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Analysis of Northern Region Electricity Board (NREB) Grid Disturbance

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The Northern Regional Electricity Board (NREB) consists of generating and transmission power utilities of the states UP, Rajasthan, J&K, Punjab, Himachal Pradesh, Haryana, and the central utilities viz Powergrid, NTPC, NPC, BBMB, DVB etc. NREB is the largest regional electricity board. The NREB grid experienced several major grid disturbances in the recent past resulting in cascade tripping of 400 kV lines and generating units. This resulted in separation of grid into several isolated parts with disruption of power supply. On certain occasions several EHV lines tripped leading to total blackout. This paper deals with the analysis of the grid disturbance that occurred on 26th Nov'96. In this paper main emphasis is given to superimpose dynamic variation of characteristic impedance on relay characteristics. The effectiveness of Power System Stabilizer (PSS) to avoid/minimize such grid disturbances is attempted.

1.0 INTRODUCTION

Grid disturbance is caused by a sudden change in the operating conditions of a power system, due to either change in load-generation balance or change in transmission system configuration. Some of these large disturbances lead to complete power failure usually termed as grid collapse. This results in the tremendous loss of revenue to the utilities, loss of production to the industry and inconvenience to consumers apart from damage to the equipment. Frequent occurrence of such disturbances therefore has serious impact on the national economy. Since, the effect of such disturbances is more severe to the weakly interconnected systems like the one we have in India, it is important that immediate attention be paid to this problem and sincere effort be made to minimize its cause. The general causes for the grid disturbances are: Low frequency operation, Inadequate reactive compensation, Protection malfunctioning, Grid indiscipline, Tripping due to lack of protection co-ordination and Human error Regional power grids experience grid disturbances due to any of the reasons.

2.0 SYSTEM DETAILS

To carryout power system operational problems, realistic data just before the grid collapse must be considered, and the collection of such data is time consuming. In the present study, most of the relevant operational data is collected from the field for the purpose of analysis. The NREB system is modeled upto 132 kV level for simulation studies, comprises of 475 Nodes, 641 Lines, 190 Transformers, 255 Shunt impedance's, 255 Loads and 54 generators represented along with excitation systems. To handle bulk power transmission, $+/-500$ kV, HVDC bi-pole link between Rihand-Dadri with a capacity of 1500 MW is in service to evacuate power from eastern to western and northern side of the grid. Besides to improve stability of the system $2 * 140$ MVAr SVC is in service at Kanpur.

2.1 General Performance of the System

Before attempting to analyse the grid disturbance network, it is preferable to study the general performance of the system. For this purpose it is essential

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to study the system stability under steady state and dynamic conditions. Some of the important 400 kV line outages chosen for this purpose are (i) Singrauli-Lucknow (ii) Singrauli-Kanpur (iii) Dadri-Panipat (iv) Obra-Anpara (v) Panki-Muradnagar (vi) Moradabad-Lucknow (vii) Panki-Obra and (viii) Anpara-Varanasi. It is observed that for a Single Line to Ground fault at Singrauli and Lucknow, the system becomes unstable due to Anpara machine losing synchronism. It is observed that there is a wide fluctuation of active power in Dadri-Ballabgarh, Kanpur-Balllabgarh, Kanpur-Agra and Dadri-Panipat lines. The general observation based on these studies is that, the overall system damping is poor and needs to be improved.

3.0 ANALYSIS OF THE GRID DISTURBANCE OCCURRED ON 26TH NOV'96

NREB system experienced several grid disturbances leading to system collapse, due to various reasons. In this paper an attempt is made to analyse the grid disturbance that occurred on 26th Nov'96. Just before the grid failure it is observed that some of the 400 kV bus voltages were low, and noted that triggering event is due to voltage collapse.

3.1 Generators and Lines Tripped during the Grid Disturbance

It is reported that, the voltage collapse in the western part of the grid, resulted in tripping of transmission lines connecting eastern and western parts. Also, some generating units at Singrauli, Anpara and Unchahar also tripped due to high voltage/high frequency. Following are the lines connecting between eastern and western parts of UPPCL tripped as indicated below:

1. Lucknow – Muradabad line tripped in Zone 3, at Lucknow end
2. Panki – Muradnagar line tripped in Zone 2 at Panki end
3. Kanpur – Ballabhgarh line tripped in Zone 1 at Kanpur end
4. Kanpur – Agra line tripped on Power Swing.

3.2 Simulation of Pre-disturbance Condition

The incident took place due to inadequate reactive compensation and inadequate load management to take care of MW/MVAr deficits. This is a case of voltage collapse. Basic steady state pre-disturbance condition is obtained by performing repeated load-flow studies by adjusting the generation bus voltages, reactive power compensation etc. This was necessary, to match the power-flows and bus voltages on important lines and buses with pre-disturbance values. This analysis has become unavoidable due to scarce in operational data for such a system of large magnitude. Table 1 shows comparative results of Bus voltages and line flows between actual values and simulated values. The simulated values are very close to actual values. The comparative bus voltage magnitudes and power flows at certain buses and lines are given in Table 1. From Table 1(a) it can be noted that voltage profile is not in acceptable limits.

TABLE 1(a)
BUS VOLTAGES

Sl. No.	Bus Name	Bus Voltage (kv) before the incident	Bus Voltage (kv) obtained through simulation
1	Singrauli	404	404.8
2	Kanpur	350	352.9
3	Moradnagar	340	340.4
4	Dadri	353	344.7
5	Agra	352	349.42
6	Ballabhgarh	350	341.2
7	Jaipur	337	341.4
8	Panipat	356	348.9

TABLE 1(b)
POWER FLOWS

No.	Line	Power Flow before the incident	Power Flow obtained through simulation
1	Kanpur-Agra	537 MW	560 MW
2	Singrauli-Kanpur	435 MW	443 MW
3	Kanpur-Ballabhgarh	497 MW	454 MW

3.3 Studies on Dynamic Stability

Dynamic stability studies have been conducted by disconnecting the transmission lines between western and eastern UP system one at a time. It is found that system becomes unstable due to disconnection of Lucknow - Moradabad line. The system takes longer time to stabilize, while other lines are disconnected. Thus, the tripping of Lucknow - Moradabad line has been identified as more critical line in maintaining the system stability and considered as initiator of the disturbance in the present study. The system becomes unstable at 5.31 sec, due to the disconnection of Lucknow-Moradabad line. For this period, entry time of dynamic variation of characteristic impedance into different zones in R-X plane is plotted for all these critical lines and noted the time of entry of locus into various zones. Thus, the sequence of line tripping has been obtained. This sequence of events is given in Appendix.

3.4 Simulation of Events

The sequence of events as given in Appendix I, is simulated. Due to the disconnection of major 400 kV lines, connecting the Eastern-Western UP system, which are carrying huge amount of power, the system lost its stability at 5.35 sec. At this point of time, the minimum bus voltage reached at important buses is given in Table 2. From this table it observed that bus voltage reaches to very low, unacceptable values. From the plot of variation of bus voltage it is observed that, there is sudden decline in bus voltage to a very low unacceptable value; subsequently it tries to improve. But by this time the dynamic simulation comes to a halt due to system instability. The variations of dynamic impedance in R-X plane have been plotted and observations are given in Table 3 (without PSS). This is a case of voltage stability. The bus voltage at important 400 kV buses has reached to a very low unacceptable value. This has resulted in operation of under voltage relays leading to disconnection of several generating units and 400 kV lines as shown in Appendix. Naturally the whole system islanded into several mini-systems. The eastern part of the grid is separated with excess generation with less load resulting in over frequency in the system and ultimately collapsed. The western part of the grid had less generation with excessive load resulting in under frequency and ultimately collapsed.

During the dynamic simulation it is observed that the Anpara, Rihand and Singrauli machines went

TABLE 2

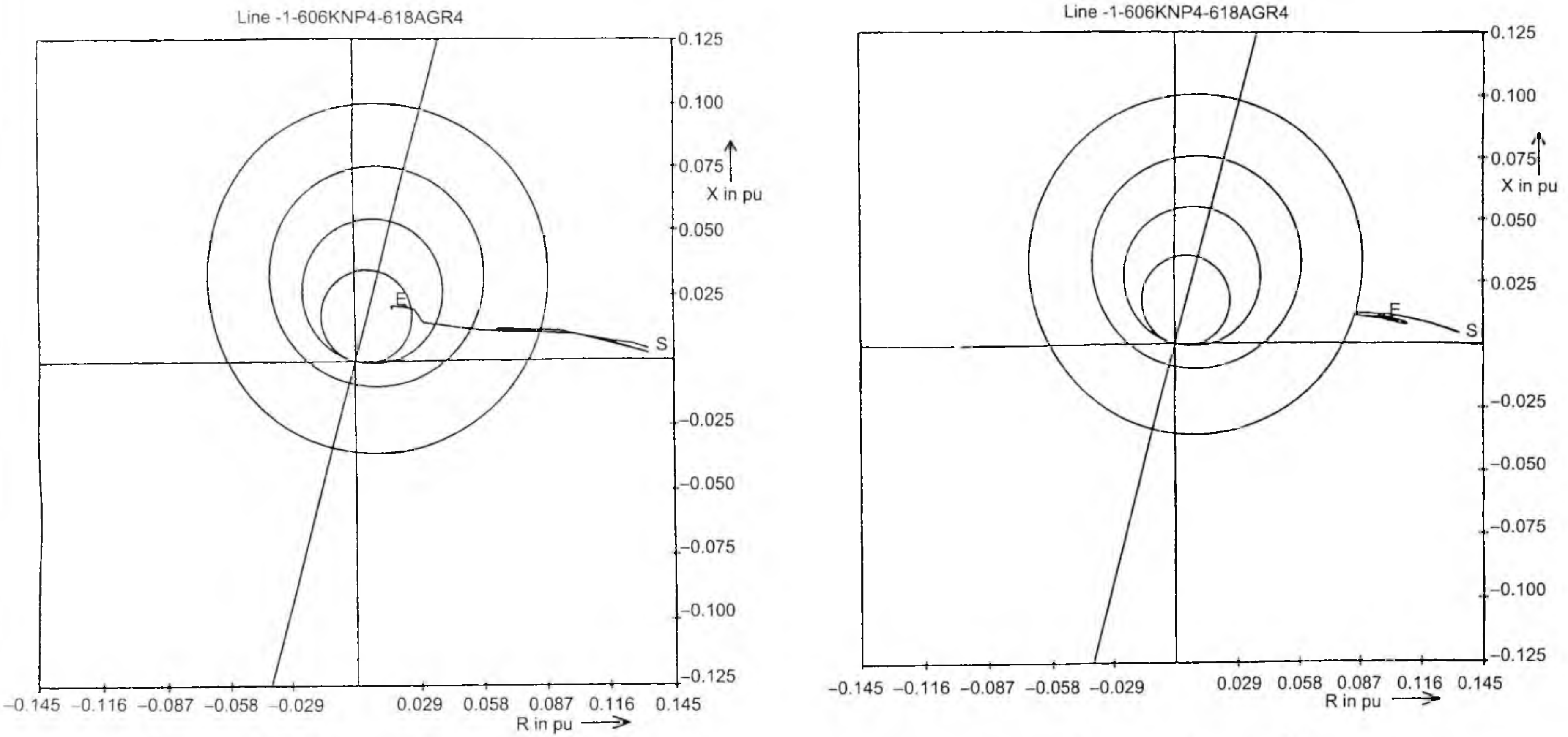
OBSERVATIONS ON BUS VOLTAGES

Sl. No.	Bus Name	Minimum Bus Voltage (pu) (at the end of simulation)
1	Kanpur	0.42
2	Ballabhghar	0.62
3	Lucknow	0.65
4	Agra	0.42
5	Moradabad	0.55
6	Moradnagar	0.55
7	Panki	0.41
8	Dadri	0.68

TABLE 3

OBSERVATIONS ON R-X DIAGRAM

Sl. No.	Line	Observations	
		Without PSS	With PSS
1	KNPR - AGRA	(a) AT KANPUR END: The locus of characteristic impedance enters into PS1 Zone at 4.236 secs and then into Zone 3 at 4.744 secs. This means that the locus stayed in PS1 Zone for about 0.508 secs. It further moves into Zone I. (Fig. 1a)	(a) AT KANPUR END: The locus of the characteristic impedance enters into PS Zone and stays there for 0.227 sec. (Fig. 2a)
		(b) AT AGRA END: The locus of char. Impedance enters into PS1 Zone at 4.526 secs and then into Zone 3 at 5.046 secs. This means that it stayed in PS1 Zone for 0.52 secs. It further enters into Zone I. (Fig. 1b)	(b) AT AGRA END: The locus of the char. Impedance does not enter the relay characteristic. (Fig. 2b) Thus this line would not have tripped due to power swing.
2	PANKI-MURADNAGAR	(a) AT MURADNAGAR: In this line the locus of char. Impedance enters into Zone 2 and never returns before the simulation comes to halt. (Fig. 1c)	(a) AT MURADNAGAR: In this line the locus of the char. Impedance enters into PS2 Zone and stays for 0.241 sec. (Fig. 2c)
		(b) AT PANKI END: The locus of char. Impedance enters into Zone 1 and never comes out. (Fig. 1d)	(b) AT PANKI END: The locus of the char. Impedance does not enter the relay characteristic. (Fig. 2d) Thus this line would not have tripped due to power swing.
3	KNPR - BLB	(a) AT KANPUR END: It can be seen that locus of the char. Impedance enters into Zone 1. (Fig. 1e)	(a) AT KANPUR END: It can be seen that the locus of the char. Impedance enters into PS2 Zone and stays for 0.486 sec. (Fig. 2e)
		(b) AT BALLABGARH END: It is observed that the locus of the char. Impedance enters into Zone 1. This tallies with the incident report. (Fig. 1f)	(b) AT BALLABGARH END: It is observed that the char. Impedance does not enter into the relay characteristic. (Fig. 2f)



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	5.171	NL	NV
Zone 2	5.067	NL	NV
Zone 3	4.744	NL	NV
PS1	4.236	NL	NV

1(a)
(without PSS)

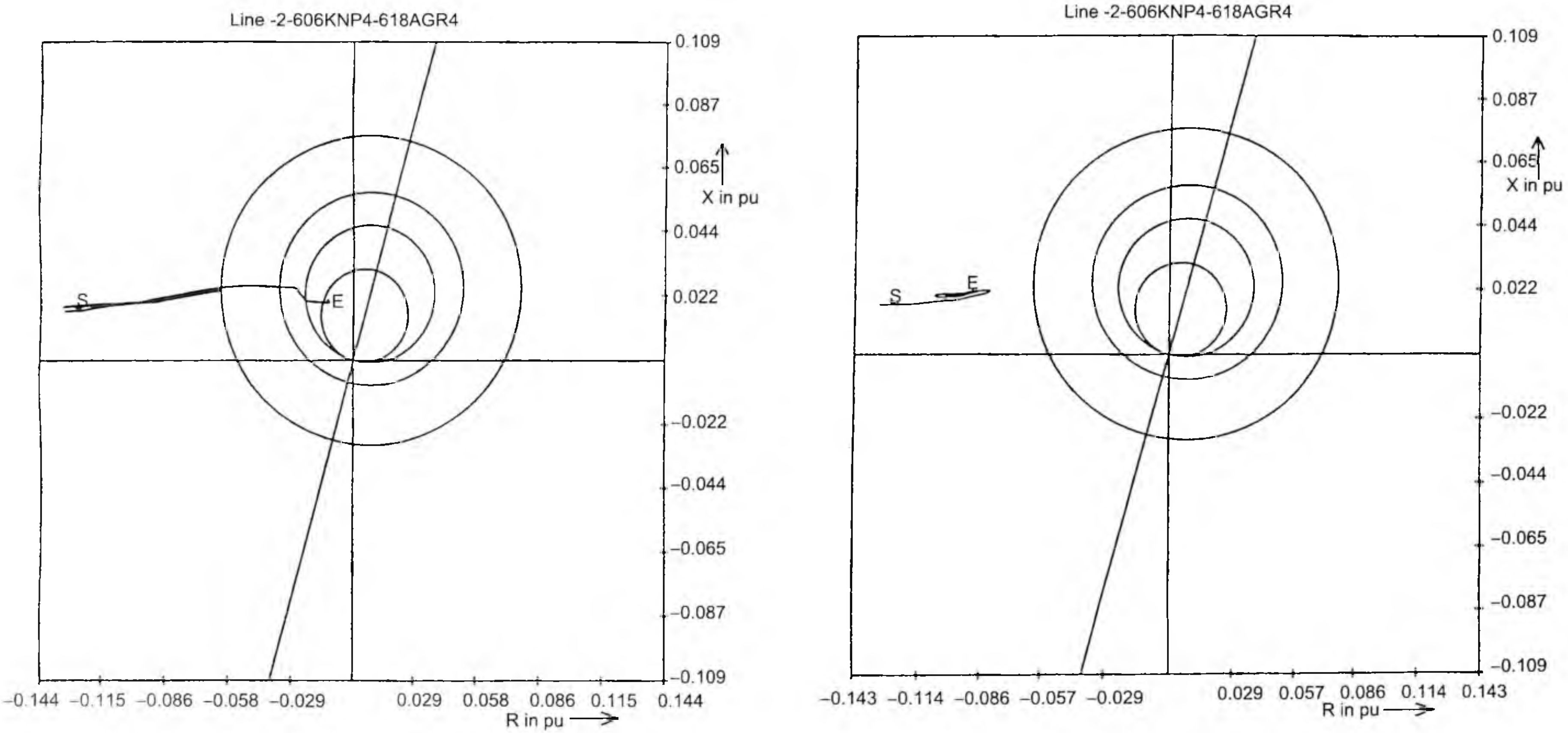
NE - Not Entered, NL - Not Left, NV - Not Valid

Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	1.925	2.152	0.227

2(a)
(with PSS)

NE - Not Entered, NL - Not Left, NV - Not Valid

FIG. 1(a), 2(a). R-X DIAGRAM FOR KANPUR-AGRA LINE AT KANPUR END



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	5.253	NL	NV
Zone 2	5.152	NL	NV
Zone 3	5.046	NL	NV
PS1	4.526	NL	NV

1(b)
(without PSS)

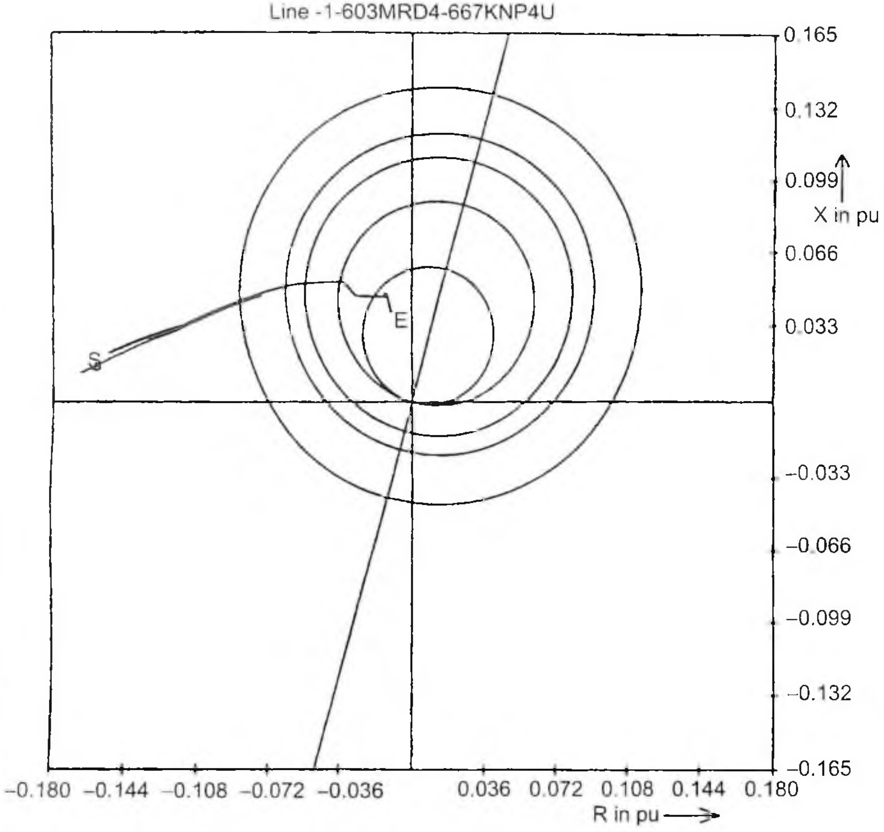
NE - Not Entered, NL - Not Left, NV - Not Valid

Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	NE	NL	NV

2(b)
(with PSS)

NE - Not Entered, NL - Not Left, NV - Not Valid

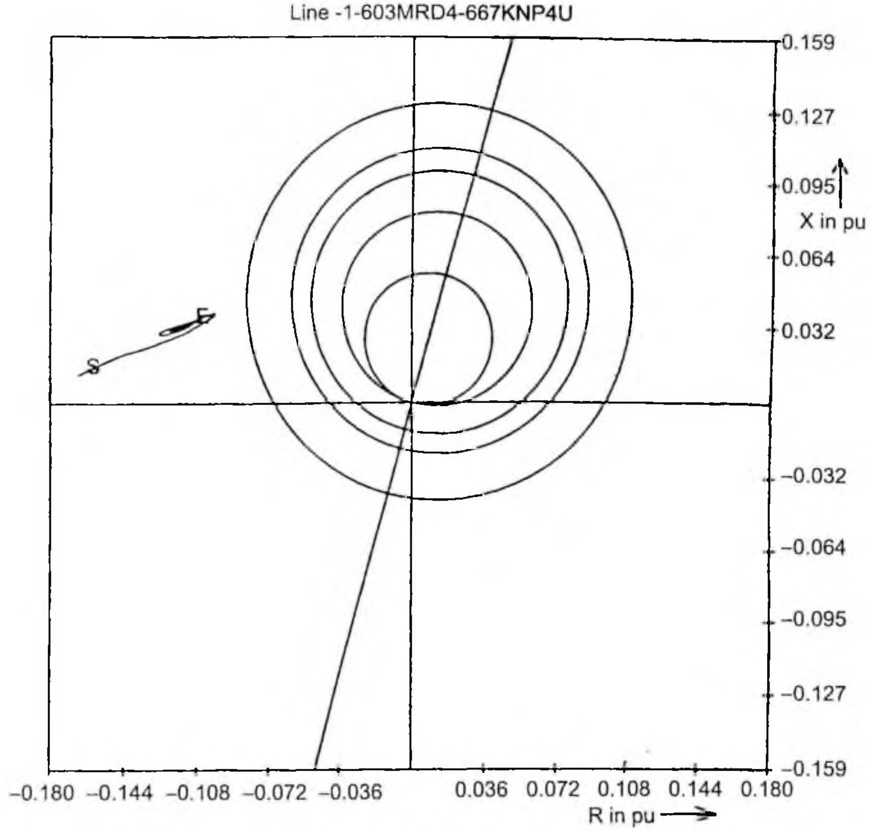
FIG. 1(b), 2(b). R-X DIAGRAM FOR KANPUR-AGRA LINE AT AGRA END



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	5.235	NL	NV
Zone 2	5.137	NL	NV
Zone 3	4.917	NL	NV
PS1	4.744	NL	NV
PS2	4.381	NL	NV

NE - Not Entered, NL - Not Left, NV - Not Valid

1(c)
(without PSS)

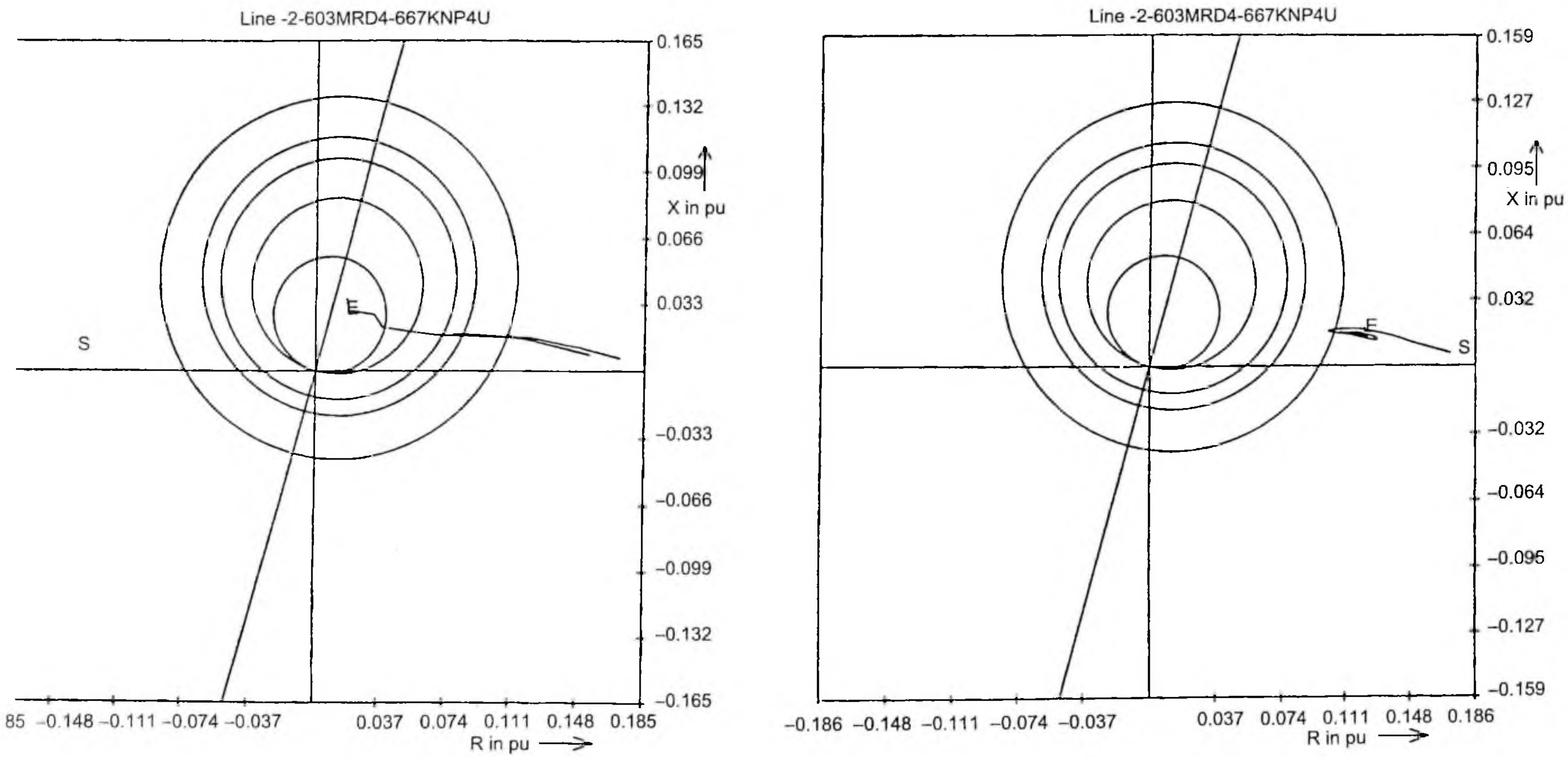


Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	NE	NL	NV
PS2	NE	NL	NV

NE - Not Entered, NL - Not Left, NV - Not Valid

2(c)
(with PSS)

FIG. 1(c), 2(c). R-X DIAGRAM FOR MORADNAGAR-PANKI LINE AT MORADNAGAR END



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	5.137	NL	NV
Zone 2	4.952	NL	NV
Zone 3	4.625	NL	NV
PS1	4.454	NL	NV
PS2	4.163	NL	NV

NE - Not Entered, NL - Not Left, NV - Not Valid

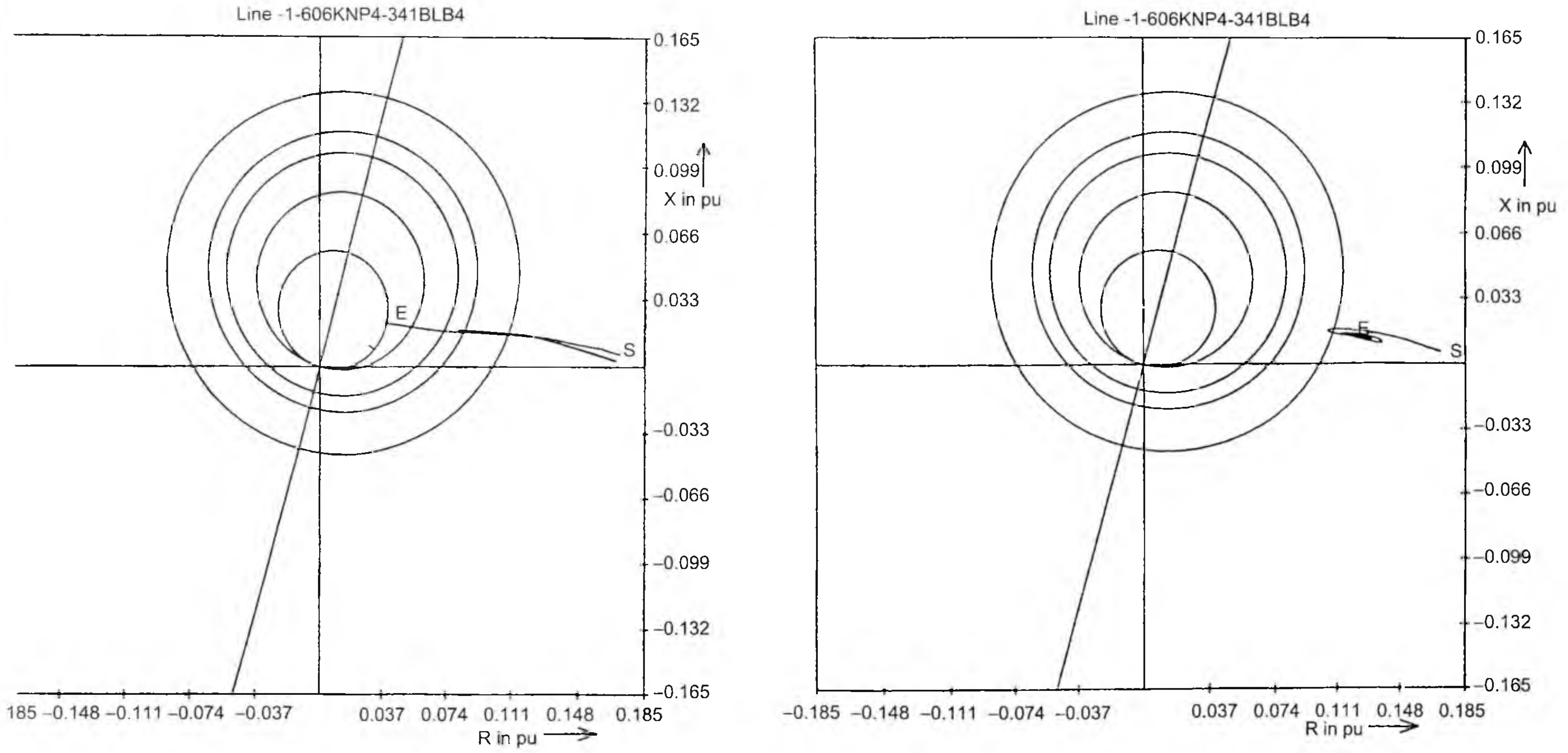
1(d)
(without PSS)

Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	NE	NL	NV
PS2	1.784	2.324	0.540

NE - Not Entered, NL - Not Left, NV - Not Valid

2(d)
(with PSS)

FIG. 1(d), 2(d). R-X DIAGRAM FOR MORADNAGAR-PANKI LINE AT PANKI END



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	5.137	NL	NV
Zone 2	4.952	NL	NV
Zone 3	4.647	NL	NV
PS1	4.479	NL	NV
PS2	4.212	NL	NV

1(e)
(without PSS)

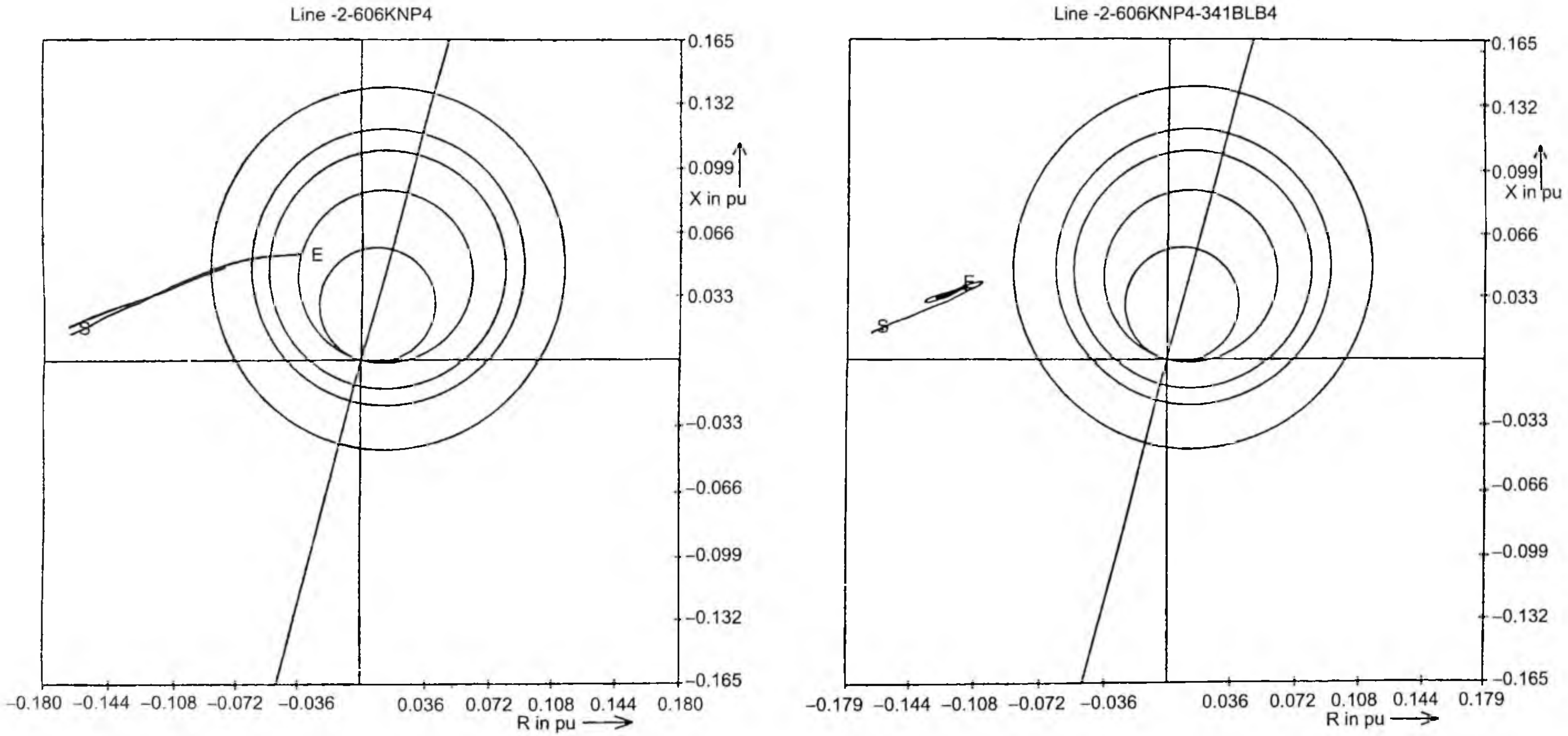
NE - Not Entered, NL - Not Left, NV - Not Valid

Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	NE	NL	NV
PS2	1.811	2.297	0.486

2(e)
(with PSS)

NE - Not Entered, NL - Not Left, NV - Not Valid

FIG. 1(e), 2(e). R-X DIAGRAM FOR KANPUR-BALLABHGARH LINE AT KANPUR END



Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	5.144	NL	NV
Zone 3	4.926	NL	NV
PS1	4.767	NL	NV
PS2	4.422	NL	NV

NE - Not Entered, NL - Not Left, NV - Not Valid

1(f)
(without PSS)

Zone Des.	Entering time (Secs)	Leaving time (Secs)	Elapsed time (Secs)
Zone 1	NE	NL	NV
Zone 2	NE	NL	NV
Zone 3	NE	NL	NV
PS1	NE	NL	NV
PS2	NE	NL	NV

NE - Not Entered, NL - Not Left, NV - Not Valid

2(f)
(with PSS)

FIG. 1(f), 2(f). R-X DIAGRAM FOR KANPUR-BALLABHGARH LINE AT KANPUR END out-of-step, and the Unchahar machine exhibited the tendency to go out-of-step. It is also observed that Anpara machine goes out of step while studying the general performance of the system, by applying single line to ground fault at Singrauli and Lucknow buses. The Unchahar machine angle reaches to 170 degrees with reference to Dadri reference machine. In the dynamic simulation if the machine angle is more than 180 degrees with reference to the reference machine, that particular machine goes out of step. This simulation is carried out with an assumption that PSS is not in service.

4.0 ANALYSIS WITH POWER SYSTEM STABILIZER (PSS)

The modern inter-connected power systems have a tendency to oscillate under certain loading and system conditions. The system generally has sufficient inherent damping to counteract this instability. However, the increasing use of high gain, continuous acting excitation systems and utilization of long transmission lines for bulk power transfer over longer distances, resulted in an overall lowering of the stability margin.

Following a system disturbance irrespective of whether it is a major disturbance or a minor incident like load cnange on the system, generating units typically oscillate around an operating point. For synchronous machine this behaviour can be described through a relationship involving angular acceleration associated with inertia, damping associated with speed variation and unbalance between electrical and mechanical torque. System stability in fact, depends on two basic components - (1) Synchronizing power and (2) Damping Power. For a system to be stable both of these should be positive and adequate. While Synchronizing torque assures restoration of rotor angle following a disturbance, the latter is necessary to damp out the oscillation. It has been observed that in the systems having moderate to high transfer impedance and heavy loading, their inherent damping capability is inadequate. Thus, following disturbances such systems exhibit prolonged low frequency oscillations, which can lead to system instability. The basic function of PSS is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. Keeping this in view, it is aimed first to examine the existing facilities. Thus, it is assumed that PSS is in service at all 210 MW and 500 MW units. PSS is considered because, PSS is an integral part of excitation system. Presently, PSS is disconnected and kept out of service in most of the generating stations. This is because the complexities involved in tuning PSS parameters in multi-machine environment. The main apprehension is also that, it aggravates the stability situation, when it is really expected to save the system. The main problem with conventional PSS is that the parameters are tuned at one particular point, but the power system never operates at one particular operating point, it keeps changing. This requires that PSS must be able to adapt itself to changing operating conditions. In the context of Indian power system, the PSS is of conventional type. In the present condition, first emphasis is given to put PSS in service with reasonable parameters to assess the relative improvement, following grid disturbances. In the present analysis, the grid disturbance is initiated with the outage of Lucknow-Muradabad line and subsequently outage of major 400 kV lines and Singrauli, Rihand, Anpara and Unchahar machines going out of step caused the grid collapse. Any suggestion of remedial measure must improve system in preventing outage of these lines and machines going out of step, that is in effect grid should not collapse. Keeping this objective in view, it is aimed to assume that the existing PSS can be utilized by putting into service.

Assuming PSS is in service the whole incident is re-simulated. The disturbance assumed to be initiated by disconnecting Lucknow - Moradabad line during the dynamic simulation. It is observed that, system is stable and the simulated time is 10 sec. This shows that grid collapse could have been avoided if PSS was in service. From this simulations it is evident that PSS will help the system by providing additional damping. The variations of dynamic impedance have been plotted and the observations are given in Table 3 (with PSS).

5.0 CONCLUSIONS

The grid disturbances taking place is definitely not a welcome feature in the operation of power system and all efforts should be made to solve/to avoid these problems. Most of the grid disturbances are caused due to the lack of discipline among the operating constituents in a deficit power scenario. The problem can be controlled through improved management and efficient planning.

Reactive power management and protection coordination should be paid attention for minimizing the grid disturbances. Tuning of PSS is essential for all large capacity units. Load-generation balanced is to be maintained.

In this paper an attempt is made to study the dynamic variation of characteristic impedance superimposed on relay characteristics. This gives clear idea about the relay tripping and in which zone. This helps in proper relay co-ordination and zone settings.

- Power System Stabilizer (PSS) plays an important role in bringing stability to any large scale Power System. It has been observed that there is remarkable improvement in the system performance when the PSS is made functional. Keeping this in view it is essential that tuning of PSS must be taken up initially at 500 MW units such as Singrauli, Anpara and Rihand.

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