.5 MW. Percentage LODF remained constant at −180,−180, 100, 0, 180, 140,−140,130, and −130, for line 2 to 4, 3 to 5, 3 to 6, 5 to 4, 6 to 4, 7 to 3, 8 to 2, 9 to 2 and 10 to 5 respectively. For these lines, the MW changed from 50.7MW to −72.4MW (a decrease), 48.5MW to −69.3MW (a decrease), 65.9MW to −82.4MW (a decrease), −100.5MW to 93.6MW (an increase), 60.5MW to 78.9MW (an increase), −76.3MW to 88.5MW (an increase), 93.5MW to 92.4MW (a slight decrease) and 89.5MW to −87.5MW (a decrease). Between lines 11 to 4, the percentage LODF has decreased from 260 to 160 even though the MW has increased from 78.5MW to 96.2MW after the bus violation. On line 12 to 3, the percentage LODF remained constant at 150 before and after the bus violation even though, the MW increased appreciably from −93.7MW to 103.4MW.

Table 1 shows that the MVA limit of the lines and all the line flows are within operational limit. The relationship between the change in real power and change in transaction is illustrated in Figure 5. From this graph, the model equation developed is

$$y = -0.009x^6 + 0.453x^5 - 8.360x^4 + 73.40x^3 - 303.0x^2 + 495.2x + 0.208$$
$$R^2 = 0.773$$

where

y: represents the Power transfer distribution factor and

x: represents the number of buses.

R^2 : represents the coefficient of determination and shows the extent to which the number of buses affect the power transfer distribution factor as well as its accuracy.

The model developed is a polynomial model of order 6. The order of the polynomial increases as more buses are injected into the system. Thus, for example, for a 24-bus system, the order of the polynomial will tend to increase from 6 to a higher order.

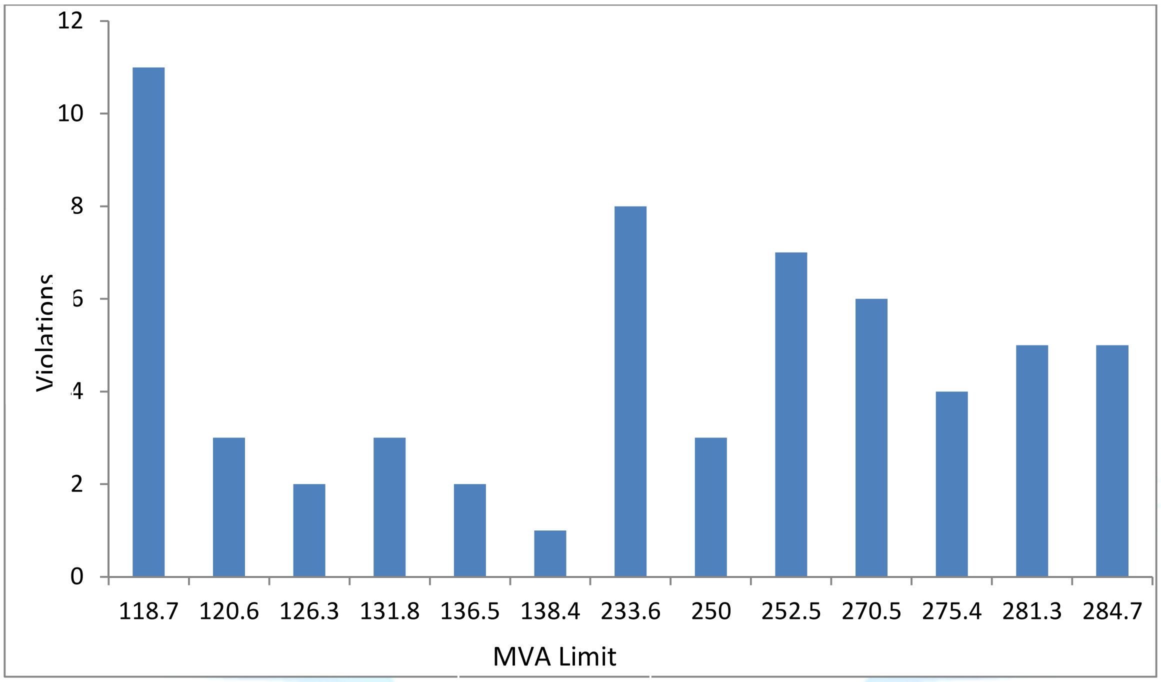

Figure 1(a): Violations versus MVA Limit

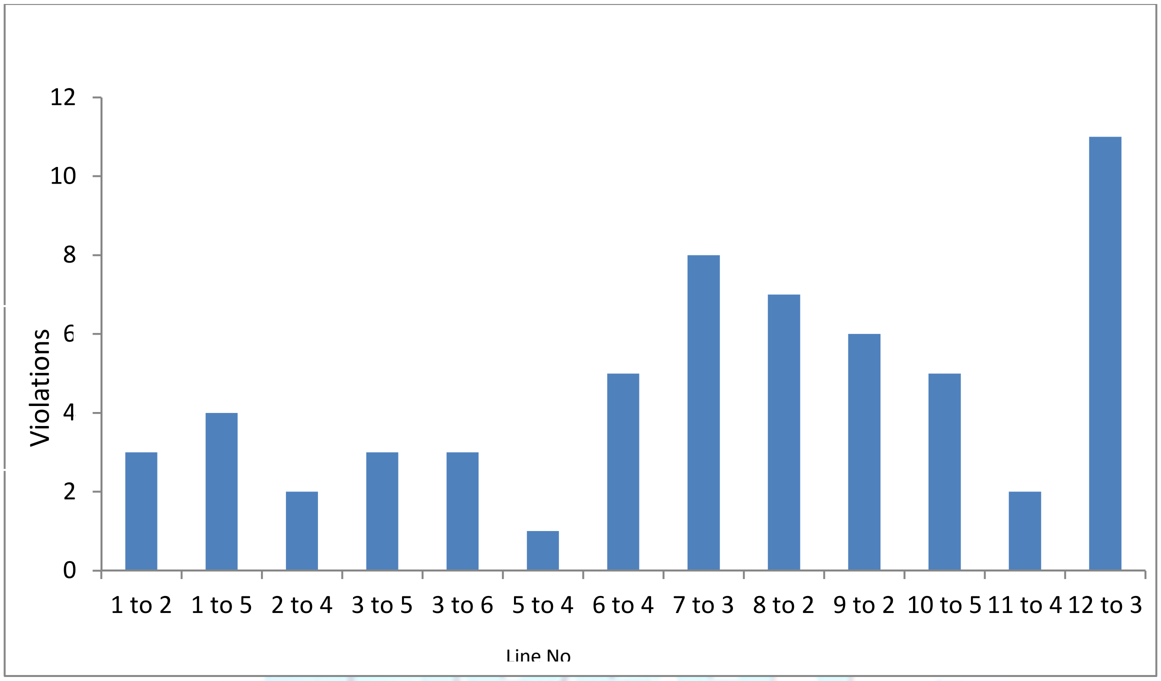

Figure 1(b): Violation versus Line No.

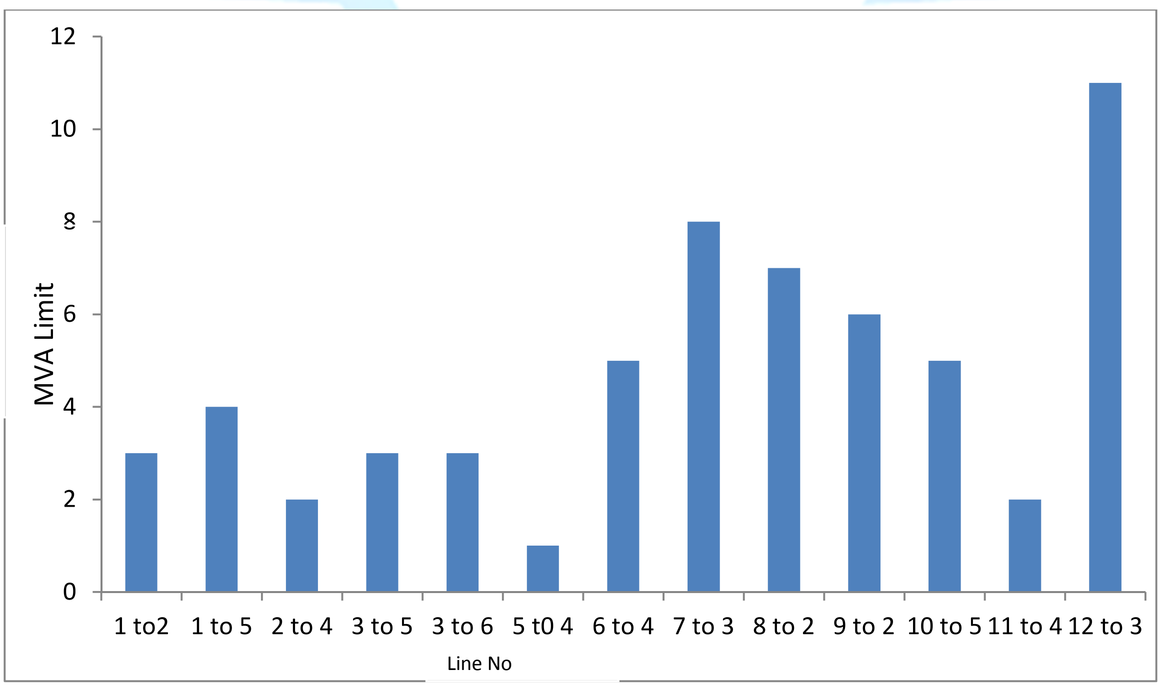

Figure 1 (c): MVA Limit versus Line No.

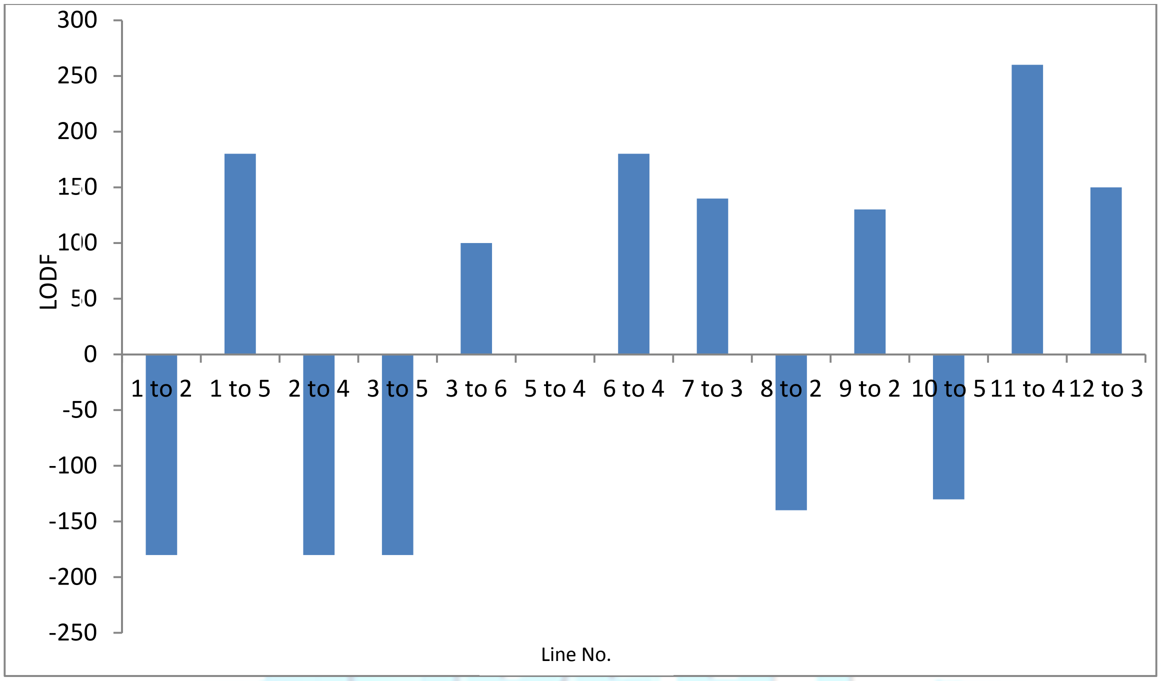

Figure 2 (a): LODF versus Line NO.

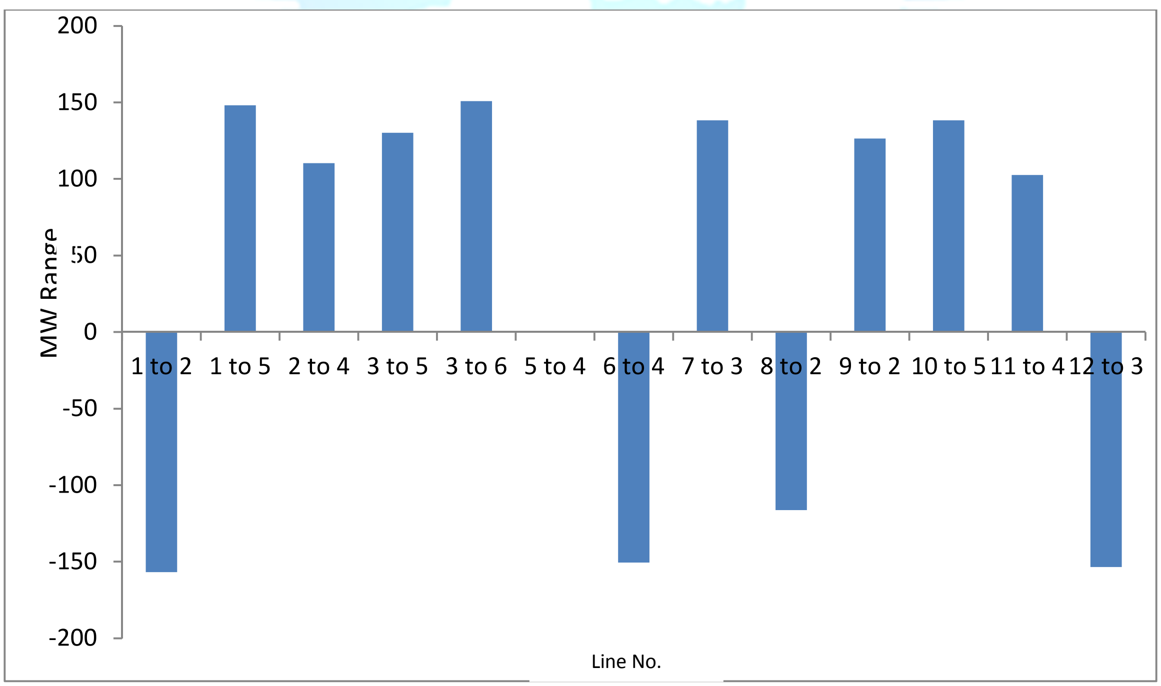

Figure 2 (b): MW range versus Line No.

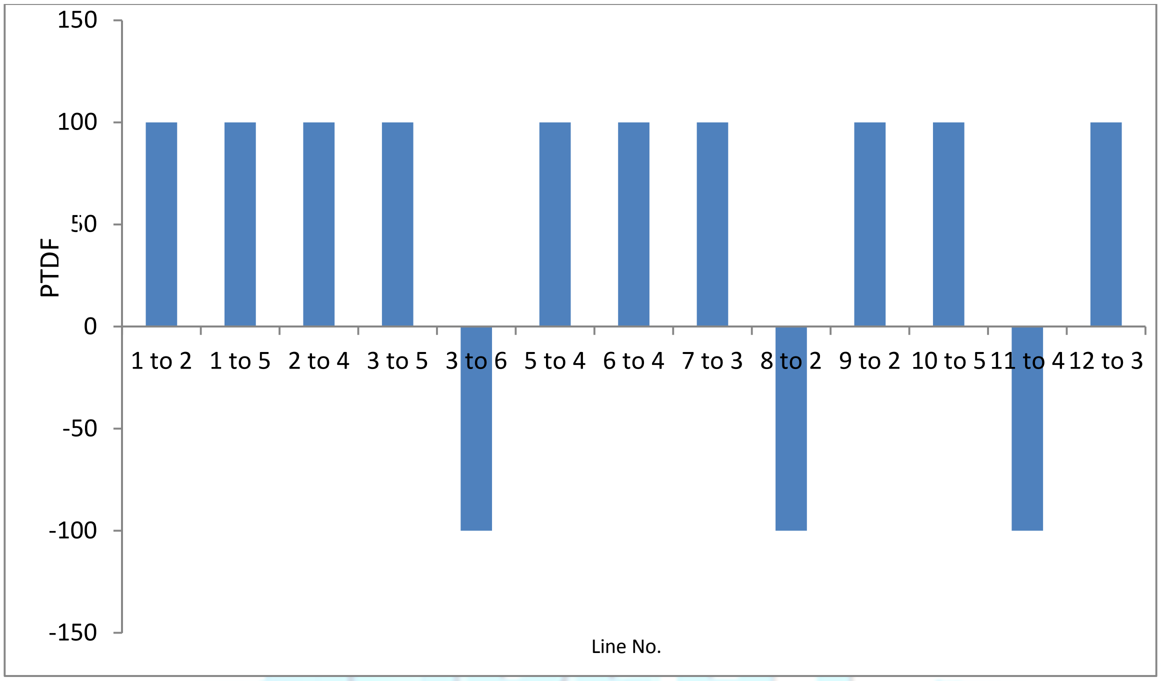

Figure 3: PTDF versus Line No. after bus violations.

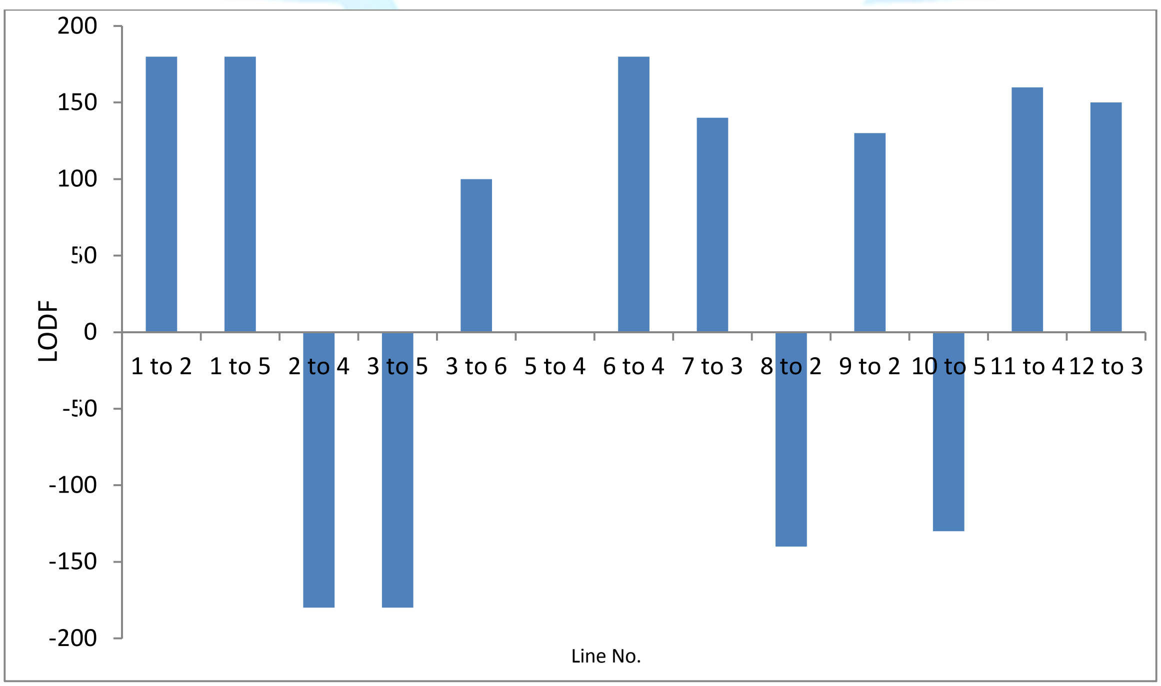

Figure 4(a): LODF versus Line No. after bus violations.

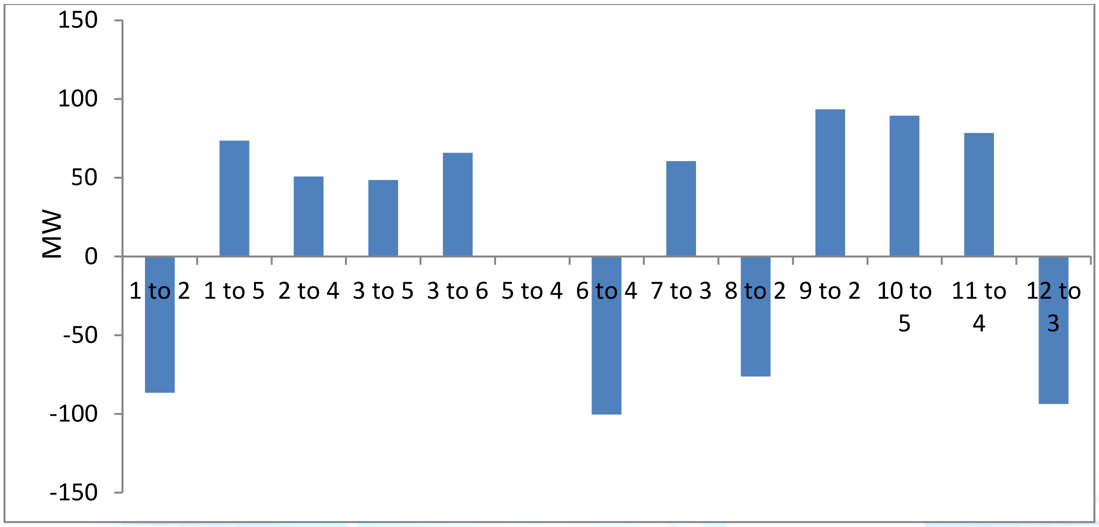

Figure 4(b): MW versus Line No. after bus violations.

Line No.

Figure 5: Change in Real power P_{ij} versus TransactionsT_m

IV. CONCLUSION

A Power Transfer Distribution Factor (PTDF) model for sensitivity analysis of line flows on power system bus injection has been presented. It is a polynomial model of order 6 whose order increases as more buses are injected into the system.

The coefficient of determination in the polynomial model determines the extent to which the numbers of buses injected into the system determine the power transfer distribution factor as well as its accuracy.

The corrective action embarked upon brought back the MW on the lines to within the operational limit so that the MVA limit of the lines and all line flows are within their operational limits.

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