ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

Power Flow Management using FACTS Controllers for Smart Grid Applications

Anwar S. Siddiqui [1], Naqui Anwer [2], Abdullah Umar [3]

Professor (EE), F/O Engineering & Technology, Jamia Millia Islamia, New Delhi, India[1]

Research Scholar (EE), F/O Engineering & Technology, Jamia Millia Islamia, New Delhi, India[2]

Abdullah Umar, Research Scholar (EE), F/O Engineering, OPJS University, Rajasthan, India[3]

Abstract: The smart grid can be viewed as a digital upgrade of the existing electricity infrastructure to allow for dynamic optimization of current operations as well as incorporate dynamic gateways for alternative sources of energy production. The smart grid is the modern day power transmission system with non conventional energy resources and FACTS controllers. The modern day power transmission system is a network of interconnection which connects systems at intra-regional, inter-regional and national level. Due to deregulation of the power sector, the basic transmission challenge is to provide a network capable of delivering contracted power from power supplies to consumers over a large geographical area. Power transfer in most integrated transmission system is constrained by transient and voltage stability. The power transfer capability of any transmission line largely depends on the reactance of the line keeping the transmission voltages constant. The mismatch of reactance between a group of transmissions lines result in uneven power sharing between them which may cause one or more lines to be overloaded beyond its rating. FACTS controllers can be effectively used to manage the flow of active and reactive powers of transmission systems such that no line is overloaded. This paper discusses the use of Series FACTS controllers in order to change line reactance and phase angle for controlling the power flow in a transmission system.

Keywords: Smart grid, transmission line, FACTS controllers, power flow, reactance.

I. INTRODUCTION

A smart grid is a digitally enabled electrical grid that accommodates attributes from suppliers as well as consumers. The smart grid can be viewed as a digital upgrade of the existing electricity infrastructure to allow for dynamic optimization of current operations as well as incorporate dynamic gateways for alternative sources of energy production. The smart grid is a combination of conventional power system infrastructure with the non conventional energy sources (wind, solar etc) [5], [10]. In the present power scenario the transmission systems are overused due to increased industrial demands and deregulation of the power supply. This necessitates the development of new technologies for maximizing the power transfers of existing transmission facilities while, at the same time, maintaining acceptable levels of network reliability and stability. Recent advancement in power electronics has proven to satisfy this need by introducing the concept of flexible AC transmission system (FACTS). The FACTS controllers are used in regulating the power flows, transmission voltages and mitigate the dynamic disturbance. Since its inception, the FACTS devices has developed in steps, the first generation being mechanically controlled capacitors and inductors. The second generation of FACTS devices replaced the mechanical switches by the thyristor valve control. This gave a marked improvement in the speed and the enhancement in concept to mitigate the disturbances. The third generation exploited the concept of converter based devices. These devices provide multidimensional control of the power system parameters [1], [2]. Power flow in a transmission line can be controlled by regulating the voltage at the two ends of the line, the phase angle or the reactance of the line. Thyristor controlled series compensators works on the principal of regulating the voltage of the transmission line by injecting voltage employing capacitor or inductor. [1] – [4]. This paper is focused on the aspect of changing the reactance of the transmission lines to manage the flow of power through the transmission lines and eliminating the possibility of overloading using series FACTS controllers.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

II. POWER FLOW IN TRANSMISSION LINES

In its most basic form, the power transmission line can be represented by a two bus system having one sending end and one receiving end side. The sending end and receiving end bus voltages are assumed to be $V_S = |V_S|\angle\delta_S$ and $V_R = |V_R|\angle\delta_R$. The active power transmitted between bus nodes is given by

$$P = \frac{|V_S||V_R|}{X}\sin(\delta_S - \delta_R) \qquad (1)$$

where X is the line impedance.

The power flow can be controlled by altering the voltages at a node, the impedance (or reactance) between the nodes and the angle between the end voltages. The reactive power is given by

$$Q = \frac{|V_S|^2}{X} - \frac{|V_S||V_R|}{X}\cos(\delta_S - \delta_R) \qquad (2)$$

Without any compensation or control, power flow over any transmission line is based on inverse of the transmission line impedances (or reactances). Consider a 4 bus transmission system in which the load is supplied from three generating stations as shown in Fig. 1. The transmission lines 1-2, 2-3, 3-4 and 4-1 are continuously rated to carry loads of 1500MW, 1500MW, 3000MW and 3000MW respectively. The generating stations are supplying 1200MW, 1600MW and 2400MW from bus 1, 2 and 3, respectively. The reactances of lines 1-2, 2-3, 3-4 and 4-1are 5Ω, 3Ω, 7Ω and 10Ω, respectively [6].

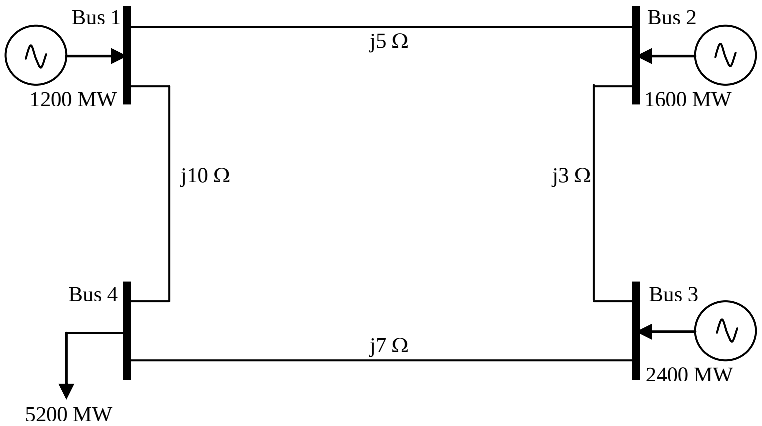

Fig. 1. A 4 Bus transmission system with generation capacities and line reactances

The power flow can be determined by calculating the power flows due to each generating station individually. It can be observed that for each generating station there are two paths for the power flow. The power flow for these two paths can be calculated and tabulated as shown in Table 1 and Fig. 2.

Bus No.	Supplied Power (MW)	Path1 for Power Flow	Path2 for Power Flow	Power Flow for Path 1	Power Flow for Path 2
1	1200	1-4	1-2-3-4	$\frac{5+3+7}{5+3+7+10}\times 1200 = 720MW$	$\frac{10}{5+3+7+10}\times 1200 = 480MW$
2	1600	2-1-4	2-3-4	$\frac{3+7}{5+3+7+10}\times 1600 = 640MW$	$\frac{5+10}{5+3+7+10}\times 1600 = 960MW$
3	2400	3-2-1-4	3-4	$\frac{7}{5+3+7+10}\times 2400 = 672MW$	$\frac{3+5+10}{5+3+7+10}\times 2400 = 1728MW$

Table 1. Power flow calculations for each generating station

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

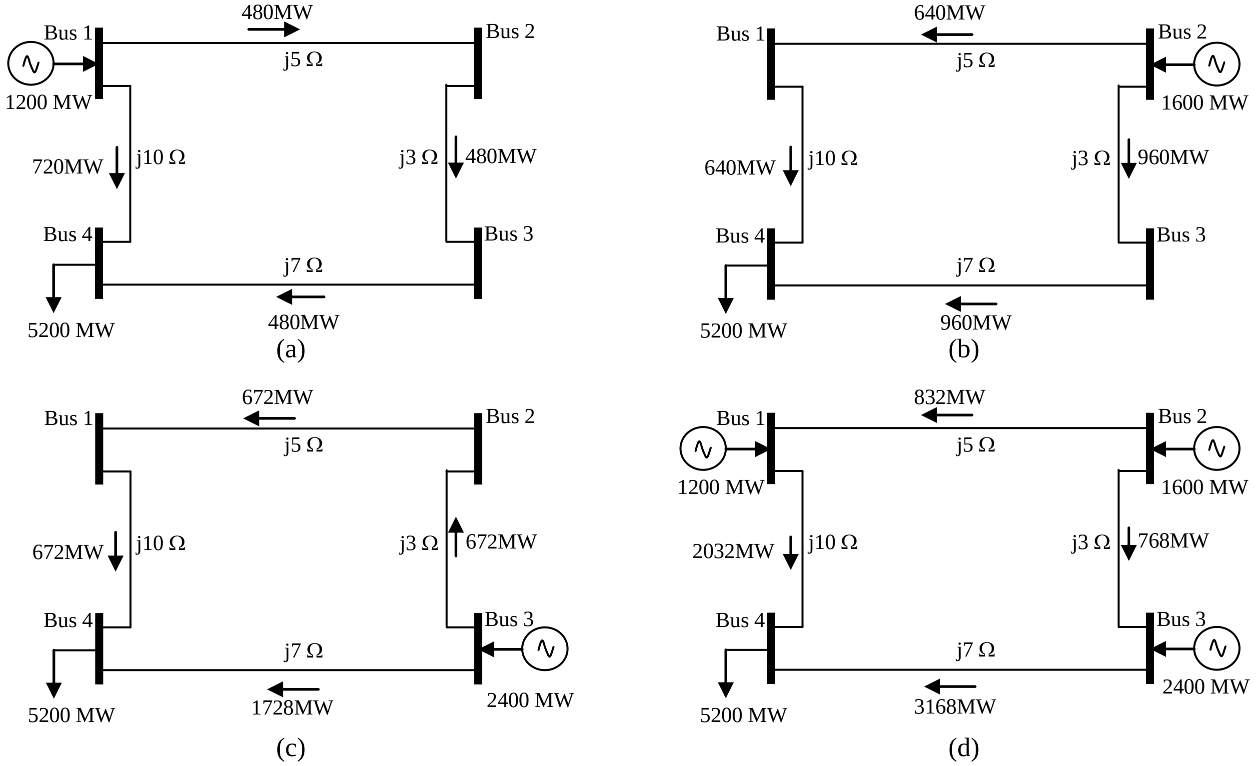

Fig. 2 Power flow in transmission lines (a) due to generating station at Bus 1 alone, (b) due to generating station at Bus 2 alone, (c) due to generating station at Bus 3 alone and (d) due to all the generating stations working simultaneously

It can be observed that there are two paths for the power flow in each case and the power flow is inversely proportional to the reactance (or impedance) offered by that path. Further, it can also be observed that line 3-4 will be overloaded beyond its capacity while other three lines remain under loaded. The overload on line 3-4 can be managed by diverting a part of the line 3-4 power (3168MW) through others lines.

From equations (1) and (2), it is evident that by changing the line parameters the load flow can be managed. The flow of power can be managed, such that no transmission line is overloaded, using the FACTS controllers. This paper is focussed on the use of series FACTS controllers, in order to change the line reactance so that power flow through each transmission line remain below its continuous rating and thus overloading can be eliminated.

III. FACTS CONTROLLERS : A REVIEW

Flexible AC Transmission System (FACTS) technology, which encompasses a number of thyristor-based power control systems, is set to be used more widely because of its ability both to increase the capacity of power lines and to improve transmission system flexibility. FACTS are a family of devices which can be inserted into a transmission system in series, in shunt and, in some cases, both in shunt and series. The shunt controllers inject a current into the line. Depending upon the phase relation between the injected current and the line voltage, the shunt FACTS controllers can handle both real and reactive power flows. Some of the popular shunt controllers are STATCOM, SVC, and TCR. The series controllers may be a variable capacitor, inductor or a variable frequency source. The operation of a series controller is based on injecting variable series voltage $(current \times variable\, reactance)$ in the line. When the injected voltage is 90^o out of phase with the line current, the controller absorbs the reactive power and for any other phase relation, it handles both the active and reactive powers [6], [11]. There are three types of series FACTS controllers

1. Static Synchronous Series Compensator (SSSC)
2. Thyristor controlled Series Capacitor (TCSC)
3. Thyristor controlled Series Reactor (TCSR)

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

1. Static Synchronous Series Compensator (SSSC)

The SSSC may have two types of configuration – with or without energy storage. In the SSSC configuration without storage (Fig. 3), the output voltage of the device is controlled independently and is 90^{o} out of phase with the line current which changes the overall reactive voltage drop across the line. In general, the series injected voltage is very small compared to the line voltage. When the SSSC is configured with storage (battery) as shown in Fig. 4, it injects a voltage vector of variable angle in series with the line.

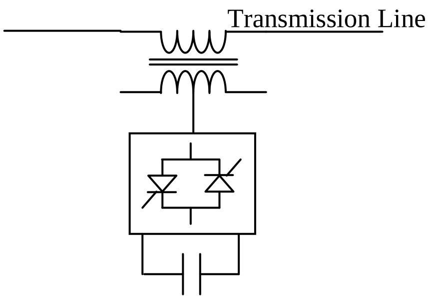

Fig. 3. SSSC without storage

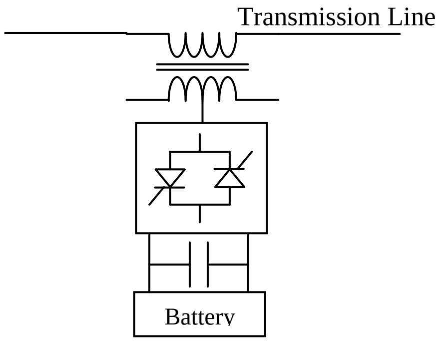

Fig. 4. SSSC with storage

2. Thyristor controlled Series Capacitor (TCSC)

The TCSC (Fig. 5) consists of a series capacitor bank in parallel with a thyristor controlled reactor (TCR) which provides smooth variable series capacitance control. When the triggering delay angle of TCR is 180^{o}, the reactor becomes non-conducting and the series capacitor has its normal impedance. As the triggering delay angle of TCR is reduced to less than 180^{o}, the capacitive reactance increases. When the triggering delay angle of TCR is 90^{o}, the rector becomes fully conducting, and the total impedance become inductive.

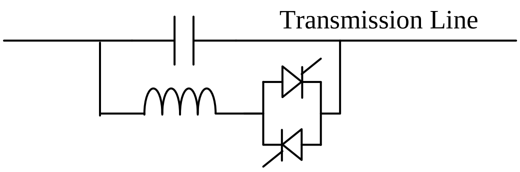

Fig. 5. TCSC

3. Thyristor controlled Series Reactor (TCSR)

A TCSR (Fig. 6) consists of a series reactor in parallel with TCR so as to provide smooth variable series reactance control. When the triggering delay angle of TCR is 180^{o}, the reactor becomes non-conducting and the uncontrolled reactor acts as a fault limiter. For the triggering delay angle below 180^{o}, the net inductance decreases until the triggering becomes 90^{o}, at which the inductance value becomes equal to the parallel combination of the two inductances [8],[15].

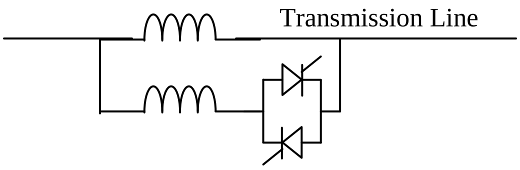

Fig. 6. TCSR

IV. POWER FLOW MANAGEMENT USING FACTS CONTROLLERS

It is evident from Fig. 2(d), that line 3-4 is overloaded, while other lines remain under loaded. The proposed solution for eliminating this overloading is to adjust the reactances of the transmission lines by series FACTS controllers. Now, suppose a TCSC (or any other controller) is connected in line 4-1 to provide a variable capacitive reactance of 5Ω. Therefore, the net reactance of line 4-1 will be reduced to 5Ω as shown in Fig. 7.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

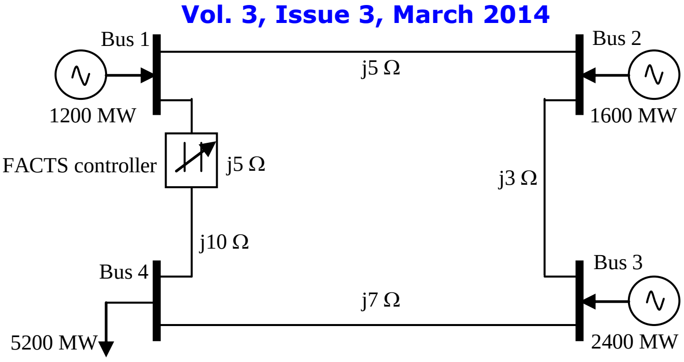

Fig. 7. The 4 Bus transmission system reconfigured with FACTS controller in line 4-1 to introduce capacitive reactance of j5Ω

The power flow for the reconfigured system with FACTS controllers can be calculated in the similar way as shown in Table 2 and Fig. 5.

Bus No.	Supplied Power (MW)	Path1 for Power Flow	Path2 for Power Flow	Power Flow for Path 1	Power Flow for Path 2
1	1200	1-4	1-2-3-4	$\frac{5+3+7}{5+3+7+5} \times 1200 = 900MW$	$\frac{5}{5+3+7+5} \times 120 = 300MW$
2	1600	2-1-4	2-3-4	$\frac{3+7}{5+3+7+5} \times 1600 = 800MW$	$\frac{5+5}{5+3+7+5} \times 1600 = 800MW$
3	2400	3-2-1-4	3-4	$\frac{7}{5+3+7+5} \times 2400 = 840MW$	$\frac{3+5+5}{5+3+7+5} \times 2400 = 1560MW$

Table 2. Power flow calculations for each generating station with FACTS controller (of j5Ω capacitive reactance) in line 4-1

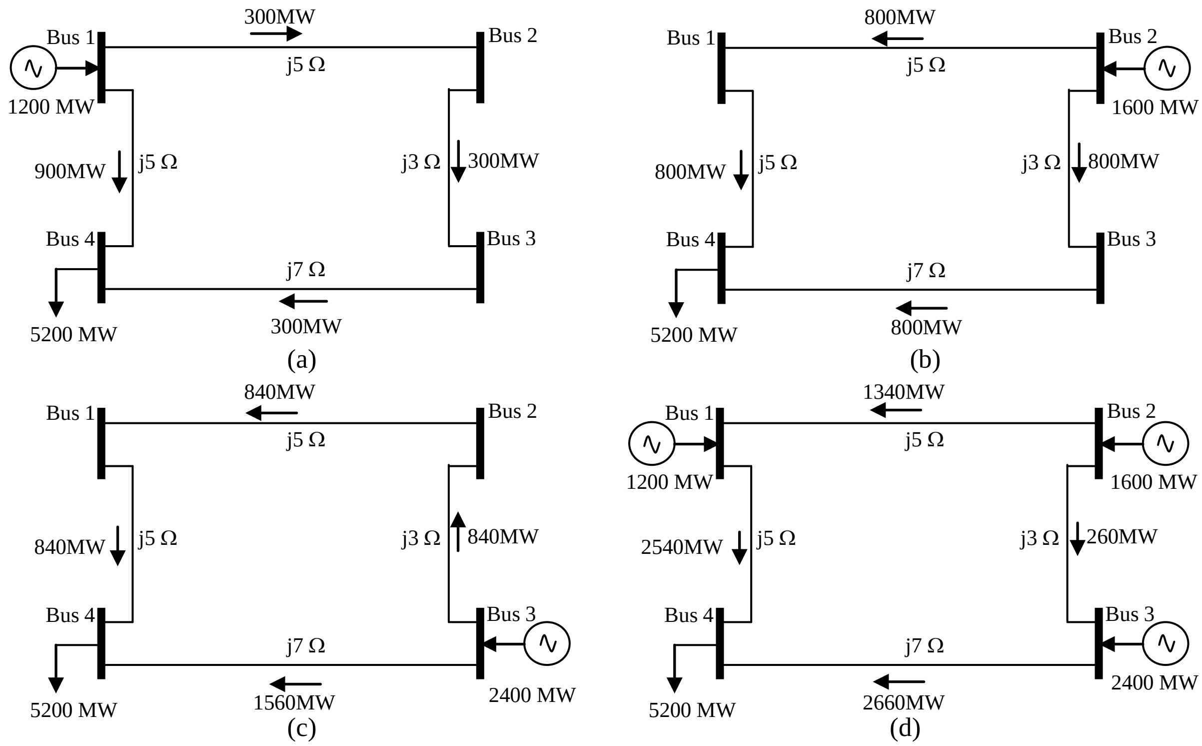

Fig. 8 Power flow in transmission lines reconfigured with FACTS controller in line 4-1 (a) due to generating station at Bus 1 alone, (b) due to generating station at Bus 2 alone, (c) due to generating station at Bus 3 alone and (d) due to all the generating stations working simultaneously

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

It can be observed that by adjusting capacitive reactance of the controller in line 4-1 at the synchronous frequency to 5Ω, the power flow in the line changes and is shown in Fig. 8. In this way the line 3-4, which was overloaded, can be managed to share load below its continuous rating and the overloading can be eliminated.

V. CONCLUSION

Smart grid is at the intersection of existing power infrastructure and new communication technologies. The deregulation of electrical energy and more private players in the power sector enforces that the transmission lines must be loaded to their full capacity. It is evident, that the some of the transmission lines in any transmission system are vulnerable to overloading conditions while many of them remain under utilised. The power flow in a transmission line is inversely proportional to their reactance. Therefore, a change in transmission line reactance (or impedance) will cause a change in the power flow in the system. In this paper, it has been proved that by introducing reactance (capacitive) in a transmission line through series FACTS controller, the reactance and thus the power flow can be managed in such a way that no transmission line is overloaded. The FACTS controllers are fully thyristor controlled, therefore, can be operated as many times as required. It is to be noted from the section IV that only one type of series controllers, out of several types discussed in section III, is required to be connected in one line out of all the lines to adjust power flows in a transmission system.

REFERENCES

[1] Hingorani N. G, 'High Power Electronics and Flexible AC Transmission System', IEEE Power Engineering Review, pp. 3-4, 1988.
[2] N. G. Hingorani 'Flexible ac transmission', IEEE Spectrum, pp. 40-45, 1993.
[3] N.G Hingorani, L. Gyugyi, 'Understanding FACTS. Concepts and Technology of Flexible AC Transmission Systems', IEEE Press, NewYork, 2000.
[4] Naqui Anwer, Anwar S. Siddiqui, Abdullah Umar, "Analysis of UPFC, SSSC with and without POD in Congestion Management of Transmission System", 5th IEEE International Conference on Power Electronics, Delhi Technological University, New Delhi, December 06-08, 2012.
[5] Ganesh K. Venayagamoorthy, "Potentials and Promises of Computational Intelligence for Smart Grids" , 2009
[6] T.K.Nagsarkar, M.S.Sukhija, Power System Analysis. Oxford University Press, 2007.
[7] D.G. Ramey, R.J. Nelson, J. Bian and T.A. Lemak, "Use of FACTS Power Flow Controller to Enhance Transmission Transfer Limits." Paper presented at American Power Conference, Chicago, Ill., USA, April 26, 1994
[8] C.R. Fuerte-Esquivel E. Acha, H. Ambriz-Perez, 'A comprehensive Newton-Raphson UPFC model for the quadratic power flow solution of practical power networks', IEEE Trans. on Power Systems, Vol. 15, No. 1, pp. 102-109, 2000.
[9] X. Lei, D. Jiang and D. Retzmann, "Stability improvement in power systems with non-linear TCSC control strategies", *ETEP*, vol. 10, No. 6, pp. 339-345, 2000.
[10] Naqui Anwer, Anwar S. Siddiqui, Ahmad S. Anees, "A Lossless Switching Technique for Smart Grid Applications", Elsevier International Journal of Electrical Power and Energy Systems, Vol. 49, pp 213-220, 2013.
[11] Anwar S. Siddiqui, Naqui Anwer, Abdullah Umar, "Reducing Parametric Limitations of Transmission Lines Using Series FACTS Controllers", IEEE sponsored National Conference, Galgotias College of Engineering & Technology, Greater Noida, India, 2014