Network Simulation with STATCON Devices to avoid Voltage Collapse in the Interconnected System

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Abstract
In this paper reactive power control with the help of STATCON has been simulated. Converter operation and switching sequence has been briefed. Real data of Wapda 500/220 kV power system regarding extreme cases of voltage control has been simulated on power system simulator PSS/E. Different rating of simulated STATCON has been suggested at various stations to overcome voltage collapse problem, increase steady state, dynamic and transient stability.

1. Introduction
In moving power from generator to loads, the transmission network introduces both real and reactive losses. Real or active power transfer depends mainly on the power angle. Reactive power transfer depends mainly on voltage magnitude and flows from highest voltage to the lowest voltage. The reactive-power nature of transmission lines is associated with the geometry of the conductors themselves and the geometry of the conductor configuration.

Contrasted with real power, reactive power simply cannot be transmitted long distances. To minimize reactive losses transfer of reactive power must be minimized and possible reactive power should be generated close to the point of consumption. Transmission lines both produce and consume reactive power. Transmission line shunt capacitance produces reactive power proportional to the square of voltage. Transmission line series inductance consumes reactive power proportional to the square of current. The reactive-power behavior of transmission lines is complicated by their inductive and capacitive characteristics. At low line loadings, the capacitive effect dominates, and generators and transmission-related reactive equipment must absorb reactive power to maintain line voltages within their appropriate limits. On the other hand, at high line loadings, the inductive effect dominates, and generators, capacitors, and other reactive devices must produce reactive power. The balance point at which the inductive and capacitive effects cancel each other (what is called surge-impedance
loading) is typically about 40% of the line's thermal capacity.

The shunt capacitors are used across an inductive load to supply part of the reactive VARs required by the load so that the reactive VARs transmitted over the line are reduced. Thereby, the voltage across the load is maintained within certain desirable limits. Similarly, the shunt reactors are used across capacitive loads or lightly loaded lines to absorb some of the leading VARs again to control the voltage across the load to within certain desirable limits. The disadvantage of the use of shunt capacitors or reactors is that with the fall of voltage at a particular node the correction VARs are also reduced. Similarly, on light loads when the corrective VARs required are relatively less, the capacitor output is large.

Capacitors and inductors are passive devices that generate or absorb reactive power. They accomplish this without significant real power losses or operating expense. The output of capacitors and inductors is proportional to the square of the voltage. Thus, a capacitor (or inductor) bank rated at 100 MVAR will produce (or absorb) only 90 MVAR when the voltage dips to 0.95 pu but it will produce (or absorb) 110 MVAR when the voltage rises to 1.05 pu. This relationship is helpful when inductors are employed to hold voltages down. The inductor absorbs more when voltages are highest and the device is needed most. The relationship is unfortunate for the more common case where capacitors are employed to support voltages. In the extreme case voltages fall and capacitors contribute less, resulting in a further degradation in voltage and even less support from the capacitors. Ultimately, voltage collapses and outages occur.

Inductors are discrete devices designed to absorb a specific amount of reactive power at a specific voltage. They can be switched on or off but offer no variable control.

An SVC combines conventional capacitors and inductors with fast switching capability. Switching takes place in the sub cycle timeframe, providing a continuous range of control. The range can be designed to span from absorbing to generating reactive power. Consequently, the controls can be designed to provide very fast and effective reactive support and voltage control. Because SVCs use capacitors, they suffer from the same degradation in reactive capability as voltage drops.

The power systems of today by and large, are mechanically controlled. There is a wide spread use of microelectronic, computers and high speed communication for control and protection of present transmission system; however, when operating signals are mechanical and there is a little high speed control. Another problem with mechanical devices is that control cannot be initiated frequently, because these mechanical devices tend to wear out very quickly compared to static devices. In effect, from the point of view both dynamic and steady state operation, the system is really not controllable. The possibility of controlling power flow in an electric system without generation, rescheduling or topology changes can improve the power system performance. The concept of FACTS (Flexible AC Transmission System) was first introduced by Hingorani, N.G. in 1988. Up to now, lots of advanced FACTS devices have been put
forward due to rapid development of modern power electronic technology.

2. Static Synchronous Condenser or Compensator (STATCON)

A static synchronous generator operated as a shunt connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

The STATCON is a solid-state shunt device that generates or absorbs reactive power and is one member of a family of devices known as flexible AC transmission system (FACTS) devices. Actually STATCON is a new type of SVC based on inverter technology and GTO thyristors. STATCON is similar to the SVC in response speed, control capabilities, and the use of power electronics. Conventional capacitors and inductors combined with fast switches are replaced with the STATCON. Consequently, output capability is generally symmetric, providing as much capability for production as absorption. STATCON capacity does not suffer as seriously as SVCs and capacitors do from degraded voltage. STATCON are current limited so their MVAR capability responds linearly to voltage as opposed to the voltage-squared relationship of SVCs and capacitors. This attribute greatly increases the usefulness of STATCON in preventing voltage collapse.

The (ac to dc or dc to ac) converters are operated as a current or voltage sources and they produce reactive power essentially without reactive power storage components by circulating alternating current among the phases of the ac system. Functionally, the reactive power generation is similar to that of ideal synchronous machines whose reactive power output is varied by excitation control. Because of these similarities with rotating synchronous generators, they are termed Static Synchronous Generators (SSGs). When an SSG is operated without an energy source, and with appropriate controls to function as a shunt connected reactive compensator, it is termed, analogously to the rotating synchronous Compensator (Condenser) STATCOM or STATCON.

2.1. Voltage source converter

2.1.1 Basic Function

Voltage sourced converter valve is made up of an asymmetric turn off device such as GTO with a parallel diode connected in reverse. On the dc side, voltage is unipolar and is supported by a capacitor. The dc current can flow in either side and that it can exchange dc power with the connected dc system in either direction. Basically, a voltage sourced converter generates ac voltage from a dc voltage. It is for historic reasons, often referred to as inverter, even though it has the capability to transfer power in either direction. With a voltage sourced converter, the magnitude, the phase angle and the frequency of the output voltage can be controlled.

2.2. Single Phase Full Wave Bridge Converter Operation

Fig. 3 shows a single phase full wave bridge converter consisting of four valves, (1-1') to (4-4'), a dc capacitor to provide stiff dc voltage, and two ac connection points, a and b. The designated value numbers represent their sequence of turn on, turn off. The dc
voltage is converted to ac voltage with appropriate valve turn-on, turn-off sequence.

2.3. Sequence of Valve Conduction

Fig. 1 shows an ac voltage waveform of one phase leg (with respect to the dc mid point), with a varying phase angle with respect to an assumed sinusoidal current flow. During the first one cycle segment of inverter operation with unity power factor, device 1 is turned on with the current flow from +Vd/2 bus into the ac phase for the first full half cycle. This is followed by turn off of device 1 and turn on of device 4, which results in the current flow from the ac phase into the -Vd/2 bus.

For the next half cycle, the turn off of device 1 and turn on of device 4 is delayed by 60 degrees in order to change the phase angle for the segment 2 in Fig. 1 by 60 degrees. It is seen that as current polarity reverses, the current transfers from device 1 to diode 1'. For the one cycle segment 2, the converter operates as an inverter with current lagging the voltage by 120 degrees, i.e., with inductive reactive power. In this one cycle segment, turn off device 4 conducts for 120 degrees feeding power from dc to ac (inverter action), and then diode 4' conducts for 60 degrees feeding power back from ac to dc (rectifier action). This is followed by 120 degrees conduction of device 1 feeding power from dc to ac and diode 1' feeding power from ac to dc for the final 60 degrees. The transfer from turn off device 4 to turn off device 1 takes place via diode 4' and from 1 to 4 via diode 1'.

For turn off devices the maximum current have to turn off is accompanied by the magnitude of forward voltage jump during turn off.

Fig. 1 Operation of a phase leg through four quadrants: a) Phase Leg; b) Waveform and phasor diagram through all four Quadrants.

3. Power System Simulator and Engineering (PSS/E)

The PTI power system simulator is a package of programs for studies of power system transmission network & generation performance under steady state & dynamic conditions. PSS/E handles power flow, fault
analysis (balance & unbalanced), network equivalent construction & dynamic simulation. PSS/E is structured around a carefully designed set of data files called working files. These working files are set up in a way that optimizes the computational aspects of the key power system simulation functions: network solution & equipment dynamic modeling. The working files, occupy dedicated areas of disk memory, are operated upon by a comprehensive set of functional program modules called activities. Each activity performs a distinct computational function needed in the course of power flow, short circuit, equivalent construction, or dynamic simulation work.

PSS/E is entered by starting one of two master program modules. The master module immediately invites to select an activity. The selected activity is immediately executed, performing its processing operation on the working files. The activity retains control until either:

- Its processing is completed.
- Its processing encounters an error condition.
- It is interrupted & terminated by the user.

Each of these conditions returns control back to the master module, leaving the working files such that they reflect the results of the processing by this activity.

4. Voltage Control measures by using STATCON through PSS/E in WAPDA Power System

In normal practice it is much more practical and economical to size the power system according to the maximum demand for real power and to manage the reactive power by means of compensators and other equipment which can be deployed more flexibly than generating units and which make no contribution to fault levels. But in WAPDA power system the same generating units are mostly used for reactive power managements. Followings are the voltage problems at 500/220 kV WAPDA network that will cause system collapse if remedial measures are not taken. In order to avoid forced load shedding, at the end of each problem different ratings of STATCON are suggested at optimal locations and their impact on voltage profile is shown.

4.1. Low Voltage Problem

4.1.1. Low Water Indent during period of CANAL CLOSURE

During the month of canal closure most of power comes from South to meet the load demand of North region. Due to low water indent machines of Tarbela & Mangla remain off the bar for most of time.

In evening and morning peak hours machines of Tarbela and Mangla are synchronized and shortly after peak hours machines are desynchronized to meet the daily water indent scheduled by IRSA (Indus River System Authority). During these days keep the voltage of Hubco high and transfer the MVAR on 500 kV lines towards North region.

Due to low water indent machine of Ghazi Barotha should be desynchronized shortly after peak hours. During this time voltages are so depressed that there is a chance of system collapse. To avoid the
system collapse WAPDA forcefully shed the load.

In order to avoid load shedding and for system security different ratings of simulated STATCON were installed at different stations shown below. These STATCON will supply MVAR to the system, which will help in stabilizing the system voltages.

<table>
<thead>
<tr>
<th>S No</th>
<th>220 kV Station</th>
<th>MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mardan</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>Gakhar</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>Sialkot</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Kala Shah Kaku</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>Ravi</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>Bund Road</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Sarfaraznagar</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 1 Simulated STATCON at stations.

After installing STATCON at different stations voltages improved without implementing the load shedding.

5. Conclusions & Recommendations

The voltage control problems have been investigated in different prospective for the WAPDA power system. The areas which face low voltage problem also need reactive power absorption during high voltage. The primary system is basically designed to meet the load demand. For this purpose, power houses have been located at optimal locations. The same power houses are primarily used to control the voltages. As a result, whenever power houses are OFF the bar for economic dispatch, scheduled maintenance outage and forced outages cause severe voltage problems.

In this research with the aid of power system simulator, various rating of static condenser has been simulated at various locations to overcome the problem. Static Condenser (STATCON) has the ability to synthesize the need of reactive power demand thus keeping the voltages within permissible range & allowing nearby generators to operate near unity power factor. It also increases steady state, dynamic state and transient stability. This device creates reactive power margins on generators & transformers. The system is so stable that it can face any major disturbance thus saving the billions of rupees revenue to WAPDA.

6. References