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A new dynamic control strategy for power transmission congestion management using series compensation

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ABSTRACT

The growth of electricity market due to increase in demand and infrastructure made the power system more complex. Managing the transmission congestion is one of the main challenges faced by the utilities. To relieve from the bottlenecks, Flexible AC Transmission Systems (FACTS) and Distributed FACTS (D-FACTS) devices can be used in controlling the transmission line power flows. The real power flow control is realized by varying the transmission line impedance. The power flow in transmission line should satisfy inequality constraints to maintain the system in normal state. To achieve this, an algorithm is developed to control the FACTS/D-FACTS devices connected to all the transmission lines of n-bus system. The significant changes required in line impedance which will be deployed by FACTS devices are decided by the algorithm. In this paper, a 5 bus system and a 14 bus system with FACTS devices in all the transmission lines is considered. The transmission lines of the 5 and 14 bus systems are made to be overloaded in different combinations by choosing appropriate loading conditions. The control algorithm is tested on all the overloaded conditions to overcome the congestion. The FACTS devices controlled by the algorithm removes the overloading effect and improve the reliability of the network.

Introduction

The increasing penetration of renewable energy, the growing demand of electrical power, and the aging of networks congest the transmission network. Moreover, the difficulty owed to loop flows and increasing congestion on the transmission network lowers the system security. A line gets outage due to overloading, creates cascading outages and leads to extreme state. Hence, the power grid infrastructure is in vital need of automation.

Possibly, active power flow control is the most significant issue in terms of grid utilization. The control on real power flow is exhaustive by the highly interconnected composition of transmission networks. Further, loop flows redistribute power throughout the grid without violating the law of physics. When such power flow is transferred between two areas, the impact reflects on the other lines, even effectively for the transmission lines which are far away. This inadvertent power flow in an interconnected network can confine transmission capability and inhibits the event of several transfers. The circumstance is considerably severe when next-door lines are running below capacity, but is not utilized to control the uncontrolled loop flow which creates overload in the transmission network.

In recent years, advances in high power solid-state switches, have led to the development of transmission controllers that provide controllability and flexibility for power transmission [1]. The concept of Unified Power Flow Control (UPFC) [2–4], Series reactance compensation [5,6] and Static Synchronous Series Compensator (SSSC) [7–8] which are Flexible AC Transmission System (FACTS) devices [9–11] are introduced for power flow control applications. Hybrid Flow Controller (HFC), a new member of FACTS controllers [12,13] and partial power conversion device [14] has been realized for the same purpose. In order to reduce congestion, placement of FACTS devices is one of the criteria under consideration and different methodologies were proposed [15–18]. Overcoming the barriers encountered in FACTS devices; a new concept called Distributed FACTS (D-FACTS) [19–22] is introduced. These active impedance modules are attached to the transmission lines for varying the line reactance [23,24].

The most pressing issue in the control schemes using FACTS devices is local control. This is not enough for modern smart and deregulated power system to control the power flow as desired without congestion. Hence the control strategies for the power flow control devices is to be developed, which aid in safeguarding the system for secured operation under overloaded conditions.

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This possibly will afford the future power grid to be realized as smart and receptive.

This paper discusses the abstraction of series compensators utilized in the transmission conductors of the power system network. Series compensators are passive elements such as series capacitors when employed in the power system network can increase the power transfer capability and enhance the power system controllability [25], thereby relieving the loop flows. In order to mitigate congestion, a self-automated and self-healing control algorithm has been developed to send control signals for the passive elements on the transmission lines from the control center. Thus the line reactance is increased or decreased based on the control signal. This manages the power flow and relieves congestion on the transmission line. Thereby, the proposed control strategy provides self-healing solution to the smart grid during congestion in transmission lines. This paper details the concept of real power flow control in Section 'Static series compensation'. The control algorithm for congestion management is developed in Section 'De velopment of control algorithm'. The system considered for study is furnished in Section 'System model'. The algorithm is applied on the 5 bus system and 14 bus system for different overloading conditions and the congestion management using series compensation is verified in Section 'Simulation results and discussions'. The conclusion is derived in Section 'Conclusion'.

Static series compensation

The passive devices like inductor/capacitor incorporated on the transmission line vary the line reactance and provides significant control on the power flow. A simple two-bus system shown in Fig. 1 is considered for illustration. The two bus system is with two transmission lines in which the source is connected to bus 1 and the load is connected to bus 2.

The real and reactive power flow in transmission lines are governed by Eqs. (1) and (2).

$$P_{12} = \frac{|V_1||V_2|\sin\delta}{X} \tag{1}$$

$$Q_{12} = \frac{|V_2|^2 - |V_1||V_2|\cos\delta}{X} \tag{2}$$

where δ is the voltage phase angle difference ($\delta_1 \sim \delta_2$) between the sending end voltage V_1 and receiving end voltage V_2. X is the net impedance of the line ($X_1||X_2$), assuming to be purely inductive. Either by varying the impedance of the transmission line or by varying the power angle differences, power flow control can be achieved. Series compensators vary the effective impedance of the line by introducing physical inductors or capacitors on the transmission lines. This can also be achieved by injecting active voltage source [2].

Let us consider a series compensator i.e., FACTS Controllers is deployed in transmission line 2 of Fig. 1. As the load increases, the power flow in each of the transmission line also increases. If the power flow increases beyond the stability limit in any one of the line, the series compensator will reroute the excess power by adjusting the line reactance. If the FACTS device acts as a capacitor, the line reactance will decrease and the power flow will increase. Similarly the power flow will decrease if the line reactance is increased by the FACTS device.

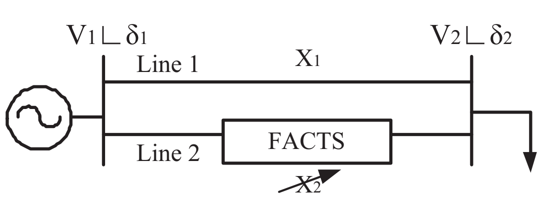

Fig. 1. Power rerouting by series compensation.

Fig. 2 depicts the case when capacitance comes in effect with transmission line 2, the reactance of line decreases. This increases the power flow in line 2 and automatically decreases the power flow in line 1 for power balance. This demonstrates the rerouting of power between the two parallel lines for congestion management.

This technique can be extended to an n bus system. By developing a control algorithm, the FACTS devices in the lines can be controlled for varying the line reactance to overcome the congestion through rerouting.

Development of control algorithm

In this paper, a generalized control algorithm capable of handling n bus system considering the inequality constraint is developed to control the power flow in transmission lines from the control center. When one or more transmission lines gets overloaded, the power flow has to be rerouted by varying the transmission line reactance as explained in Section 'Static series compensation'. For any overloading in transmission lines, the control algorithm has to take decision on which of the line reactance to be varied of what quantity such that effective rerouting of power takes place.

The line reactance is to be increased/decreased within the constraint to reduce/increase the power flow in overloaded/under loaded transmission lines. The line in which the FACTS device acts is decided by the control algorithm based on the priority list created. The top order in the priority list is for overloaded lines. The magnitude of overloading decides the toping in that priority list. The remaining order is created based on the closeness to the overloaded lines.

The algorithm for the congestion management is developed and presented as flowchart in Fig. 3.

Step 1: Read line data and bus data.
Step 2: Do load flow analysis using Newton Raphson method.
Step 3: Calculate real Power Flow (PF) in transmission lines.
Step 4: Calculate the Power Flow Difference (PFD) between Maximum Power Flow (PFmax) limit and the actual Power Flow (PF).

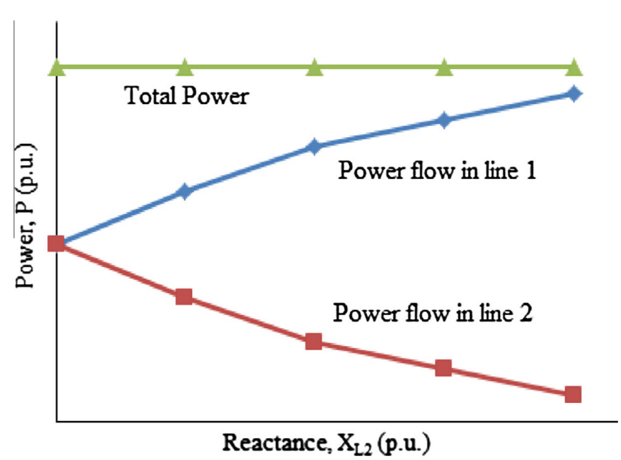

Fig. 2. Variation of power flow in transmission lines by passive impedance injection.