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Improvement of Power System Stability Margins using real power scheduling under normal and network contingencies

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Abstract: Power system planning and operation in present day are more in favour of economic factors and less in terms of technical aspects such as: system security, reliability and stability analysis. Case in point being: the generator scheduling or the pattern in load sharing among the various generators forms a major part in power system planning. Scheduling primarily based on economic criteria, essentially means power contracts that favour cheaper generators, tend to lead to heavy flows, resulting in greater losses threatening stability and security and also leading to lower reserve margins making the system less reliable and thus making such generation patterns undesirable. Such patterns may be economically viable, but with increasing load on existing transmission systems, the problem of voltage stability and voltage collapse become a major concern. In this paper, a fresh approach to generator scheduling, from the transmission system point of view, is based on the generator-load location (Relative Electrical Distance concept). Also, a new network sensitivity index known as L-Index and minimum singular value [MSV] are used as the basis to analyse the improvement in the voltage stability of the system under both normal and line contingency conditions. Detailed case studies with base case and optimized results for practical Indian power systems of 25 bus and 30 bus are presented.

Keywords: generator scheduling, voltage stability, relative electrical distance.

1. Introduction

The concepts of Relative Electrical Distance (RED),voltage stability index and the L-Index [1]are used to develop a desirable load sharing model of the generators as Desired Proportions of Generation (D_{PG}) to improve system stability margins. It is a known fact that unlike the present, earlier power systems were self-sufficient islands to match generation and load, and had a good system wide planning for reserve margins and adequate transmission and reactive power capabilities. However, present day systems have developed as a large interconnected grid to take advantage of the integrated operation for both technical and economic factors. Although interconnection has great advantage to each individual system, being a competitive market, power contract agreements are entered based on cost economics with an aim to transact with the cheapest generator available in the connected grid. This may not always be the desired approach as it may lead to transmission bottlenecks. In essence, maintaining voltage stability in the current stressed power systems is a concern. Thus, though cost economics is important, system security has to be given highest priority while the capability of the transmission network and the losses incurred have to be considered. This paper presents the most desirable way to schedule generators under both normal and contingency conditions to ensure better system security, better voltage profiles and also minimize transmission losses.

2. Voltage Stability Index (L-index)

The proposed static voltage stability L-index[1] for on-line application is based on normal load flow solution. The authors have shown that the value of this L-index lie within unity, with L-index ranging from ‘0’ at no load on the system to ‘1’ at static voltage stability limit. The value of L-index is computed for each load bus in the system. The bus having the maximum value of the L-index is the weakest bus in the system. The stability margin for the system in this case is obtained as a distance of maximum L-index from the unity value, i.e. (1-L). The values of L-index of individual buses are useful in identifying voltage critical buses. The advantage of this method lies in the simplicity of numerical calculations and the expressiveness of the result. Consider a system having n=total number of buses, with 1,2,….,g generator buses (g), g+1,g+2,…,(g+s) Switchable VAr Compensators(SVC)buses(s), g+s+1,g+s+2,…..,n the remaining buses ($r = n - g - s$) and ‘t’ number of OLTC transformers.
For a given system operating condition, using load flow results, the voltage stability,

L-index is computed as

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \quad (2.1)$$

Where j=g+1….n, and all the terms within the sigma on the right hand side are complex quantities and 'g'=number of generators. The values of F_{ji} are obtained from the Y-bus matrix formulated from the network. For a given operating condition,

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (2.2)$$

Where I_G, I_L, V_G and V_L represent complex current and voltage vectors at the generator nodes and load nodes. The sub-matrices$[Y_{GG}]$,$[Y_{GL}]$,$[Y_{LG}]$ and $[Y_{LL}]$ are the corresponding partitioned portions of the Y-bus matrix of the network. That is,

$$[I_G] = [Y_{GG}][V_G] + [Y_{GL}][V_L]$$
$$[I_L] = [Y_{LG}][V_G] + [Y_{LL}][V_L]$$

Rearranging the above equation

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (2.3)$$

Where $[F_{LG}] = -[Y_{LL}]^{-1}[Y_{LG}]$ (2.4)

The L-index equation for the j^{th} node can be written as,

$$L_{j=} \left| 1.0 - \sum_{i=1}^{i=g} \frac{V_i}{V_j} \left(F_{ji}^{r} + F_{ji}^{im} \right) \right| \quad (2.5)$$

There are different methods such as PV curves, Z-Index, etc to determine the static voltage stability of the system or to check the vulnerability of a bus tending towards instability. Most of these methods give a general picture of the proximity of the system from voltage collapse point, whereas the L-Index gives a scalar number to each load bus indicating its proximity from collapse point. The state estimation results, the L-Index value computed at a load bus is given as,

$$L_j = \left| 1 - \sum_{i=1}^{i=g} F_{ji} * \frac{Vi}{Vj} \right|_{j=g+1 \text{ to } n} \quad (2.6)$$

n = total number of buses in the system

g = total number of generator buses, F_{ji} are the corresponding complex elements of the F_{LG} matrix from network Y_{bus} matrix. V_k is the complex voltage at the node k. The L-Index for a given load condition is computed for all load buses. It uses transmission network information for ease in computation, and for consistency in results. In this paper uses L-Indices as stability improvement. The L-Index value closer to zero indicates greater stability margin and near to 1.0 indicates that most vulnerable for voltage collapse. The real power contributed by various sources is evaluated based on Relative Electrical Distances using F_{LG} values.

3.1Computation of Desired proportion of generation [D_{PG}] and Relative Electrical Distance[R_{ED}] matrices

The [F_{LG}] matrix from equation(2.3) gives the relation between the load bus and the generator bus distance and forms the basis for evaluation of desirable generator scheduling. From the system security point of view, the load must predominantly be met by the nearest generator of sufficient size. The concept of RED is derived from the transmission network admittance matrix. The equation (2.1) can be written as:

$[I_G] = [Y_{GG}][V_G] + [Y_{GL}][V_L]$ (2.7)
$[I_L] = [Y_{LG}][V_G] + [Y_{LL}][V_L]$ (2.8)

From Equation (2.8):

$[Y_{LL}]^{-1}[I_L]=[Y_{LL}]^{-1}[Y_{LG}][V_G]+[V_L]$ (2.9)
$[V_L]=[Y_{LL}]^{-1}[I_L]-[Y_{LL}]^{-1}[Y_{LG}][V_G]$ (2.10)

Substituting equation (2.10) intoequation (2.7), and generator current is given by,

$[I_G] = [Y_{GG}][V_G] + [Y_{GL}]\{[Y_{LL}]^{-1}[I_L] - [Y_{LL}]^{-1} [Y_{LG}][V_G]\}$ (2.11)

Equations (2.10) and (2.11) can be rewritten as:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (2.12)$$

Where $[F_{LG}] = -[Y_{LL}]^{-1}[Y_{LG}]$
$[K_{GL}] = [Y_{GL}][Y_{LL}]^{-1}$ &
$[Y_{GG}] = \{[Y_{GG}] - [Y_{GL}][Y_{LL}]^{-1}[Y_{LG}]\}$ (2.13)

F_{ji} are complex elements of the F_{LG} matrix, its columns correspond to the generator bus number and the rows correspond to the load bus number. Also, the sum of each row is close to (1, 0). The absolute value of each element indicates the proportion of load to be met by the corresponding column's generator and Desired Real Power $[D_{PG}]$and it is given computed by

$[D_{PG}] = \text{abs}\{ [F_{LG}] \}$ (2.14)

Mathematically, Desired Generation Schedule $[D_{GS}]$ at G^{th} generator bus is computed using equation (2.15).

$$[D_{GS}]_{G^{th}} = \sum_{j=g+1}^{n} ([D_{jG}] \text{ X } [P_j]) \quad (2.15)$$

Where $[P_j]$ is the load at j^{th} bus and values of $[D_{JG}]$ are taken from $[D_{PG}]$.This gives the Desired Generation Schedule (D_{GS}) for a given load condition. State estimation results based on this D_{GS} shows improved stability margins and voltage profiles under normal conditions and line outage contingencies. The relative location of load nodes with respect to generator nodes is computed as,

$[R_{ED}] = [M] – [D_{PG}]$ (2.16)
Where [M] is a unit matrix of size [LxG].

3.2 Evaluation of real generation schedule considering transmission losses of the system

After the generators are scheduled as per Required Generation Schedule(R_{GS})for a given load and voltage, the current at load buses are computed by using equation

$[V_L] = [Z_{LL}][I_L]+[F_{LG}][V_G]$ (2.17)

L=No. of load buses & G=No. of generator buses.$[V_G]$, $[V_L]$ and $[I_L]$ are obtained from the state estimation. The load bus current values of $[I_L]$ vector are represented as a diagonal matrix and its complex conjugate is taken. Pre-multiplying equation (2.17) by the conjugate of load current matrix, $[I^*_L]$,

$[I^*_L][V_L] =[I^*_L][Z_{LL}][I_L]+[I^*_L][F_{LG}][V_G]$ (2.18)

Each term in equation (2.18) can be interpreted in complex power form as,

$[S^{load}]_{Lx1}= [S^{Loss\text{-}contb}]_{Lx1}+[S^{Gen\text{-}contrb}]_{Lx1}$ (2.19)

The real part of the equation (2.19) is given by

$[P^{load}]_{Lx1}=[P^{Loss\text{-}contb}]_{Lx1}+[P^{Gen\text{-}contrb}]_{Lx1}$ (2.20)

Each element of $[P^{Loss\text{-}contb}]$,matrix is a negative quantity. The dimension of $[P^{Gen\text{-}contrb}]$is fragmented into L x G matrix by multiplying with the $[F_{LG}]$ matrix. Therefore, each fragment of $[P^{Gen\text{-}contrb}]_{Lx\,G}$ gives the contribution of generator in the G^{th} column to meet the "load and losses" due to L^{th} load bus. Sum of each column gives the Desired Generator Scheduling (D_{GS}) for each generator to improve the system stability margin and voltage profile.

4. Case Study

The developed approach is tested on 25-bus Indian power system and IEEE modified 30 bus systems.

4.1 25 Bus Indian Equivalent EHV Power System Network

To illustrate the proposed method of load sharing/generation scheduling, the practical Indian 25 bus power system is considered. It consists of 4 generators, 21 load buses and 28 transmission lines. Static VAR compensators are at 4 buses and shunt loads connected to 12 buses. It's single line diagram is shown in Figure 1.

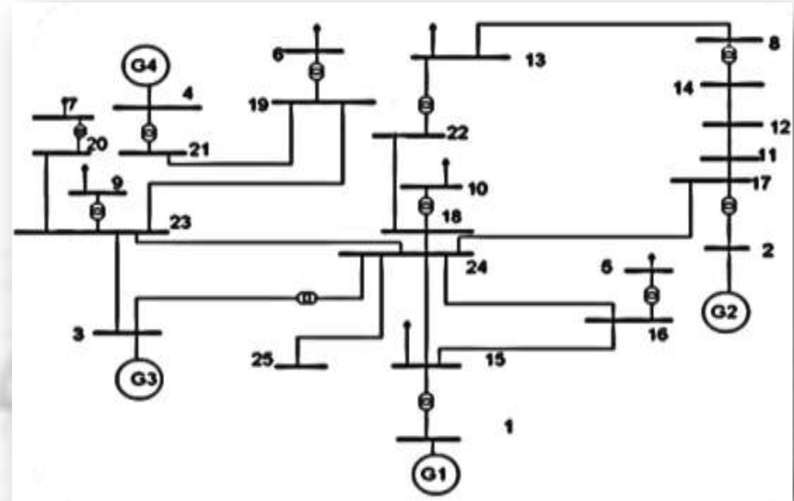

Figure 1: Single Line Diagram of 25 busIndian practical system

4.1.1 Under Normal Conditions

The [F_{LG}] matrix computed for the 25 bus system is shown in Table 1. It can be observed from Table 1 that the sum of each row element in the matrix is close to (1, 0). The real power schedule of generation is always approximately equal to load demand and it is computed by taking the absolute values of [F_{LG}], which is the[D_{LG}]matrix given in Table 2.

Table 1: F_{LG} computed for 25 bus Indian power system network

Load Bus NO:	Generator 1	Generator 2	Generator 3	Generator 4
5	0.5535 + 0.0006i	0.0789 + 0.0004i	0.3335 - 0.0050i	0.0857 + 0.0006i
6	0.1349 + 0.0036i	0.0838 - 0.0004i	0.1771 - 0.0010i	0.6770 - 0.0071i
7	0.1713 + 0.0037i	0.0789 - 0.0000i	0.2249 - 0.0023i	0.5963 - 0.0063i
8	0.2166 + 0.0044i	0.2237 - 0.0075i	0.2843 - 0.0034i	0.4008 - 0.0040i
9	0.2769 + 0.0042i	0.1156 - 0.0007i	0.3633 - 0.0061i	0.3488 - 0.0055i
10	0.2945 + 0.0039i	0.1322 - 0.0011i	0.3864 - 0.0073i	0.2911 - 0.0036i
11	0.1826 + 0.0049i	0.5131 - 0.0100i	0.2397 - 0.0013i	0.1680 -

				0.0016i
12	0.1931 + 0.0046i	0.4598 - 0.0098i	0.2535 - 0.0021i	0.2209 - 0.0027i
13	0.2193 + 0.0041i	0.1819 - 0.0016i	0.2879 - 0.0039i	0.4293 - 0.0076i
14	0.2119 + 0.0042i	0.2894 - 0.0069i	0.2782 - 0.0034i	0.3553 - 0.0049i
15	0.8413 - 0.0046i	0.0286 + 0.0010i	0.1209 + 0.0017i	0.0310 + 0.0011i
16	0.5535 + 0.0006i	0.0789 + 0.0004i	0.3335 - 0.0050i	0.0857 + 0.0006i
17	0.1689 + 0.0055i	0.5752 - 0.0108i	0.2218 + 0.0001i	0.1027 + 0.0008i
18	0.2945 + 0.0039i	0.1322 - 0.0011i	0.3864 - 0.0073i	0.2911 - 0.0036i
19	0.1346 + 0.0036i	0.0836 - 0.0003i	0.1767 - 0.0010i	0.6755 - 0.0071i
20	0.1713 + 0.0037i	0.0789 - 0.0000i	0.2249 - 0.0023i	0.5963 - 0.0063i
21	0.0919 + 0.0033i	0.0515 +0.0004i	0.1207 +0.0004i	0.7911 - 0.0074i
22	0.2213 + 0.0042i	0.1488 - 0.0019i	0.2905 - 0.0039i	0.4515 - 0.0071i
23	0.2769 + 0.0042i	0.1156 - 0.0007i	0.3633 - 0.0061i	0.3488 - 0.0055i
24	0.3579 + 0.0047i	0.1111 + 0.0001i	0.4697 - 0.0089i	0.1207 + 0.0004i
25	0.1350 + 0.0036i	0.0839 - 0.0004i	0.1772 - 0.0010i	0.6777 - 0.0073i

The [D_{LG}] matrix in Table2, gives the relative proportions in which load demand at that particular load bus (row) is split among the 4 different generators. For example, for load bus 19, percentage of real power received from generators G1, G2, G3 and G4 are 13.46%, 8.36%, 17.67% and 67.55% respectively.

Table 2: Relative proportions of generation based on F_{LG}

Load bus No:	Gnerator 1	Generator 2	Generator 3	Generator 4
5	237.9847	33.9168	143.3908	36.8295
6	37.7628	23.4650	49.5772	189.5711
7	54.8217	25.2510	71.9621	190.8091
8	38.9805	40.2669	51.1655	72.1407
9	33.2226	13.8718	43.6007	41.8523
10	17.6677	7.9298	23.1853	17.4634
13	98.6915	81.8627	129.5350	193.1843
15	656.1845	22.2868	94.2753	24.1988
25	5.3996	3.3552	7.0889	27.1061
Summation of Column, P_{G}, MW	1180.71	254.20	613.78	793.15

The new P_g values of the 4 generators are obtained as shown in Table3and state estimation is carried out for these new values. The final DGS is found by factoring the losses and estimating the load and loss sharing contribution among the 4 generators.

Table 3: RGS under base case with transmission losses

Load bus No:	G1	G 2	G 3	G4
5	236.5626	33.7142	142.5339	36.6094
6	38.3534	23.8320	50.3525	192.5358
7	54.7252	25.2066	71.8355	190.4735
8	36.0220	37.2108	47.2823	66.6656
9	31.9230	13.3292	41.8952	40.2151
10	17.0568	7.6556	22.3836	16.8595
13	91.4265	75.8365	119.9995	178.9634
15	650.6730	22.0996	93.4835	23.9956
25	5.1682	3.2114	6.7851	25.9445
Summationofeach column, P_G	1161.91	242.09	596.55	772.26

The introduction of RPG improves voltage magnitude and voltage stability indices and it is shown in Table4.Theoverall improvement of the system with respect to performance parameters is given in Table 6.

Table 4: Bus voltages and voltage stability indices at each load bus

Sl.No	Without RPG		With RPG	
Load Bus No:	Bus Voltage (p.u)	L-Index	Bus Voltage (p.u)	L-Index
5	0.9179	0.3144	0.9333	0.3075
6	0.8575	0.4482	0.8581	0.4455
7	0.8516	0.4603	0.8578	0.4542
8	0.8469	0.5513	0.8627	0.5354
9	0.9009	0.3732	0.9193	0.3632
10	0.9044	0.3520	0.9239	0.3423
11	0.9685	0.2016	0.9801	0.1980
12	0.9532	0.2696	0.9671	0.2636
13	0.8427	0.5507	0.8580	0.5353
14	0.8768	0.4719	0.8932	0.4585
15	0.9694	0.0912	0.9781	0.0906
16	0.9422	0.2069	0.9571	0.2034
17	0.9861	0.1211	0.9941	0.1198
18	0.9148	0.3179	0.9342	0.3096
19	0.8878	0.3436	0.8883	0.3412
20	0.8840	0.3541	0.8899	0.3498
21	0.9372	0.2058	0.9347	0.2051
22	0.8716	0.4470	0.8857	0.4361
23	0.9227	0.3042	0.9406	0.2970
24	0.9655	0.1465	0.9786	0.1448
25	0.8531	0.4603	0.8537	0.4577

From Table5, it is observed that there is an improvement in Minimum Singular Value (MSV) from 0.717066 to 0.871918. The percentage change of transmission loss is quite appreciable. The maximum voltage stability index decreases from 0.551255 to 0.535390. The reduction in the sum of squared value of voltage deviations at all load buses (V_e)and sum of squared value of L-Indices of all load buses (L_i)is observed.

Table 5: Overall System Parameters with and without RPG

Generator P_g in MW	Without RPG				With RPG			
	G1	G2	G3	G4	G1	G2	G3	G4
	1820.0	160.0	350.0	520.0	1161.91	242.09	596.55	772.26
MSV	0.717066				0.871918			
Transmission Loss	67.926430 MW				51.150295 MW			
% power Loss	2.38%				1.84%			
V_{min} (p.u)	0.842732 (bus no: 8)				0.853745 (bus no: 8)			
L_{max}	0.551255 (bus no: 8)				0.535391 (bus no: 8)			
V_e	0.221550				0.182990			
L_i	4.450239				4.398553			

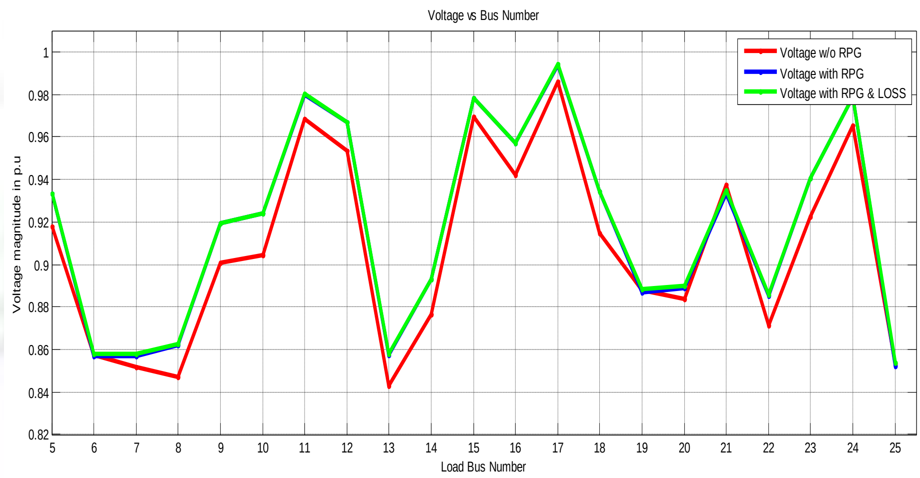

Figure 2: Variation of Voltage Profile at every load bus of the system

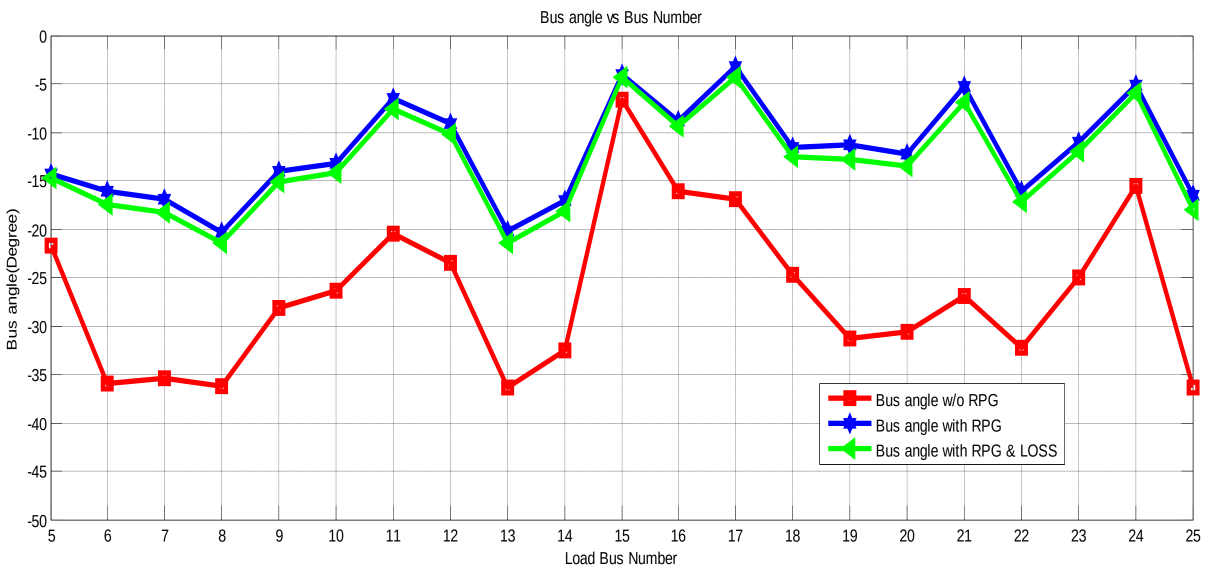

Figure 3: Variation of bus angle at load buses

4.2: Line outage contingency analysis

The developed approach is analysed by considering selected line outage of the system. Outage of line connected between buses 15 and 16 is considered and detailed results discussed.

4.2.1: Line Outage L_{15-16}

The relative proportions of generation (R_{PG}) for the 25-bus system under line outage contingency connected between buses15 and bus 16is shown in Table 6. The RG Scomputed are considering the transmission losses of the system.

Table 6: New RPG considering the transmission losses

Load Bus No.	G 1	G 2	G 3	G4
5	127.9357	52.5843	222.2975	57.1005
6	31.9616	25.2156	55.5612	196.1633
7	45.5687	27.0466	79.2023	194.4167
8	29.9580	38.6201	52.0668	68.4763
9	26.5878	14.3891	46.2013	41.6785
10	14.2137	8.2327	24.6972	17.5944
13	76.0074	79.1851	132.0928	183.5942
15	674.8254	18.3188	77.4960	19.8902
25	4.3031	3.3948	7.4803	26.4098
$\sum P_G$	1031.36	266.99	697.09	805.32

Table 7showsthat the improved results inboth voltage stability L-Index and bus voltage magnitude byrescheduling generators as per D_{GS}.

Table 7: Variation of voltage magnitude and voltage stability indices

Sl.No	Without RPG		With RPG	
Load Bus No:	Bus Voltage (p.u)	L-Index	Bus Voltage (p.u)	L-Index
5	0.8461	0.4778	0.8790	0.4480
6	0.8370	0.4839	0.8450	0.4707
7	0.8276	0.5021	0.8436	0.4834
8	0.8148	0.6111	0.8452	0.5738
9	0.8681	0.4217	0.9021	0.3972
10	0.8701	0.4012	0.9061	0.3770
11	0.9463	0.2264	0.9677	0.2167
12	0.9279	0.3006	0.9532	0.2859
13	0.8108	0.6107	0.8406	0.5741
14	0.8456	0.5234	0.8763	0.4922
15	0.9600	0.0816	0.9752	0.0809
16	0.8733	0.3463	0.9048	0.3267
17	0.9681	0.1393	0.9839	0.1346
18	0.8810	0.3638	0.9165	0.3426
19	0.8682	0.3728	0.8759	0.3623
20	0.8611	0.3883	0.8763	0.3744
21	0.9242	0.2219	0.9259	0.2173
22	0.8412	0.4967	0.8690	0.4696
23	0.8908	0.3464	0.9238	0.3277
24	0.9324	0.1823	0.9604	0.1747
25	0.8325	0.4968	0.8406	0.4835

Table 8: Overall System Parameters with transmission losses

	Without RPG				With RPG			
Generator P_g in MW	G1	G2	G3	G4	G1	G2	G3	G4
	1820.0	160.0	350.0	520.0	1031.36	266.99	697.09	805.32
MSV	0.501680				0.711037			
P_{Loss}	91.268878 MW				57.698125 MW			
% Power Loss	3.20%				2.06%			
V_{min} (p.u)	0.810754 (bus no:8)				0.840572 (bus no: 13)			
L_{max}	0.611125 (bus no:8)				0.574095 (bus no: 13)			
V_e	0.361315				0.252498			
L_i	5.183905				4.908532			

Table 8, shows that there is an improvement in system parameters such as Minimum Singular Value (MSV) and voltage stability L-indices with reduction in the sum of squared voltage deviations of all the load buses (V_e), and in sum of squared L-Indices of all load buses (L_i).

Figure 4 &5 is the graphical representation showing variation of voltage magnitude and voltage angle.

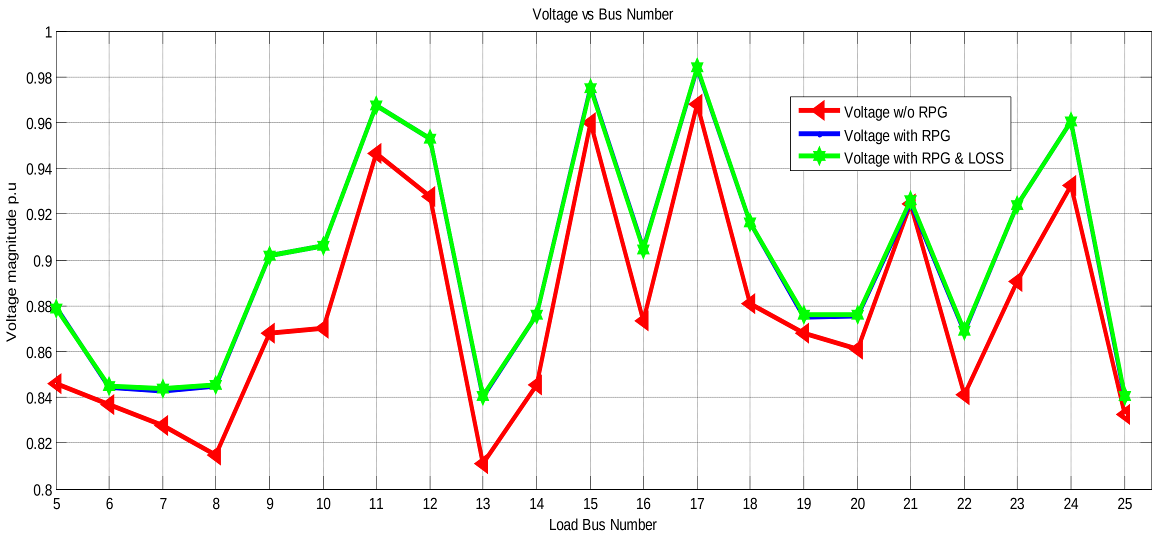

Figure 4: Variation of Voltage profile after interchange of scheduling

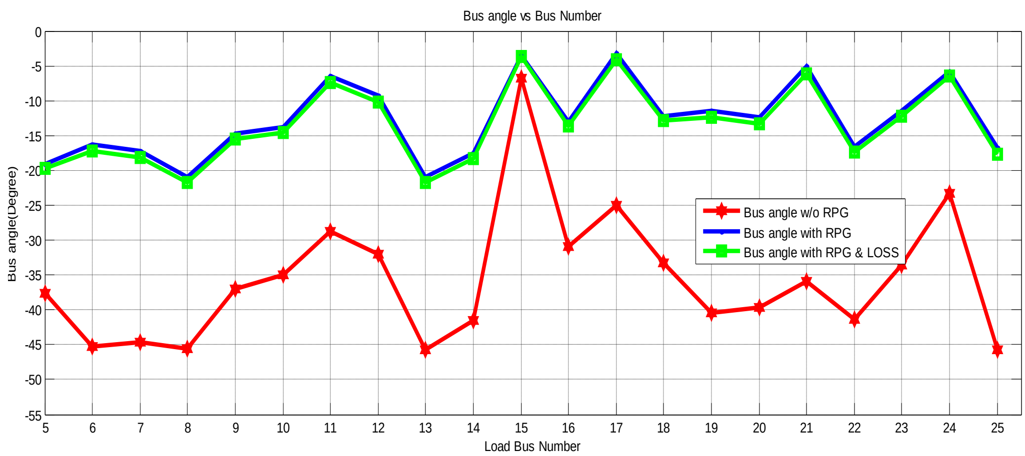

Figure 5: Variation of Voltage angle for undesired scheduling

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Case 3: Undesired Generation Schedule

The RGS is the actual value of generator schedule at any state of the system. In the previous sections generator schedule computed are used to get load flow results. In undesired generator schedule the actual desired generation schedule are schedule to other generators without considering their schedule ratings. For chosen random undesired generation schedule is shown in Table 9. The random number 1 shows the maximum transmission losses. Also the stability index L-index and MSV is more compared to other undesired schedule.

Table 9: Undesired generation rescheduling

Sl. No.	Generator Scheduling (MW)				L_{max}	MSV	Transmission Loss (MW)
	G1	G2	G3	G4			
1	242.09	596.55	772.26	1161.91	0.6386	0.8688	102.950634
2	772.26	596.55	242.09	1161.91	0.5512	0.7171	67.9264
3	1161.91	596.55	242.09	772.26	0.5596	0.8681	62.8198
4	242.09	596.55	1161.91	772.26	0.5865	0.8656	86.2658

The most desired scheduling is as per the $D_{LG,}$ with improvement in the system stability and performance parameters are within reasonable range.

4.3 Modified IEEE 30 Bus system

Under normal operation, with and without RPG, after rescheduling of real power of generation, the voltage magnitude and L-index at different load buses are given for IEEE modified 30 bus system as shown in Table 10**.**

Table 10: The L-indices and bus voltages with RPG and without RPG

Load Bus No:	Without RPG		With RPG	
	Bus Voltage (p.u)	L-Index	Bus Voltage (p.u)	L-Index
7	0.973782	0.036827	0.976038	0.036661
8	0.977898	0.026743	0.981583	0.026590
9	0.982033	0.068966	0.984051	0.068599
10	0.965853	0.129115	0.967783	0.128421
11	0.972714	0.030802	0.977651	0.030594
12	0.983054	0.083670	0.987830	0.082986
13	0.979494	0.027556	0.982429	0.027417
14	0.959497	0.122719	0.964360	0.121706
15	0.953779	0.130077	0.957671	0.129086
16	0.963673	0.117592	0.966425	0.116851
17	0.956907	0.137060	0.959339	0.136262
18	0.937920	0.162755	0.941101	0.161657
19	0.933728	0.173488	0.936537	0.172397
20	0.940436	0.164609	0.943016	0.163616
21	0.947222	0.151450	0.949392	0.150590
22	0.948639	0.149010	0.950869	0.148152
23	0.941285	0.148648	0.944845	0.147543
24	0.938288	0.154699	0.941412	0.153633
25	0.965742	0.100645	0.968583	0.100003
26	0.937437	0.134538	0.940365	0.133595
27	0.996910	0.052510	0.999321	0.052243
28	0.974631	0.041675	0.976693	0.041479
29	0.965341	0.102053	0.967841	0.101519
30	0.947163	0.135764	0.949715	0.135046

Table 11, indicates the overall improvement in system parameterssuch as Minimum Singular Value (MSV) of the modified Power flow Jacobian, reduction in total transmission loss, reduction in the sum of squared voltage deviations of all the load buses (V_e) and reduction in sum of squared L-Indices of all load buses (L_j). Figure 8 and Figure 9,show the variation of voltage magnitude and voltage angle of all load bus of the system.

Table 11: Performance parameters

	Without RPG						With RPG					
Generator P_g in MW	G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G 6
	30 0.0	40. 0	20. 0	20. 0	20. 0	20. 0	1 2.1	27.0	25.3	70.7	27.1	49.82
MSV	0.232212						0.240385					
Total Transmission Loss	9.586008						6.173516					
% Power Loss	2.28%						2.91%					
V_{min} (p.u)	0.933728						0.936537					
L_{max}	0.173488						0.172397					
V_e	0.045277						0.039848					
L_i	0.442362						0.437695					

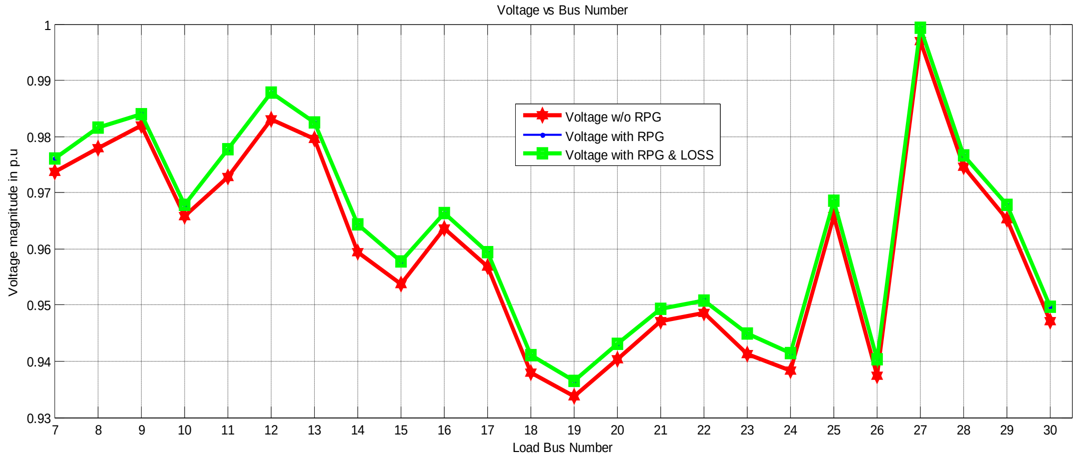

Figure 6: Variation of Voltage Profile in every load bus

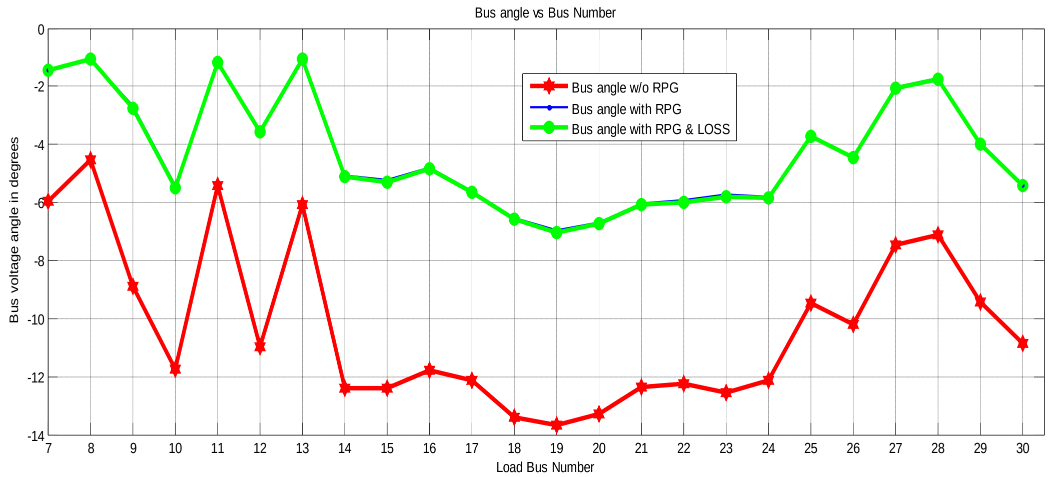

Figure 7: Variation of Voltage angle in every load bus

Therefore if the load sharing/generation schedules deviates from the desired load sharing/ generation (D_{GS}), then the system will move away from secure operating condition.

Conclusion

The main emphasis of the current work is on the technical aspects of real power scheduling in power systems. A new concept, the Relative Proportion of Generation along with the voltage stability index (L-Index) is used for determining load sharing among generators and to evaluate the system stability. It gives a simple way to improve stability margins using the existing generation and transmission facilities. It can also be used effectively under contingency conditions. The results of the practical bus systems illustrate the usage of the approach in large power systems.

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