Congestion Management in Transmission Lines using FACTS Devices

Kunj Thekdi
BE Electrical 2018
Faculty of Technology & Engineering,
The Maharaja Sayajirao University of Baroda
Vadodara, Gujarat, India

Vishwajeetsinh Varnamiya
BE Electrical 2018
Faculty of Technology & Engineering,
The Maharaja Sayajirao University of Baroda
Vadodara, Gujarat, India

Deep Desai
BE Electrical 2018
Saradar Vallabhbhai Patel Institute of Technology,
Vasad, Vadodara, Gujarat, India

***Abstract*— This report presents a mathematical model of Available Transfer Capability (ATC) deals with congestion management situation in transmission lines. This report contains the simulation of IEEE 9-bus system in software "Power World – Simulation Education-Evaluation 20" , which defines whether the system is in congestion or not using the values of ATC in every case. ATC can be calculated using Power Transfer Distribution Factor (PTDF) which is taken from standard IEEE 9-bus system data from Power world simulator. This report also contains modeling of a FACTS device i.e. Thyristor controlled series capacitor (TCSC). This report also contains that using this device in series with the line, it changes the susceptance of line and ultimately it improves the ATC of the line hence congestion is managed.**

Keywords*— *Available Transfer Capacity(ATC), Power Transfer Distribution Factor(PTDF), Flexible AC Transmission System(FACTS), Thyristor Controlled Series Capacitor(TCSC)

I. INTRODUCTION

In all over the world, interconnections and loadings in the modern power system networks are growing. Power utilities are facing a major challenge in maintaining desired security of power supply. Power system security and analysis forms an essential part of modern energy management system. The economic downturn coupled with environmental and ecological pressures have obliged the electric utilities, all over the world, to serve the augment in load demand without corresponding increase in generation and transmission facilities. This has forced the utilities to operate their generators and transmission systems to their maximum capabilities. And system running under its maximum capabilities is called system under congestion. Hence, the re-regulation of the power system has been derived for getting maximum economical benefits to the society.

II. CONGESTION MANAGEMENT IN TRANSMISSION LINES

A. Congestion Management

In deregulated environment all simultaneous transactions will pull the power system in unstable state or it is in congestion. Any violations in physical or operational constraints will results congestion. The constraint has been listed as under:

- Voltage Limits
- Thermal Limits
- Stability Limits

B. Available Transfer Capability (ATC)

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III. AVAILABLE TRANSFER CAPABILITY (ATC) AND EQUATIONS

In deregulated environment all simultaneous transactions will pull the power system in unstable state or it will be in congestion. Any violation in physical or operational constraints will result in congestion. The physical structure of transmission line cannot modify as it requires a huge amount of investment. Hence, power can be imported and exported in open access market with the same lines in congestion management. The possible boundaries that may be violated in case of congestion are:

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(1) Thermal limits of transmission lines
(2) Emergency ratings of the Transformer
(3) Voltage limits
(4) System stability.

A. ATC Calculation using PTDF [1]

One way of calculating ATC from node A to node B is to use DC load flow (explained later) repetitively by increasing the amount of transaction until a limit of any of the corridor is reached. However, this is computationally inefficient. Instead, the Power Transfer Distribution Factor (PTDF) can be used to calculate the maximum allowable flow for a given pair of injection and take-off points. It is also necessary to consider the effects of contingencies like line outages. This can be achieved using Line Outage Distribution Factor (LODF). Let us first see the details of DC load flow model.

B. DC Load Flow Model [1]

With the assumptions, power flows over transmission lines connecting bus i and bus j is given as:

$$P_{lm} = \frac{1}{x_{lm}}(\theta_l - \theta_m)$$

Where,

x_{lm} line inductive reactance in per unit

θ_l phase angle at bus l

θ_m phase angle at bus m

The total power flowing into the bus i, Pi, is the algebraic sum of generation and load at the bus and is called a bus power injection. Thus,

$$P_i = \sum_j P_{ij} = \sum_j \frac{1}{x_{ij}}(\theta_i - \theta_j)$$

This can be expressed in a matrix form as:

$$\begin{bmatrix} P_1 \\ M \\ P_n \end{bmatrix} = \begin{bmatrix} B_X \end{bmatrix} \begin{bmatrix} \theta_1 \\ M \\ \theta_n \end{bmatrix}$$

Where, the elements of the susceptance matrix BX are functions of line reactances. One node is assigned as a reference node by making its angle zero and deleting corresponding row and column in $[B_X]$ matrix. Thus,

$$[X_{init}] = [B_{X,reduced}]^{-1}$$

The dimension $[X_{init}]$ of obtained is $(n-1 \times n-1)$. Let us augment it by adding zero column and row corresponding to reference bus. The angles in equation 4.3 can be found out as

$$\begin{bmatrix} \theta_1 \\ M \\ \theta_n \end{bmatrix} = [X] \begin{bmatrix} P_1 \\ M \\ P_n \end{bmatrix}$$

Thus, power flow over line lm can be found out using this equation.

A. ATC calculation Using PTDF

ATC is determined by recognizing the new flow on the line from node l to node m, due to a transaction from node i to node j. The new flow on the line is the sum of original flow P^0_{lm} and the change.

$$P_{lm} = P^0_{lm} + PTDF_{lm,ij}P_{ij}$$

Where, P^0_{lm} is the base case flow on the line and P_{ij} is the magnitude of proposed transfer. If the limit on line lm, the maximum power that can be transferred without overloading line lm, is P^{max}_{lm}, then,

$$P^{max}_{ij,lm} = \frac{P^{max}_{lm} - P^0_{lm}}{PTDF_{lm,ij}}$$

$P^{max}_{ij,lm}$ is the maximum allowable transaction from node i to node j constrained by the line from node l to node m. ATC is the minimum of the maximum allowable transactions over all lines.

Using the above equation, any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

$$ATC_{ij} = \min\left(P^{max}_{ij,lm}\right) \quad \forall lm$$

Using the above equation, any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

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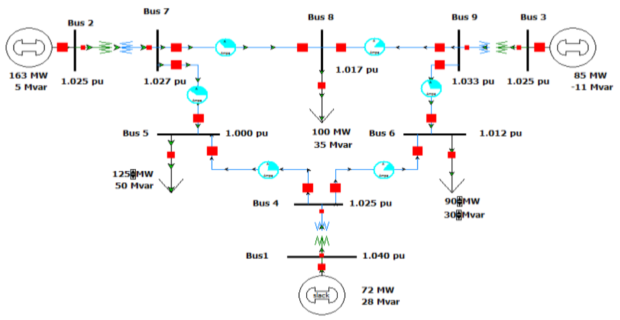
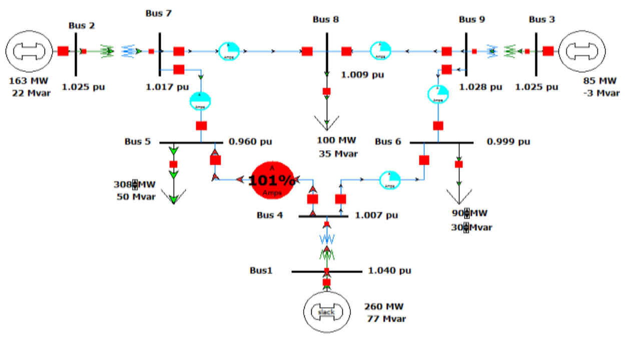
IV. STANDARD DATA AND NORMAL CONDITION: IEEE 9 BUS SYSTEM



IEEE 9 bus system in normal condition

FROM BUS	TO BUS	Absolute % PTDF
5	4	89.59
6	4	10.41
7	5	10.41
9	6	10.41
7	8	10.41
8	9	10.41

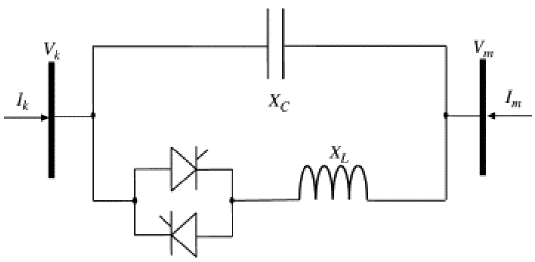
PTDF values of IEEE 9 bus system from POWER WORLD SIMULATOR.



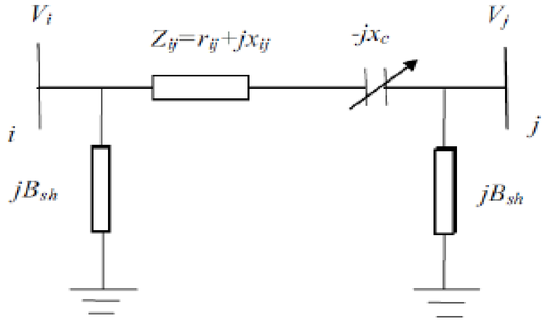
IEEE 9 bus system in congested condition

V. FACT DEVICE – TCSC

Thyristor-controlled series capacitor (TCSC) is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance.



Further figure shows a model of a transmission line with a TCSC connected between buses i and j. The transmission line is represented by its lumped π-equivalent parameters connected between the two buses. During the steady state, the TCSC can be considered as a static reactance -jXC. This controllable reactance, XC is directly used as the control variable to be implemented in the power flow equation. [5]



Line flows

- Without TCSC
  $G_{ij} + jB_{ij} = [r_{ij} / (r_{ij}2 + x_{ij}2)] + j[-x_{ij}2 / (r_{ij}2 + x_{ij}2)]$
- With TCSC (-jxc)
  $G'_{ij}+ jB'_{ij} = [1/\{r_{ij} + j(x_{ij} – x_c)]*[r_{ij}- j(x_{ij} – x_c)]/[r_{ij} - j(x_{ij} – x_c)]$

Where,

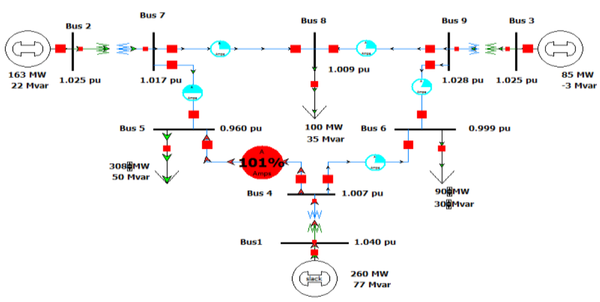
$B'_{ij} = [-(x_{ij} – x_c) / \{r_{ij}2 + (x_{ij} – x_c)2\}]$
$G'_{ij} = [r_{ij}/\{r_{ij}2 + (x_{ij} – x_c)2\}]$

Assumptions

- We have taken Xc =0.9153 pu and using this we have calculated the B'ij which comes out to be B'ij =1.18 pu. So, After connecting TCSC in series with the line 45 the new B'ij is 1.18 pu instead of the previous values (0.176 pu) . Now , whenever we use TCSC the line susceptance between 4-5 will be B'ij=1.18 pu.
- We have taken G'ij=0 pu .

VI. CASES

1. CASE I – NEGATIVE ATC



IEEE 9 bus system in congested condition – without TCSC

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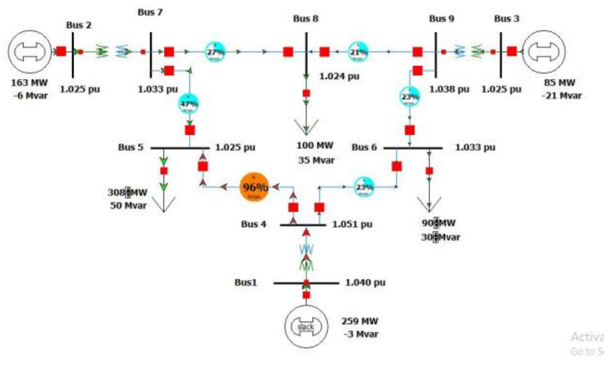
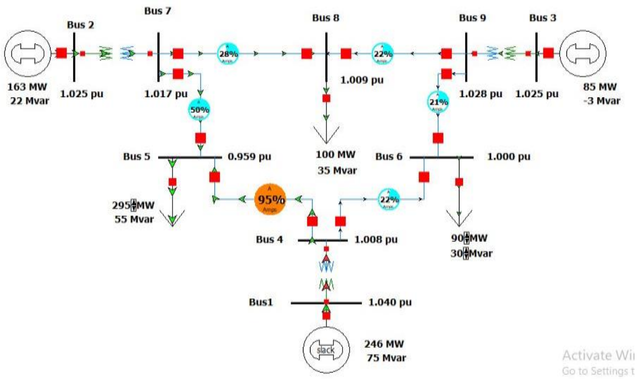
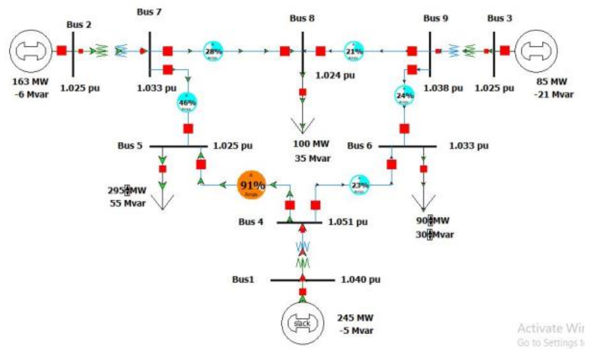


IEEE 9 bus system in congested condition – with TCSC

2. CASE II – CRITICAL ATC

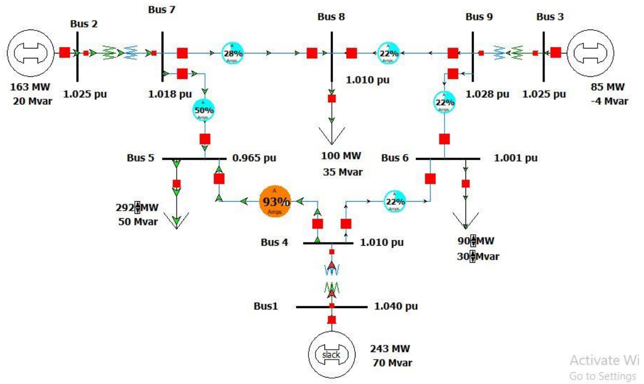


IEEE 9 bus system in congested condition – without TCSC

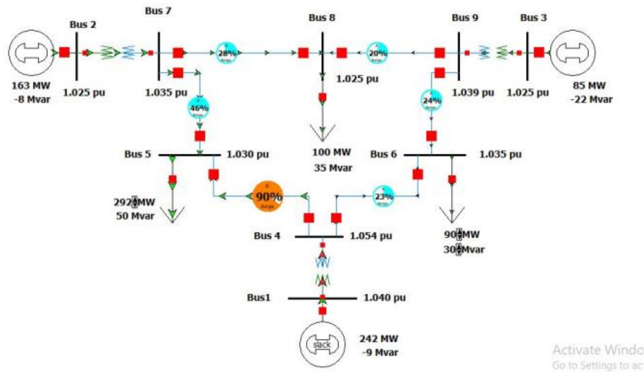


IEEE 9 bus system in congested condition – with TCSC

3. CASE III – POSITIVE ATC



IEEE 9 bus system in congested condition – without TCSC



IEEE 9 bus system in congested condition – with TCSC

VII. RESULT TABLE

CASES	ATC WITHOUT TCSC in MW	ATC AFTER USING TCSC (IMPROVED ATC) in MW
I – negative	-13.56	-12.98
II - critical	-0.0446	0.5692
III - positive	3.18	3.73

VIII. CONCLUSION

It concludes that the development of the AC Power Transmission Congestion Distribution factor (PTCDF) suitable for computing change in any line quantity for a change in MW bilateral transaction. With PTCDF ATC can be calculated. For multiple transactions ATC calculation is very important and mandatory too. ATC calculations can be used to solve congestion problem in restructured electrical power network.

In case of negative ATC where ATC falls below zero i.e. negative in congested situation, as discussed in chapter 5:case-I, can be improved in negative as well, though it is not a good situation for the transmission system.

In case of critical ATC, before using TCSC, ATC is negative and it can be brought to positive using TCSC and it is quite useful method in practice. The results for the same are described in chapter 5:case-II.

While in case of positive ATC, it can be improved using TCSC and the results for the same is shown in chapter 5:case-III, which is the situation, market faces frequently.

In all cases, TCSC injects MVAR to the line that reduces the real power flow in the line.

IX. APPENDIX

IEEE 9-BUS DATA

Bus Data

Bus Num.	Type	Pd	Qd	Area	Vm	Base KV	Zone	Vmax	Vmin
1	3	0	0	1	1	345	1	1.1	0.9
2	2	0	0	2	1	345	1	1.1	0.9
3	2	0	0	1	1	345	1	1.1	0.9
4	1	0	0	1	1	345	1	1.1	0.9
5	1	90	30	1	1	345	1	1.1	0.9
6	1	0	0	1	1	345	1	1.1	0.9
7	1	100	35	2	1	345	1	1.1	0.9
8	1	0	0	2	1	345	1	1.1	0.9
9	1	125	50	2	1	345	1	1.1	0.9

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Generator Data									
Bus Num.	Pg	Qg	Qmax	Qmin	Vg	Mbase	Status	Pmax	Pmin
1	0	0	300	-300	1	100	1	250	10
2	163	0	300	-300	1	100	1	300	10
3	85	0	300	-300	1	100	1	270	10

Branch Data												
From Bus	To bus	R	X	B	Rate A	Rate B	Rate C	Ration	Angle	Status	Ang. Min.	Ang. Max
1	4	0	0.0576	0	250	250	250	0	0	1	-360	360
4	5	0.017	0.092	0.158	250	250	250	0	0	1	-360	360
5	6	0.039	0.17	0.35	150	150	150	0	0	1	-360	360
3	6	0	0.058	0	300	300	300	0	0	1	-360	360
6	7	0.011	0.100	0.20	150	150	150	0	0	1	-360	360
7	8	0.008	0.072	0.14	250	250	250	0	0	1	-360	360
8	2	0	0.062	0	250	250	250	0	0	1	-360	360
8	9	0.032	0.161	0.30	250	250	250	0	0	1	-360	360
9	4	0.01	0.085	0.17	250	250	250	0	0	1	-360	360

X. REFERENCES

[1] NPTEL : http://nptel.ac.in/courses/108101005/20 (module 4: Transmission congestion management)
[2] Umesh Laljibhai Makwana,"Available Transfer Capability (atc) management in restructured electrical power network", department of electrical engineering faculty of technology & engineering the maharaja sayajirao university of baroda, vadodara 390 002, February 2017
[3] Hiren patel, Ravikumar, "Congestion management in deregulated power system using FACTS devices",IJAET 2015, vol.8,issue 2,pp. 175-184
[4] N.Sambasivaroa, J.Amarnath, V.Purnachandrarao,"congestion management using facts devices in deregulated power system", IJRET, eISSN: 2319-1163 | pISSN: 2321-7308
[5] K. R. Padiyar, "FACTS controller in power transmission and distribution"
[6] Manisha Chadar, Thesis on "Mitigation of voltage sag by thyristor controlled series capacitor and PWM generator and their comparision", IJTPD, vol. 1, issue 1, PP: (71-98)
[7] Liangzong Yao, Phill Cartwright, Laurent Schmitt, Xiao-Ping Zhang, "Congestion Management of Transmission systems using FACTS", IEEE Conference 2005, pp 1-5