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Power Flow Congestion Management Using Distributed FACTS Devices

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ABSTRACT:
Power systems are becoming more and more stressed and burdened with the continuous increase in consumption and demand. The modern lifestyle demands increasing amounts of affordable and reliable electricity. To tackle this expansion of the existing system is needed. However, in the face of increasing public safety concerns and environmental hazards brought about by the expansion of the existing power structure has forced the search for alternate methods. This has made the development of methods for more efficient use of the existing structure very critical. In pursuit of increasing the efficiency of the existing power infrastructure this work proposes the implementation of Distributed-Flexible AC Transmission System (D-FACTS) devices in the existing power infrastructure to increase the capacity of power transmission and the stability of the system.

Keywords – Distributed FACTS, FACTS, Power World, Power System, Transmission System.

I. INTRODUCTION

Power systems worldwide is becoming complex day by day and continuous requirements for stable, secured, controlled, economic and better-quality power is predominant all over. The modern industrial infrastructure demands increasing amounts of affordable and reliable electricity. Yet, in a semi regulated utility environment and in the face of increasing public sentiment against locating power lines in their communities, the ability to use the existing asset base more effectively has become a critical issue [1].

Demand of electric power is ever increasing but unfortunately even in developed countries due to the weakness of existing transmission networks the quality of power is becoming poor and unreliable. Amongst all the challenges facing utilities the most vital is the issue of eliminating transmission constraints and bottlenecks. Increasing congestion and loop flows on the transmission and sub-transmission system degrades system reliability, increases energy prices and prevents full utilization of existing assets. Nevertheless, the job done by utilities in ensuring the availability of reliable electricity is quite good. But for this a gradual movement had to be made from radial power distribution to a system that is increasingly network.

In the evolving utility environment, financial and market forces are, and will continue to, demand a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems. To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure is required. Demand response, i.e. the use of price signals as motivation for electricity market's participants to reduce their consumption and therefore participate in congestion management, is one possible approach [2]. This being said, power flow optimization can be seen as another way to solve the problem of congestion. This process will require controlling of specific parameters in the power system

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leading to full usage of existing transmission capacity. Power flow control defined as steering the electric power to a desired path by adjusting line impedances, bus voltage magnitudes or phase angle differences is a means for power flow optimization. It can potentially increase the transfer capacity of the transmission system by diverting the power from congested lines to the lines with spare capacity [3].

Power flow in alternating current (AC) systems is unlike other flow problems such as in transportation or telecommunications. In a transportation system, trucks can be routed along a desired path from a source to a destination. Similarly, in a communications system, packets can be routed such that they travel along a shortest path between a sender and a receiver. However, electricity must follow the laws of physics, so power flow is not routable and cannot be directly controlled. Power flow control is also different from other types of flow problems since electricity must also be produced exactly when it is needed. Generation must constantly track the load as the customers' demands change. In other systems for distributing goods and services, products are stored in a warehouse until they need to be sent to the end user. If the desired supply is unavailable, the end user can wait and it will arrive later. In power systems, customers are in control of how much power they use and always expect that amount of power to be available [4].

Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics-based equipment, or FACTS, provide proven technical solutions to address these new operating challenges being presented today. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines. Traditional solutions to upgrading the electrical transmission system infrastructure have been primarily in the form of new transmission lines, substations, and associated equipment. However, as experiences have proven over the past decade or more, the process to permit, site, and construct new transmission lines has become extremely difficult, expensive, time-consuming, and controversial. FACTS technologies provide advanced solutions as cost-effective alternatives to new transmission line construction [5]. For the different approach for realizing the functionality of FACTS devices (series FACTS devices in particular), at lower cost and higher reliability the concept of distributed FACTS (D-FACTS) devices has recently been adopted.

Distributed flexible AC transmission system (D-FACTS) devices, such as the Distributed Static Series Compensator (DSSC) have been designed to address power control types of problems. D-FACTS devices attach directly to transmission lines and can be used to dynamically control effective line impedance. Also, D-FACTS devices are smaller and less expensive than traditional FACTS devices which may make them better candidates for wide scale deployment. From a power systems perspective, D-FACTS devices have many potential benefits [6].

II. LITERATURE REVIEW

In order to meet the ever-growing power demand, several problems have arisen in the power flow control in transmission grid such as congestion and power flow limitations. To overcome these, engineers are continuously upgrading and expanding the power systems. But in this process several economic and environmental barriers are faced by the energy planners. Some of these are exhausting energy resources, land use restrictions and lack of capital and time required. As a result, researchers have introduced the concept of flexible AC transmission systems (FACTS) devices. However, the major disadvantage of using FACTS devices is their reliability concern and high cost. The concept of distributed FACTS or D-FACTS is hence incorporated to help in achieving cost effective power flow control. Johal et al. have

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proposed a distributed series impedance (DSI) and a distributed static series compensator (DSSC) to dynamically and statistically control the power flow by changing the impedance of a power line [7]. Kakkar et al. have made a study on the recent trends of FACTS and D-FACTS to reveal that D-FACTS controllers have more reliable and cost saving approach as compared to FACTS controllers and can be applied where robust, sensitive and optimum performance is required [8]. FACTS devices are mainly high voltage power converters operating at 138 to 500 kV and 10 to 300 MVA which control power flow in transmission line. These devices are used on multiple lines throughout the system to achieve desired line flow objectives. The impact of installing D-FACTS devices on the sensitiveness of power system quantities such as voltage magnitude, voltage angle, bus power injection, line power flows and real power losses was investigated by Baby et al. [9]. Distribution Generation (DG) is mostly used nowadays in power community for sustainable energy alternative in renewable energy source. But this has disadvantage also. Some Distributed Generation has high penetration levels. It has adverse effect on i) transmission and distribution losses and ii) reliability and power quality. D-FACTS (Distributed-Flexible AC Transmission Systems) help to relax restriction on the maximum penetration capacity of Distribution Generation units as shown by HuiRen et al [10]. Monte Carlo simulation is used to simulate the commission and operation of distributed generation in multiple locations. This simulation shows that the limitations of distributed power's position and capacity.The relationship between different power system quantities of lines, buses and flow in a system is expressed by linear sensitivities. Using these linear sensitivities like voltage magnitude, voltage angle, bus power injections, line power flow and real power losses with respect to line impedance, non-linear problems such as real power loss minimization and voltage control can be solved. The advantage of installing D-FACTS according to the impact of the linear sensitivities and its effects on loss minimization and voltage control are explored by Rogers et al. [11]. Distributed Generation decreases transmission loss, has a short period of construction and low investment. But due to the increased penetration of capacity and undesirable locations of distributed generation cause bad impacts on the transmission losses of the distribution network, on voltage stability and network reliability which affects power loss. Monte Carlo simulations used to simulate the commission and operation of distributed generationwith the application of D-FACTS have been done by HuiRen et al. to show that limitations of distributed power generators position and capacity can be effectively reduced by the use of DFACTS. They also analyse how D-FACTS helps to release restrictions on the location and maximum penetration capacity of Distributed Generation units [12]. Due to the aging and congestion in power grid, though FACTS devices were implemented in the lines, a new cost-effective and more reliable component was needed. That is the reason for proposing the new devices named D-FACTS. Now the implementation of D-FACTS devices by studying series var compensation and the system stability would help in improvement in system capability and minimize the grid congestion. Another concept of distributed series impedance (DSI) can help in realizing variable line impedance and controlling of active power flow [13].FACTS devices increase the flexibility of power systems, makes them more controllable and allows optimum utilization of existing networks. These devices can control power flow in the transmission system to improve asset utilization, relieve congestion and limit loop flows. It provides improved voltage regulation and also improves load sharing between parallel ac transmission lines. But high cost and reliability concerns have restricted their use in these applications. The DSSC modules are distributed, a few conductors per mile, and thereby the required power flow control is achieved simply by altering the line reactance. The DSSC inverters are self-powered by induction from the line itself and can be used to either increase or decrease the line impedance, allowing current to be 'pushed' away from or 'pulled' into a transmission line in a networked system. Thus, the

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DSSC concept overcomes few major limitations of FACTS devices and helps achieve power flow control with Distributed FACTS or D-FACTS devices [14].Non-linear devices are introduced to electrical system to improve the power quality of the voltage and current. But they have limitations, viz, i) they cannot be restricted at transmission and distribution level because of their compactness and power handling capacity and ii) but also draw non-linear current degrading the power quality. But when the controller is placed at the distribution side between utility and the customer is shown to be a remarkable approach for the improvement of the quality of power supply. The D-FACTS device consists of two controllers, i.e., constant dc voltage controller and ac voltage controller. The constant dc voltage controller maintains constant dc voltage while ac voltage controller maintains the required RMS value of the voltage at the load side [15].

The characteristics of the power supplied when D-FACTS are in use is hold good for both balanced and unbalanced supply. Therefore D-FACTS are successfully used for improvement of quality of the supply.

III. MATHEMATICAL MODEL

The AC power injection equations for real power P and reactive power Q at a bus I are stated in (1) and (2).

$$P_{i,calc} = V_i \sum_{j=1}^{n} V_j \left[G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right] \quad (1)$$

$$Q_{i,calc} = V_i \sum_{j=1}^{n} V_j \left[G_{ij}\sin(\theta_i - \theta_j) + B_{ij}\cos(\theta_i - \theta_j)\right] \quad (2)$$

Where n is the number of buses. Real and reactive power balance is expressed by the concatenated vector $f_{pq}(s_{\theta,V})$ of Δp and Δq which must be equal to zero.

$$\Delta p_i = P_{i,calc} - (P_{i,gen} - P_{i,load}) \quad (3)$$

$$\Delta q_i = P_{i,calc} - (Q_{i,gen} - Q_{i,load}) \quad (4)$$

$$f_{pq}(s_{\theta,V}) = [\Delta p, \Delta q]^T \quad (5)$$

Where $s_{\theta,V}$ is a vector of bus voltage states represented in polar coordinates by magnitude V and angle θ

$$s_{\theta,V} = [\theta, V]^T \quad (6)$$

And G+jB is the system admittance matrix. Admittance matrix elements depend explicitly on reactive line impedances x as well as resistance r.

$$G_{ij} = -\frac{r_{ij}}{r_{ij}^2 + x_{ij}^2} \quad i \neq j \quad (7)$$

$$B_{ij} = -\frac{x_{ij}}{r_{ij}^2 + x_{ij}^2} \quad i \neq j \quad (8)$$

A line between buses i and j has both a sending end and a receiving end power flow which differ by the line's losses. All real power line flows for the system comprise P_{flow}.

$$P_{flow,ij} = V_i^2[-G_{ij}] + V_i V_j \left[G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right] \quad (9)$$

Analogously, all the reactive power flows in the system are given by Q_{flow}.

$$Q_{flow,ij} = V_i^2[B_{ij}] + V_i V_j \left[G_{ij}\sin(\theta_i - \theta_j) + B_{ij}\cos(\theta_i - \theta_j)\right] \quad (10)$$

The system real power losses are equal to the summation of the real power flows on all the lines:

$$P_{loss} = \sum_{i}^{n} \sum_{j}^{n} P_{flow,i,j} \quad i \neq j \quad (12)$$

The above equations are used to analyze the impact of D-FACTS devices in power systems.

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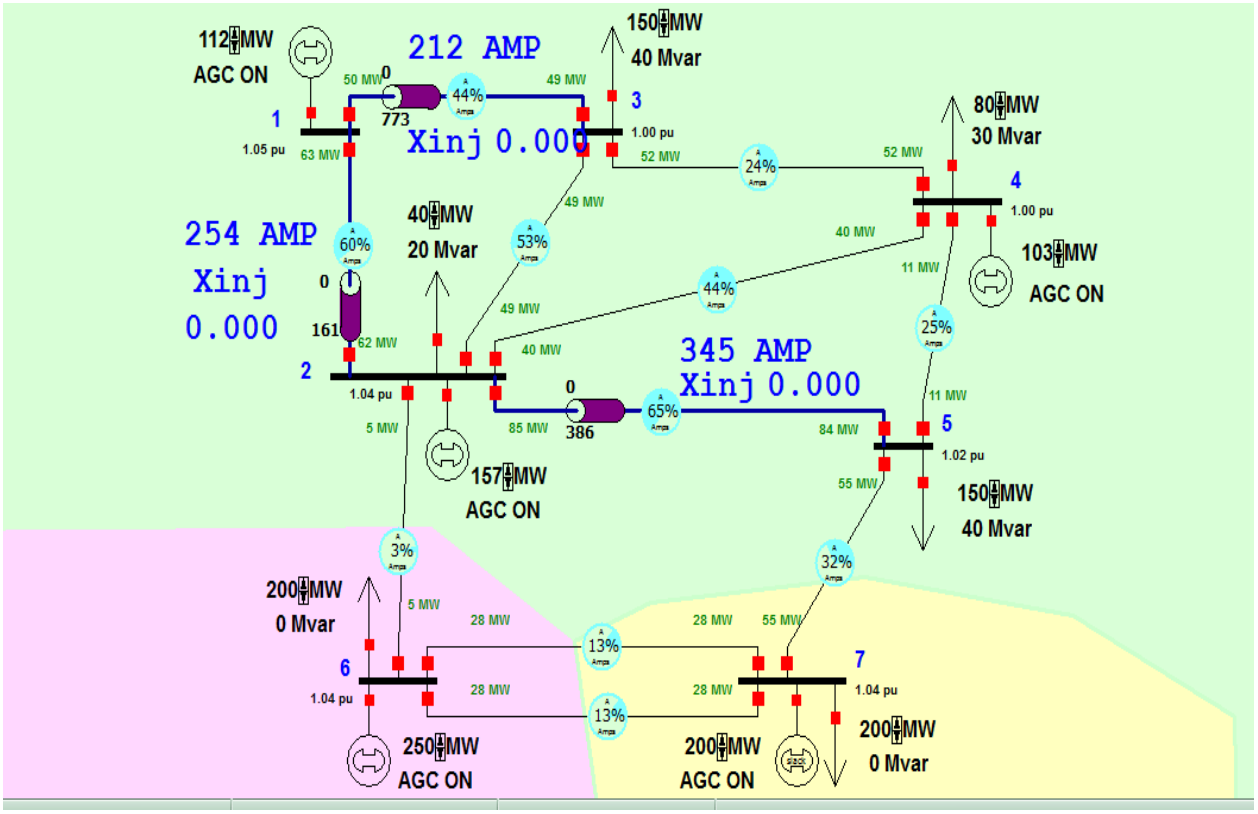
IV. SIMULATION AND RESULT

The following 7 bus circuit has been simulated in Power world software

Fig 1: Seven Bus simulation circuit



In this case we discuss about the D-FACTS devices connected between Bus 1 and Bus 2. In PowerWorld D-FACTS devices, the value of series reactive impedance X on the line is set as a function of the line current. Here for each line with D-FACTS devices, the user enters the number of modules and the reactive impedance per module. There is two specified current amount I_0 and $I_{lim.}$ Below I_0, the D-FACTS devices are not activated and Above I_{lim}, the cumulative impedance injection of the D-FACTS devices on the line is at its maximum value.

At first total number of modules are 161 and not a single module is activated as shown in Fig 2 to 4. But when the load at Bus 5 was increased not only D-FACTS devices connected between Bus 2 and Bus 5 is activated as shown in fig 5 to 7. As current flowing through the transmission line between Bus 1 and Bus 2 is become greater than the "Activation Current" = 373.56 Amp, the D-FACTS device become activated. When current flowing through that transmission line is 394 Amp (>373.56 Amp), the device is activated. 47 modules among 161 are started to work. Here the mode of operation is "limit based on current".

So by limiting the current or reactance in line we can control the activation process of D-FACTS devices.

Case 1: Normal Power Flow

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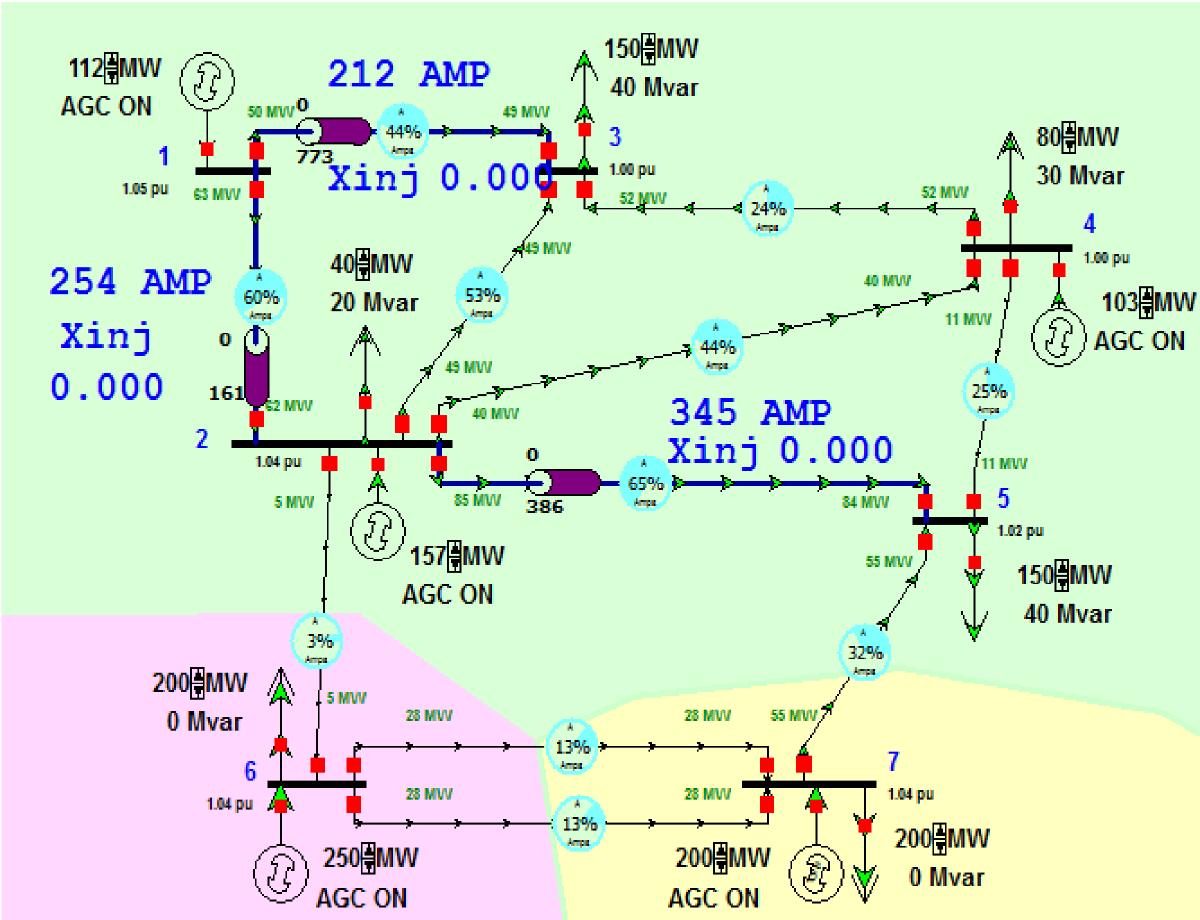

Fig 2: Normal Power Flow

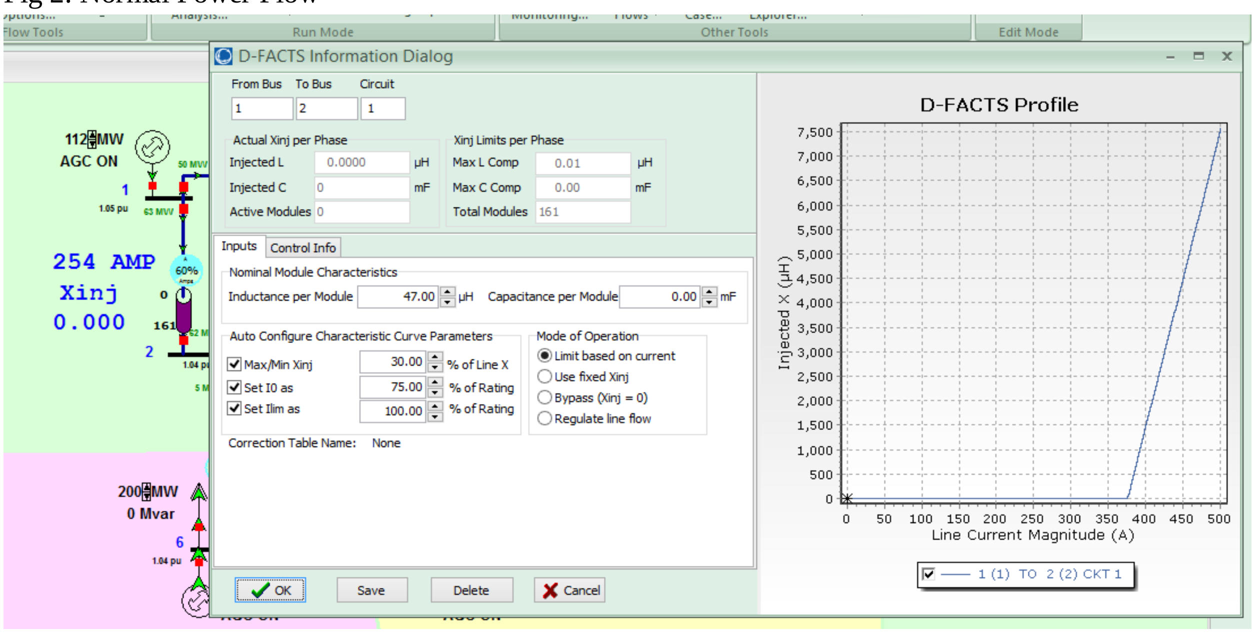

Fig 3: Parameters when DFACTS not activated

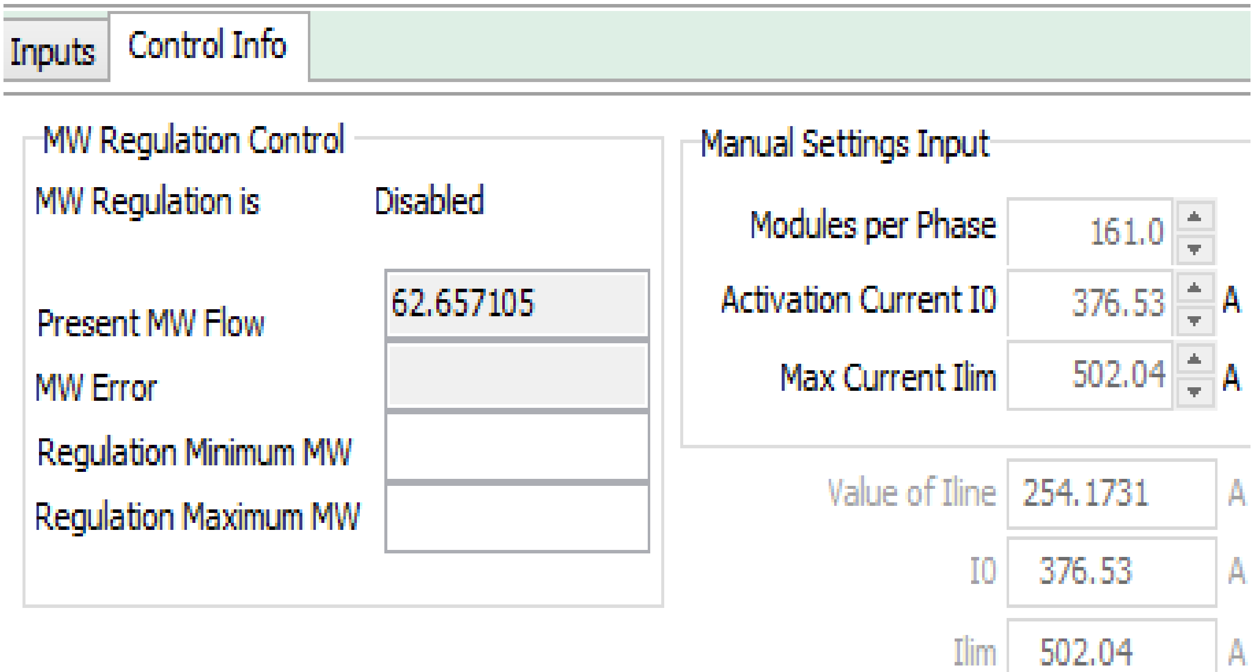

Fig 4: Control Info when DFACTS is not activated

Case 2: Increase the load at Bus 5 and D-FACTS devices become active

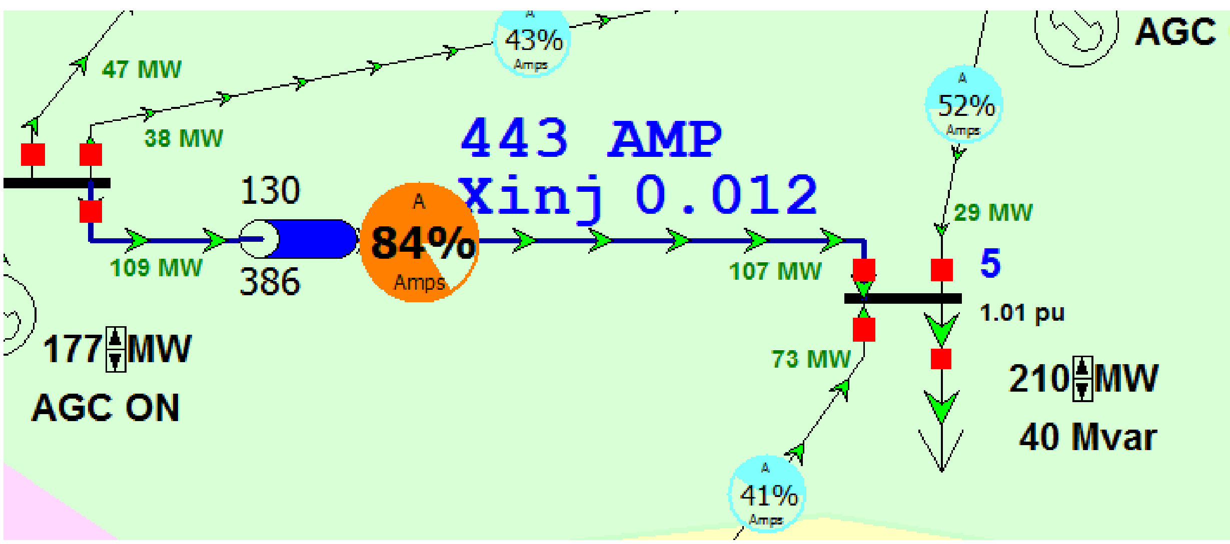

Fig 5: Load at bus 5 increased

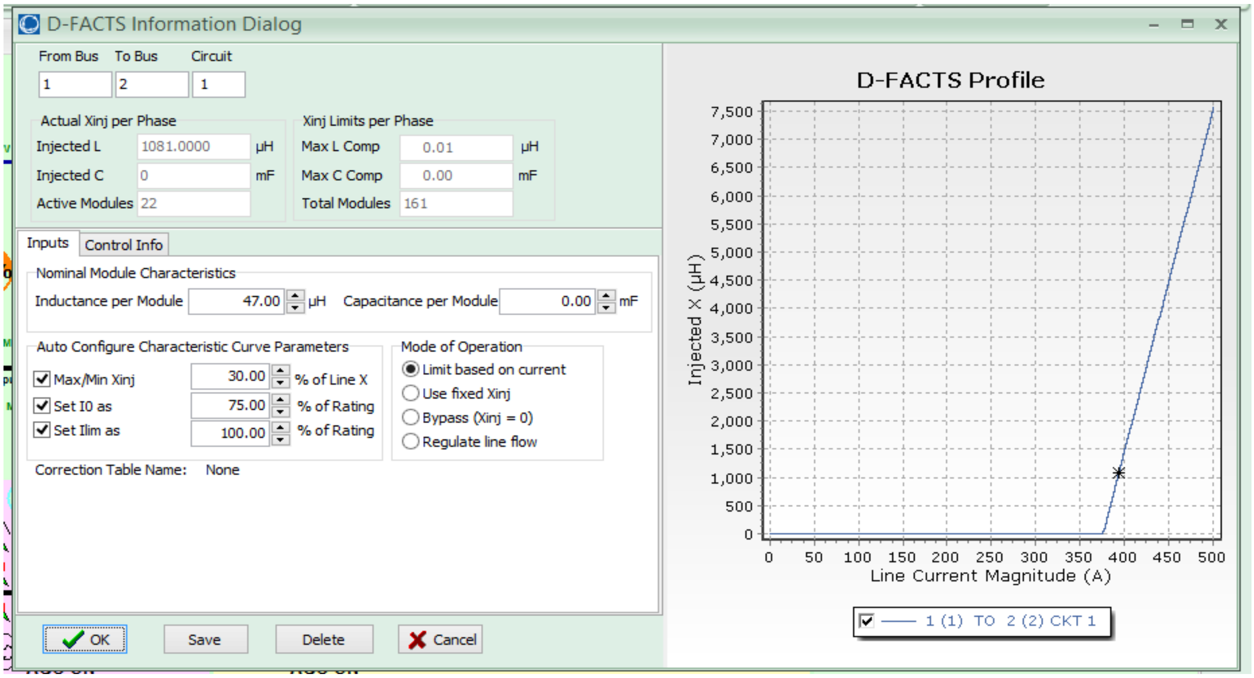

Fig 6: DFACTS parameters when load at bus 5 increased

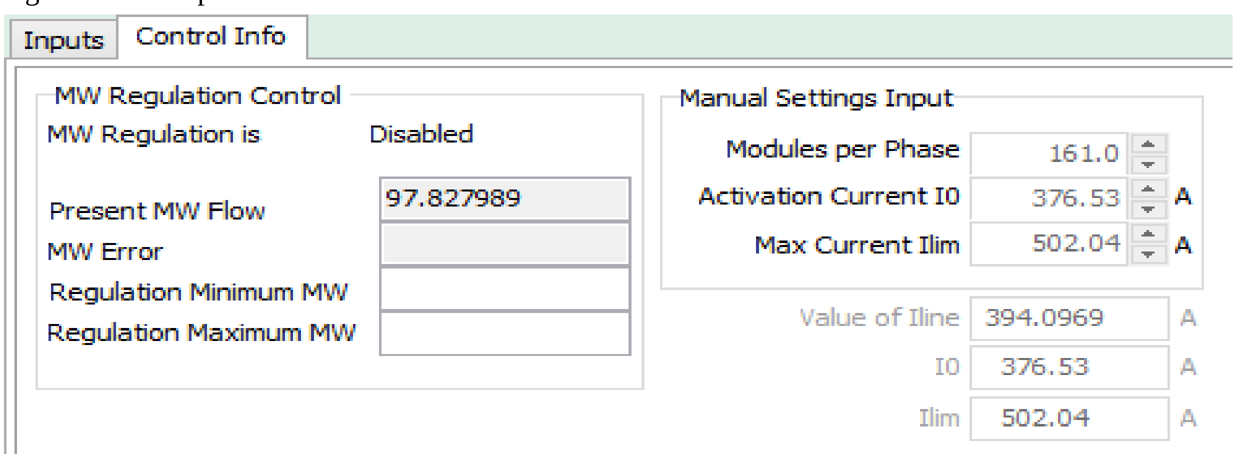

Fig 7: Control Info when DFACTS is activated

V. CONCLUSION

In this work DFACTS controllers are placed in different branches of transmission system and power flow control in the lines due to Distributed Series Impedance change are observed. It is also shown how the DFACTS modules are activated if any branch become overloaded. According to the requirement, mode of operations can be changed, which make the controllers more flexible. In this incorporation of DFACTS controllers how the transmission system problems can be solved, are also discussed here.

Few researches are done by the researchers to make this incorporation operationally and economically beneficial. Therefore, a better way to find optimal allocation of DFACTS controllers in transmission lines can be done. Although the benefits of DFACTS controller over FACTS are discussed, there is work to be done to understand the effects of DFACTS on system stability and to develop a corresponding cyber secure method for control. In this way the ability to control line impedance using series VAR injection represents a critical need for the power industry

REFERENCES

[1] S.Abraham. (2002, May).National Transmission Grid Study.Washington, DC: U.S. Dept. Energy, [Online].

[2] E. Bompard, E. Carpaneto, G. Chicco, and G. Gross, "The role of load demand elasticity in congestion management and pricing" Power Engineering Society Summer Meeting, pp. 2229-34, 2000.

[3] H. Johal, "Distributed series reactance: a new approach to realize grid power flow control", PhD dissertation, Dept. Elect. Eng., Georgia Institute of Technology, GA, 2008

[4] Power System Control with Distributed Flexible AC Transmission System Devices by Katherine Margaret Rogers ,B.S., University of Texas, 2007, Urbana, Illinois

[5] How FACTS Controllers Benefit AC Transmission Systems John J. Paserba, Fellow, IEEE

[6] Some Applications of Distributed Flexible AC Transmission System (D-FACTS) Devices in Power Systems, K. M. Rogers, Student Member, IEEE, and T. J. Overbye, Fellow, IEEE

[7] Karl E. Stakopf and Mark R. Wilhem "Tighter Control for Busier Systems" IEEE Spectrum, April 1997 pp48-52

[8] Proposed terms and definitions for flexible AC transmission system (FACTS), IEEE Transactions on Power Delivery, volume 12, Issue 4,October 1997, pp. 1848-1853.

[9] Flexible AC Transmission Systems (FACTS)-Seimens

[10] How FACTS Controllers Benefits AC Transmission Systems, John J. paserba, fellow, IEEE

[11] International Journal for Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-3, Issue-4, April 2014, "A Review of Benefits of FACTS Devices in Power System", Ranjit Kumar Bindal

[12] Facts about flexible AC transmission system(FACTS) controllers: Practical installation and benefits. Article on Researchgate, source: OAI by NareshAcharya, MithulanathanNadarajah, A. Sode-Yome

[13] S.N. Singh, A.K. David, "Optimal Location of FACTS Devices for Congestion Management", Elsevier Science, Electric Power System Research 58 (2001) 71-79

[14] K.S. Verma, S.N. Singh, H.O. Gupta, "Location of Unified Power Flow Controller for Congestion Management", Electric Power System Research 58 (2001) 89-96.

[15] Y Xia, YH Song, CC Liu, YX Sun, "Available Transfer Capability Enhancement Using FACTS Devices", IEEE Trans. P. S, 2003

[16] C. A. Canizares, A. Berizzi, P. Marannino, "Using FACTS Controllers to Maximize Available Transfer Capability", Bulk Power System Dynamcis and Control IVRestructuring, August 24-28, 1998, Santorini, Greece

[17] C. P. Gupta, S. C. Srivastava and R. K. Varma, "Enhancement of static voltage stability margin with reactive power dispatch using FACTS devices", 13th PSCC in Trondheim, June 28- July 2nd, 1999

[18] P. Rao, ML Crow, Z Yang, "STATCOM Control for Power System Voltage Control Applications", IEEE Trans. Power Delivery, 2000.

[19] JY Liu, YH Song, P Metha, "Strategies for Handling UPFC Constraints in Steady-State Power Flow and Voltage Control", IEEE Trans. Power System, 2000.

[20] C. A. Canizares, Z. T. Faur, "Analysis of SVC and TCSC Controllers in Voltage Collapse", IEEE Trans. PS. Vol. 14, No. 1, pp. 158-165, Feb 1998

ISSN- 2394-5125 VOL 7, ISSUE 07, 2020

[21] L.Gyugyi, “Dynamic Compensation of AC Transmission Lines by Solid-State Synchronous Voltage Sources”, IEEE Trans. PD, Vol. 9, No. 2, pp. 757-763, April 1994.

[22] Deepak Divan, Harjeet Johal, “Distributed FACTS- A New Concept for Realizing Grid Power Flow Control”

[23] Harjeet Johal, Deepak Divan, “Design Considerations for Series-Connected Distributed FACTS Converters”

[24] Deepak M. Divan, Fellow, IEEE, William E. Brumsickle, Senior Member, IEEE, Robert S. Schneider, Member, IEEE, Bill Kranz, Randal W. Gascoigne, Dale T. Bradshaw, Member, IEEE, Michael R. Ingram, Senior Member, IEEE, and Ian S. Grant, Fellow, IEEE “A Distributed Static Series Compensator System for Realizing Active Power Flow Control on Existing Power Lines” IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 22, NO. 1, JANUARY 2007