A REAL TIME DIRECT ALGORITHM TO ALLEVIATE LINE OVERLOADS IN POWER SYSTEM

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Abstract: *Congestion in transmission line is the main challenge faced by the utilities. The system loading condition can create congestion issue in any of the transmission lines. Proper control decision has to be taken at the central control centre to relieve congestion by rerouting the power. The power can be rerouted either by controlling the generation or by line compensation. The control centre should coordinate the generators, compensators and load to manage the overloading. In this paper, an attempt has been made to develop a direct algorithm to relieve congestion in any transmission line of n bus system using generation shifting, series capacitor compensation and load shedding. To prove the effectiveness of the control algorithm, it is tested on IEEE 5 bus system where different lines over loading are created. The algorithm relieves the congestion and keeps the system in normal state without reducing the line loadability.*

Key words: *Congestion management, series compensation, generation shifting, direct control algorithm.*

1. Introduction.

Electric utilities are forced to operate near to its stability and loadability margins due to competitive market, limitations on energy sources and environmental pressures. Optimal utilization of transmission corridors without overloading is the main challenge. Though enhancement of transmission infrastructure gives solution, it is not feasible due to financial and environmental issues. At operational level, solution has to be obtained using existing infrastructure and control techniques. If the line congestion is not removed before any outages, the power system will be pushed to extremis state. Therefore, there is a crucial requirement for a control algorithm which can relieve the congestion using existing control devices with coordination. Moreover, the solution should be simple, less time consuming and adaptable for the control centre.

A comprehensive literature survey has been carried out in the area of congestion management. The Congestion Management is done in two stages. First stage is at the planning level and the next stage is in real time. At planning level, congestion management is handled through reconfiguration of transmission grid based on deterministic approach [1], thermal consideration [2] and voltage stability [3], optimal power flow based on least congestion cost [4], and congestion distribution factor based on dc power flow [5] and ac power flow [6]. Under deregulated environment, the congestion is managed [7] at planning level through transmission management [8], Price area congestion management [9], FACTS devices [10] and Locational Marginal Pricing [11].

In real time, congestion management is handled by the system operator for the safe operation. The operator employs cost free and not cost free methods to manage congestion. The literature survey classifies the real time congestion management solution as direct method and optimal methods [6, 12]. The optimal methods alleviate congestion using generic load model, congestion clearing time, quasi dynamic thermal rating and FACTS devices. All these methods use optimization techniques which are complicated and time consuming from the computational point of view especially for large systems. Under emergency conditions, the operator, has to make quick decisions, with little concern for the optimality of the operating point. Hence an efficient, reliable and direct method is always required.

In direct method, based on sensitivity of line overloads to bus power increments [13], and relative ability of different buses [14] the algorithms are developed. These algorithms did unnecessary and excessive load shedding. The direct method is further made simple by considering only the terminal buses of overloaded lines [15] and through local optimization to reduce bus number [16]. The effectiveness of direct method is further improved by considering the cost and sensitivity [17]. Most of the previous investigation does not consider line reactance control as an alternative for the direct method. In [18], line reactance control alone is considered for the direct method. Load Frequency Control operation is considered when load changes in a two area system for consistent power supply in [19]. Location of Thyristor Controlled Series Compensator is determined for secured power flow in grid system is proposed in [20]. So far no attempt has been made by any researcher to develop an efficient direct method which alleviate congestion using generation shifting, line reactance control and load shedding.

This paper makes an attempt to develop a direct method to alleviate congestion based on generation shifting, line reactance control and load shedding. The main contributions in this paper are summarized as follows:

- The direct control algorithm for congestion management developed in this paper is applicable for n bus system.
- Generation shifting is given the top most priority because of the existing Automatic Generation Control infrastructure. Line reactance control is given the next priority due to the requirement of extension in the infrastructure using FACTS devices. Load shedding which disturbs the consumers are given the least priority.
- The reference value for the generation and line reactance control are decided globally by the algorithm. In general, the FACTS and AGC operation is based on the local set value decided by the specific component of the power system. In this paper, the set values are decided by the algorithm looking power system in global perspective.
- In line reactance control only series capacitor compensation is considered. Because, increase in reactance using series inductor will decrease the line loadability whereas, decrease in line reactance using series capacitor will increase line loadability.

The rest of the paper is organized as follows. Section II presents preliminaries for better understanding of the control algorithm. The logics behind the generation scheduling and line reactance control in algorithm are explained in this section. Section III devotes to presenting the flowchart and algorithm of the proposed congestion management algorithm applicable for n bus system. Section IV, presents the system in which the control algorithm is tested. In section V, case studies are presented with different over loadings and the superior performance of our novel methodology is illustrated. Finally, Section VI summarizes the contribution of the paper based on the simulation results.

2. Preliminaries of Proposed Algorithm

In this section, the logics behind the alleviation of line overloads are explained. The change in line flows can be achieved by modifying the phase angles, reactance of the transmission line and magnitudes of bus voltages. By varying the power injection of the generator, reactance of the line and power consumption of loads, the bus voltage magnitudes and angles can be varied. Therefore the algorithm proposed in this paper use generation shifting, line reactance control and load shedding as the control parameters to alleviate the line congestions.

2.1 Generation shifting

The difference between the generated power and the load connected to the bus is the injected power to that bus. In bus i the increment in injected power (ΔP_i) is defined as [13]

$$\Delta P_i = \Delta Pg_i - \Delta Pl_i \quad (1)$$

$$\Delta P_i = \Delta Pg_i^{new} - Pg_i^{old} - (Pl_i^{new} - Pl_i^{old}) \quad (2)$$

Where

ΔPg_i and ΔPl_i are the change in power generated and consumed by load in i^{th} bus.

Pg_i^{old} and Pg_i^{new} are the scheduled generation at bus i before and after alleviating line overload;

Pl_i^{old} and Pl_i^{new} are the scheduled load at bus i before and after alleviating line overload;

At a generator bus, the increase in generation will change the voltage magnitude and angle in that bus as per equation (3)

$$P_i = \sum_{j=1}^{n} |V_i V_j Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (3)$$

Where,

V_i and V_j are the bus voltages in i^{th} and j^{th} bus respectively.

δ_i and δ_j are the voltage angles at i^{th} and j^{th} bus respectively.

$Y_{ij}\angle\theta_{ij}$ is the element of bus admittance matrix.

If ΔP_i increases because of increase in generation at ith bus (P_{gi}), the power flow in the line connected between bus i and bus j (P_{ij}) will increase if it taps power from the bus. Similarly during ΔP_i increase, P_{ij} will decrease if the line delivers power to the bus i.

The power flow in the line can be alleviated with the help of generation rescheduling. The sensitivity of the generator to the line loading depends on the distance between the generator and line. The generator at the sending and receiving ends of the loaded line will always be more sensitive [15]. In this paper, the generator shifting in the adjacent buses are also considered as shown in Figure 1(a) to 1(c). In Figure 1 (a), the line is connected between two generators. If any congestion happens in this line, it can be relieved by shifting the generation from Gi to Gj and vice versa based on the power flow direction.

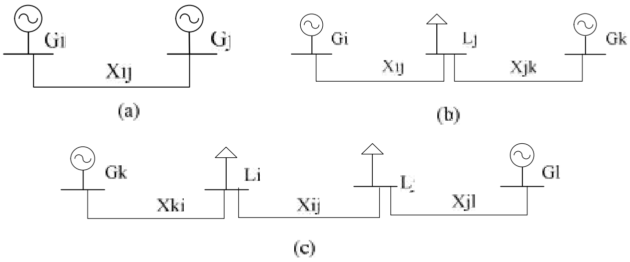

Figure 1 Congestion relieving by generation shifting

Similarly in Figure 1(b) the congestion in transmission line (Xij) connected between a generation (Gi) and load (Lj) can be relieved by shifting the generation if another generator (Gk) is connected to the load bus (Lj). This also varies the power flow in line Xjk. The generation shifting is also possible if the system has the connection as shown in Figure 1 (c). Though the overloaded line (Xij) is connected between load buses (Li and Lj), the Generation (Gk) and (Gl) connected to the respective loads through the lines (Xki) and (Xjl) respectively relieves congestion by generation shifting. For any other network connection, congestion can be relieved only by line reactance control.

2.2 Line reactance control

This paper gives second priority to line reactance control. The equation (4) which describes the power flow in transmission line clearly shows that the power flow can be varied by varying the line reactance (X).

$$P_{12} = |V_1||V_2|sin\delta/X \tag{4}$$

The increase in line reactance decreases the power flow in the line as per equation (4). The increase in line reactance affects the surge impedance (SI) as per equation (5), which in turn seriously affects the Surge Impedance Loading (SIL) as in equation (6).

$$SI = \sqrt{\frac{L}{C}} \tag{5}$$

$$SIL = \frac{kV^2}{SI} \tag{6}$$

This reduces the loading capability of the line [21]. If the line reactance is reduced by series capacitor compensation, the power flow in that line increases as per equation (4) and SI decreases as per equation (5). This also leads to increase in line loadability as per equation (6) [21].

Hence in this work only series capacitor compensation is considered. If the generation has reached the maximum limit, line reactance control is preferred to relieve congestion. In case of network shown in Figure 2, the congestion in line (Xij) can be relieved by series capacitor compensation in X_{jk}. This can be done until the line reaches the maximum compensation limit.

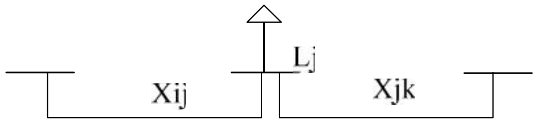

Figure 2 Congestion management by reactance control

2.3 Load shedding

Further reduction in line congestion is possible only through load shedding. The final priority is given to load shedding because it affects the customers. As per equations (1 and 2), If ΔP_i increases because of increase in demand P_{li}, the power flow in the line (P_{ij}) will decrease if it taps power from the bus i. Similarly during ΔP_i increase, P_{ij} will increase if the line delivers power to the bus i. Since load shedding affects the customer interest, the proposed algorithm gives least priority to this method to alleviate the congestion.

3. Control Algorithm for Congestion Management

In this section, the algorithm based on generation shifting, series capacitor compensation and load shedding is developed to control the power flow in transmission line. Due to sudden increase in system demand or unexpected outage of generator or a transmission line or a failure in any of the system components will push the system into emergency state. Transmission line overloading during emergency state is one of the critical problem faced by the power system. If the control centre does not take necessary action, the system will move to extremis state. This algorithm helps the system to move from emergency state to normal state automatically during line congestion.

The flow chart of the congestion management algorithm is presented in Figure 3. The algorithm gets the line data, bus data and contingencies if any and do load flow analysis. If the power flow in all the lines is within the specified limits, no control action will be taken. If any violation happens, the algorithm will look for possibilities to solve the overloading through generation shifting as explained in section 2. If generation shifting is not possible, the algorithm will identify the suitable parallel path of the overloaded line and reduce its line reactance in steps using series capacitor compensation. If the series compensation exceeds the limits or there are no parallel paths, load shedding is preferred. The algorithm does load shedding in the ending bus of the overloaded line. If there are radial connections from the ending bus of overloaded line, the load shedding will be shared by those radial buses.

In this paper, the magnitude of generation shifting, series compensation and load shedding are considered to be 1 MW, 0.01 p.u. and 1 MW respectively. Based on the system capacity, these values can be altered. Based on the flowchart, the detailed algorithm is developed and presented below. The algorithm is suitable for applying to an n bus system to relieve congestion in any transmission line.

Step 1: Read Line Data and Bus Data.

Step 2: Read the maximum generation capacity (P_{Gmax}) and Maximum series capacitor compensation (X_{Cmax}).

The P_{Gmax} decides the amount of generation shifting and X_{Cmax} decides the amount of series compensation that can be done. If violates, the priority of control will change.

Step 3: Do load flow using Newton Raphson method. In actual power system, the line flows can be computed from the results of state estimation algorithm or phasor measurement unit.

Step 4: Check for overloaded line by comparing the power flows (P_{Line}) with power flow limit (P_{Lmax}). If $P_{Lmax} – P_{line}$> 0 for all lines, GOTO Step 20.

Step 5: Identify the maximum overloaded line.

Step 6: After first iteration i.e. after doing a control, if overloading magnitude or number of overloaded lines increases, GOTO Step 19.

Step 7: Check Starting Bus (SB) and Ending Bus (EB) of overloaded line has generator. If not GOTO Step 9.

This step checks the system satisfies Figure 1.a. to do generation shifting.

Step 8: If Power Generation (Starting Bus) (PG (SB)) > Power Generation (Minimum)(PGmin) & Power Generation(Ending Bus)(PG(EB)) < Power Generation(Maximum)(Pgmax), GOTO Step 13 Else Step 15.

Step 9: Check SB of loaded line has generator and EB of loaded line has load and receives power from adjacent generator (APG) through another line. Else GOTO Step 11.

This step checks the system is similar to Figure 1.b. to do generation shifting.

Step 10: If PG (SB) > PGmin &APG (EB) < Adjacent generator (Maximum) (APGmax), GOTO Step 13 Else Step 15.

Step 11: Check SB and EB of loaded line has load and receives power from another generator (APG) using another line. Else GOTO Step 15.

This step checks for the system satisfying Figure 1.c to do generation shifting.

Step 12: If APG (SB) < PGmin or APG (EB) > APGmax, GOTO Step 15.

Step 13: Do generation shifting by 1 MW

PG(SB)/PG(SB)/APG(SB) =
PG(SB)/PG(SB)/APG(SB) + 1 MW

PG(EB)/APG(EB)/APG(EB) =
PG(EB)/APG(EB)/APG(EB) – 1 MW

Step 14: GOTO Step 3

Step 15: If rerouting/parallel path not possible for overloaded line GOTO step 19.

Step 16: Identify the next/nearest line to do compensation.

Step 17: Check line reactance with compensation applied is greater than line reactance with maximum compensation. If X_{Line} - $X_{comp,applied}$< X_{Line} - $X_{comp,max}$(X_{Cmax}) GOTO Step 16.

Step 18: New line reactance (Xlinenew) = Old line reactance(Xlineold) – 0.01 GOTO Step 3.

Step 19: Do load shedding (PD) by 1 MW. GOTO step 3 If EB and Adjacent Ending Bus (AEB) are Load bus (PQ) then do load shedding in both the buses If EB is PV and AEB is PQ then do load shedding in AEB alone

Step 20: End.

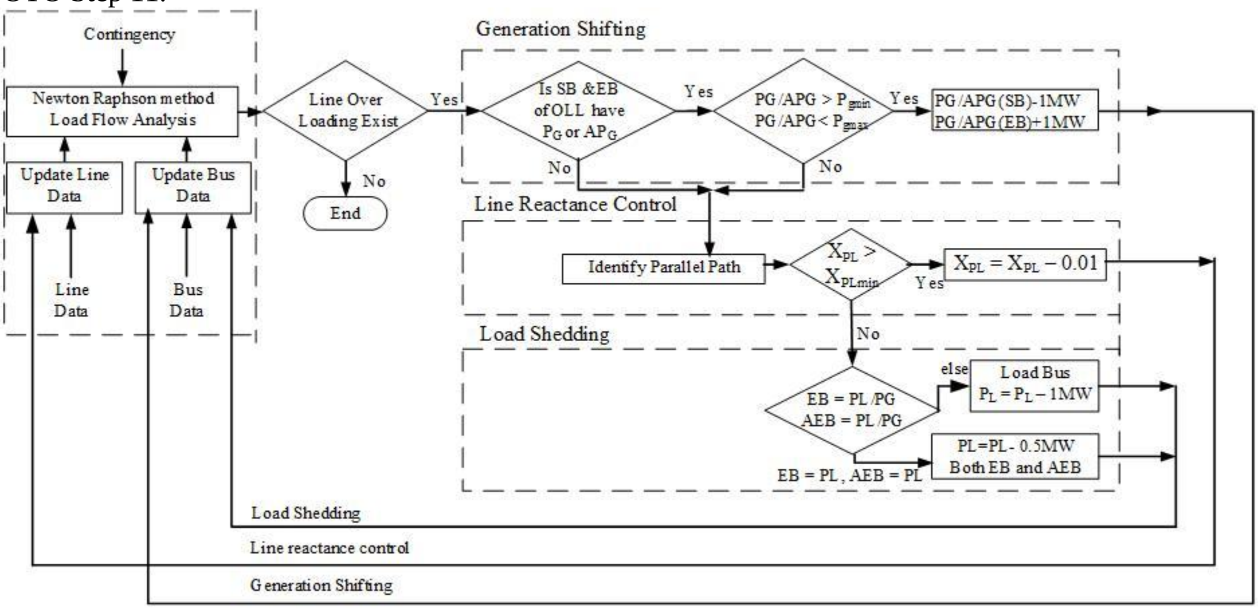

Figure 3 Flow chart of proposed congestion management algorithm

The limitations on generation and series compensation are considered by the algorithm. Only if the inequality constrains of generation or series compensation is satisfied as per equation (7) & (8), the algorithm do generation shifting or series capacitor compensation.

$$Pg_{min} \leq Pg \pm \Delta Pg \leq Pg_{max} \quad (7)$$

$$X_{min} \leq X \pm \Delta X \leq X_{max} \quad (8)$$

4. System Model

The control algorithm used for relieving congestion developed in section 3 is to be tested on a power system to validate the effectiveness of the control strategy. In this paper, 5 bus system shown in Figure 4 is considered as the test system.

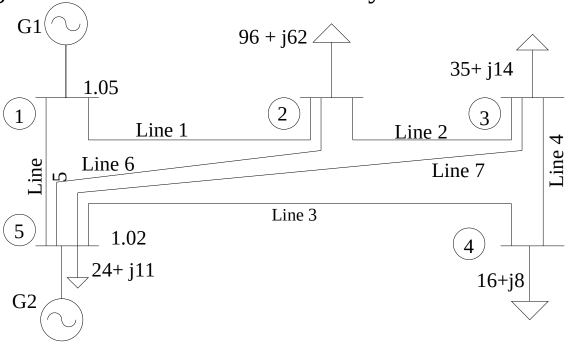

Figure 4 Five bus system

Bus 1 is considered as the slack bus, bus 5 as the P-V bus and buses 2 to 4 as P-Q bus. The data of seven lines connecting the buses are furnished in Table 1. The maximum power that can flow through a transmission line is specified as the power limit in MW. In this paper, only series capacitor compensation is considered. 20% compensation in line 1 can reduce the line reactance by 80% of the actual value. i.e., X of line 1 can be reduced to 0.08 p.u. (X_{min}) from 0.1 p.u.

5. Simulation Results and Discussions

In the above mentioned five bus system, system conditions are changed to create overloading in transmission line. Further, the developed congestion management algorithm is applied to relieve the congestion.

Case i. line 1 overloading

In this case, the real power demand in bus 3 is increased from 35 MW to 50 MW and the real power demand is increased to 30 MW from 16 MW in bus 4. The load flow analysis is conducted for the system. It is found that line 1 connecting bus 1 and 2 gets overloaded to 119.3 MW. The maximum limit of the line 1 is 100 MW. The developed congestion management algorithm is applied to this system to relieve the congestion in line 1. The step by step action taken by the algorithm is furnished in Table 2.

Table 1 Line data of five bus system

Line (bus tobus)	Series Impedance R+jX (p.u)	Line charging Y/2 (p.u)	PowerLimit (MW)	Xmin (p.u)	Compensation (%)
1-2	0.02+j0.10	j0.030	100	0.08	20
1-5	0.05+j0.25	j0.020	50	0.2125	15
2-3	0.04+j0.20	j0.020	50	0.16	20
2-5	0.05+j0.25	j0.020	50	0.2125	15
3-4	0.05+j0.25	j0.025	100	0.2	20
3-5	0.08+j0.40	j0.010	50	0.36	10
4-5	0.10+j0.50	j0.075	50	0.45	10

Table 2 Congestion relieving in five bus system for case (i)

Iter. no.	**PG1 (MW)**	**PG2 (MW)**	**Line 1**		**Line 2**		**Line 3**		**Line 4**		**Line 5**		**Line 6**		**Line 7**		**PD2 MW**
			X (p.u.)	**P (MW)**	**X (p.u.)**	**P (MW)**	**X (p.u.)**	**P (MW)**	**X (p.u.)**	**P (MW)**	**X (p.u.)**	**P (MW)**	**X (p.u.)**	**P (MW)**	**X (p.u.)**	**P (MW)**	
0	**156**	**48**	0.1	***119.3***	0.2	32.7	0.5	23.4	0.25	6.9	0.25	36.7	0.25	11.9	0.4	24.5	96
1	**155**	**49**	0.1	***118.8***	0.2	32.6	0.5	23.5	0.25	6.8	0.25	36.2	0.25	12.3	0.4	24.6	96
5	**150.8**	**53**	0.1	***116.8***	0.2	31.9	0.5	23.7	0.25	6.6	0.25	34	0.25	13.5	0.4	23.7	96
7	**148.8**	**55**	0.1	***115.9***	0.2	31.6	0.5	23.8	0.25	6.5	0.25	32.9	0.25	14.1	0.4	25.3	96
8	148.8	55	0.1	***115.4***	0.2	31.4	0.5	23.9	0.25	6.4	**0.2425**	33.4	0.25	14.4	0.4	25.4	96
9	148.8	55	0.1	***114.9***	0.2	31.2	0.5	23.9	0.25	6.4	**0.235**	33.9	0.25	14.7	0.4	25.5	96
12	148.8	55	0.1	***113.3***	0.2	30.7	0.5	24.1	0.25	6.2	**0.2125**	35.5	0.25	15.7	0.4	25.8	96
13	147.8	55	0.1	***112.5***	0.2	30.8	0.5	24.1	0.25	6.2	0.2125	35.2	0.25	15.6	0.4	25.8	**95**
20	140.6	55	0.1	***106.9***	0.2	31.3	0.5	23.9	0.25	6.4	0.2125	33.7	0.25	14.6	0.4	25.4	**88**
29	131.9	55	0.1	**99.6**	0.2	32	0.5	23.7	0.25	6.7	0.2125	31.7	0.25	13.4	0.4	25	**79**

In the Table 2, iteration zero gives the system condition before congestion management algorithm is applied. The zeroth iteration shows that the line connected between bus 1 and bus 2 gets overloaded. Since overloaded line have network connection like Figure 1.b, the algorithm prefers generation shifting. From the table it is evident that from iteration 1 to 7, generation shifting is applied by the algorithm to shift power from bus 1 to bus 2 till the generator at bus 2 reaches its maximum limit. The algorithm proceeds to Step 15 and identify line 5 to do series compensation. From 8thiteration, line 5 reactance is decreased for rerouting the power. Maximum line compensation happens during 12th iteration. From 13th iteration onwards, the algorithm prefers load shedding as per step 19 till the congestion is relieved completly. The congestion in line1 is relieved during the 29th iteration.

The generation shifting in bus 2, line reactance variation in line 5, load shedding in bus 2, power flow variation in line 1 and the power flow variations in other lines are furnished in Figure 5 to Figure 9 respectively.

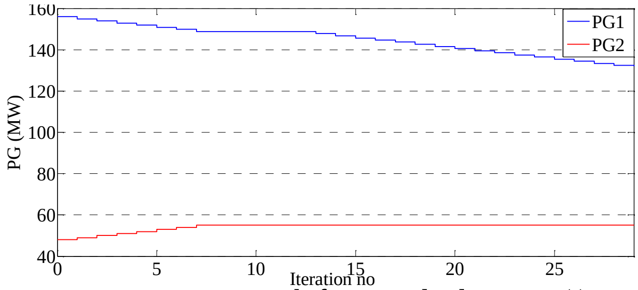

Figure 5 Generation shifting applied to case (i)

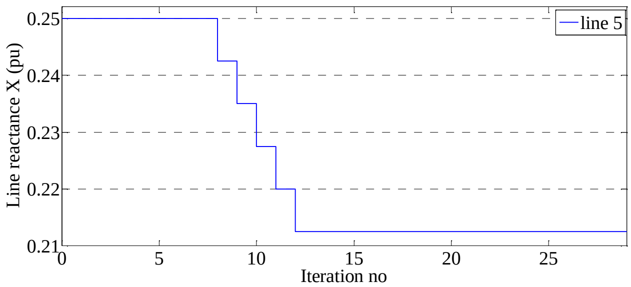

Figure 6 Line5 reactance control during case (i)

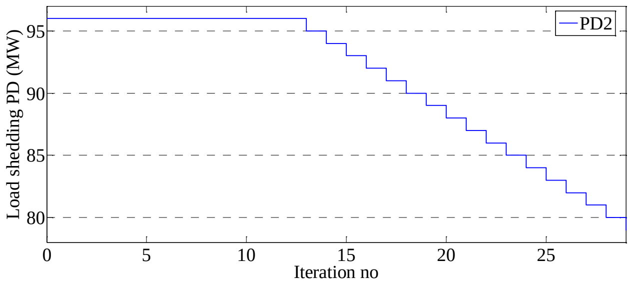

Figure 7 Load shedding in bus 2 for case (i)

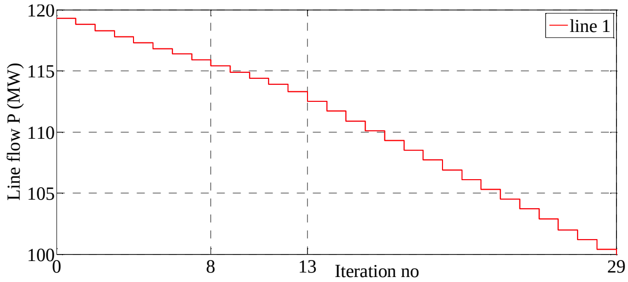

Figure 8 Power flow variation in line1 for case (i)

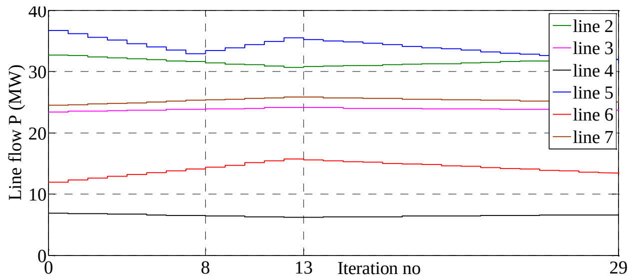

Figure 9 Power flow variation in lines for case (i)

On analysing figures from Figure 5 to Figure 9, it is evident that the shifting of generation from bus 1 to bus 5 during first 8 iteration reduces the power flow in line 1 to 115.9 MW from 119.3 MW by rerouting the excess power through line 6. At the same time power flow in line 5 also decreases. Since the power generation at bus 5 has reached the maximum value of 55 MW, the algorithm explained in section 3 decides to vary the line reactance in line5 to relieve congestion in line 1.The reduction in line reactance in line 5 during 9th to 12th iteration decreases the power flow in line 1 to 113.3 MW from 115.9 MW by increasing the power flow in line 5 as shown in Figure 8 and 9. This also increases the power flow in line6 to provide power to the load in bus 2. By the end of 12th iteration, line 5 has reached the maximum compensation of 15%. This makes the algorithm to do load shedding to manage congestion.

From iteration 13 to 29, the demand in bus 2 is reduced in steps from 96 MW to 79 MW .This reduces the power flow in line 1 from 113.3 MW to 99.6 MW and relieves the congestion. It is evident that the proposed congestion management algorithm effectively relieves congestion by applying generation shifting, series capacitor compensation and load shedding of required quantity at the specific location.

Case (ii): Line 5 overloading

When the system is made with 48 MW in bus 2, 20 MW in bus 3 and 110 MW in bus 5, overloads the line 5 to 57.1 MW. The rated value for line 5 is only 50 MW. The sytem information is provided for the developed congestion management algorithm. The results are tabulated in Table 3. Since the SB and EB of overloaded line has generation as shown in Figure 1.a, the algorithm do generation shifting from bus1 to bus 2 to relieve congestion. The generation in bus 2 is varied from 48 MW to the maximum capacity of 55 MW during the first seven iteration. At the same time, the generation at bus1 is reduced from 150.8 MW to 143.4 MW as shown in Figure 10. This generation shifting reduces the power flow in line 5 from 57.1 MW to 53.3 MW. To relieve the congestion further, the algorithm decides to reduce line reactance in line 1. From iteration 8 to 12, the line reactance is varied from 0.096 p.u. to 0.08 p.u using series capacitor compensation as shown in Figure 11. The line reactance reduction in line 1 increases the power flow in that line from 90.2 MW to 94.4 MW and reduces the power flow in line 5 from 53.3 MW to 49.2 MW and thus relieves the congestion in line 5 as shown in Figure 12. The power flow variation in other lines are furnished in Figure 13. During generation shifting, the real power flow in line 1, line 2, line 4 and line 6 decreases whereas, the power flows in line 3 and line 7 increases till 7th iteration. Similarly, during line reactance control from 8th to 12th iteration the real power flows in line 3 and line 7 decreases. To balance the power requirement, the power flows in line 1, line 2, line 4 and line 6 are increased. The algorithm has chosen appropriate control such that the power flow in line 5 is continuously decreasing to relieve congestion.

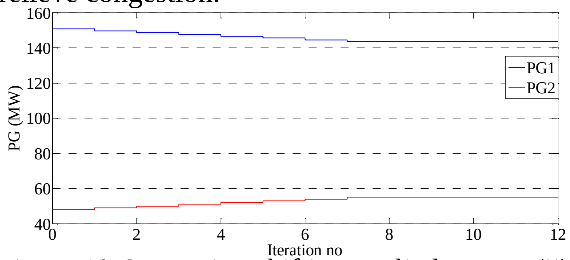

Figure 10 Generation shifting applied to case (ii)

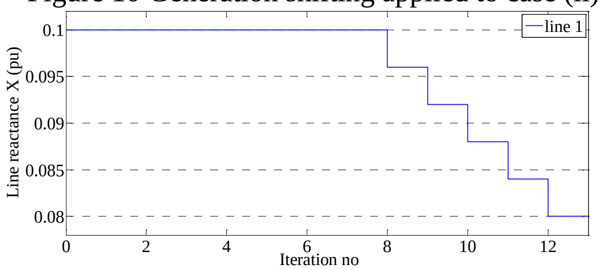

Figure 11 Line reactance variation in case (ii)

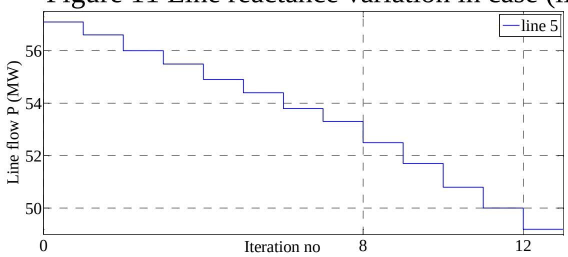

Figure 12 Power flow variation in line 5 for case (ii)

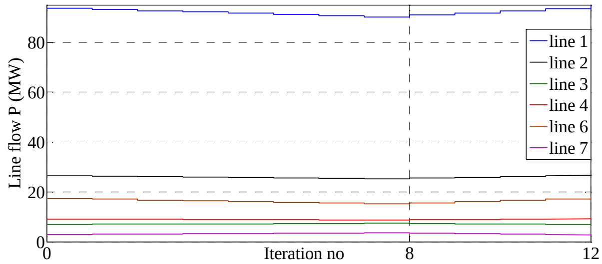

Figure 13 Line flow variation during case (ii)

Case (iii) Two lines overloading

The Load at bus 2, bus 3 and bus 4 are varied to 70MW,68MW and 50MW from 96MW,35MW and 16MW respectively. This overloads the line 1 and line 2 to 122.8MW and 54.3MW respectively. To relieve the congestion, the developed algorithm is applied to the system. The step by step results provided by the algorithm is presented in Table 4. Table 4 clearly shows that the algorithm applies generation shifting from bus 1 to bus 2 during the first 7 iteration. When the generated power at bus 2 reaches the maximum at 7th iteration, the algorithm starts line reactance control. It varies the line reactance in line 5 through series capacitor compensation till 12th iteration. Since the line 5 compensation has reached its maximum limit, the algorithm prefers line reactance control in line 7. From 13th to 17th iteration, reactance of line 7 is varied by the algorithm. Finally, load shedding is preferred at bus 3 to relieve congestion totally. The generation shifting, line reactance control and load shedding are shown in Fig. to Fig. 16 respectively.

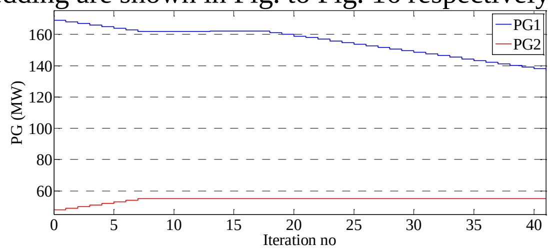

Figure 14 Generation shifting in case (iii)

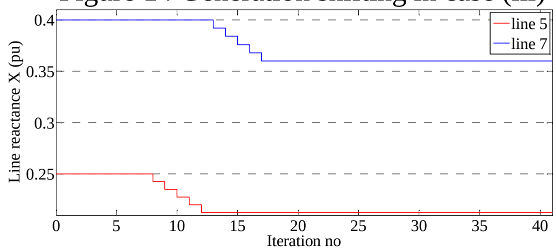

Figure 15 Line reactance variation during case (iii)

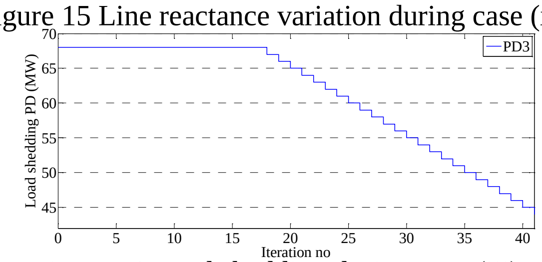

Figure 16 Load shedding during case (iii)

Table 3 Congestion relieving in five bus system for case (ii)

Iter No	PG1 (MW)	PG2 (MW)	Line 1		Line 2		Line 3		Line 4		Line 5		Line 6		Line 7	
			X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)
0	**150.8**	**48**	0.1	93.7	0.2	26.5	0.5	7	0.25	9.1	0.25	***57.1***	0.25	17.4	0.4	2.9
1	**149.7**	**49**	0.1	93.2	0.2	26.3	0.5	7.1	0.25	9	0.25	***56.6***	0.25	17.1	0.4	3
7	**143.4**	**55**	0.1	90.2	0.2	25.3	0.5	7.4	0.25	8.7	0.25	***53.3***	0.25	15.2	0.4	3.6
8	143.4	55	**0.096**	91	0.2	25.6	0.5	7.3	0.25	8.8	0.25	***52.5***	0.25	15.6	0.4	3.4
9	143.4	55	**0.092**	91.8	0.2	25.8	0.5	7.2	0.25	8.9	0.25	***51.7***	0.25	16.1	0.4	3.3
12	143.6	55	**0.08**	94.4	0.2	26.7	0.5	6.9	0.25	9.2	0.25	**49.2**	0.25	17.7	0.4	2.7

Table 4 Congestion relieving in five bus system for case (iii)

Iter. no.	PG 1 (MW)	PG2 (MW)	Line 1		Line 2		Line 3		Line 4		Line 5		Line 6		Line 7		PD 3 (MW)
			X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	X (p.u.)	P (MW)	
0	**169**	**48**	0.1	***122.8***	0.2	***54.3***	0.5	33.8	0.25	16.6	0.25	46.2	0.25	4.4	0.4	31	68
1	**168**	**49**	0.1	***122.3***	0.2	***54.2***	0.5	33.8	0.25	16.5	0.25	45.7	0.25	4.7	0.4	31.1	68
7	**161.9**	**55**	0.1	***119.4***	0.2	***53.2***	0.5	34.2	0.25	16.2	0.25	42.5	0.25	6.5	0.4	31.8	68
8	161.9	55	0.1	***118.8***	0.2	***53***	0.5	34.3	0.25	16.1	**0.2425**	43.1	0.25	6.9	0.4	31.9	68
9	161.9	55	0.1	***118.1***	0.2	***52.8***	0.5	34.4	0.25	16.1	**0.235**	43.8	0.25	7.3	0.4	32	68
12	161.9	55	0.1	***116.1***	0.2	***52.1***	0.5	34.6	0.25	15.9	**0.2125**	45.8	0.25	8.6	0.4	32.5	68
13	162	55	0.1	***116***	0.2	***51.9***	0.5	34.5	0.25	16	0.2125	45.9	0.25	8.4	**0.392**	32.9	**68**
14	162	55	0.1	***115.9***	0.2	***51.6***	0.5	34.3	0.25	16.1	0.2125	46.1	0.25	8.3	**0.384**	33.4	**68**
17	162	55	0.1	***115.5***	0.2	***50.7***	0.5	33.9	0.25	16.5	0.2125	46.5	0.25	7.7	**0.36**	34.8	**68**
18	161	55	0.1	***114.8***	0.2	***50.1***	0.5	33.8	0.25	16.7	0.2125	46.2	0.25	7.8	0.36	34.5	**67**
19	160	55	0.1	***114.2***	0.2	**49.5**	0.5	33.6	0.25	16.8	0.2125	45.8	0.25	7.8	0.36	34.2	**66**
25	153.8	55	0.1	***110.3***	0.2	**46.1**	0.5	32.8	0.25	17.7	0.2125	43.5	0.25	8.2	0.36	32.4	**60**
40	137	55	0.1	**99.8**	0.2	**36.9**	0.5	30.5	0.25	20	0.2125	37.2	0.25	9.1	0.36	27.7	**44**

The algorithm reduces the power flow in both the line 1 and line 2. The congestion in line 2 is relieved during the 19th iteration and in line 1 during 40th iteration as shown in Figure 17. The change in power flow in other lines are furnished in Figure 18. The generation shifting during first 7 iteration decreases the power flow in line 1, line 2, line 4 and line 5 whereas the power flow increases in line 3, line 6 and line 7. During reactance control in line5, the power flow in line 1, line 2 and line 4 decreases and the power flow in line 3, line 5, line 6 and line 7 increases between iteration 8 and 12. When the line reactance is controlled in line 7 during the iteration 13 to 17, the line 1, line 2, line 3 and line6 power flow decreases. This increases the power flow in line 4, line 5 and line 7. The load shedding from iteration 18 reduces the power flow in all the lines except line 4 and line 6. On comparing this algorithm performance with the algorithm developed by Kirthika et. al. [18], the proposed algorithm do only series capacitor compenstion. Whereas in [18] both inductance and capacitor series compensation are done.

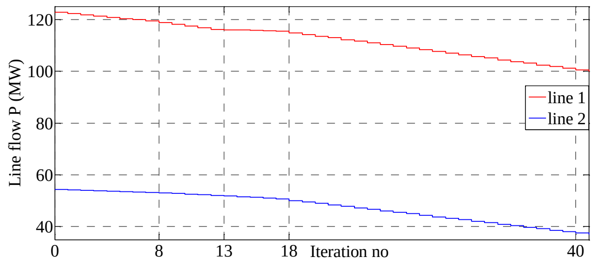

Figure 17 Change in power flow in line 1 and line 2 for the case (iii)

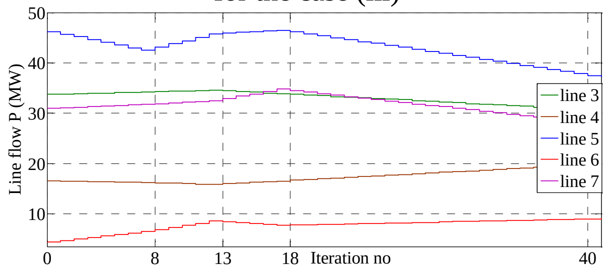

Figure 18 Power flow variation in lines in case (iii)

Though [18] gives solution, it derates the line during series inductance compensation which is mostly preferred by that algorithm. Therefore, the proposed direct algorithm alliviate congestion effectively without derating the line.

6. Conclusion

The direct algorithm developed in this paper to relieve overloading in any transmission line is applicable to n bus system. The control algorithm do generation shifting, line compensation and load shedding to manage congestion. Under series compensation, only capacitor compensation is considered to increase the line loadability. The inequality constraint of the generator and line compensator are considered by the algorithm. On testing the control algorithm with IEEE 5 bus system with different line overloading, the congestion is effectively relieved. With the help of this algorithm, the central control centre can relieve congestion in transmission line effectively.

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