Enhancement of Power System Stability Using Load Shedding Method

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ABSTRACT

Present day economic and environmental constraints push power system to be operated closer to their limits. A common limiting factor for power transmission is the risk of voltage instability in recent years. As the ultimate countermeasure to voltage collapse, load shedding is normally considered the last resort, when there are no other alternatives to stop an approaching voltage collapse. In this paper enhancement of voltage stability using load shedding method is studied. Different methods have been proposed to solve the load shedding problem in either the dynamic or steady state cases. According to the classification of power system states (i.e. normal, alert, emergency, extreme emergency and restorative), load shedding would be allowed under the emergency and extreme emergency states, when many system variables are out of their normal ranges, and hence the system is driven toward collapse. The main objective is to find stability of a system before load shedding and after load shedding and also to find the weak bus in a system.

KEYWORDS- voltage stability, load shedding, optimal power flow, loadability, equality constraints, inequality constraints

1. INTRODUCTION

Power system blackouts have become a serious problem for electric utilities especially in recent years. This may be in part the consequence of new restrictions imposed by power system deregulation. Due to these limitations modern power systems are operating at ever-smaller capacity and stability margins. In this situation, traditional entities involved in securing the power system have become inadequate. Recent system blackouts have occurred due to voltage instability [3].There is a tendency that power transmission systems of today are operating closer and closer to their limits. With the limiting factors of these transmission systems, it is common that the voltage of the system will be unstable. As a consequence, at least some 15 major incidents of voltage collapses occurred worldwide during the 1970s and 1980s. For example a voltage collapse in the North American Western Systems Coordinating council on July 2, 1996 resulted in service interruptions to more than 6 million people. When the necessity of electricity to industry and community in all fields of the life is considered, the importance of a blackout can be understood more easily.

The voltage stability problem is now a serious concern to the electric utility industry. Many large interconnected power systems are increasingly experiencing abnormally high or low voltages and voltage collapse. These voltage problems are associated with the increased loading of transmission lines, insufficient local reactive supply and the shipping of power across long distances. The heart of the voltage stability problem is the voltage drop that occurs when the power system experiences a heavy load and one type of serious voltage instability is voltage collapse. Voltage collapse is characterized by an initial slow progressive decline in the voltage magnitude of the power system buses and final rapid decline in the voltage.

A voltage collapse of part of the electrical system is an indication that for the existing conditions and contingencies, some portion of the combined generation and transmission system has been operated beyond its capability. Voltage collapse can also be symptoms of a much larger problem, and when the system starts to collapse, there is a real danger that the localized problem will cascade into wider areas. The purpose of proper system planning and operating philosophies is for the system to function reliably, and Failing that, to contain the impacts of disturbances to localized areas. Voltage collapse or uncontrolled loss of load or cascading may occur[1]. Therefore, in an event that the system is approaching blackout, some corrective controls need to be made. There are many methods to control voltages i.e. shunt capacitor, series capacitor, shunt reactors, synchronous condenser, static var system if these methods are failed then load shedding is another method to keep voltage stable .Load shedding; however, it should be implemented in a very careful way in order to satisfy most customers. No loads should be shed more than the necessary amount to get to the voltage back to its stability. Therefore, it is important to make the most benefit from such a drastic control action as shedding load.

Load shedding is defined as the set of controls, which results in a decrease of load in the power system in order to reach a new equilibrium state. Different methods have been proposed to solve the load shedding problem in either the dynamic or steady state cases. According to the classification of power system states (i.e. normal, alert, emergency, extreme emergency and restorative), load shedding would be allowed under the emergency and extreme emergency states, when many system variables are out of their normal ranges, and hence the system is driven toward collapse. The minimum load shedding is determined using optimal power flow equations of the power system. The dynamics associated with voltage stability are often slow, and hence static approaches may represent a good approximation. The basic idea behind this approach is to identify a feasible solution to the power-flow equations [6]. In order to design such a scheme, the following tasks are equally important recognizing the approaching of voltage collapse, determine the best load shedding locations, minimizing the amount of load shedding

2. GENERAL CONCEPT

The optimal power flow is a power flow problem in which certain controllable variables are adjusted to minimize an objective function such as cost of active power generation or losses or to maximize the loadability, while satisfying physical and operating limits on various controls, dependent variables and control of variables. The types of control that an optimal power flow must be able to accommodate are active and reactive power injections, generator voltages, transformer tap ratios and phase shift angles. In other words an optimal power flow seeks to find an optimal profile of active and reactive power generations along with the voltage in such a manner as to minimize the total operating costs of thermal electric power system, while satisfying network security constraints.

Maximize the loadability (λ) of the system,
$F=Min\ (-\lambda)$...(2.1)

Subject to
a. Active power balance in the network
$P_i(V,\delta) - P_{gi} + P_{di} = 0 \quad (i=1,2,\ldots, NB)$.....................................(2.2)

b. Reactive power balance in the network
$Q_i(V,\delta) - Q_{gi} + Q_{di} = 0 \ (i=NV+1,NV+2,\ldots, NB)$.................(2.3)

c. Security related constraints called soft constraints.
- limits on real power generations

$P_{gi}min \le P_{gi} \le P_{gi}max$ (i= 1, 2,…NG) ....(2.4)

- limits on voltage magnitudes

$V_i min \le V_i \le V_i max$ (i = NV+1, NV+2,…NB).......................(2.5)

- limits on voltage angles

$\delta_i min \le \delta_i \le \delta_i max$ (i=2,3,….NB)... (2.6)

d. Functional constraints which is function of control variables.

- limits on reactive power generations

$Q_{gi}min \le Q_{gi} \le Q_{gi}max$ (i=1,2,….,NG) ....(2.7)

- limits on active power flow on the line and reactive power flow of line can be applied.

Real Power Flow equations are

$$P_i = \sum_{i=1}^{NB} ViVj(Gij\cos(\delta i - \delta j) + Bij\sin(\delta i - \delta j)) \quad (2.8)$$

Reactive power flow equations are

$$Q_i = \sum_{\square=1}^{NB} ViVj\,(Gij\sin(\delta i - \delta j) - Bij\cos(\delta i - \delta j)) \quad (2.9)$$

Where,

NG is number of generator buses
NB is number of buses
NV is number of voltage controlled buses
P_i is active power injection into bus i
Q_i is reactive power injection into bus i
P_{di} is active load on bus i
P_{gi} is active generation on bus i
Q_{gi} is reactive generation on bus i
V_i is the magnitude of voltage at bus i
Δ_i is voltage phase angle at bus i
$Y_{ij} = G_{ij} + B_{ij}$ (are the elements of admittance matrix)

PROBLEM FORMULATION

A load shedding applied on a bus to control the magnitudes of bus voltages. The real power load and reactive power load equations are as follows:-

$P_l=P_{l0-x}\,(2*nbus-1)*P_{l0}$..(2.10)

$Q_l=Q_{l0-x}\,(2*nbus-1)*Q_{l0}$..(2.11)

3. PROPOSED METHOD

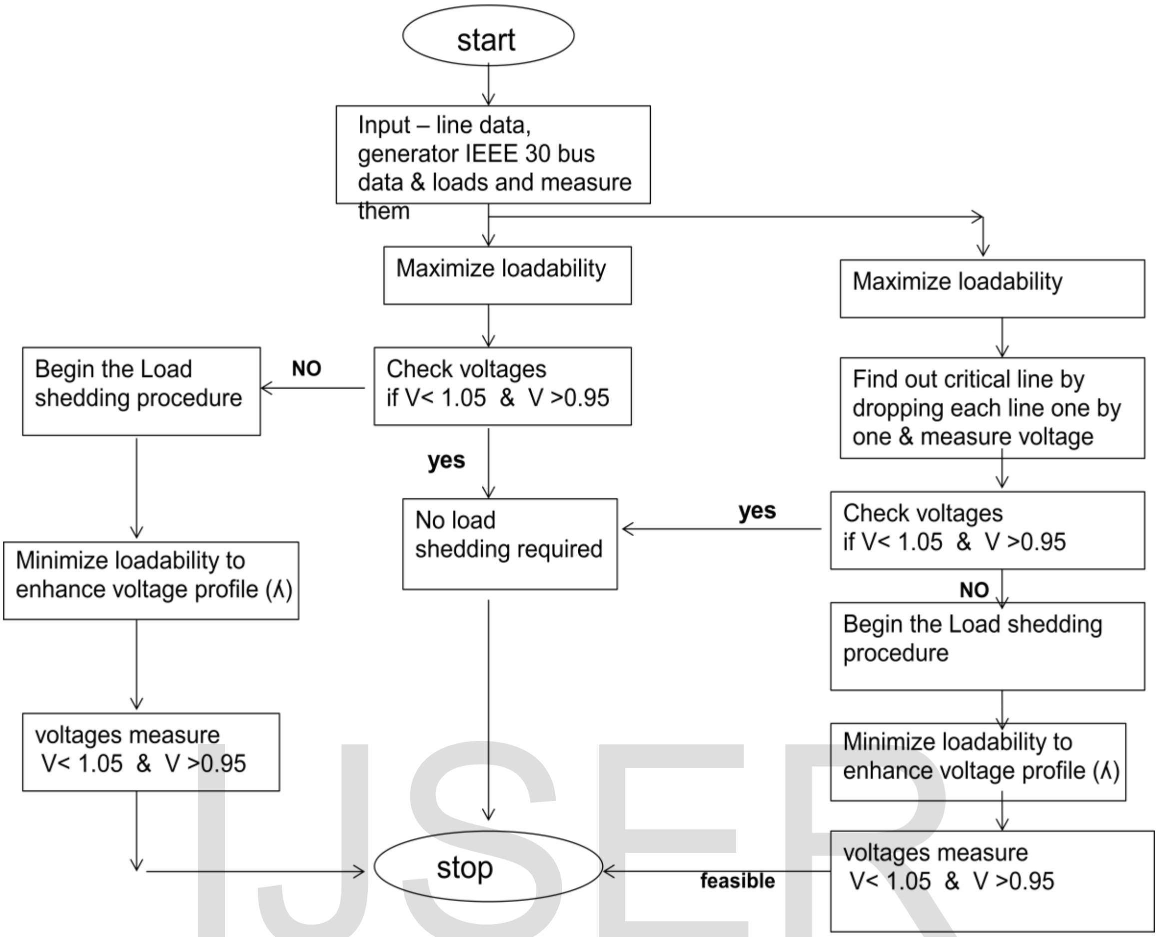


Figure 1: Flow chart for proposed method

Above flow chart explains how the desired results would be achieved. In this algorithm IEEE 30 Bus system has been taken and itsloadability has been maximized.

This data has been used in two places firstly voltages at buses is checked if voltage is less than 1.05 and greater than 0.95 then load shedding is not required if not then those buses has to undergo load shedding procedure in which loadability is minimized to enhance voltage profile, after this enhancement of voltage is measured and program is terminated.

Secondly maximized loadability data is used to find the critical lines by measurement of voltages, dropping each line one by one. Again these voltages are checked if voltage is less than 1.05 and greater than 0.95 then load shedding is not required if not then those buses has to undergo load shedding procedure in which loadability is minimized to enhance voltage profile to get feasible solution.

The main objective function is to maximize Loadability Max (ʎ), Subject to

Equality Constraints:

Power balance at each node – power flow equation

$$Pi= \sum_{i=1}^{NB} ViVj(Gij\cos(\delta i-\delta j)+Bij\sin(\delta i-\delta j))$$

$$Qi= \sum_{i=1}^{NB} ViVj\,(Gij\sin(\delta i-\delta j)-Bij\cos(\delta i-\delta j))$$

Inequality Constraints:
Network operating limits (line flow, voltages)

Table 1: Limits on control variable

No.	Inequality Constraints	Limits
1	$V_i min<V_i<V_i max$	0.95<0<1.05
2	$\delta_i min \leq \delta_i \leq \delta_i max$	0< 0< 2π
3	$P_{gi} min \leq P_{gi} \leq P_{gi} max$	1.1<0<1.6
4	$Q_{gi} min \leq Q_{gi} \leq Q_{gi} max$	-0.10<0<0.625

IEEE 30 BUS TEST SYSTEM

Below fig. 2 shows the IEEE 30 Bus test system. At the Buses 1, 2, 5,8,11 and 13 the generator is connected. The system data is taken from references. The load, transmission line and shunt capacitance data is provided in Table 2, 3 and 4 respectively. The data is on 100 MVA base.

Figure 2: IEEE 30 Bus test system

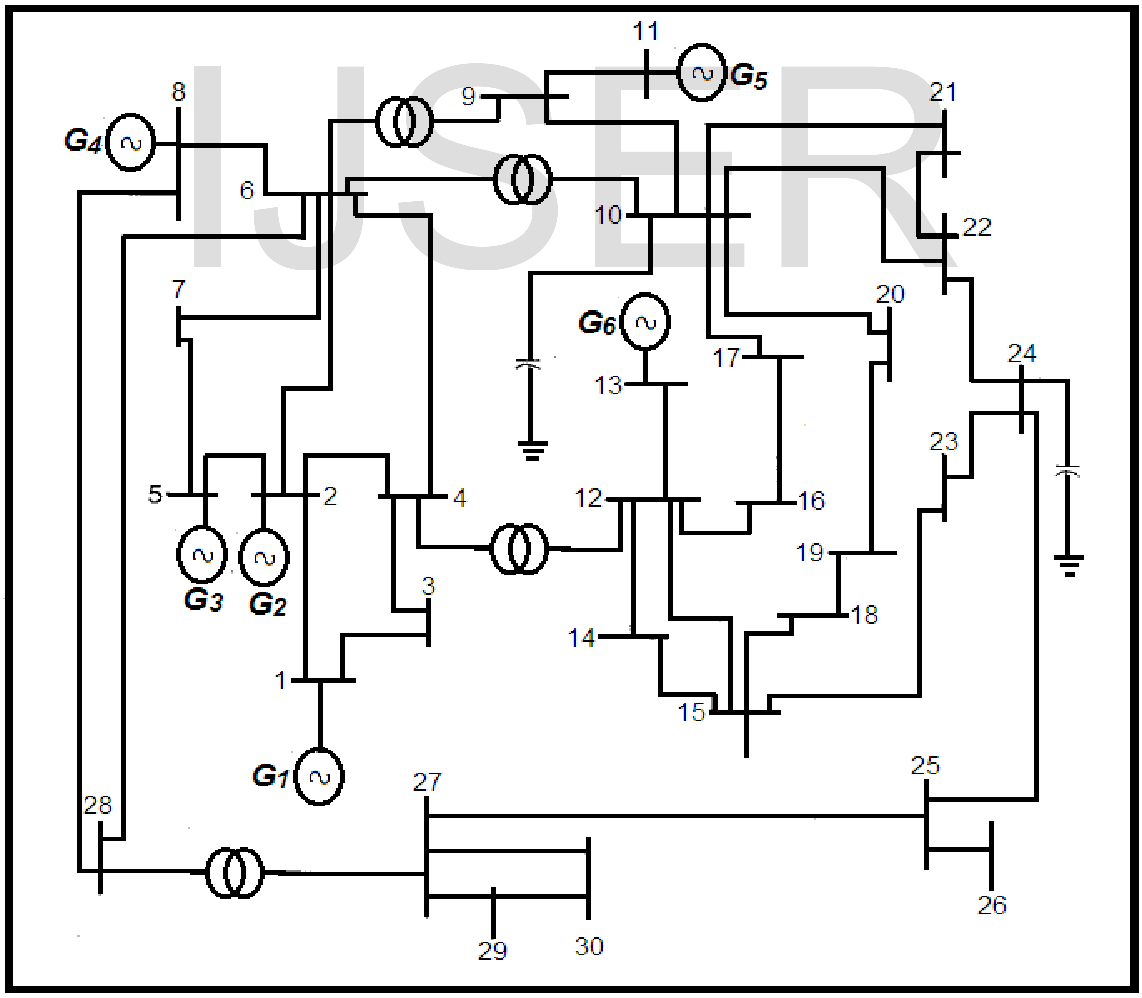


Table 2: Transmission Line Data Bus

Line no.	**From bus**	**To bus**	**Line impedence R(p.u)**	**Line impedence X(p.u)**	**Half line charging Susceptance (p.u)**	**MVA Rating**
1	1	2	0.0192	0.0575	0.0264	130
2	1	3	0.0452	0.185	0.0204	130
3	2	4	0.057	0.1737	0.0184	65
4	3	4	0.0132	0.0379	0.0042	130
5	2	5	0.0472	0.1983	0.0209	130
6	2	6	0.0581	0.1763	0.0187	65
7	4	6	0.0119	0.0414	0.0045	90
8	5	7	0.046	0.116	0.0102	70
9	6	7	0.0267	0.082	0.0085	130
10	6	8	0.012	0.042	0.0045	32
11	6	9	0	0.208	0	65
12	6	10	0	0.556	0	32
13	9	11	0	0.208	0	65
14	9	10	0	0.11	0	65
15	4	12	0	0.256	0	65
16	12	13	0	0.14	0	65
17	12	14	0.1231	0.2559	0	32
18	12	15	0.0662	0.1304	0	32
19	12	16	0.0945	0.1987	0	16
20	14	15	0.221	0.1997	0	16
21	16	17	0.0824	0.1923	0	16
22	15	18	0.1073	0.2185	0	16
23	18	19	0.0639	0.1292	0	16
24	19	20	0.034	0.068	0	16
25	10	20	0.0936	0.209	0	32
26	10	17	0.0324	0.0845	0	32
27	10	21	0.0348	0.0749	0	32
28	10	22	0.0727	0.1499	0	32
29	21	22	0.0116	0.0236	0	32
30	15	23	0.1	0.202	0	16
31	22	24	0.115	0.179	0	16
32	23	24	0.132	0.27	0	16
33	24	25	0.1885	0.3292	0	16
34	25	26	0.2544	0.38	0	16
35	25	27	0.1093	0.2087	0	16
36	27	28	0	0.396	0	65
37	27	29	0.2198	0.4153	0	16
38	27	30	0.3202	0.6027	0	16
39	29	30	0.2399	0.4533	0	26
40	8	28	0.0636	0.2	0.0214	32
41	6	28	0.0169	0.0599	0.0065	32

Table 3: Shunt Capacitor Data

Bus no.	Susceptance (p.u.)
10	0.19
24	0.04

Table 4: Load Data

Bus no.	Load P(MW)	Load Q(MVAR)	Bus no.	Load P(MW)	Load Q(MVAR)
1	0	0	16	3.5	1.8
2	21.7	12.7	17	9	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19	20	2.2	0.7
6	0	0	21	17.5	11.2
7	22.8	10.9	22	0	0
8	30	30	23	3.2	1.6
9	0	0	24	8.7	6.7
10	5.8	2	25	0	0
11	0	0	26	3.5	2.3
12	11.2	7.5	27	0	0
13	0	0	28	0	0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9

Analytical Study of IEEE 30 bus test system is carried out by using computer programming in MATLAB software. The test system consists of 6 generator buses (bus no. 1, 2, 5 ,8, 11, and 13), 24 load buses (bus no. 3, 4, 6, 7, 9, 10, 12, 14 ,15, 16, 17, 18,19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30) and 41transmission lines. The results for loadability of power system and voltages at various buses are obtained without load shedding and with load shedding, the data provided below is before load shedding (BLS) &after load shedding (ALS).

Table 4: Comparison of Normal voltage, voltage before load shedding , real power load(PL) and reactive power load (QL)

Bus	Normal voltage	Voltage before load shedding	PL(BLS)	QL(BLS)
1	1.05	1.05	0	0
2	1.0338	1.044587	0.045421	0.026583
3	1.0334	1.038231	0.005023	0.002512
4	1.0263	1.034954	0.015908	0.003394
5	1.0058	1.05	0.197172	0.039769
6	1.0208	1.036478	0	0

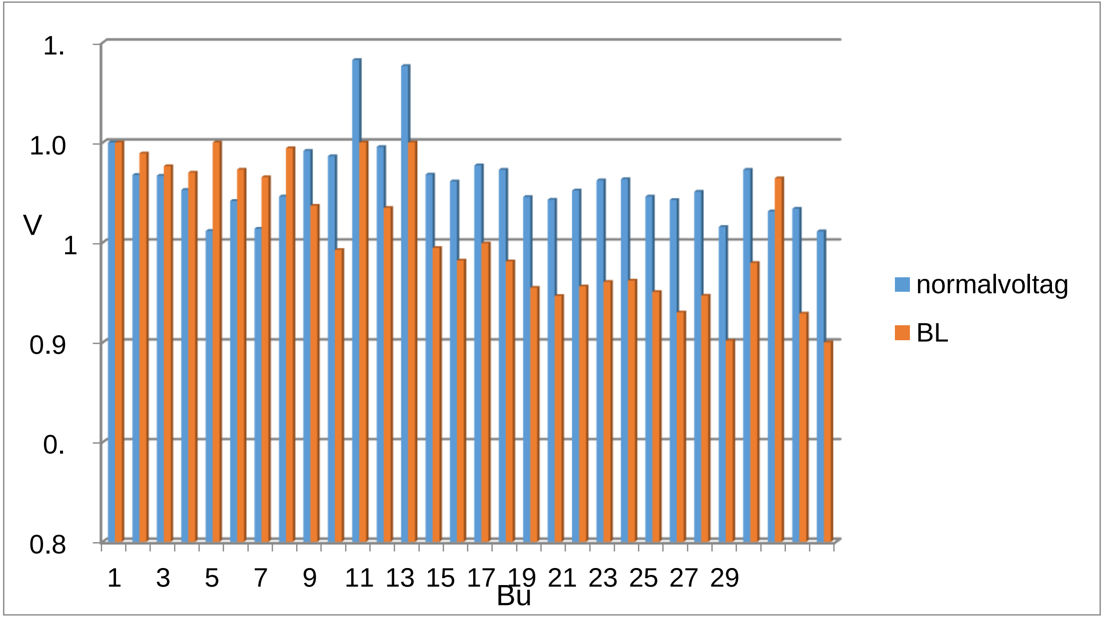
7	1.0069	1.032677	0.047723	0.022815
8	1.0230	1.047204	0.062794	0.062794
9	1.0459	1.018416	0	0
10	1.0432	0.996248	0.01214	0.004186
11	1.0913	1.05	0	0
12	1.0478	1.017315	0.023443	0.015698
13	1.0883	1.05	0	0
14	1.0340	0.997287	0.012977	0.003349
15	1.0306	0.990966	0.017164	0.005233
16	1.0386	0.999546	0.007326	0.003768
17	1.0364	0.990567	0.018838	0.01214
18	1.0228	0.977359	0.006698	0.001884
19	1.0214	0.97328	0.019885	0.007117
20	1.0260	0.978032	0.004605	0.001465
21	1.0311	0.980327	0.03663	0.023443
22	1.0317	0.980964	0	0
23	1.0230	0.975282	0.006698	0.003349
24	1.0213	0.965026	0.01821	0.014024
25	1.0254	0.9509	0	0
26	1.0078	0.9509	0.007326	0.004814
27	1.0364	0.989771	0	0
28	1.0156	1.032148	0	0
29	1.0169	0.9645	0.026623	0.001884
30	1.0056	0.95	0.022187	0.003977

Above table shows normal voltage, voltage before load shedding, real power load (PL) and reactive power load (QL). When system load increases by 0.0293 (ʎ=20.93%) some voltages are in unstable condition. Buses 24, 26, 29 & 30 have low voltages. real power load (PL) of bus 24 has increased by 1.821 % and QL increased by 1.4024%, PL for bus 26 has increased by 0.7326% and QL increased by0.4814%, PL for bus 29 has increased by 2.6623%and QL has increased by 0.1884% and PL for bus 30 has increased by 2.2187%and QL increased by 0.3977% as shown in table 5.

Table 5: load Percentage Increment

Bus no	Voltage BLS	Voltage ALS	PL(BLS)%	QL(BLS)%
24	0.965026	0.969085	1.821	1.4024
26	0.9509	0.956367	0.7326	0.4814
29	0.9645	0.966967	2.6623	0.1884
30	0.95	0.955034	2.2187	0.3977

Figure 3: Comparison of voltage profile between normal voltage and voltage BLS



Above fig.3 shows the comparison of voltage profile between normal voltage and voltage before load shedding. When system load increases by 0.2093 (ʎ=20.93%) voltages are in unstable condition. buses 24, 26, 29 & 30 voltages decreased and gone unstable when load maximized.

Table 6: Comparison of voltage before load shedding, real power load (PL) and reactive power load (QL)

Bus No.	Voltage BLS	Voltage ALS	PL(ALS)	QL(ALS)
1	1.05	1.035881	0	0
2	1.044587	1.028352	0.21171	0.12171
3	1.038231	1.026537	0.01871	0.00671
4	1.034954	1.023634	0.07071	0.01071
5	1.05	0.996905	0.93671	0.18471
6	1.036478	1.02276	0	0
7	1.032677	1.00443	0.22271	0.10371
8	1.047204	1.036101	0.29471	0.29471
9	1.018416	1.012764	0	0
10	0.996248	0.992722	0.05271	0.01471
11	1.05	1.042533	0	0
12	1.017315	1.018948	0.10671	0.06971
13	1.05	1.049999	0	0
14	0.997287	1.001842	0.05671	0.01071
15	0.990966	0.994699	0.07671	0.01971
16	0.999546	1.000056	0.02971	0.01271
17	0.990567	0.989265	0.08471	0.05271
18	0.977359	0.981188	0.02671	0.00371
19	0.97328	0.976513	0.08971	0.02871
20	0.978032	0.979722	0.01671	0.00171

21	0.980327	0.97984	0.16971	0.10671

22	0.980964	0.980463	0	0
23	0.975282	0.979904	0.02671	0.01071
24	0.965026	0.969085	0.08171	0.06171
25	0.9509	0.9755	0	0
26	0.9509	0.956367	0.02971	0.01771
27	0.989771	0.987605	0	0
28	1.032148	1.020696	0	0
29	0.9645	0.966967	0.01871	0.00371
30	0.95	0.955034	0.10071	0.01371

Above table 6 shows voltage before load shedding, voltage after load shedding, real power load (PL) and reactive power load (QL). When system load decreases by 0.005296 (ʎ=0.5296%) voltages are in stable condition. voltage profile of Buses 24, 26, 29 & 30 have improved. real power load (PL) of bus 24 has decreased by 8.171 % and QL decreased by 6.171%, PL for bus 26 has decreased by 2.971% and QL decreased by1.771% ,PL for bus 29 has decreased by 1.871%and QL has decreased by 0.371% and PL for bus 30 has decreased by 10.071%and QL increased by 1.371% as shown in table 7.

Table 7: Load percentage Decrement

Bus no	Voltage BLS	Voltage ALS	PL(ALS)% increased	QL(ALS)% increased
24	0.965026	0.969085	8.171	6.171
26	0.9509	0.956367	2.971	1.771
29	0.9645	0.966967	1.871	0.371
30	0.95	0.955034	10.071	1.371

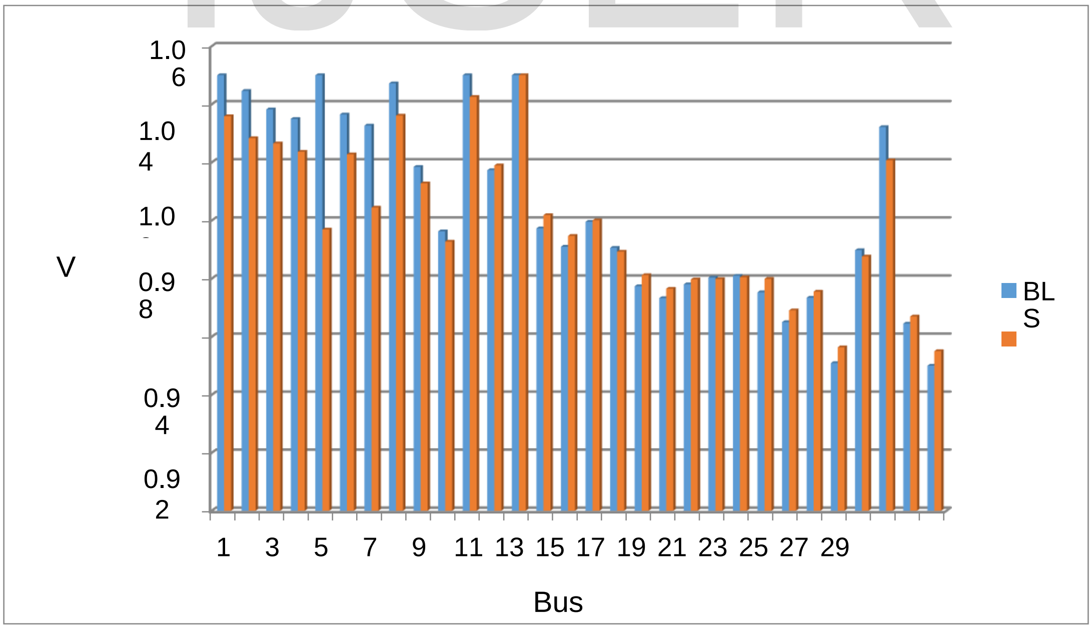


Figure 4: Comparison of voltage profile between voltage BLS and voltage ALS

Above fig. 4 shows the comparison of voltage profile between voltage before load shedding and voltage after load shedding. When system load decreases by 0.005296 (ʎ=0.5296%) voltages are in stable condition. buses 24, 26, 29 & 30 voltages increased and goes stable when load minimized

Table 8: Voltage at weak buses

Bus no	Voltage BLS	Voltage ALS
24	0.965026	0.969085
26	0.9509	0.956367
29	0.9645	0.966967
30	0.95	0.955034

Weak buses are the buses which has lowest sustainable load in the system, since it can withstand a small amount of load before causing voltage collapse. Above table 8 shows the voltage at weak buses before load shedding , when system load increased by 20.93% the voltage at bus 24, 26, 29 & 30 was low and unstable hence considered weak bus and after load shedding , system load decreases by 0.005296 (ʎ=0.5296%) and voltages enhanced.

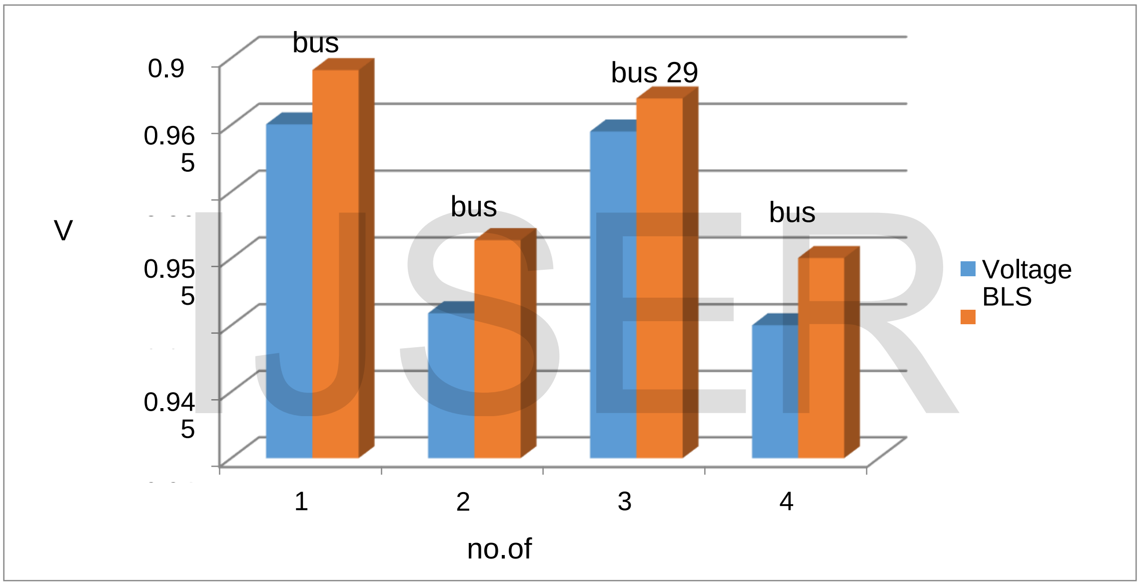


Figure 5: Weak buses

Above fig. 5 shows Enhancement of voltages at weak buses 24, 26, 29 & 30 after load shedding

Table 9: Critical lines and Voltage profile before load shedding and after load shedding

Bus no.	Critical lines	Voltage BLS	Voltage ALS	BLS PL	BLS QL	ALS PL	ALS QL
21	14	0.94833	0.95	-0.00004	-0.00013	0.0074	0.0047
26	35	0.9454	0.95	-0.00016	-0.00010	0.004659	0.003062
27	36	0.9475	0.9656	-0.00398	-0.00071	0.054848	0.009831
29	36	0.9320	0.9557	-0.00090	-0.00033	0.012418	0.004657
29	37	0.9472	0.95	-0.00006	-0.00025	0.003782	0.001418
30	38	0.9444	0.95	-0.00059	-0.00010	0.021827	0.003912

Critical lines in power system network are lines, outage of which can cause serious blackout in the system. In above table 9 shows the Critical lines and voltage profile before and after load shedding. After maximizing loadability critical lines are identified by measuring voltages of all buses while dropping each line one by one. Lines 14, 35, 36, 37 & 38 are determined as critical lines These critical lines show feasibility after load shedding, also few lines shows infeasibility.

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