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Transmission Congestion Management by Using Series Facts Devices and Changing Participation Factors Of Generators

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Abstract: *The deregulated power system is quite popular in now a days. The increased power demand has forced the power system to operate very closer to its stability limits. So transmission congestion and voltage instability problems are arise in the power system. Due to the congestion in the network, not always possible to transmit the all contracted power. Congestion management is a tough task in deregulated power system. In this paper two different methodologies were used to manage the congestion in the network. The first methodology is congestion managed using series FACTS device. This method is tested on modified IEEE 5 bus system. The second method is congestion management by changing participation factors of generators. This method is tested on modified IEEE 9 bus system.*

Key Words: *Deregulated power system, congestion, Available Transfer Capability (ATC), Thyristor Controlled Series capacitor (TCSC), Transmission Load Relief (TLR) factors, Participation Factors.*

I. INTRODUCTION

In present days all our basic needs are relates with electricity. Like the growth of population, the demand for electricity is also tremendously increases day to day. So there may be a need to enhance either the existing power system or establish the new system to supply the power to meet the particular load demands. The establishment of new power system is very costliest choice. So we mostly concentrate on the first choice that is enhancing the existing power system. The main objective of the deregulation of a power industry is creating a competitive environment in between the power producers and prevents monopolies and also provides many choices to consumers to pick up a good utility. Due to the lack of coordination in between generation and transmission utilities, transmission congestion is occurs. So due to this transmission congestion, there may not be possible to dispatch all contracted power transactions. The series FACTS device TCSC is placed in series with the line for congestion management. In [1], sensitivity approach is used to find the optimal location for placement of TCSC. The reduction of total system reactive power losses method is one used to find optimal location of FACTS devices [4-7]. In this method, an over loaded sensitivity factor (power flow index) is used for optimal location of series FACTS device (i.e. TCSC) for static congestion management [8]. But for large systems, this enumerative approach is not practical given to the large number of combinations that have to be exam. In [2], here congestion is managed by Transmission line relief (TLR) method used in deregulated power industry [3]. In deregulated power systems, before permitting the power transactions, feasibility of transmission network components is required to be determined. It can be detected by evaluation of Available Transfer Capability (ATC) of the network for various applied power transactions [9-10]. ATC is an important term in restructured power system that affects the planning and controlling of transmission infrastructure. The FACTS devices are used to enhance ATC in deregulated power system [11]. Main constraints for ATC are thermal limits, voltage limits and steady state stability limits. The variable load is considered as data to calculate ATC of network, considering various sets of generator participation factors [12].

II. MODELLING [STATIC] OF TCSC

For static application like congestion management FACTS devices can be modelled as power injection model. The TCSC model shown as follows

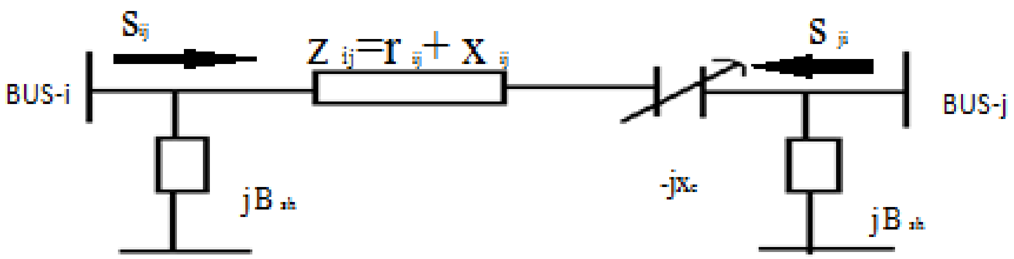


fig1. Modelling of TCSC

Let the complex voltage at bus i and bus j be denoted as $V_i \angle\delta_i$ and $V_j \angle\delta_j$ respectively. The expressions for real and reactive power flows from buses i to j and j to i can be written as follows

$$P^c_{ij}= V_i^2 G_{ij} - V_iV_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad \& \quad P^c_{ji} = V_j^2 G_{ij} - V_iV_j (G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij}) \quad (1)$$

$$Q^c_{ij}=-V_i^2(B_{ij}+B_c)-V_iV_j(G_{ij}\sin\delta_{ij}-B_{ij}\cos\delta_{ij}) \quad \& \quad Q^c_{ji}=-V_j^2(B_{ij}+B_c)-V_iV_j(G_{ij}\sin\delta_{ij}+B_{ij}\cos\delta_{ij}) \quad (2)$$

Hence, the change in the line flows due to series capacitance, the real power flow injection at bus i is

$P_{ic} = V_i^2\,\Delta G_{ij} - V_iV_j\,(\Delta G_{ij}\cos\delta_{ij} + \Delta B_{ij}\sin\delta_{ij})$ (3)

$P_{jc} = V_j^2\,\Delta G_{ij} - V_iV_j\,(\Delta G_{ij}\cos\delta_{ij} + \Delta B_{ij}\sin\delta_{ij})$ (4)

$Q_{ic} = -V_i^2\Delta B_{ij} - V_iV_j\,(\Delta G_{ij}\sin\delta_{ij} - \Delta B_{ij}\cos\delta_{ij})$ (5)

$Q_{jc} = -V_j^2\Delta B_{ij} + V_iV_j\,(\Delta G_{ij}\sin\delta_{ij} + \Delta B_{ij}\cos\delta_{ij})$ (6)

Where $\Delta G_{ij} = \frac{x_c\, r_{ij}\,(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\,(r_{ij}^2 + (x_{ij} - x_c)^2)}$ & $\Delta B_{ij} = \frac{-x_c\,(r_{ij}^2 - x_{ij}^2 + x_c\, x_{ij})}{(r_{ij}^2 + x_{ij}^2)\,(r_{ij}^2 + (x_{ij} - x_c)^2)}$

The above equations were used to model (static) the TCSC for congestion management in deregulated power system.

III. SELECTION OF BEST LOCATION FOR TCSC PLACEMENT

The optimal location of FACTS devices is one of the important concepts. The main goal of the congestion management is to perform a best utilization of the existing transmission lines.

3.1 OPTIMAL PLACEMENT OF TCSC BASED ON SENSITIVITY APPROACH:

Based on sensitivity approach, we find the optimal location of TCSC for congestion management.

3.1.1 MITIGATION OF TOTAL SYSTEM VAR POWER LOSS:

A method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. The reactive power loss sensitivity factors with respect to these control variables may be given as follows:

1. Loss sensitivity with respect to control parameter X_{ij} of TCSC placed between buses i and j,

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} \quad (7)$$

These factors can be computed for a base case power flow solution.

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} = [V_i^2 + V_j^2 - 2\,V_iV_j\cos(\delta_i - \delta_j)]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2 + X_{ij}^2)^2} \quad (8)$$

IV. LOAD CURTAILMENT METHOD BASED ON TLR SENSITIVITIES:

Transmission load relief sensitivities can be used for the purpose of congestion alleviation by load curtailment. In the method of congestion alleviation using load curtailment, TLR sensitivities at all load buses for the most overloaded line is considered**.** The TLR sensitivity at a bus k for a congested line i-j is S_{ij}^k and is calculated by

$$S_{ij}^k = \frac{\Delta P_{ij}}{\Delta P_k} \quad (9)$$

The excess power flow on transmission line i-j is given by

$$\Delta P_{ij} = P_{ij} - \Delta P_{ij}^* \quad (10)$$

Where P_{ij} = actual power flow through transmission line i-j

P_{ij}^* = flow limit of transmission line i-j

ΔP_k = change in load after curtailment at bus k

V. ATC CALCULATION

The Net work response method is the usual method for calculating ATC. In which bilateral transactions are only considered and then, whether the transaction is feasible for the network or not is concluded.

Mathematically, ATC is defined

$$ATC = TTC - TRM - [ETC + CBM] \quad (11)$$

Where, TTC= Total Transfer Capability

TRM = Transmission Reliability Margin

ETC=Existing Transmission Commitments

CBM= Capacity Benefit Margin

In above equation [11], the terms except TTC are decided by the load serving entities. If TRM and CBM are not considered, TTC represents ATC at the base load flow conditions. The term TTC is variable and changes according to the change in line flows, line limits and the transacted power between the buses.

5.1 PARTICIPATION FACTOR

This is an important factor in generator details. This participation factor is used to determine how the real power output of the generator changes in response to changes in load demand. It is given as,

$$X_i = \frac{\Delta T_{ik}}{\Delta P_k} \quad (12)$$

Where X_i = participation factor of generator

ΔT_{ik} = generator power changes at i^{th} bus due to change in load at k^{th} bus

ΔP_k = load change at k^{th} bus

The buyer and seller transactions are specified for the purpose of calculating ATC. This can be a single bus, slack, injection group, areas etc. when the multiple generators are exists in the transaction such as the case of areas or injection groups, participation factors needed to be assigned. So as to know the participation of generators or loads, the load flow solution must be known.

VI. SIMULATION RESULTS FOR MODIFIED IEEE 5 BUS SYSTEM:

In this study a modified IEEE 5 bus system has been analysed for congestion management.
By optimal placement of FACTS device such as TCSC using power world simulator software based on sensitivity indices approach.
Fig 2 shows the modified IEEE 5 bus system drawn in power world simulator

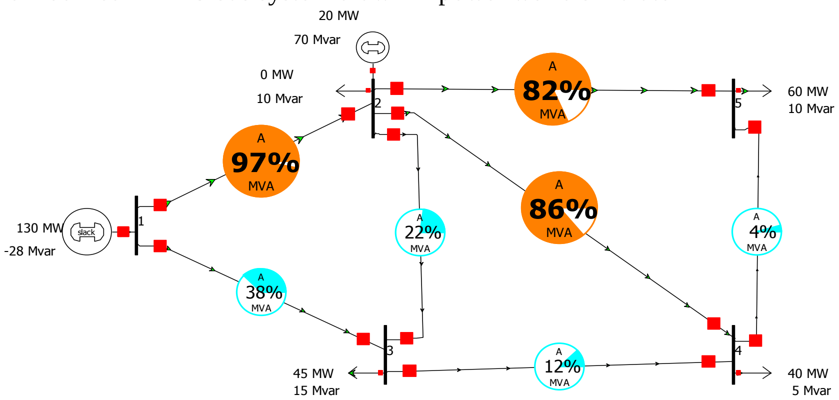


Fig 2: modified IEEE 5 bus system without TCSC

Fig 2 shows the transmission line flows without TCSC. It is observed that the lines 1-2, 2-4 and 2-5 are congested/overloaded compared to other lines.
The percentage loadability values for modified IEEE 5 bus system is tabulated below.

Table 1: OPF result without TCSC

LINES	FROM BUS	TO BUS	LODABILITY (%)	LINES	FROM BUS	TO BUS	LODABILITY (%)
1	1	2	**96.9**	5	2	5	**82.9**
2	1	3	37.6	6	3	4	11.8
3	2	3	22.4	7	4	5	4.1
4	2	4	**86**				

From the above table 1, the maximum loadable lines are 1-2, 2-4 and 2-5. Due to the increased loading, these lines are congested. So by using TCSC, congestion is going to be alleviated.

6.1 Mitigation of total system VAR power loss:

For placing TCSC at optimal location, we use sensitivity analysis. The sensitivity indices table of modified IEEE 5 bus system is shown below.

Table 2: Sensitivity indices

LINES	FROM BUS	TO BUS	SENSITIVITY INDEX (a_{ij})	LINES	FROM BUS	TO BUS	SENSITIVITY INDEX (a_{ij})
1	1	2	-7.759671	5	2	5	-1.69700
2	1	3	**-0.120364**	6	3	4	-32.19711
3	2	3	-0.303177	7	4	5	**-0.026715**
4	2	4	-1.145739				

From the above table 2, the lines 1-3 and 4-5 have the most positive sensitivity factors. So these are the best locations for placement of TCSC to relieve congestion in the network. By placing the TCSC in line 1-3, the congestion in the network is relieved.

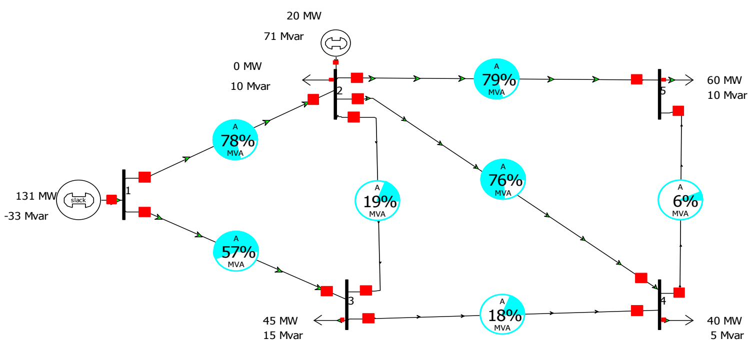


Fig 3: modified IEEE 5 bus system with TCSC in line 1-3

The fig 3 shows the transmission line flows with TCSC. It is observed that after placing TCSC the congestion in the network is relieved.
The list of power flows with and without TCSC is listed below as follows

Table 3: Power flow list of modified IEEE 5 bus system with and without TCSC

LINES	FROM BUS	TO BUS	WITH OUT TCSC	WITH TCSC		
				TCSC (20% COMP)	TCSC (40% COMP)	TCSC (65% COMP)
1	1	2	92.36	87.94	82.62	74.42
2	1	3	37.57	42	47.47	56.12
3	2	3	20.01	17.27	14.01	9.03
4	2	4	33.13	32.09	30.81	28.74
5	2	5	57.36	56.89	56.22	55.45
6	3	4	11.13	12.62	14.14	17.35
7	4	5	4.01	4.47	5.02	5.86

The Comparison of power flows with and without TCSC is shown as

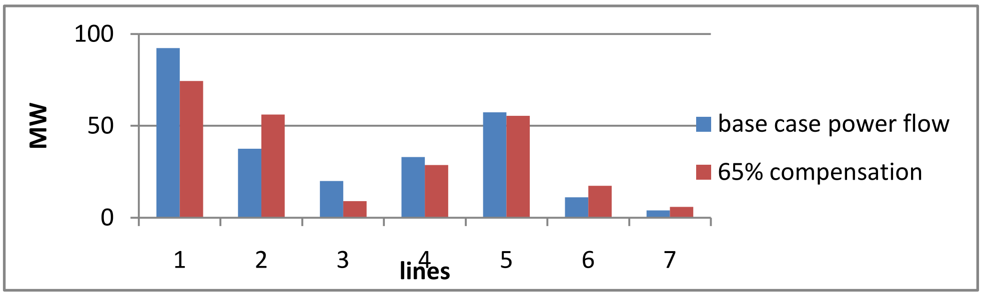


Chart 6.1: Comparison of power flows with and without TCSC

6.2 Transmission Load Relief (TLR) sensitivity method:

This transmission load relief method is based on the load curtailment. In this method of congestion management, TLR sensitivities at all the load buses for the most overloaded line are considered.

The TLR sensitivity values of modified IEEE 5 bus system is shown as follows

Table 4: TLR sensitivities

BUSES	CONGESTED LINES i-j		
	1-2	3-4	2-5
1	0	0	0
2	-0.857	0.032	0.016
3	**-0.571**	**-0.127**	**-0.063**
4	-0.762	-0.466	-0.233
5	-0.825	-0.134	-0.734

From the above table 4, the most positive TLR sensitive valued bus is bus3 from all congested lines. So by doing load curtailment on bus3 i.e. from 45 M.W to 5 M.W, then congestion is relieves from 97% to 72% at line 1-2, congestion is relieves from 86% to 72% at line 2-4 and congestion is relieves from 82% to 78% at line 2-5.

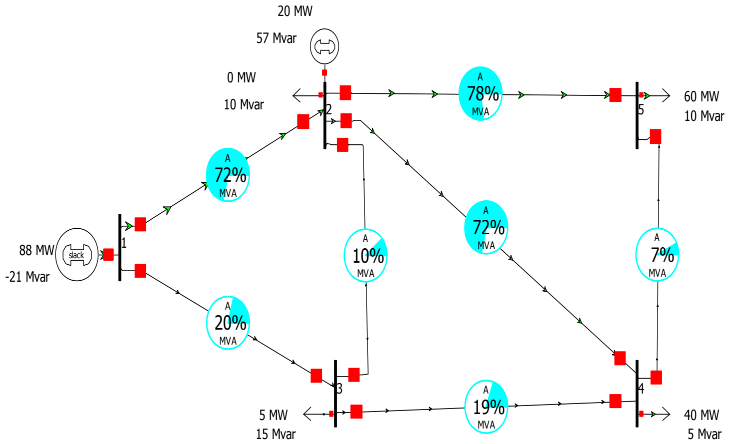


Fig 4: congestion relief by load curtailment at bus 3

So by doing load curtailment based on TLR sensitivity method at bus3 the congestion is relieved.

VII. SIMULATION RESULTS FOR MODIFIED IEEE 9 BUS SYSTEM:

The effect on ATC of the network by changing generator participation factors and by varying the load has been carried on below modified IEEE 9 bus system. In this modified IEEE 9 bus system, the bus1 is a slack bus, bus 2 and bus3 are generator buses. The bus5, bus7, bus9 are load buses. It is assumed that the load sharing by generator buses are x_i times the change in load.

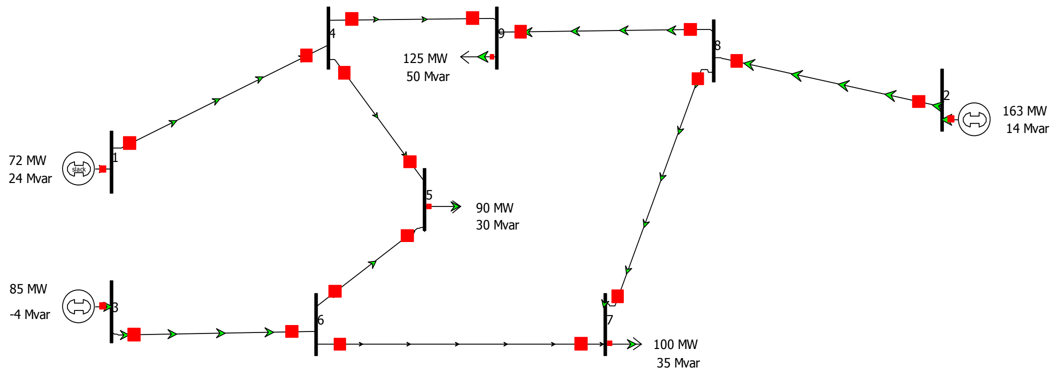


Fig 5: modified IEEE 9 bus system based on generator participation factor

For example, if 0.2, 0.2, 0.6 are the participation factors for the generators 1, 2, 3 respectively. For a change in load 10 M.W, then generator 1 additionally supplies 2 M.W, generator 2 additionally supplies 2 M.W and generator 3 additionally supplies 6 M.W.

The ATC contributions with changing generator participation factors and increment of load at particular bus is shown as follows

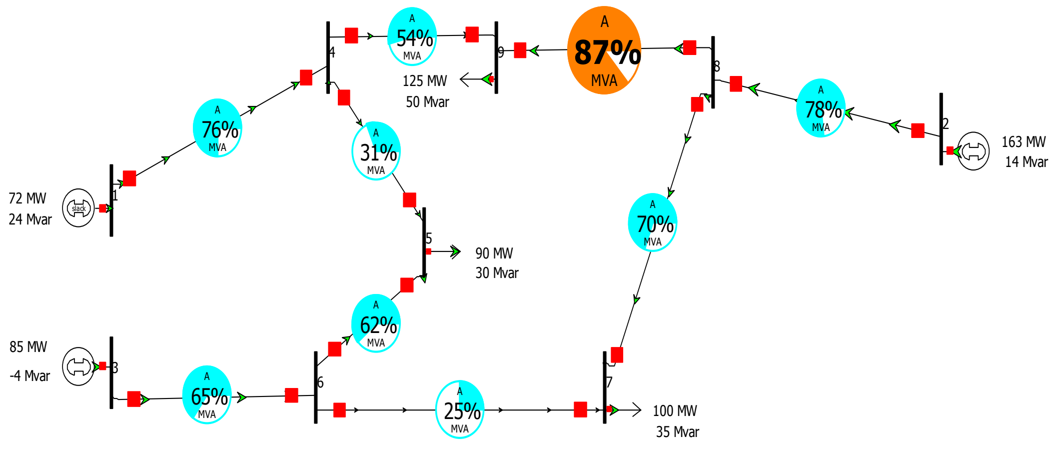
TABLE 5: Avilable Transfer Capability With Consideration Of Individual Bilateral Transactions And Changes In Load At Bus 5 (Initial Load At Bus 5=90mw And Participation FACTORS ARE x1=0.2, x2=0.2, x3=0.6)

S.NO	Applied change in load at bus 5 (MW)	Total load at bus 5 (MW)	Generator to load bus pair	Transacted power (MW)	Losses (MW)	N/W ATC for individual transactions (MW)	N/W ATC for simultaneous power transaction from all generator to bus 5 (MW)
1	10	100	1-----5	2	0	25.67	31.53
			2-----5	2		20.35	
			3-----5	6		41.04	
2	10	110	1-----5	5	1	23.25	21.54
			2-----5	4		13.90	
			3-----5	12		28.03	
3	10	120	1-----5	7	1	20.80	11.55
			2-----5	6		7.45	
			3-----5	18		15.03	
4	10	130	1----5	10	2	18.31	1.56
			2----5	8		1.01	
			3-----5	24		2.03	
5	10	140	1-----5	12	3	15.79	0
			2-----5	10		0	
			3-----5	31		0	

TABLE 6: AVILABLE TRANSFER CAPABILITY WITH CONSIDERATION OF INDIVIDUAL BILATERAL TRANSACTIONS AND CHANGES IN LOAD AT BUS5(INITIALLOAD AT BUS 5=90MW AND PARTICIPATION FACTORS ARE x1=0.4,x2=0.5,x3=0.1)

S.NO	Applied change in load at bus 5 (MW)	Total load at bus 5 (MW)	Generator to load bus pair	Transacted power (MW)	Losses (MW)	N/W ATC for individual transactions (MW)	N/W ATC for simultaneous power transaction from all generator to bus 5 (MW)
1	10	100	1----------5	4	0	22.14	37.65
			2----------5	5		24.30	
			3----------5	1		44.40	
2	10	110	1----------5	8	0	17.79	30.85
			2----------5	10		19.92	
			3----------5	2		40.16	
3	10	120	1----------5	13	1	13.42	24.06
			2----------5	15		15.53	
			3----------5	3		31.32	
4	10	130	1----------5	17	1	9	17.29
			2----------5	20		11.6	
			3----------5	4		22.50	
5	10	140	1----------5	21	1	4.56	10.52
			2----------5	25		6.79	
			3----------5	5		13.69	
6	10	150	1----------5	26	2	0.08	0.40
			2----------5	30		2.43	
			3----------5	6		4.89	
7	10	160	1----------5	30	2	0	0
			2----------5	35		0	
			3----------5	7		0	

Fig 6: congestion in network for participation factors x1=0. 2, x2=0.2, x3=0.6



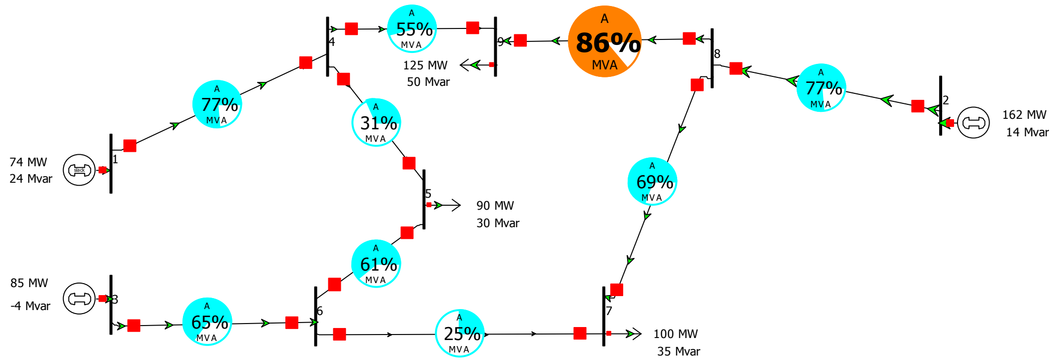


Fig 7: congestion in network for participation factors x1=0.4, x2=0.5, x3=0.1

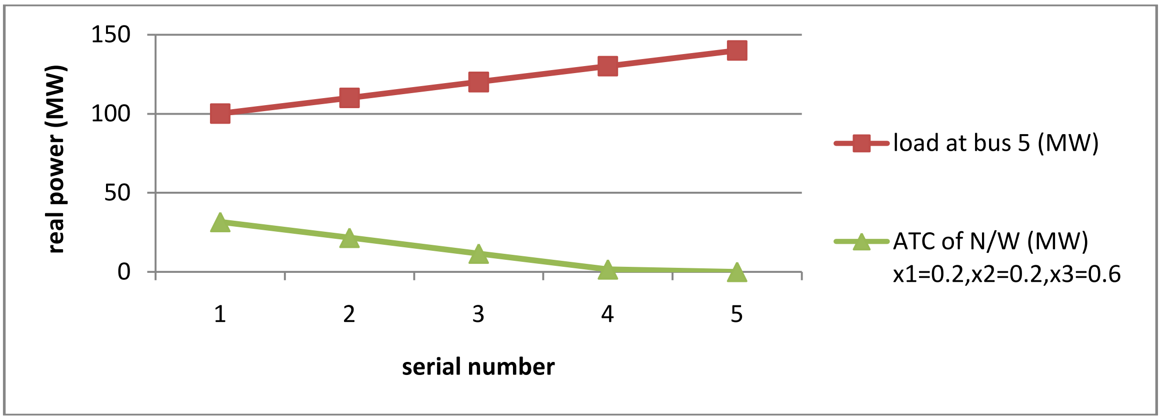
The tables 5 and 6 represents the calculation of ATC values for increasing load is showed. For computation of Network ATC, the load at bus 5 is continuously increased in steps of 10 M.W till is leads to congestion in one or more transmission line of the power system. According to the initially placed generator participation factors, the generators responses for corresponding changes at the load bus 5. This change of load is shared by the generators as per the participation factors.

From the above tables it is observed that the ATC values of the network are decreases when the load at bus5 increases and also observed that ATC value of the network is changes when the generator participation factor is changed. The ATC values are also determined by power world simulator 16. The above table's shows that the total maximum load applied at load bus 5 for generator participation factors are

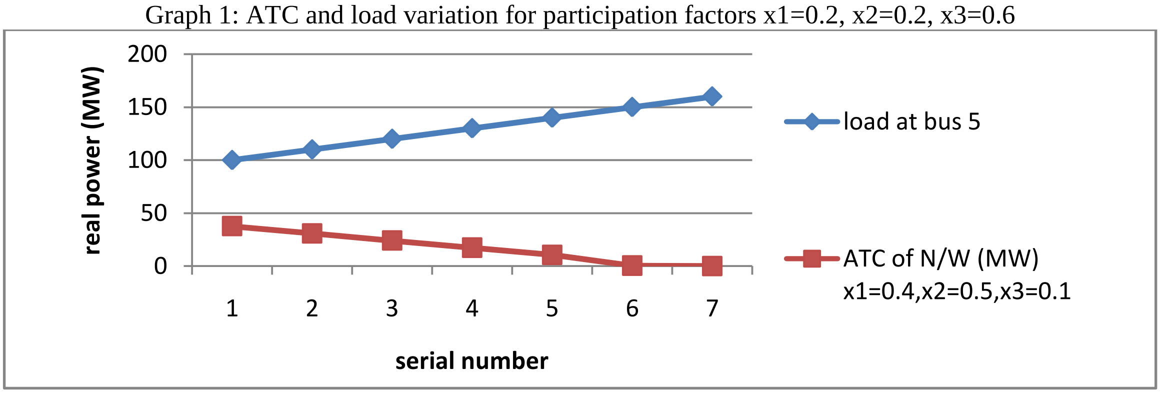
140 M.W for participation factors x1=0.2, x2=0.2, x3=0.6 and

160 M.W for participation factors x1=0.4, x2=0.5, x3=0.1.

The ATC values are determined by conventional Network response method. Generator with larger participation factor can have a more positive effect on improving the system power transfer capability. It can be observed from above two tables that as the load is continuously increased, ATC of network decreases leading to congestion in the transmission line. The below graphical representation shows the ATC and load variations for corresponding generator participation factors.



Graph 1: ATC and load variation for participation factors x1=0.2, x2=0.2, x3=0.6



Graph 2: ATC and load variation for participation factors x1=0.4, x2=0.5, x3=0.1

VIII. CONCLUSION

Congestion management is one of the challenging and toughest tasks in deregulated power system environment. In this paper two different types of approaches were successfully used to relief the congestion in the network. One of approach is congestion management by use of FACT device i.e. TCSC and another approach is by changing generator participation factors to alleviate congestion. The method of Mitigation of total system VAR power loss is used to allocate the TCSC in optimal location and transmission load relief (TLR) method is used to find load curtailed bus for congestion relief in the network. The loading on the network continuously increases, then ATC of the network will goes on decreases. From the results, it can be observed that the maximum load that can be applied to a particular bus also; there is no causing of network congestion because of changing generator participation factors. So generator participation factors are also used as one of tool for management of congestion in the network.

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