Multi-Zone Congestion Management using FACTS Device in Deregulated Power System

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ABSTRACT
This paper deals with the, AC power flow approximation has been used to calculate new real Power Transmission Congestion Distribution Factors (PTCDFs), considering the presence of an UPFC. These factors have been utilized to form the single and multiple zones for the congestion management. The UPFC has been optimally placed in the system based on the factors, called as Line Loading Distribution factor (LLDFs) as presented in this paper. An Ant Colony based OPF formulation has been suggested for congestion management including UPFC in the system model and its effectiveness has been established by observing the overall system performance improvement. The effectiveness of the proposed methods has been tested on 75-bus systems. The test results are also compared with the method suggested in previous papers.

Keywords
Congestion management, ACO-OPF, PTCDFs, FACTS,, Optimal placement, LLDFs .

1. INTRODUCTION
In the electricity market at present, each utility manages the transmission system congestion [13, 14, 15,] using its own rules and guidelines based on certain physical or financial mechanism. However, there is still a need of an effective and more reliable method to solve this problem. Various congestion management such theory [1], has been proposed by Hogan for the pool type market in [27] proposed an alternative approach which is based on parallel market s for link based transmission capacity rights and energy trading under a set of rules defined and administered by the System Operator (SO). These rules specify the transmission capacity rights, required to support bilateral transactions, and adjusted continuously to reflect the changing system conditions. Several Optimal Power Flow (OPF) based congestion management schemes have been proposed in [5, 6, and 7]. In [16, 17], suitable for different electricity market structure, have been reported in the literature. The contract path and nodal pricing approach [1], using spot pricing.

With the help of Flexible Ac Transmission System (FACTS) controllers [2, 3, 9], transmission network capability is utilized in a better and congestion can be managed in an efficient and effective manner [8, 10, 11,]. Among various types of FACTS controller, Unified Power Flow Controller (UPFC) is more promising due to its ability to work as series and shunt Compensator together .In these papers a new set of system loading distribution factor have been found to be quite effective for optimal placement of the UPFC. OPF based congestion management scheme are being used in several markets utilizing up and down regulating bids of generator and also in few market, the load curtailment bids of the buyers. In a market, covering power system network spread over large geographical area, many of these regulating bids may be of relatively lower value but may not be effective in reducing transmission congestion.

In view of this, a congestion cluster based method, which identifies the group of system users according to their impact on transmission constraints of interest, has been proposed. These methods have tried to create an efficient congestion management market, where the readjustment of transaction in the most sensitive cluster is used to eliminate congestion. In [8] and Dc power flow and [14] used AC power flow approximation to calculate the distribution factors. Further, [12] used liberalized power flow model in optimal power flow to calculate the congestion cost. However, these cluster /zones based congestion management method s did not consider the impact of FACTS controller in the system. A two–step OPF is suggested with UPFC placed in congested line for the congestion management [16]. However, it did not address improvement of overall performance of the system, such as enhancing the loading capability , reducing the system real power loss, reducing the real and reactive power nodal prices, generation cost etc.

In this paper, AC power flow approximation has been used to calculate new real Power Transmission Congestion Distribution Factors (PTCDFs), considering the presence of an UPFC. These factors have been utilized to form the cluster /zones for the congestion management. The UPFC has been optimally placed in the system based on the factors, called as System Loading Distribution factor (SLDFs). An OPF formulation has been suggested for congestion management including UPFC in the system model and its effectiveness has been established by observing the overall system performance improvement. The effectiveness of the proposed methods has been tested on 39-bus New England system. The test results are also compared with the method suggested in [12].

2. CONGESTION MANAGEMENT USING OPTIMALLY PLACED UPFC AND TRANSMISSION RE DISPATCH
The re-dispatch of transaction for congestion management in a pool model is formulated as a nonlinear programming problem and has solved using, Ant Colony Optimization Technique.

Mathematically, the OPF has been formulated to minimize an objective function,

$$Minimize\,(\Delta P_{Gi})\ \sum_{i=1}^{N_G} C_{Pi}(\Delta P_{Gi}) \times \Delta P_{Gi} \qquad (1)$$

Subject to the power balance equations (equality constraints)

$$\left.\begin{aligned} P_i(\delta,V) - P_{G_i} + P_{D_i} - P_{iu} &= 0, \\ Q_i(\delta,V) - Q_{G_i} + Q_{D_i} - Q_{iu} &= 0; \end{aligned}\right\} i \forall N_b \qquad (2)$$

And various operating constraints (inequality constraints)

$$\left.\begin{aligned} & P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}, Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max}; \forall i \in N_G \\ & V_i^{\min} \le V_i \le V_i^{\max}, \forall i \in N_G, |S_m|, < S_m^{\max}; \forall m \in N_l \\ & 0 \le V_{si} \le V_{si}^{\max}, -2\pi \le \phi_{si} \le 2\pi, I_{qi}^{\min} \le I_{qi} \le I_{qi}^{\max}; \forall m \in N_u \end{aligned}\right\} \qquad (3)$$

Where,

$C_{pi}(\Delta P_{Gi})$ is the bid function of i^{th} generator,

ΔP_{Gi} is the rescheduled real power output i^{th} generator,

P_i, Q_i is the net real and reactive power injection without UPFC at bus-*I*,

V_i, δ_i are the voltage magnitude and angle at bus-*I*,

P_{Gi}, Q_{Gi} are the real and reactive power generations at bus-*I*,

P_{Di}, Q_{Di} are the real and reactive power demands at bus-*I*,

P_{iu}, Q_{iu} are the net real and reactive power injection due to UPFC at bus-*i*

$S_m, S_m^{\max}$ are the apparent power flow and its maximum limit on line-*m*,

$V_s^{\max}$ is the maximum injected voltage magnitude limit of UPFC,

ϕ_s is the injected voltage angle by UPFC,

I_q is the shunt current injection due to UPFC, which has been taken as zero in this work.

3. SYSTEM STUDIES

The proposed concept of cluster based congestion management, in presence of UPFC, has been illustrated on 75-bus system

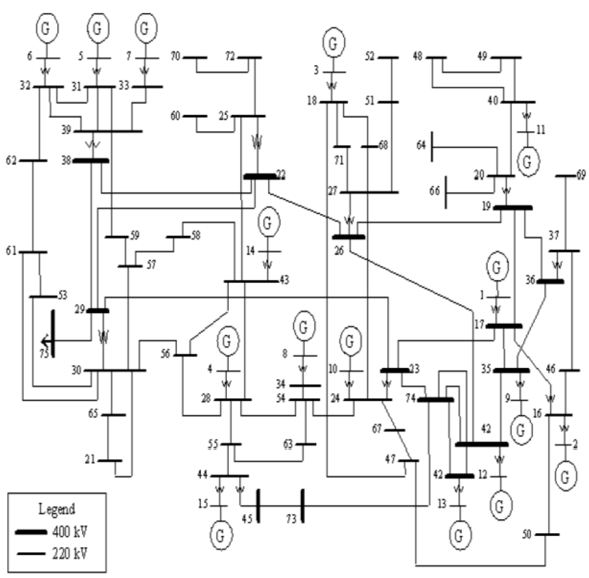

Fig1: Clusters / zones in 75-bus system for multi-Congestion case

3.1 Multi Congestion Case (75-Bus System)

The cluster for a multi-congestion case can be obtained by superposing the clusters formed for the individual line congestions. A multi-congestion case has been studied in the 75-bus system considering congestion of line between buses 26-41 and 16-50 simultaneously. The PTCDFUs for this congestion and the new congestion cluster are given in Table 1and 2 and (see in Figure 1), respectively. For managing the congestion one additional generator G9 was selected from cluster -1 along with the generator G3, G12 and G13 based on their qualifying bids (similar to single congestion case) in the market. The congestion bid taken for generator G9 is 20$/MWh. at the congestion cost increases, if more than one line is congested

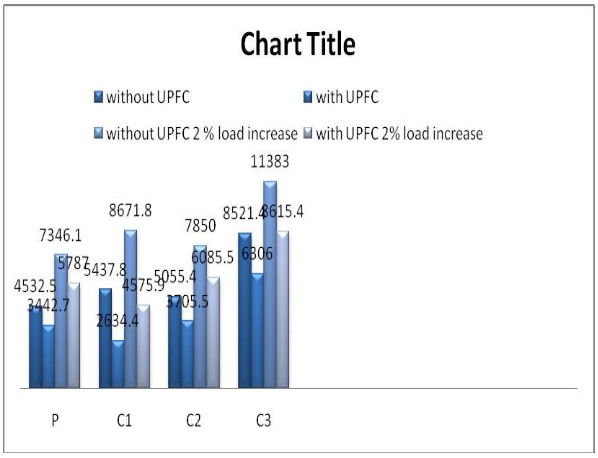

Fig 2: Congestion cost for Multi zone

Table 1: Cluster /zones and PTCDFUs 75-bus system of Zone-1 (Multi-congestion)

Zone-1					
Bus	**PTCDFU**	**Bus**	**PTCDFU**	**Bus**	**PTCDFU**
1	-0.0124	26	0.0819	51	0.1416
2	-0.1167	27	0.1382	52	0.1436
3	0.2294	28	0.1049	54	0.1198
4	0.1054	34	0.1196	55	0.1051
8	0.1207	35	0.0157	63	0.1117
9	0.0185	36	0.0095	67	0.1660
10	0.1470	37	-0.0163	68	0.2081
12	0.0257	41	0.0235	69	-0.0193
13	0.0271	42	0.0250	71	0.1559
16	-0.1260	44	0.0940	73	0.0890
17	-0.0015	45	0.0905	74	0.0790
18	0.2256	46	-0.1010		
23	0.0816	47	0.2708		
24	0.1465	50	0.5500		

Table 2: Cluster /zones and PTCDFUs 75-bus system of Zone-2 and 3 (Multi-congestion)

Zone-2		Zone-3			
Bus	**PTCDFU**	**Bus**	**PTCDFU**	**Bus**	**PTCDFU**
11	0.0299	5	0.0958	39	0.0955
19	0.0317	6	0.0961	43	0.1013
20	0.0297	7	0.0955	53	0.0979
40	0.0295	14	0.1021	56	0.1018
48	0.0289	15	0.0951	57	0.0992
49	0.0287	21	0.0977	58	0.1003
64	0.0287	22	0.0939	59	0.0986
66	0.0293	25	0.0954	60	0.0967
		29	0.0950	61	0.0978
		30	0.0974	62	0.0967
		31	0.0953	65	0.0977
		32	0.0954	70	0.0969
		33	0.0951	72	0.0967
		38	0.0948	75	0.0949

Table 2: Congestion costs in 75-bus system (multi-congestion)

Market model	ΔP_G (pu),cost($/hr) , V_s (pu) and ϕ_s (rad)	Without UPFC(Base case)	With UPFC(Base case)	Without UPFC(2% load increase)	With UPFC(2%load increase)
P	ΔP_{G3}	0.8969	0.7000	1.3873	1.1411
	ΔP_{G9}	-0.3713	-0.2957	-0.6622	-0.5329
	ΔP_{G12}	-0.4738	-0.3407	-0.8267	-0.5742
	ΔP_{G13}	0.2000	0.1400	0.3000	0.2400
	Cong. Cost	**4432.5**	**3342.7**	**7340.1**	**5781.0**
	V_s	-	0.0476	-	0.0591
	ϕ_s	-	3.1416	-	3.1416
C1	ΔP_{G3}	1.0808	0.5242	1.6377	0.9451
	ΔP_{G9}	-0.4098	-0.1723	-0.7246	-0.3817
	ΔP_{G12}	-0.5981	-0.1897	-1.0242	-0.4249
	ΔP_{G13}	0.2400	0.2000	0.3600	0.2000
	Cong. Cost	**5437.8**	**2634.4**	**8671.8**	**4575.9**
	V_s	-	0.0917	-	0.1000
	ϕ_s	-	3.1416	-	3.1416
C2	ΔP_{G3}	1.0000	0.7769	1.4985	1.2000
	ΔP_{G9}	-0.4302	-0.3068	-0.7120	-0.5493
	ΔP_{G12}	-0.5475	-0.3349	-0.8899	-0.6334
	ΔP_{G13}	0.2000	0.1600	0.3000	0.2400
	Cong. Cost	**5055.4**	**3705.5**	**7850.0**	**6085.5**
	V_s	-	0.0545	-	0.0664

	ϕ_s	-	3.1416	-	3.1416
C3	ΔP_{G3}	1.6000	1.2000	2.1000	1.6555
	ΔP_{G9}	-0.6125	-0.1615	-0.3530	-0.8349
	ΔP_{G12}	-1.1682	-1.1315	-2.0833	-0.8936
	ΔP_{G13}	0.3200	0.2400	0.4200	0.3400
	Cong. Cost	**8521.4**	**6306.0**	**11383.0**	**8615.4**
	V_s	-	0.0735	-	0.0920
	ϕ_s	-	3.1416	-	3.1416

4. CONCLUSIONS

In this chapter, a cluster/zonal based congestion management approach, using real power rescheduling of generators along with optimal setting of the Unified Power Flow controller (UPFC), has been optimally placed to improve the system performance. A set of distribution factor $SLDF^*$, as proposed in the previous chapter, has been used for the optimal placement of UPFC. The clusters/zones have been formed utilizing the proposed line real power flow sensitivity indices, computed at different set of loading patterns, in presence of the UPFC. An optimal power flow model that minimizes the congestion cost to determine rescheduling of generator and UPFC parameters under different market structures with pool, bilateral and multilateral contracts, has been proposed. The test results on 75- bus Indian system as following.

Congestion cost obtained by the proposed method in different scenarios are found to be quite less as compared to that obtained with the method suggested in other methods given in references .Presence of the UPFC, optimally placed utilizing the proposed factors, reduces the congestion cost considerably. The amount of real power rescheduling of generator for congestion management reduces considerably in the presence of the UPFC. In case of multi-line congestion, the proposed approach is also quite effective. The proposed approach is quite simple to adopt. It utilizes a set of AC sensitivity factors, which can be easily updated from the base case load flow results.

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