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Some Studies Based on Red, Load Modeling, Line Outage using Voltage Stability Analysis

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Abstract: There are many methods for overload relieving which have been reported for determining a secure operating point. Most of these methods use conventional optimization techniques, which are generally time–consuming from a computation point of view, especially for large systems. Further the conventional optimization technique updates all the controllers for most of the operating conditions. Under emergency conditions the operator, has to make quick decisions, with little concern for the theoretical optimality of the operating point and also the operator cannot move all the controllers to different settings within less time. In this context a simplified approach has been proposed in this paper for security oriented power system operation. The contribution of each generator for a particular overloaded line is first identified, then based on Relative Electrical Distance (RED) concept the desired proportions of generation for the desired overload relieving is obtained. Then based on the Generation Shift Sensitivity Factor (GSSF) concept the desired proportions of generation for the desired overload relieving is obtained. An attempt is also made to curtail the number of generators to be rescheduled based on GSSF for overload relieving Results obtained for network overload alleviation of 5 bus meshed system, IEEE 30-bus New England system are presented for illustration purposes. The change in load sharing and generation scheduling was examined when the slack bus was changed, generator node changed and placed in the midpoint of the system, increase in generator number, load modeling was calculated. For all the above cases the voltage stability indices (Ve, Lindex and MSV) were calculated, recorded and then compared for best performance to the previous cases. The generation scheduling was determined with line outage and subsequent load shedding.

***Keywords- Relative Electrical Distance, Generation Shift Sensitivity Factor, Congestion, Load modeling, slack bus, load sharing, power flow analysis, optimal power flow*.**

I. INTRODUCTION

For secure operation of a power system, the network loading has to be maintained within specified limits.

Overloading of a transmission network in a power system can occur due to various reasons including line outage. The network overloading may lead to tripping of overloaded lines, consequential tripping of other lines, and in some cases to voltage stability problem. Network overloading can be relieved by different controls such as:

1. real power generation rescheduling;
2. phase shifting transformers;
3. flow control through HVDC link(s);
4. line switching;
5. load shedding.

Real power generation rescheduling is the most widely used control for network overload alleviation [1-3]. This is due to,

- ease of control application, and
- no requirement of additional investment

Control actions like use of phase shifting transformers and line switching involves additional investments and control actions through load shedding leads to disruption of power supply. Hence, In this paper we consider real power generation rescheduling for alleviation of network overloads. Reference [1] presented approach for alleviation of network overloads using RED and Voltage Stability Indices. This method is well suited for vertically integrated power systems. Further, this method has not made any attempt for curtailment of generators to be rescheduled. Reference [4] addresses the congestion management problem avoiding off line transmission capacity limits related to stability. Instead, it relies on imposing OPF-based constraints that target voltage instabilities. This technique results in both more economical and more secure operating conditions than those resulting for imposing off line transmission capacity limits.

When congestion occurs in a deregulated power system, generation has to be rescheduled to ensure system security. AC optimal generation reschedule approach has been proposed in [2] with the least congestion relief cost. This approach not only considers the incremental cost brought by the generation reschedule, but also considers the incremental cost coming from the change in transmission loss caused by the generation change. But in this approach only line MW flow violations are considered, while the thermal ratings of the lines are based on MVA flows in the line. Reference [5] presents papers/ literature on load modeling issues in the deregulated electricity markets. Reference [3] has described an optimization method to analyze and solve the transmission overloads that arise in each hourly scenario of the Spanish power system, after the electricity market has been cleared. Over loads are solved in the Spanish market by increasing and decreasing generation of connected units, and by connecting off-line units.

However this optimal power flow calculation is computationally expensive and is much time consuming. Thus there is a need for an efficient and fast method that is also sufficiently close to the truly optimal solution, so that operators can make quick efficient decisions under normal and contingency conditions of the power system.

Another concern of on-line OPF implementation may be convergence problem for large power systems. OPF method does not yield a solution unless

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and until all constraints are satisfied. To overcome all these limitations of the conventional optimization technique, simplified and an efficient method has been reported in [8]. It presents an approach for alleviation of network over loads in the day-to-day operation of power systems under deregulated environment. In this approach the control used for overload alleviation is real power generation rescheduling based on Relative Electrical Distance (RED) concept. The method estimates the relative location of load nodes with respect to the generator nodes.

The contribution of each generator for a particular over loaded line is first identified, then based on RED concept the desired proportions of generations for the desired overload relieving is obtained, so that the system will have minimum transmission losses and more stability margins with respect to voltage profiles and bus angles. Using the same approach the results are obtained initially in this paper and the results are obtained using Generation Shift Sensitivity Factor approach (proposed approach). The results obtained from both the methods are compared. In the proposed approach an attempt has been made for curtailing the number of generators to be rescheduled using Generation Shift Sensitivity Factors and available physical margins of the generators.

II VOLTAGE STABILITY INDEX–L AND RELATIVE ELECTRICAL DISTANCES (RED)

Consider a system where n is the total number of buses with 1, 2…g, g number of generator buses, and g+1…n, remaining (n-g) buses. For a given system we can write,

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \qquad (1)$$

Where *IG* , *IL* and *VG* ,*VL* represent complex current and voltage vectors at the generator nodes and load nodes Y_{GG}, Y_{GL}, Y_{LG} and Y_{LL} are corresponding partitioned portions of network Y-bus matrix.

Rearranging (1) we get

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \qquad (2)$$

Where $F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}]$

The elements of $[F_{LG}]$ matrix are complex and its columns correspond to the generator bus numbers and rows correspond to the load bus numbers. This matrix gives the relation between load bus voltages and source bus voltages. It also gives information about the location of load nodes with respect to generator nodes that is termed as Relative Electrical Distance (RED) between load nodes and generator nodes.

For a given system operating condition, using the operational load flow (state estimation) results, the static voltage stability L-index is computed as [7], The overall improvement in voltage stability has also been analyzed with

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \qquad (3)$$

$$Ve = \sum_j (V_{jdes} - V_{jact})^2 \qquad (4)$$

Sum squared voltage deviations $(V_{jdes}-V_{jact})$ of all the load busses j Where V_{jdes} at jth load is usually set to 1.0 Pu

MSV: $X = A^{-1}b = (U\sum V^T)^{-1}b$ (5)

Minimum Singular Value of the modified power flow Jacobian

Where j = g+1…n and all the terms within the sigma on the RHS of equation (3) are complex quantities. *F ji* are the complex elements of $[F_{LG}]$ matrix. The L-indices for a given load condition are computed for all load busses. For stability, the bound on the index Lj must not be violated (maximum limit=1) for any of the nodes j. Hence, the global indicator L describing the stability of the complete subsystem is given by L=maximum of Lj for all j (load buses).

The $[F_{LG}]$ gives the information, for each load bus, about the amount of power that should be taken from each generator under normal and network contingencies, as far as the system performance is considered with respect to the voltage profiles, bus angles and voltage stability index. This matrix is used as the basis for the desired load sharing/generation scheduling and is explained with a sample system in the next section. If each consumer takes the power from each generator according to the $[F_{LG}]$ matrix the system will have minimum transmission loss, minimum angle separation between generator buses and minimum L-indices.

III RED AND DESIRED PROPORTIONS OF GENERATION (DPG)

A. Sample system

The sample system is considered for explaining Relative Electrical Distances (RED) and Desired Proportions of Generation for load sharing/generation scheduling.

The sample system 1 shown in Figure 1 has two sources at buses 1 and 2, three loads at buses 3, 4 and 5. It is assumed that the lines L1, L2, L3 and L4 are of 50 km,100 km, 200 km and 150 kms length respectively. The line parameters in per unit

per 100 kms are R=0.00165, X=0.02059.

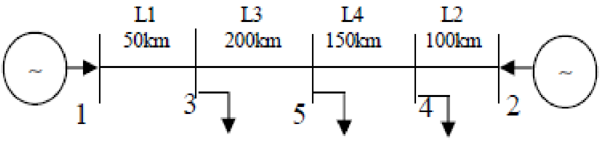

Figure 1. Sample System

Table1showing generation rescheduling

Load bus No	Power taken from gen(MW)		Load at bus (MW)
	G1	G2	
3	180	200	200
4	30	120	150
5	150	150	300
Gen Sum	360	290	650

The $[F_{LG}]$ matrix corresponding to the load/generator buses for the network is given by

$$[F_{LG}] = \begin{bmatrix} .9000+0.0000i & .1000+0.0000i \\ .2000+0.0000i & .8000+0.0000i \\ .5000+0.0000i & .5000+0.0000i \end{bmatrix}$$

The elements of $[F_{LG}]$ matrix are complex and its columns correspond to the generator bus numbers 1, 2 and rows correspond to the load bus numbers 3, 4 and 5.

It can be observed that the sums of the each row elements of the [F_{LG}] matrix are close to (1.0, 0.0).

The relative electrical distances i.e., the relative locations of load nodes with respect to the generator nodes are obtained from the [F_{LG}] matrix and is given by

$$[R_{LG}]=[E]-abs\{[F_{LG}]\} \quad (4)$$

Where [E] is the matrix with (n-g) rows and g number of columns of all elements equal to '1'. For the sample system the Relative Electrical Distance matrix is given by Since the load bus 3 is at a distance of 50 kms from the generator 1 and 450 kms from the generator 2, which is nine times of 50 kms, the corresponding elements of [R_{LG}] matrix are 0.10 and 0.90. The load bus 4 is at a distance of 100 kms from the generator 2 and 400 kms from the generator 1 the corresponding elements of [R_{LG}] matrix are 0.80 and 0.20.

Similarly, the load bus 5 is at a distance of 250 kms from the generator 1 and 250 kms from the generator 2, the corresponding elements of [R_{LG}] matrix are 0.50 and 0.50. These values, which are taken as relative electrical distances, can also be used for the evaluation of transmission charges in open access.

The desired proportions of generation for the desired load sharing/generation scheduling is also obtained from the [F_{LG}] matrix and is given by,

DLG=Abs(FLG) (6)

For the sample system 1 the desired proportions of generation, for the desired load sharing/generation scheduling, are given by

$$[D_{LG}]=\begin{bmatrix} 0.90 & 0.10 \\ 0.20 & 0.80 \\ 0.50 & 0.50 \end{bmatrix}$$

For example, the load at bus 3 is 200 MW then it should take 0.90x200=180 MW of load from generator 1 and the partial remaining load of 0.10x200=20 MW from generator 2. Similarly the load at other buses also should take according to the corresponding elements of the [D_{LG}] matrix. If the load sharing/generation scheduling is according to the [D_{LG}] matrix, then the system will have minimum transmission losses and more stability margins with respect to voltage profile, bus angles and L-indices. The desired load sharing/generation scheduling for the sample system 1 is given in Table I.

Table2 shows generation and voltage stability indices

Case No:	**Power taken from Gen (MW)**		**Loss (MW)**	**Parameters indicating voltage stability**		
	G1	**G2**		**V**	**ΣL^2**	
1	464.191	200	14.191	0.0032	0.0301	5.6043
2	414.123	250	14.123	0 .0017	0.0300	.5288
3	**374.023**	**290**	**14.023**	**0 .0010**	**0.0290**	**5.4695**
4	314.085	350	14.085	0.0012	0.0295	5.4823
5	264.117	400	14.117	0.0016	0.0300	5.5112

losses are also a minimum. Further from the above table 3.2 it can be concluded that the point above the optimum i.e., results in bold letters, which is the direct result from Relative Electrical Distance is as shown above. In this the results above and below the optimum value will have greater loss in power. Further the voltage stability parameters also it can be observed that voltage deviation, L-index and Minimum Singular Value were having the least values compared with the others. In this manner the RED concept is extremely useful.

IV APPROACH

For the given operating condition identify the fully loaded and over loaded lines, then estimate the contribution of each generator to all the congested lines using the procedure given in the reference [6].Then the Generators are classified into two groups based on the generators direction of contribution to the congested line. Generation in one group of Generators is increased (GI) while in the other group, generations are reduced. Generators which are contributing (generators contributing in the direction of overloading) to all the congested lines are identified as GD group (where generation decrease is recommended), and the generators which are not contributing (generators contributing in the opposite direction) to all the congested and fully loaded network elements are categorized under GI group (where generation increase is recommended. For a given operating condition the total generation change in GI group must be change as the total generation change in the GD group. The amount of generation change required to relieve the congestion of the mostly congested line is estimated. Then the total amount of required change is shared by the generators of the GD group in proportion to the margins available on these generators. Here, the margins of the generators of GD group are estimated based on DLG matrix as explained in the reference [8]. Similarly the amount of generation change required among the generators of GI group is obtained based on the elements of DLG matrix [8]. Hence, initially desired generation rescheduling for desired overload relieving based on RED concept is obtained.

The generation on each generator is disturbed by 1 MW and change in flow through the congested line is observed and hence the Generation Shift Sensitivity Factors of all the generators with respect to the congested line are obtained. Using the Generation Shift Sensitivity Factors of GI group, Negative least sensitive generators are identified for increasing the generation. Instead of selecting all the generators of GI group for rescheduling only few generators of GI group are selected for rescheduling based on the GSSF and the availability of the physical margin of each generator. In this way some generators of GI are curtailed without disturbing their generation. So, the number of generators of GI group to be rescheduled is minimized for overload relieving. Under emergency operating conditions the amount of time available for the operator in decision making is very much less. Hence, under emergency operating conditions with the proposed approach the operator need not move all the generators to different settings for overload relieving and hence followed by the transmission line tripping the operator can bring back the system to normal state with few numbers of generators within the less time and hence the security of the system is improved.

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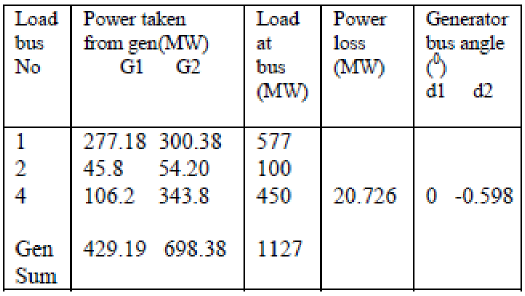
V TEST SYSTEM STUDIES

The sample system has two sources at bus 3 and 5, and three load/sinks at buses 1,2 and 4. The system line data is given in the table 3.3 and the connections are shown in Fig. 2

Table3 shows system impedance parameters



Load bus No	Power taken from gen(MW) G1	G2	Load at bus (MW)	Power loss (MW)	Generator bus angle (^{0}) d1	d2
1	277.18	300.38	577			
2	45.8	54.20	100			
4	106.2	343.8	450	20.726	0	-0.598
Gen Sum	429.19	698.38	1127			

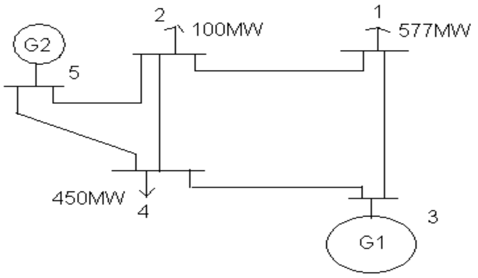


Figure 2. 5 bus meshed system

The Table explains the Line Data having line resistance and reactance through the lines flowing from and to the system having two sources.

Table4 shows generation rescheduling based on RED

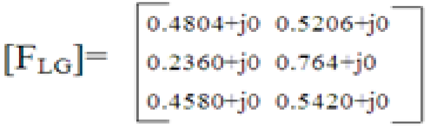
From Bus	To Bus	Line Resistance	Line Reactance
1	2	0.02	0.035
1	3	0.03	0.08
3	4	0.0	0.06
5	4	0.0	0.08
2	5	0.04	0.15
2	6	0.01	0.03
5	6	0.05	0.18

The desired load sharing/generation for the sample system 2 using the $[D_{LG}]$ matrix, from this at load 577MW at bus 1 it should take 277.1908MW from generator at bus 3(G1) and 300.3862MW from (G2). Similarly for load at 2 (100MW), it should take 45.8MW from G1 and 54.20MW from G2 and so-on and the results are tabulated as shown

The calculations for the power generation at different values of G2, total load, power losses, Generators bus angles, and the voltage stability parameters

For a given system loading condition, the generators can approximately share the transmission losses in the same proportion of the desired generation schedule. For the case1, the power loss of 20.735MW has been distributed between the generators G1 and G2 in proportion to their desired generation schedule (1:1.6). Power flow results and contributions of various generators to the loads are obtained for the sample system 2 with different combinations of generations (cases 1, 2, 3 and 4) for the same loading conditions and are summarized. From these results it can be seen that the power loss in MW and angle separation between the Generators is less when the load sharing/ generation schedule is according to the $[D_{LG}]$ matrix as indicated.

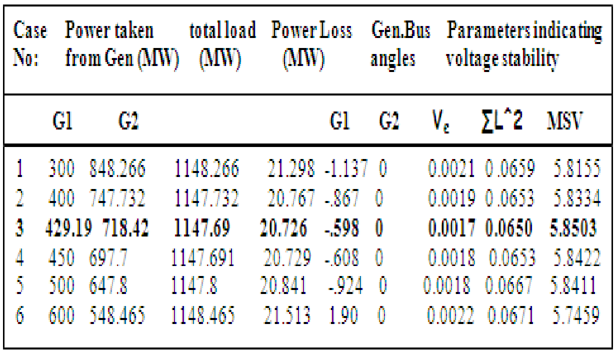
When the same five bus system is considered with change in the slack bus.at node 5 (G2) is changed to node 3(G1)



$$[F_{LG}]=\begin{bmatrix} 0.4804+j0 & 0.5206+j0 \\ 0.2360+j0 & 0.764+j0 \\ 0.4580+j0 & 0.5420+j0 \end{bmatrix}$$

The desired load sharing/generation for the sample system 2 using the $[D_{LG}]$ matrix, from this at load 577MW at bus 1 it should take 277.1908MW from generator at bus 3(G1) and 300.3862MW from (G2). Similarly for load at 2 (100MW), it should take 45.8MW from G1 and 54.20MW from G2 and so-on and the results are tabulated as shown.

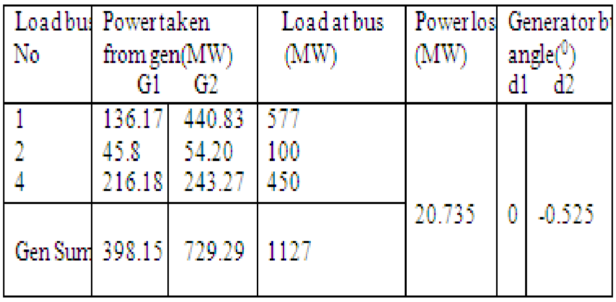
Table5 shows generation and voltage stability indices



Case No:	Power taken from Gen (MW)		total load (MW)	Power Loss (MW)	Gen.Bus angles		Parameters indicating voltage stability		
	G1	G2			G1	G2	V_e	∑L^2	MSV
1	300	848.266	1148.266	21.298	-1.137	0	0.0021	0.0659	5.8155
2	400	747.732	1147.732	20.767	-.867	0	0.0019	0.0653	5.8334
3	**429.19**	**718.42**	**1147.69**	**20.726**	**-.598**	**0**	**0.0017**	**0.0650**	**5.8503**
4	450	697.7	1147.691	20.729	-.608	0	0.0018	0.0653	5.8422
5	500	647.8	1147.8	20.841	-.924	0	0.0018	0.0667	5.8411
6	600	548.465	1148.465	21.513	1.90	0	0.0022	0.0671	5.7459

The calculations for the power generation at different values of G2, total load, power losses, Generators bus angles, and the voltage stability parameters were shown tabulated

Table6 shows generation rescheduling for generator node changed from node 2 to 15based on RED



Load bu No	Power taken from gen(MW) G1	G2	Load at bus (MW)	Power los (MW)	Generator b angle(^{0}) d1	d2
1	136.17	440.83	577	20.735	0	-0.525
2	45.8	54.20	100			
4	216.18	243.27	450			
Gen Sum	398.15	729.29	1127			

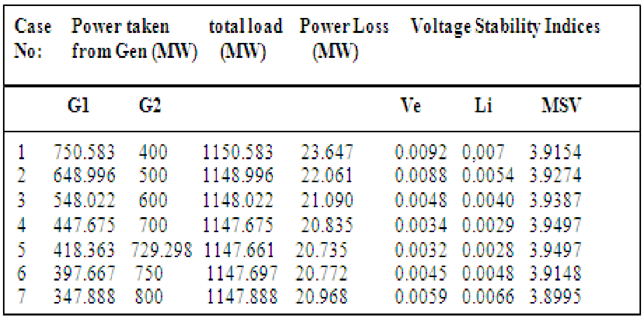
For a given system loading condition, the generators can approximately share the transmission losses in the same proportion of the desired generation schedule. For the case1, the power loss of 20.726MW has been distributed between the generators G1 and G2 in proportion to their desired generation schedule (1:1.6). Power flow results and contributions of various generators to the loads are obtained for the sample system 2 with different combinations of generations (cases 1, 2, 3 and 4) for the same loading conditions and are summarized. From these results it can be seen that the power loss in MW and angle separation between the generators is less when the load sharing/ generation schedule is according to the $[D_{LG}]$ matrix as indicated.

Effect of Slack Bus on the System

When the same five bus system is considered with change in the slack bus.at node 5 (G2) is changed to node 3(G1).

From this for a load of 577MW at bus 1, Table No:3.4 it should take 136.17MW from generator at bus 3 (G1) and 440.83MW from generator at bus 5 (G2). Similarly for load at bus 2 (100MW), it should take 45.8MW from generator at bus 3 (G1) and 54.20MW from generator at bus 5 (G2). With this generation rescheduling the system will have minimum transmission loss of 20.735MW.

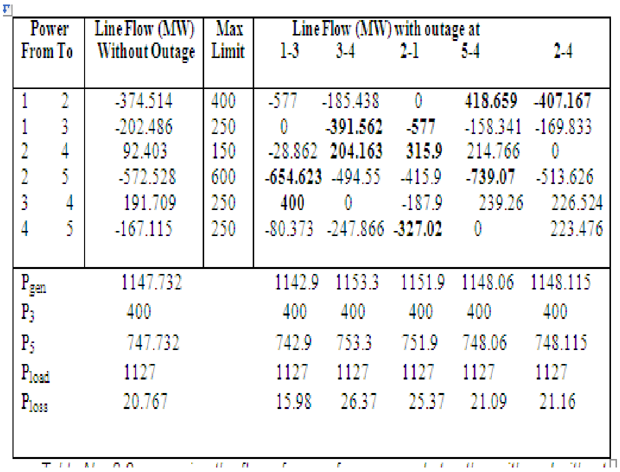
Table7 shows generation and voltage stability indices Effect of Outage on the system



Case No:	Power taken from Gen (MW)		total load (MW)	Power Loss (MW)	Voltage Stability Indices		
	G1	G2			Ve	Li	MSV
1	750.583	400	1150.583	23.647	0.0092	0,007	3.9154
2	648.996	500	1148.996	22.061	0.0088	0.0054	3.9274
3	548.022	600	1148.022	21.090	0.0048	0.0040	3.9387
4	447.675	700	1147.675	20.835	0.0034	0.0029	3.9497
5	418.363	729.298	1147.661	20.735	0.0032	0.0028	3.9497
6	397.667	750	1147.697	20.772	0.0045	0.0048	3.9148
7	347.888	800	1147.888	20.968	0.0059	0.0066	3.8995

In the same five buses system, if there is any outage, the line flows and the voltage at the particular bus changes. There may be some lines getting overloaded and others under loaded or have very low influence. It is because of the reason that the power flow through the outage line will be zero; the power has to be diverted to other lines in the network. If there is an outage in line 1-3. So the power has to flow from 3 to 4 and from 4 to 2, to get the desired power at node 1. Therefore the lines 1-2, 1-5 and 3-4 will be overloaded and lines 1-4 and 4-5 were under-loaded as shown

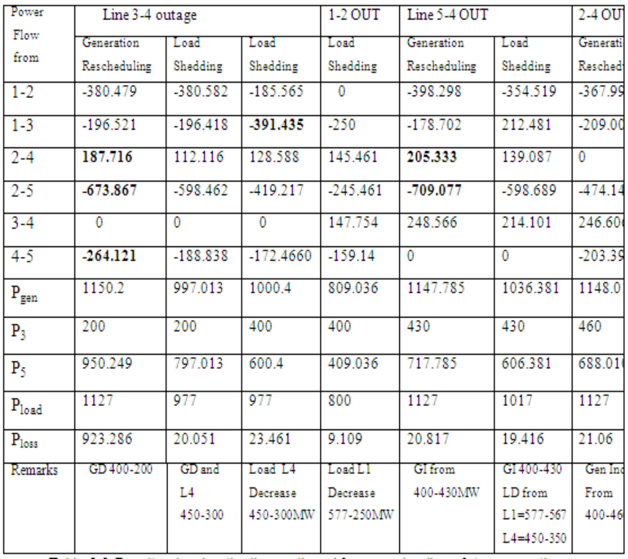
Table 8 shows line flows when an outage occurs



Power From	To	Line Flow (MW) Without Outage	Max Limit	Line Flow (MW) with outage at 1-3	3-4	2-1	5-4	2-4
1	2	-374.514	400	-577	-185.438	0	**418.659**	**-407.167**
1	3	-202.486	250	0	**-391.562**	**-577**	-158.341	-169.833
2	4	92.403	150	-28.862	**204.163**	**315.9**	214.766	0
2	5	-572.528	600	**-654.623**	-494.55	-415.9	**-739.07**	-513.626
3	4	191.709	250	**400**	0	-187.9	239.26	226.524
4	5	-167.115	250	-80.373	-247.866	**-327.02**	0	223.476
P_{gen}		1147.732		1142.9	1153.3	1151.9	1148.06	1148.115
P_3		400		400	400	400	400	400
P_5		747.732		742.9	753.3	751.9	748.06	748.115
P_{load}		1127		1127	1127	1127	1127	1127
P_{loss}		20.767		15.98	26.37	25.37	21.09	21.16

The case in table 3.8, with line 3-4 outage, when G1=400 and G2=742.9MW, severity of lines 1-3, 2-4 was high. So, these lines have to be relieved from over load. The generation rescheduling in this case with 3-4 outage alone is not having any influence on overload relieving. Now the load at node 4 has been shed from 450 to 300 MW. Comparing the load shedding at node 4 with and without rescheduling, we can observe that without rescheduling and load shedding, line 1-3 is still yet to be relieved from overload.

Table9 shows line flows for bus system when an outage occurs at different lines



Power Flow from	Line 3-4 outage			1-2 OUT	Line 5-4 OUT		2-4 OU
	Generation Rescheduling	Load Shedding	Load Shedding	Load Shedding	Generation Rescheduling	Load Shedding	Generati Resched
1-2	-380.479	-380.582	-185.565	0	-398.298	-354.519	-367.99
1-3	-196.521	-196.418	**-391.435**	-250	-178.702	212.481	-209.00
2-4	**187.716**	112.116	128.588	145.461	**205.333**	139.087	0
2-5	**-673.867**	-598.462	-419.217	-245.461	**-709.077**	-598.689	-474.14
3-4	0	0	0	147.754	248.566	214.101	246.60
4-5	**-264.121**	-188.838	-172.4660	-159.14	0	0	-203.39
P_{gen}	1150.2	997.013	1000.4	809.036	1147.785	1036.381	1148.0
P_3	200	200	400	400	430	430	460
P_5	950.249	797.013	600.4	409.036	717.785	606.381	688.01
P_{load}	1127	977	977	800	1127	1017	1127
P_{loss}	923.286	20.051	23.461	9.109	20.817	19.416	21.06
Remarks	GD 400-200	GD and L4 450-300	Load L4 Decrease 450-300MW	Load L1 Decrease 577-250MW	GI from 400-430MW	GI 400-430 LD from L1=577-567 L4=450-350	Gen Inc From 400-46

Table10 shows ranking for bus system when an outage occurs

Common Number	Rank of Bus	Load Bus Number	Generator Contribution	Percentage Contribution
1	1	2	G5	100
2	2	1	G3 & G5	55.48 & 44.52
3	2	4	G3 & G5	60.78 & 39.22

Similarly considering case 1-2 outage, decreasing load L1 from 577 to 250MW has relieved all the lines from overload. It is because of the fact that when line 1-2 was out, for the load at node 1 having 577MW, the desired load has to be supplied by generator G1 alone. The power has to flow from the mode 3 to 1 only, but have only 250MWs capacity. So load has to be shed from 577 to definitely 250MWs.

Now considering outage of line 5-4, the load relieving is by rescheduling and load shedding. The generator G1 must rescheduled from 400 to 430MWs and load decreasing at nodes 1 and 4 from 577 to 567MW and 450 to 350MW to relieve all lines from overload. It is because, when the line 5-4 was dropped the power from G1 has to flow from 3-4 and from G2, the power has to flow from 5-2 and 2-4 lines. Line 3-4 was not overloaded but, 1-2, 2-4 and 2-5 were overloaded. So dropping of load at node 4 and load at node 1 to some extent will be the definite solution for overload relieving.

It can be observed since the line 1-3 got outage; no power is flowing through that line. Because of this outage, line 1-2 was overloaded from 374.5 to 577MW where as line 4-5 has under-loaded from 167 to 80MW after line outage. Similarly, for other cases with line outages at 3-4, 2-1, 5-4 and 2-4, the overloaded lines were shown bold. The maximum limit of the power transfer in a line is taken arbitrary with respect to the parameters from the line flow without outage.

All the lines which were overloaded because of any line outage, those lines have to be relieved, so that they must not reach thermal limit. The table above shows the results for generation rescheduling and load outage for particular line outages.

The approach for contingency ranking is applied on 5 bus meshed system which has 2 generator buses and 3 other buses. The system total peak load is about 577MW at node 1, 300MVAR at node 4. The ranking of all the line outage contingencies, using the approach proposed is given in Table.

Since most of the contingencies may not threaten system security/stability, those contingencies that pose serious system security/stability are selected. *Rank-1 contingency (line outage 4–3):* In this contingency, for a peak-load condition, the overall total real power loss is 23.286MW (2.02%). The minimum voltage is 1.0 p.u. at bus 3 and the maximum voltage-stability index Lmax is 0.0070 at bus 1. This is considered to be most sevierely affected line when congestion occurs. Least rank entails most seviere if any congestion occurs to the bus. From percentage contribution also we can conclude that the node bus 2 will have more impact than other lines, either it may overload or underload if any line outage occurs.

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A Case Study with IEEE 30- BUS SYSTEM

In this study a IEEE 30 bus system is investigated for generation scheduling using RED, effect of slack bus on scheduling, voltage stability using Ve, L-indices and MSV methods. Further outage of a single line and its effect are studied. To limit the various line flows within their limits, when a line outage occurs, load shedding is investigated. For this, a sensitivity analysis is carried out to determine changes needed for the generation scheduling.IEEE 30 bus system with the following data is considered.

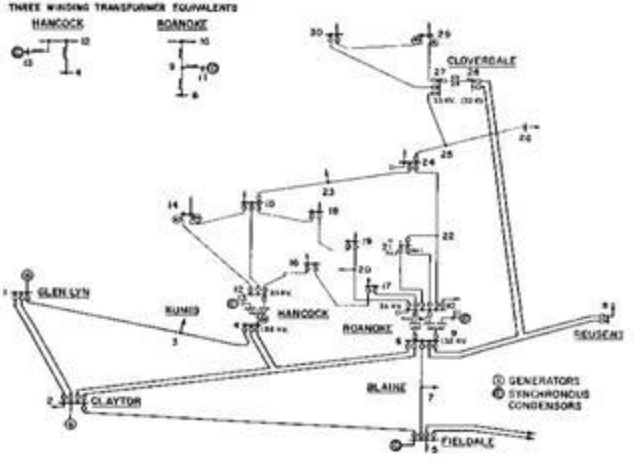


Fig 3 shows the 30 bus New England system

At P2=96.3541, the generation is a minimum and the losses are also minimum. Further from the above table it can be concluded that the point above the optimum i.e., results in bold letters, which is the direct result from Relative Electrical Distance is as shown above. In this the results above and below the optimum value will have greater loss in power. Further from the voltage stability parameters it can be observed that voltage deviation, L-index and Minimum Singular Value were having the least values (in bold) compared with the others. It is clear that there is an improvement in parameters Ve, L-indices and MSV.It means that, if load sharing/ generation-scheduling deviate from desired sharing/generation scheduling (RED based), then the system will move from the secure operating condition. It is clear that there is an improvement in parameters Ve, L-indices and MSV.

Table11shows generation at different powers with stability indices

P1	P2	Ptotal	Ploss	Ve	L-Index	MSV
218.735	80	298.735	15.354	.8170	.3767	1.340
213.512	85	298.512	15.112	.7931	.3725	1.344
208.279	90	298.279	14.879	.7667	.3706	1.349
201.640	**96.35**	**298.995**	**14.595**	**.7331**	**.3630**	**1.355**
198.238	100	298.238	14.938	.7334	.3681	1.348
188.412	110	298.412	15.012	.7350	.3701	1.341

It means that, if load sharing/generation were scheduling deviates from desired sharing/generation scheduling, then the system will move away from the secure operating condition. Hence, in the proposed approach, while relieving the overloaded lines, the generators should rescheduled so that the system will move towards the desired operating condition.

Change in power flows when generator at bus 2 is shifted to bus 15.

Table12 generation rescheduling at different powers with voltage stability indices for generator2 is at node 15

S.No	P1	P15	Ptotal	Ploss	Ve	L-Indices	MSV
1	223.137	75	298.137	14.737	.7331	.3669	1.339
2	213.008	85	298.008	14.617	.7319	.3632	1.340
3	**207.999**	**90**	**297.999**	**14.608**	**.7317**	**.3631**	**1.341**
4	201.686	96.3541	298.040	14.640	.7321	.3634	1.341
5	198.090	100	298.090	14.698	.7324	.3645	1.340
6	178.303	120	298.303	14.932	.8167	.3762	1.339

In the previous case, generation was at buses 1 and 2 which are connected directly by a line. Since, the network is large and no other generator is present at any farther bus to study the effect of change of generation on line flows, losses and Voltage Stability Indices generation at bus 2 is shifted to bus 15 in this chapter. The RED and stability parameters were again calculated and then compared with the previous chapter results.

At P1= 208MWat node 1 and P2=90MW at node 15, the generation is a minimum (RED) and the losses are also minimum. The results above and below the optimum value contain greater loss in power. Further from the voltage stability parameters also it can be observed that voltage deviation; L-indices and Minimum Singular Value are having the least values compared with the others. It is clear that there is a improvement in parameters V_e, L-indices and MSV.

It means that, if load sharing/generation were scheduling deviate from desired sharing/generation scheduling, then the system will move away from the optimal operating condition. Hence in this proposed approach, the overloads through congested lines, the generators should reschedule such that the system will move towards the desired operating condition. Comparing with table (4.1) changing the generator position in the system did not have much impact on the optimal solution.

Load Modeling when a=1; b=2

All the load flow studies assume constant real and reactive powers at buses of the consumers. However, in reality the loads comprise motors of different types, heating, and lighting, arc welding and other types of static electrical installations. The real and reactive power characteristics of these various types of load differ from each other. Under quasi- static conditions of operation it can be assumed that the real and reactive powers of voltage only as the frequency are maintained constant.

From the measurements taken on networks in Poland, Sweden, USA, Federal Republic of Germany and Soviet Union it is found that a=0.6 to 1.4 and b=1.5 to 3.2. In our case **a=1; b=2**

$P=(V/Vn)^a Pn$ (For real power)------------ 1

$Q=(V/Vn)^b Qn$ (For reactive power)----------2

$P' = Ao + A_1 (V_L/V_n)^{k1} + A_2 (V_L/V_n)^{k2}$ ----------3

$Q' = Bo + B_1 (V_L/V_n)^{k3} + B_2 (V_L/V_n)^{k4}$ ---------4

With the generation at node 2, 80MW the load flow was computed and slack bus power P1 and losses, Voltage Stability parameters calculated and were recorded.

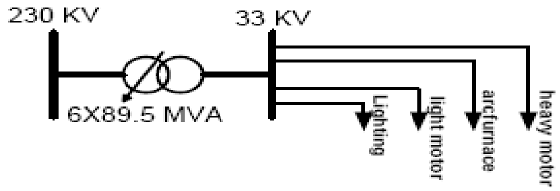


Fig 4 example of load modeling-Steel industrial load model in Khuzestan power system

At P2=96.3541, the generation is a minimum and the losses are also minimum. Further from the above table 7.1 Comparing with

Table13 generation rescheduling at different powers with voltage stability indices for load modeling

S.No	P1	P2	Ptotal	Ploss	Ve	L-indices	MSV
1	225.64	80	305.647	16.406	0.8681	0.3968	1.360
2	225.60	85	305.403	16.156	0.8629	0.3802	1.371
3	215.168	90	305.168	15.915	0.8369	0.3783	1.389
4	**208.53**	**96.35**	**304.880**	**15.620**	**0.7541**	**0.3732**	**1.406**
5	205.32	100	305.322	16.058	0.8854	0.3865	1.392

Table 13, there is an increase in the losses when considering the static load modeling compared with normal case of chapter 4. There is an increase in the values of voltage deviation, L-indices and MSV values for static model.

The results above and below the optimum value will have greater loss in power. Further the voltage stability parameters also it can be observed that voltage deviation, L-indices and Minimum Singular Value were having the least values compared with the others. It is clear that there is an improvement in parameters Ve, L-indices and MSV. It is to be noted that the higher values are due to the increase in total load from 298MW to 304.88MW.

It means that, if load sharing/generation were scheduling deviates from desired sharing/generation scheduling, then the system will move away from the secure operating condition. Hence in the proposed approach, while relieving. It is shown for 30 bus system, with static load modeling, which RED results have good voltage stability margin compared with other cases having different generator sharing as per table 7.1.

The loss for the RED case is very low and also voltage deviation & L-index also low for this case, where as MSV being highest.

Losses raised, MSV,L-index and V_e increased compared to the results without load modeling or normal load flow.

Case Study with 30 Bus Three Generator System

To the 30 bus system studied in the previous chapters, a third generator is added. All the computations are performed for the 2 generator system are repeated for three generator 30 bus system without any static load model I.e, constant P,Q.

Table14 generation rescheduling at different powers with voltage stability indices for generator at nodes1, 2 & 9

S.No	P1	P2	P3	Pgen	Pload	Ploss
1	30	105	157.000	292.000	285.2	6.800
2	40	105	146.983	291.983	285.2	6.783
3	29.68	113.416	148.86	291.96	285.2	6.763
4	20	115	157.001	292.001	285.2	6.801
5	40	115	136.987	291.987	285.2	6.787
6	30	125	136.973	291.973	285.2	6.773
7	40	125	127.044	292.044	285.2	6.844

At P2=96.3541, the generation is a minimum and the losses are also minimum. Further from the above table 7.1 it can be concluded that the point above the optimum i.e., results in bold letters, which is the direct result from Relative Electrical Distance is as shown above. In this the results above and below the optimum value will have greater loss in power. Further the voltage stability parameters also it can be observed that voltage deviation, L-indices and Minimum Singular Value were having the least values compared with the others. It is clear that there is an improvement in parameters Ve, L-indices and MSV. It is to be noted that the higher values are due to the increase in total load from 298MW to 304.88MW. It means that, if load sharing/generation were scheduling deviates from desired sharing/generation scheduling, then the system will move

away from the secure operating condition. Hence, in the proposed approach, while relieving the overloaded lines, the generators should re-scheduled so that the system will move towards the desired operating condition.

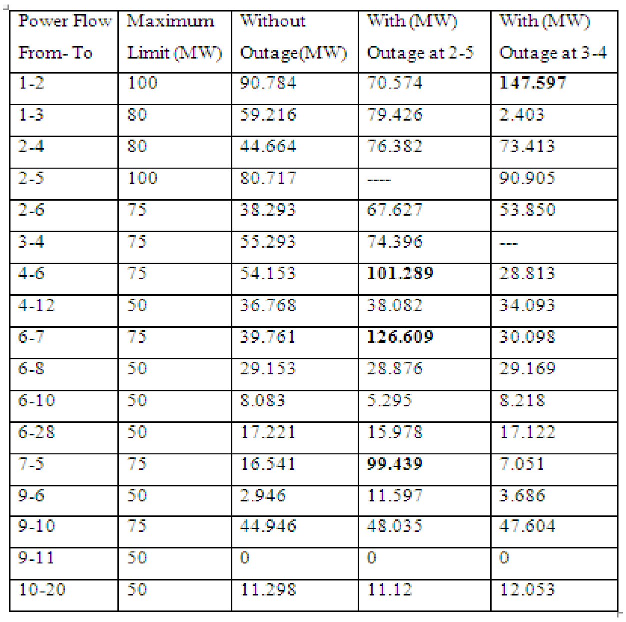
Case Study with 30 Bus Three Generator System with a Single Line Outage

In the 30 Bus system with three generators and outage of any line, then the power flow through that line will zero. Therefore, the power from the generator(s) has to go to the loads via other lines making some lines over loaded and other getting under loaded.

When a line is overloaded, there will be a decrease in voltage compared to pre-outage condition. In such a condition, the power transfer through that line may exceed its carrying capability (Load Transfer capability). Therefore, there is a necessity for the line to relieve from overloading. To relieve the line from over loading and to improve the voltage, some methods are essential.

If the line cannot be relieved from overloading by any means, then the shedding part of the load or in full may be required.

Table15 power flow in the respective line when an outage occurs

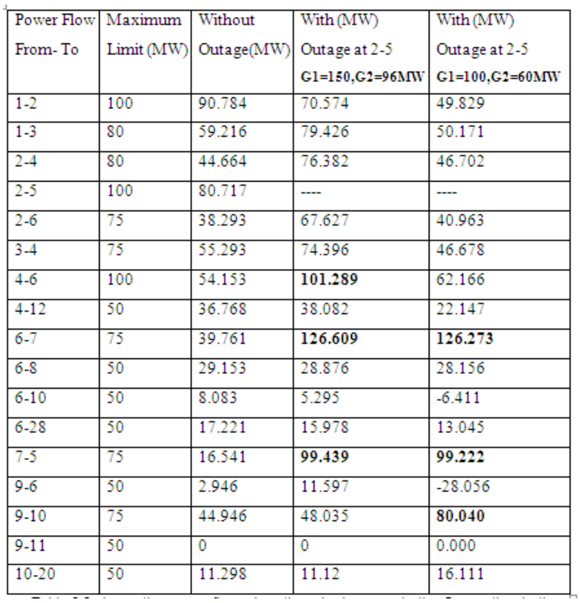


Power Flow From- To	Maximum Limit (MW)	Without Outage(MW)	With (MW) Outage at 2-5	With (MW) Outage at 3-4
1-2	100	90.784	70.574	**147.597**
1-3	80	59.216	79.426	2.403
2-4	80	44.664	76.382	73.413
2-5	100	80.717	----	90.905
2-6	75	38.293	67.627	53.850
3-4	75	55.293	74.396	---
4-6	75	54.153	**101.289**	28.813
4-12	50	36.768	38.082	34.093
6-7	75	39.761	**126.609**	30.098
6-8	50	29.153	28.876	29.169
6-10	50	8.083	5.295	8.218
6-28	50	17.221	15.978	17.122
7-5	75	16.541	**99.439**	7.051
9-6	50	2.946	11.597	3.686
9-10	75	44.946	48.035	47.604
9-11	50	0	0	0
10-20	50	11.298	11.12	12.053

The above table 15 depicts the line flow with and without outage. In this table, the lines that were having influence because of outage were tabulated and other line flows were not. If we consider the line outage at 2-5 line, lines 1-3, 2-4 had increased line flows and lines 4-6, 6-7 and 7-5 were over loaded, where as for the outage at line 3-4, line 1-2 was overloaded. If we decrease or increase the generation at generating buses, the effect on line flow can be studied. Therefore, if we apply Sensitivity Test for the outage at line 2-5, i.e., decreasing the generations at G1 and G2 from 150, and 96MW to 100 and 60MW, there was an obvious increase in the other bus (slack bus) generation. This resulted in line flow readjustment.

From the table 9.3 the overloading in the lines (6-7 & 7-5) decreases as the load at node 5 was decreased from 94.2MW to approximately 50% (49.3MW) with generation at G1=150 and G2=96MW. When the load at node 5 decreased to 70MW from 94.2MW, the power flow in line 7-5 was 72.8. Therefore, this line was relieved from overload.

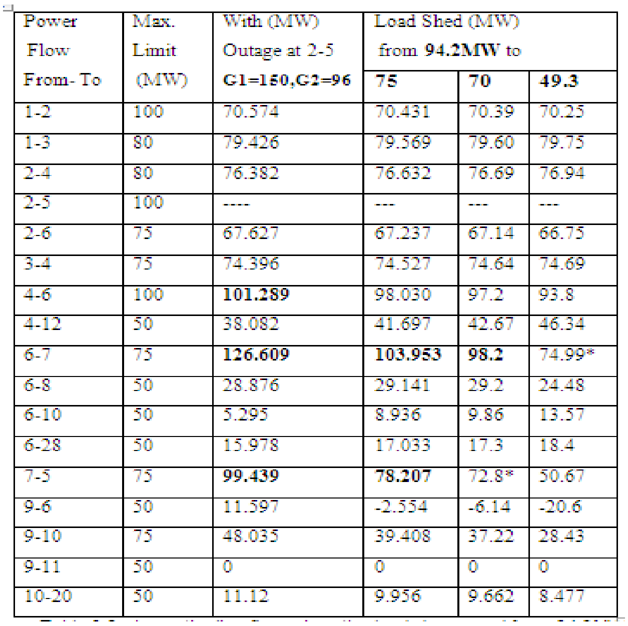
Table 16 shows the power flow when there is decrease in the Generation in the generators G1 and G2.



Power Flow From- To	Maximum Limit (MW)	Without Outage(MW)	With (MW) Outage at 2-5 G1=150,G2=96MW	With (MW) Outage at 2-5 G1=100,G2=60MW
1-2	100	90.784	70.574	49.829
1-3	80	59.216	79.426	50.171
2-4	80	44.664	76.382	46.702
2-5	100	80.717	----	----
2-6	75	38.293	67.627	40.963
3-4	75	55.293	74.396	46.678
4-6	100	54.153	**101.289**	62.166
4-12	50	36.768	38.082	22.147
6-7	75	39.761	**126.609**	**126.273**
6-8	50	29.153	28.876	28.156
6-10	50	8.083	5.295	-6.411
6-28	50	17.221	15.978	13.045
7-5	75	16.541	**99.439**	**99.222**
9-6	50	2.946	11.597	-28.056
9-10	75	44.946	48.035	**80.040**
9-11	50	0	0	0.000
10-20	50	11.298	11.12	16.111

Similarly, further decrease in the load from 70 to 49.3MW, all the lines including line 6-7. All the lines were allievated from overload at this load of 49.3MW.

Table 17 shows the line flow when the load decreased from 94.2MW

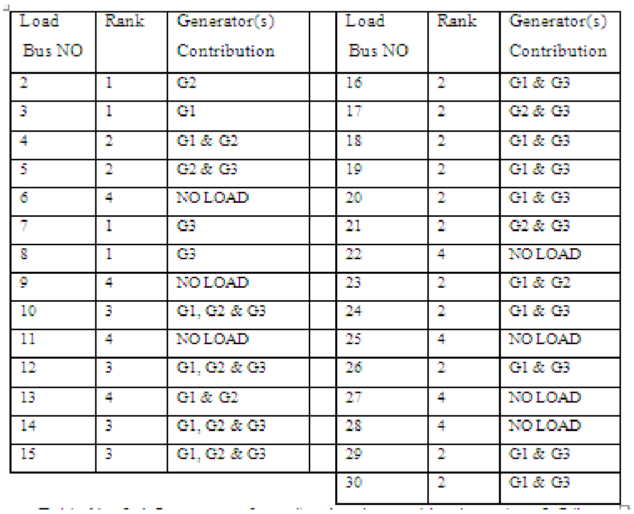


Power Flow From- To	Max. Limit (MW)	With (MW) Outage at 2-5 G1=150,G2=96	Load Shed (MW) from 94.2MW to		
			75	**70**	**49.3**
1-2	100	70.574	70.431	70.39	70.25
1-3	80	79.426	79.569	79.60	79.75
2-4	80	76.382	76.632	76.69	76.94
2-5	100	----	---	---	---
2-6	75	67.627	67.237	67.14	66.75
3-4	75	74.396	74.527	74.64	74.69
4-6	100	**101.289**	98.030	97.2	93.8
4-12	50	38.082	41.697	42.67	46.34
6-7	75	**126.609**	**103.953**	**98.2**	74.99*
6-8	50	28.876	29.141	29.2	24.48
6-10	50	5.295	8.936	9.86	13.57
6-28	50	15.978	17.033	17.3	18.4
7-5	75	**99.439**	**78.207**	72.8*	50.67
9-6	50	11.597	-2.554	-6.14	-20.6
9-10	75	48.035	39.408	37.22	28.43
9-11	50	0	0	0	0
10-20	50	11.12	9.956	9.662	8.477

Contingency ranking

The approach for contingency ranking is applied on a IEEE system of a 30-bus, as shown in Fig. 3. The system has 2 generator buses and 28 other buses. The system has 4 tap regulating transformers, and 30 transmission lines. The system total peak load is about 50MW at node 5, 30MVAR at node 8. There are shunt reactors connected at various buses for transient-overvoltage protection. The ranking of all the line outage contingencies, using the approach proposed in previous Section, is given in Table 18.

Table No: 18 Summary of results showing ranking based on 2-5 line outage Most severe contingencies in each zone



Load Bus NO	Rank	Generator(s) Contribution
2	1	G2
3	1	G1
4	2	G1 & G2
5	2	G2 & G3
6	4	NO LOAD
7	1	G3
8	1	G3
9	4	NO LOAD
10	3	G1, G2 & G3
11	4	NO LOAD
12	3	G1, G2 & G3
13	4	G1 & G2
14	3	G1, G2 & G3
15	3	G1, G2 & G3
16	2	G1 & G3
17	2	G2 & G3
18	2	G1 & G3
19	2	G1 & G3
20	2	G1 & G3
21	2	G2 & G3
22	4	NO LOAD
23	2	G1 & G2
24	2	G1 & G3
25	4	NO LOAD
26	2	G1 & G3
27	4	NO LOAD
28	4	NO LOAD
29	2	G1 & G3
30	2	G1 & G3

Since most of the contingencies may not threaten system security/stability, those contingencies that pose serious system security/stability are selected. A set of most severe contingencies in each zone, in the order of severity, is identified which needs additional supporting devices. Based on the above set of network contingencies, a few transmission lines are considered. Least rank has maximum sevierity due to any line outage and vice-versa. Nodes 2, 3, 7 & 8 having Rank 1 may have maximum sevierity and stability influence compared to other lines. As there are three generators, the maximum ranking will be three. But there are some nodes having no-load, so these nodes were represented by 4 means have no or less impact due to line outage.

Getting optimal solution and voltage stability limits for any network using RED is time saving, efficient and simple in programming. Relieving of lines which were overloaded because of line outage may be very easy using RED based generation re-scheduling. We can easy get the stability margin using this RED technique.

It is shown for 30 bus system, calculated RED results have good voltage stability margin compared with other cases having different generator sharing. For cases with single line outage for 30 bus system, over load relieving was done by generation rescheduling by increasing or decreasing generation (GI or GD). If generation rescheduling alone doesn’t work, load shedding was also implemented as a last resort for overload relieving of lines.

IV CONCLUSIONS

Using RED concept we can directly compute optimum value where as using optimal load flow techniques determining optimum value is time consuming. It can be concluded that the voltage deviation, L-Indices and Minimum Singular Value are both the least for optimum Generation than for any other value.It can be clearly found that there is an improvement in the voltage stability parameters, if the generation scheduling is as per Dlg matrix compared to other possible combinations of Generator scheduling. Performance with the Static Load Model is compared to system with constant power model.

Only the diagonal elements of sub matrices J2 and J4 get changed with the assumed Static Load Model. The solution was obtained by modified NR method. The influence of changing position of generation with in network is determined and tabulated. In this case, even if there is considerable change in generation scheduling, not much change occurred in other computed results. It can be concluded that the line losses depends on R/X parameters and the generators distance from load(s). Changing generation scheduling in case of line overloading due to line or component outages is useful to some extent sensitivity of line flows with generation buses will be an useful exercise in their case. Load shudding is the last resort in case of serious line analysis

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