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A Review on Reactive Compensation in Power Plant with Short Circuit in Line Using UPFC

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***Abstract*-This paper discusses the application of reactive compensation systems which are used as part of a wind power plant. A brief history of wind plant reactive compensation system is discussed, and then the fundamental needs of why reactive compensation is required. The paper will then provide some alternatives for reactive compensation and how to size the reactive compensation, and finally some of the principles on how different compensation devices work.**

I. INTRODUCTION

The application of wind plants has grown dramatically in the recent past. Historically wind power plants (WPPs) have been smaller in size (less megawatts) per plant. The amount of wind penetration was not an issue for almost all applications. With the continued growth/increase in the individual turbine size and the number of turbines connected to the grid at a single connection point, wind plants can easily be in the hundreds of megawatts. The traditional turbine was usually a simple induction generator with little capability for voltage ride through (VRT) or power factor (PF) control. During systems disturbances the plant would most likely trip off-line. In addition, the wind plant did not have to supply any ancillary services such as voltage control, variable power factor, dynamic system support, etc. In general, older wind plants did not require reactive compensation systems. The recent generation of turbines has far greater capability. Wind power plant centralized control systems can provide the ancillary services required by the interconnection agreements. In addition, more requirements are being applied to have the wind plants respond like traditional synchronous machine generation plants during fault conditions, and to have dynamic response and control capability. All of these factors require the wind plant to have a collector system design that can accommodate these conditions.

II. CONCEPT OF REACTIVE POWER

Reactive power is the power that supplies the stored energy in reactive elements. Power, as we know consists of two components, active and reactive power. The total sum of active and reactive power is called as apparent power.

In AC circuits, energy is stored temporarily in inductive and capacitive elements, which results in the periodic reversal of the direction of flow of energy between the source and the load. Explanation for reactive power says that in an alternating current system, when the voltage and current go up and down at the same time, only real power is transmitted and when there is a time shift between voltage and current both active and reactive power are transmitted. But, when the average in time is calculated, the average active power exists causing a net flow of energy from one point to another, whereas average reactive power is zero, irrespective of the network or state of the system.

In the case of reactive power, the amount of energy flowing in one direction is equal to the amount of energy flowing in the opposite direction .That means reactive power is neither produced nor consumed. But, in reality we measure reactive power losses, introduce so many equipment's for reactive power compensation to reduce electricity consumption and cost. Capacitors are said to generate reactive power, because they store energy in the form of an electric field. Therefore when current passes through the capacitor, a charge is built up to produce the full voltage difference over a certain period of time. Thus in an AC network the voltage across the capacitor is always charging. Since, the capacitor tends oppose this change; it causes the voltage to lag behind current in phase.

III. NEED FOR REACTIVE POWER COMPENSATION

The main reason for reactive power compensation in a system is;

1) The voltage Regulation.
2) Increased system stability.
3) Better utilization of machines connected to the system.
4) Reducing losses associated with the system.

The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power.

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Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

Different reactive power compensation methods are shown in fig.1

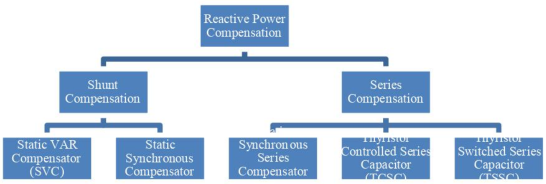

Fig 1 – Classification of Reactive Power Compensation

A. Principles of the Series Controllers: If the line voltage is in phase quadrature with the line current, the series controller absorbs or produces reactive power, if it is not, the controllers absorbs or produces real and reactive power. Examples of such controllers are Static Synchronous Series Compensator (SSSC), Thruster-Switched Series Capacitor (TSSC), Thruster-Controlled Series Reactor (TCSR), to cite a few. They can be effectively used to control current and power flow in the system and to damp system's oscillations. Among these Static Synchronous Series Compensator (SSSC) is one of the important series FACTS devices. SSSC is a solid-state voltage source inverter, injects an almost unsocial voltage, of variable magnitude in series with the transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage, which is in phase with the line current, provides the losses in the inverter.

B. Principles of the Shunt Controllers: Shunt controllers are similar to the series controllers with the difference being that they inject current into the system at the point where they are connected. Variable shunt impedance connected to a line causes a variable current flow by injecting a current into the system. If the injected current is in phase quadrature with the line voltage, the controller adjusts reactive power while if the current is not in phase quadrature, the controller adjusts real power. Examples of such systems are Static Synchronous Generator (SSG), Static Var Compensator (SVC). They can be used as a good way to control the voltage in and around the point of connection by injecting active or reactive current into the system.

C. Principles of the Combined Series-Series Controllers: A combined series-series controller may have two configurations. One configuration consists of series controllers operating in a coordinated manner in a multiline transmission system. The other configuration provides independent reactive power control for each line of a multiline transmission system and,at the same time, facilitates real power transfer through the power link. An example of this type of controller is the Interline Power Flow Controller (IPFC), which helps in balancing both the real and reactive power flows on the lines.

D. Principles of Combined Series-Shunt Controllers: A combined series-shunt controller may have two configurations, one being two separate series and shunt controllers that operate in a coordinated manner and the other one being interconnected series and shunt components. In each configuration, the shunt component injects a current into the system while the series component injects a series voltage. When these two elements are unified, a real power can be exchanged between them via the power link. Examples of such controllers are UPFC (Unified Power Flow Controller) and Thruster Controlled Phase-Shifting Transformer (TCPST). These make use of the advantages of both series and shunt controllers and, hence, facilitate effective and independent power/current flow and line voltage control.

Concept of FACTS Devices

A power electronic-based system and other static equipment that provide control of one or more AC transmission system parameters. As new technology for power transmission system, FACTS and FACTS controllers not only provide the same benefits as conventional compensators with mechanically-controlled switches in steady state but also improve the dynamic and transient performance of the power system. The power electronics-based switches in the functional blocks of FACTS can usually be operated repeatedly and the switching time is a portion of a periodic cycle, which is much shorter than the conventional mechanical switches. The advance of semiconductors increases the switching frequency and voltage-ampere ratings of the solid switches and facilitates the applications.

The Flexible AC transmission system or FACTS generally used are:

1) VAR generators.

a. Fixed or mechanically switched capacitors.
b. Synchronous condensers.
c. Thyristorized VAR compensators
   i) Thyristors switched capacitors (TSCs).
   ii) Thyristor controlled reactor (TCRs).
   iii) Combined TSC and TCR.
   iv) Thyristor controlled series capacitor (TCSC). 2)

Self Commutated VAR compensators.

a) Static synchronous compensators (STATCOMs).
b) Static synchronous series compensators (SSSCs).
c) Unified power flow controllers (UPFCs).
d) Dynamic voltage restorers (DVRs).

IV. Related Work

Many surveys and literatures have been conducted on performance evaluating the reactive power compensation methods in EHV transmission line. Some of the authors and the related works are:

S.V.N JithinSundaret.,al [1] proposed and presented his research on the controlled shunt reactor for bus voltage management in EHV system. As the permanent connection of the shunt reactors leads to reduced voltage levels and decreased transmission capacity of the lines during full load conditions. Thus, the paper introduces the solution of continuous voltage drop by introducing the Controlled Shunt Reactor which is a thyristor controlled equipment offers fast response time to take care of dynamic condiotions. In his research, the main equipment is RT (Reactor Transformer) is designed as single three phase unit or as three single phase unit. The simulation response shows the transienst response improves using controlled shunt reactor.

PasiVuorenpaaet.,al [2] proposed his research dynamic modeling of Thyristor Controlled Series Capacitor in PSCAD and RTDS . In his research, the main target is to develop new modeling techniques for Thyristor Controlled Series Capacitor (TCSC) and to investigate the interaction phenomena between TCSC and surrounding network, is presented and the effect of control system structure and surrounding network on operational characteristics of TCSC.

Salem Rahmaniet.,al [3] presented his work on the combined system of a thyristorcontrolled reactor (TCR) and a shunt hybrid power filter (SHPF) to suppress current harmonic and reactive power compensation from the load.

He established a non linear control scheme of a SHPFTCR compensator which is being simulated and implemented and hence the work shows the fast dynamic response and good performance in both steady-state and transient operations.

Rajiv K. Varmaet.,al [4] presents the potential occurrence and mitigation of Sub synchronous Resonance (SSR) caused by an induction-generator (IG) effect as well as torsional interactions, in a series-compensated wind farm. The research has done on SVC to effectively damp SSR when equipped with an SSR damping controller. While both FACTS controllers—the SVC and TCSC—can effectively mitigate SSR, the performance of TCSC is shown to be superior.

P. Suman Pramod Kumar et.,al [5] proposed the work on static synchronous series compensator(SSSC). The paper discuss about the basic operating and performance characteristics of the SSSC, and compares them to those characterizing and more conventional compensators based on thyristor switched or controlled series capacitors and the simulation of various aspects of Static Synchronous Series Compensator (SSSC), such as power oscillation damping, improving transient stability has been done.

V. Types Of Reactive Power Compensation

The following is a listing of the main types of reactive power compensation equipment and some general principles of operation.

1) Mechanically-Switched Shunt Capacitors-

Capacitors banks typically consist of a grouping of individual capacitor units. The bank is then either considered fixed or it can be switched using appropriately rated devices. These banks can either be ―metal enclosed‖ or ―open rack‖ design. It is important that special attention be paid to the switches. They should be rated for capacitor switching. It is only possible to control slow variations in reactive power. The capacitive VAr output is a function of the voltage such that the VArs decrease with the square of the voltage (i.e. 90% voltage will provide 81% VAr capability) Using a number of capacitor banks of different size, the reactive power exchange can be kept within a range. Capacitor banks typically require a 5 minute discharge time before they can be reenergized, but there are also designs that allow for shorter durations on a limited basis.

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2) Mechanically-Switched Shunt and Regulated Reactors-

Reactors are typically mechanically switched devices. Again, it is only possible to control slow variations in reactive power. The inductive VAroutput is a function of the voltage such that the VArs decrease with the square of the voltage (i.e. 90% voltage will provide 81% VAr capability). Regulated shunt reactors are shunt reactors equipped with a tap-changer as used for voltage control with a transformer. Using such a‖regulated shunt-reactor‖, a more smooth control of reactive power can be achieved.

3) Static Var Compensator

An SVC is typically a fixed shunt capacitance in parallel with reactance that is controlled using thyristors. This type of controller is made using static components. When the thyristors are used in the control process, then the controller is considered dynamic. These allow for a control of reactive power at time scales down to the order of a 100 milliseconds. Additional filters must be used to avoid harmonics which are created when the current wave shape distorts from the thyristor switching. Further details on SVC can be found in IEEE Std.1031.

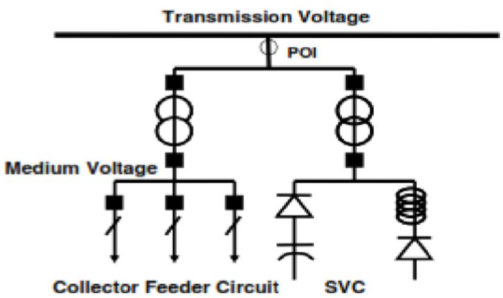

Figure 2 - Typical configuration of SVC for WPPs

4) Static Synchronous Compensator

A STATCOM is a voltage-source converter. It does not use thyristors for switching, but instead uses IGBT (Insulated Gate Bipolar Transistor) or IGCT (Integrated Gate Commutated Thyristor) switching devices to either source or sink reactive power to the electric network. Some STATCOM units may have short-time overload capabilities for 2 To 4 seconds. The VAr output is a linear function of the voltage, VArs decrease linearly with the voltage (i.e. 90% voltage will provide 90% VAr capability) since they are constant current controllers.

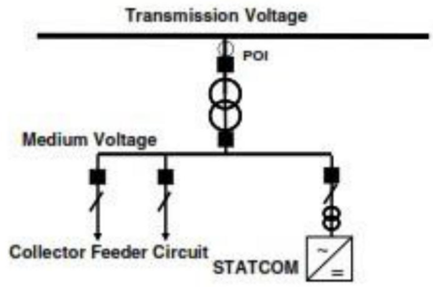

Figure 3 - Typical configuration of STATCOM for WPPs 5) WTGs

WTGs can provide or consume reactive power, depending on the type. Simple induction generators typically employ PFCCs to correct the power factor at the terminals of the machine to unity of near unity. DFIG and full converter-based WTGs can operate dynamically over a defined power factor range (e.g. 0.95 inductive to 0.95 capacitive). A specific turbine may have different steady state vs. dynamic capability. Refer to a companion WG paper for more details on WTG reactive power capabilities.

VI. Reactive Power Compensation Techniques

1) Shunt Compensation

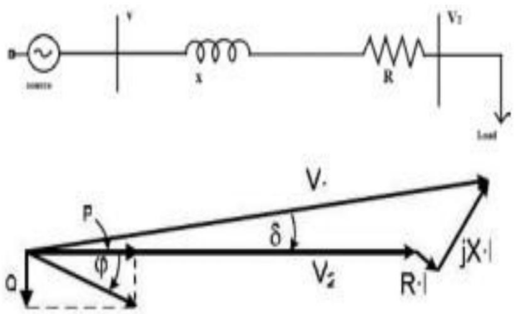

Figure 4 - Before Compensation

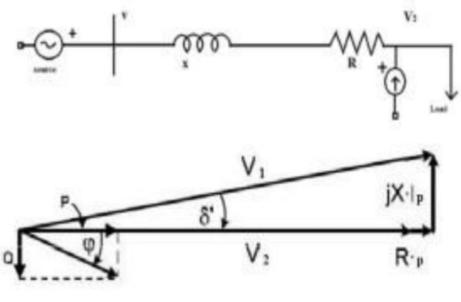

Fig 5 – After Compensation

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Above figure 4 shows the system without any type of compensation. It includes the voltage source V with an inductive load and a power line. Here the active current Ip is in phase with a load voltage V_2. As the load is an inductive therefore it requires reactive power for suitable operation. Thus, by increasing the current from the generator side and thus through power lines, it is desirable to regulate the reactive power that can be supplied near the load, the line current can be minimized, reducing the power losses and improving the voltage regulation at the load terminals. This can be done in three ways: 1) A voltage source. 2) A current source. 3) A capacitor. Therefore we can see that, a current source or a voltage source can be used for both leading and lagging shunt compensation, the main advantages being the reactive power generated is independent of the voltage at the point of connection.

ii) Series Compensation

Below figures 6 and 7 shows the series compensation which can be implemented like the shunt compensations, i.e.; with a current or a voltage source. However, series compensation techniques are different from the shunt compensation technique as here capacitors are used mostly in the series compensation technique.

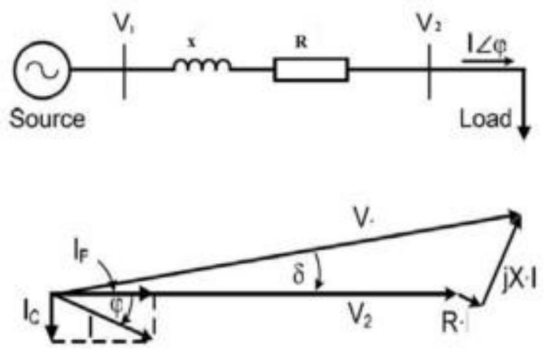

Figure 6 - Before Compensation

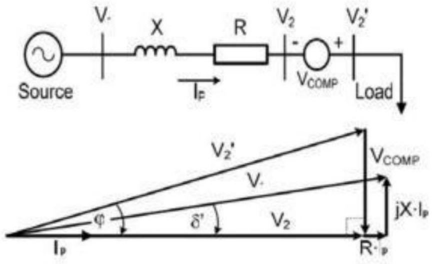

Figure 7 – After Compensation

We can see the result which are obtained by the series compensation through a voltage source and maintained till the unity power factor obtained at the voltage V_2. In this case, the voltage compensator V_{comp} has been added between the line and the load to change the angle V_2. Now this is the voltage at the load side. Hence from this unity power factor can be maintained with the proper magnitude of V_2.

Choice of reactive power compensation

The reactive power compensation for a wind plant typically consists of a combination of different technologies. Assume that the reactive power required to be generated by the wind power plant, is between inductive 50 Mvar to capacitive 100 Mvar. Some of the possible solutions could be:

Qty 2 – 25 Mvar switched shunt reactors and Qty 4- 25 Mvar switched shunt capacitors. This solution will not be able to hit a specific power factor or voltage target under all conditions. Qty 4 – 12.5 Mvar switched shunt reactors and Qty 8- 12.5 Mvar switched shunt capacitors. This solution will be able to hit more specific power factor or voltage targets, but still not all under all conditions.

Qty 1 – 25 Mvar switched shunt reactor, Qty 1- 25 Mvar regulated reactor and Qty 4 – 25 Mvar switched shunt capacitors. This solution should be able to come close to a specific power factor or voltage target under all conditions.

Qty 2 – 25 Mvar switched shunt capacitors and +/- 50 MVAR from WTG's, assuming WTG's have the capability. This solution should be able to hit a specific power factor or voltage target under all conditions.

Qty 1 – -50 to +100 Mvar SVC. This solution will be able to hit a specific power factor or voltage target under all conditions.

Qty 1 – -50 to +100 Mvar STATCOM. This solution will be able to hit a specific power factor or voltage target under all conditions.

The choice of reactive power compensation system is an economic decision considering initial investment and lifecycle cost, where the requirements set by the network operator act as an important boundary condition.

VII. CONCLUSION

We can conclude that the reactive power of the system can be compensated by using the STATCOM or using the FACTS devices, i.e. by using this above compensation techniques the flow of reactive power and the power factor of the system can be maintained at unity power factor and hence the system can be maintained at balanced condition with the proper magnitude of voltage V comp. Under light load condition, a flat voltage profile is achieved by inductive shunt compensation. Under heavy load condition, a flat voltage can be achieved by adding shunt capacitive compensation.

Series capacitive compensation may theoretically be used instead of shunt compensation to give a flat voltage profile, under heavy loading. As practically, lumped series capacitors are not suitable for obtaining a smooth voltage profile along the line. Thus, it is obvious that we get step a change in voltage occurs at points where the series capacitors are applied. However, with use of series capacitors improved voltage regulation at any point can be obtained.

Some valid conclusions to be considered are : sending end voltage for shunt compensator is more than that required for series compensator. In shunt compensator active power loss is reduced. In series compensator the active power loss remains unaffected. Total reactive power loss is reduced to substantial amount by a series compensator as compared to shunt compensator. Shunt compensator gives improved power factor than that of series compensator.

The response time of STATCOM is shorter than that of static VAR compensator due to fast switching time of IGBT of voltage source converter. STATCOM gives better reactive power support at low AC voltages than static VAR compensator. STATCOM provides better voltage stability than static VAR compensator. STATCOM exhibits higher losses and may more expensive than static VAR compensator.

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