FACTS Devices for Reactive Power Compensation of Wind Energy Conversion System

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ABSTRACT

Voltage control and reactive power compensation in a distribution network with embedded wind energy conversion system (WECS) represent main concern of this paper. The WECS is of a fixed speed/constant frequency type that is equipped with an induction generator driven by an unregulated wind turbine. The problem is viewed from time domain responses of the system to different wind speed changes. Being disturbed by a variable wind speed, the WECS injects variable active and reactive power into the distribution network exposing nearby consumers to excessive voltage changes. In the FACTS-based solution approach, the Unified Power Flow Controller (UPFC) is used at the point of the WECS network connection to solve technical issues related to voltage support and series reactive power flow control.

Keywords - *Dynamic voltage restorer (DVR), wind power generator, induction generator, power quality.*

1. INTRODUCTION

RECENTLY alternative solutions treating distributed generation of electrical energy have appeared as a consequence of strong ecological concerns with regard to almost all major industrial branches. Moreover, initiatives of potential investors come along with liberalization of electrical energy market. It results with an --additional impact to a need for conducting a new kind of technical analysis. Grid integration aspects of renewable sources have become increasingly important as incentives come in large numbers. From distribution network viewpoint, connection of small power plants with dispersed generation of electricity calls for urgent attention [1]. In case of increased power ratings, dispersed power plants could be integrated in a transmission network. Dispersed generation of electricity is often a subject of polarized discussions. At one side, experienced engineers motivated by wide knowledge of complex power system operation are concerned regarding fundamental realization of massive introduction of unregulated and uncontrollable Generators into a distribution network. At the other side, enthusiastic proponents of renewable sources believe that such generating units are a necessity in operation should domestic and international requirements for reduction of CO_2 emission be fulfilled. Moreover, they are convinced that renewable decrease dependence on dominant energy fuels (gas, oil, coal…) in times of large international crisis.

Increased penetration of renewable such as wind energy creates an uncontrollable component in electric power system. Based on weather forecasts it is possible to predict a mean wind speed in short-term time period, but not dynamic changes as well, smaller or larger, which take place around a base speed. Dynamic changes of wind speed make amount of power injected to a network highly variable [2]. Depending on intensity and rate of changes, difficulties with frequency and voltage regulation could appear making a direct impact to quality level of delivered electrical energy. Conditions of economic justification set project requirements for wind power plant installations in areas with high wind utilization. Such areas are often located in rural zones with relatively weak electrical networks. In order to establish a balance between polarized attitudes, it is necessary to provide answers concerning technical, economic, and security aspects related to grid integration of wind power plants. From that viewpoint, the objective of this paper is set as to create a countermeasure Without a countermeasure, it is possible that at some locations only a small number of wind turbines could be connected due to weak voltage conditions and increased losses in the nearby network. That would not only leave assessed wind potential unused, but

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also it could also prohibit installation of larger number of wind turbines jeopardizing the economics of the whole project. In an attempt to overcome negative dynamic impacts caused by wind speed changes, the voltage regulation and reactive power compensation problem is approached here not only from a conventional aspect, but from a FACTS based one as well [3-4]]. Wind power plant induction generator is viewed as a consumer of reactive power. Its reactive power consumption depends on active power production. Conventionally, shunt capacitor banks are connected at the generator terminals to compensate its reactive power consumption. In some schemes, shunt capacitor banks could be automatically switched on/off by using feedback signal from generator reactive power. The capacitor switching is triggered through an algorithm if a generator reactive power is outside an allowed dead-band for a specified time period. Further on, continuous voltage control and reactive power compensation at the point of the WECS network connection is provided by using FACTS-based device[5-6]. Among FACTS devices, the Unified Power Flow Controller (UPFC) is chosen due to its versatile regulating capabilities. The UPFC consists of shunt and series branches, which could be interchangeably used. Being located at the point of the WECS connection to the distribution network, it is made possible to simultaneously control the WECS bus voltage magnitude and/or series reactive power flow that WECS exchanges with the network [7-8]. This countermeasure is expected to contribute in making assessed wind site viable for connecting larger number of wind turbines.

2. FACTS CATEGORIES AND FUNCTIONS

With the rapid development of power electronics, Flexible AC Transmission Systems (FACTS) devices have been proposed and implemented in power systems [9-10]. FACTS devices can be utilized to control power flow and enhance system stability. Particularly with the deregulation of the electricity market, there is an increasing interest in using FACTS devices in the operation and control of power systems with new loading and power flow conditions. A better utilization of the existing power systems to increase their capacities and controllability by installing FACTS devices becomes imperative. Due to the present situation, there are two main aspects that should be considered in using FACTS devices: The first aspect is the flexible power system operation according to the power flow control capability of FACTS devices. The other aspect is the improvement of transient and steady-state stability of power systems [11]. FACTS devices are the right equipment to meet these challenges. In general, FACTS devices can be divided into four categories

2.1 Series facts devices

Series FACTS devices could be a variable impedance, such as capacitor, reactor, etc., or a power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need . In principle, all series FACTS devices inject voltage in series with the transmission line.

2.2 Shunt facts devices

Shunt FACTS devices may be variable impedance, variable source, or a combination of these. They inject current into the system at the point of connection.

2.3 Combined series -series facts device:

Combined series-series FACTS device is a combination of separate series FACTS devices, which are controlled in a coordinated manner.

2.4 Combined series -shunt facts devices:

Combined series-shunt FACTS device is a combination of separate shunt and series devices, which are controlled in a coordinated manner or one device with series and shunt elements. Devices used for transmission systems are as follows.

THYRISTOR CONTROLLED SERIES CAPACITORS, TCSC

TCSC is used for Power Oscillation Damping (POD), and/or Sub Synchronous Resonance (SSR) mitigation. The series capacitor is provided with a parallel branch using a reactor and a thyristor valve, see fig 1. This arrangement provides a continuously controllable reactance since the parallel thyristor reactor branch produces a current that adds up to the line current through the capacitor thereby increasing its capacitive size beyond its physical reactance obtained by the line current only. Further development, of the present design, is focusing on cost reduction and increased current handling capability.

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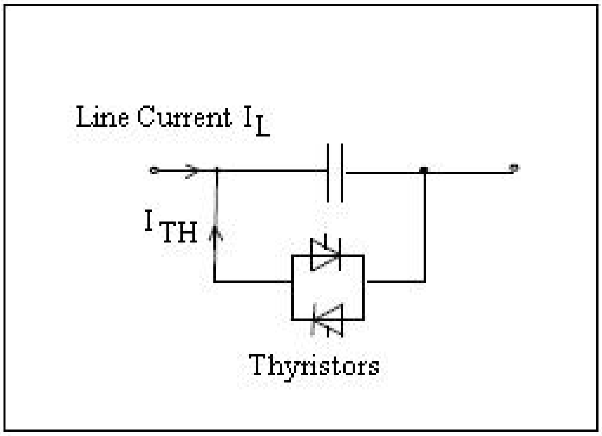

Fig. 1: Thyristor Controlled Series Capacitors (TCSC)

STATIC VAR COMPENSATOR, SVC

A typical shunt - connected static var compensator, composed of thyristor switched capacitors (TSCs) and thyristor controlled reactors (TCRs) is shown in fig 2. The compensator is normally operated to regulate the voltage of the transmission system at a selected terminal. The V - I characteristic of the SVC indicates the regulation with a given slope around the nominal voltage can be achieved in the normal operating range defined by the maximum capacitive and inductive currents of the SVC. The voltage support capability of the conventional thyristor controlled static var compensator rapidly deteriorates with decreasing system voltage. In addition to voltage support, SVCs are also employed for transient (first swing) and dynamic stability (damping) improvements.

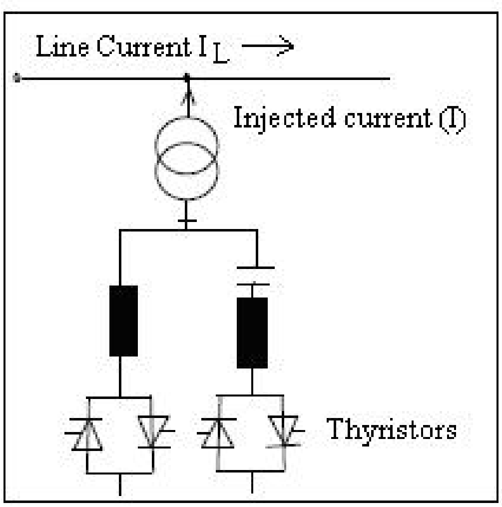

Fig. 2: Static Var Compensator (SVC)

STATIC COMPENSATOR, STATCOM

Static Synchronous Compensator (STATCOM) employing forced switching type of semiconductors in a converter that functions as a controllable synchronous voltage source, has been introduced for reactive shunt compensation as shown in fig 3. The basic principle of reactive power generation by the STATCOM is analogous to that of the conventional rotating synchronous compensator. From a DC input voltage source, provided by the charged capacitor, the converter produces a set of controllable three - phase output voltages with the frequency of the AC power system. By varying the amplitude of the output voltages produced, the reactive power exchange between the converter and the AC system can be controlled. If the amplitude of the output voltage (V) is increased above that of the AC system voltage (VT), then the current flows (Iq) through the tie reactance from the converter to the AC system, and the converter generate reactive (capacitive) power for the AC system. If V is decreased below VT, then the converter absorbs reactive (inductive) power. The STATCOM converter itself can keep the capacitor charged to the required voltage level.

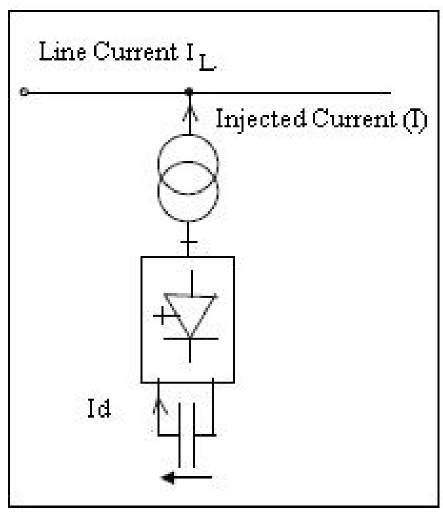

Fig. 3 : Static Synchronous Compensator (STATCOM)

STATIC SYNCHRONOUS SERIES COMPENSATOR , SSSC

The Static Synchronous Series Compensator, SSSC, offers an alternative to conventional series capacitive line compensation. The SSSC is a synchronous voltage source that internally generates the desired compensating voltage in series with the line independent of the line current as shown in fig 4.

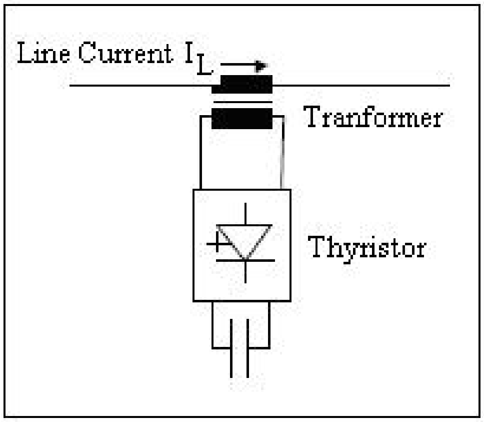

Fig. 4: Static Synchronous Series Compensator , SSSC

The SSSC can be considered functionally as an ideal generator. The SSSC can produce a set of (three) alternating voltages at the desired fundamental frequency with controllable amplitude and phase angle. Further the SSSC can generate or absorb reactive power when tied to an electric power system to function like a synchronous condenser (compensator) and convert the active power it exchanges with the AC system into a DC voltage that is compatible with an electric energy source or ` ``````````````````storage. The transmitted power becomes a parametric function of the injected voltage. The SSSC can control both reactive and active power with the AC system, simply by controlling the angular position of the injected voltage with respect to the line current. With the appropriate combinations of SVSs unique FACTS controller arrangements able to control independently real and reactive power flow in individual lines, balance real and reactive flows among line, can be devised. From the standpoint of practical applications, steady state flow control or stability improvements, the SSSC clearly has considerably wider control range then the controlled series capacitor of the same MVA rating.

PHASE SHIFTING TRANSFORMER, PST

Phase shifting transformer, PST, using tap-changers or thyristor switches for control as shown in fig 5. In order to reduce cost some units could be equipped with parallel inductor and this solution is also named Interphase Power Controller, IPC. If the PST is provided with a fast acting switching device, i.e. thyristor switches, the PST is renamed in to TCPST, Thyristor Controlled Phase Shifting Transformer, and can be used for Power Oscillation Damping, POD.

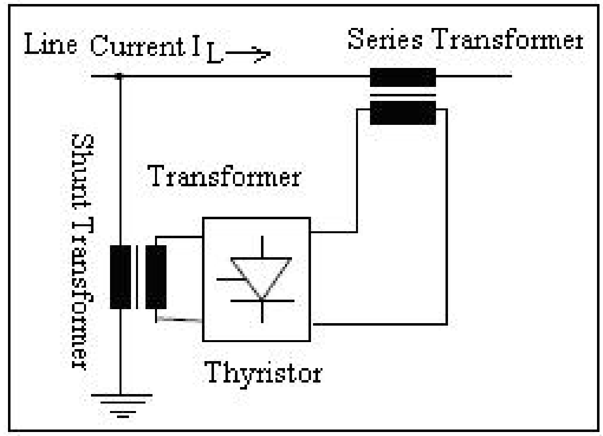

Fig. 5 : Phase Shifting Transformer (PST)

UNIFIED POWER FLOW CONTROLLER, UPFC

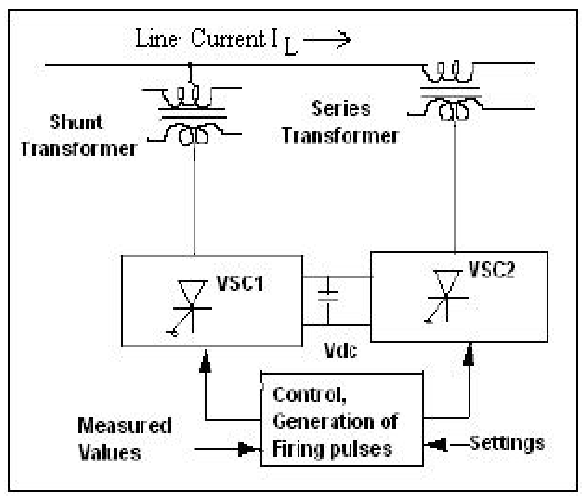

Fig. 6: Unified Power Flow Controller (UPFC)

The UPFC combines together the features of two FACTS devices: The Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC) [12-13] as shown in fig 6. The DC terminals of the two underlying VSCs are now coupled, and this creates a path for active power exchange between the

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converters. Hence, the active power supplied to the line by the series converter, can now be supplied by the shunt converter, as shown in the Figure. This topology offers three degrees of freedom, or more precisely four degrees of freedom (two associated with each VSC) with one constraint (active powers of the VSCs must match). Therefore, a fundamentally different range of control options is available compared to STATCOM or SSSC. The UPFC can be used to control the flow of active and reactive power through the line and to control the amount of reactive power supplied to the line at the point of installation. The UPFC has many possible operating modes.

VAR control mode: The reference input is an inductive or capacitive var request; Automatic Voltage Control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value. Instead, the series inverter injecting the voltage controllable in amplitude and phase angle in series with the transmission line influences the power flow on the transmission line. This series voltage can be determined in different ways:

Direct Voltage Injection mode: The reference inputs are directly the magnitude and phase angle of the series voltage; Phase Angle Shifter Emulation mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage; Line impedance emulation mode: The reference input is an impedance value to insert in series with the line impedance.

Automatic Power flow Control mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

In the presently used practical implementation, the UPFC consists of two voltage sourced converters. These back-to-back converters, labeled "VSC 1" and "VSC 2", are operated from a common dc link provided by a dc storage capacitor. As indicated before, this arrangement functions as an ideal ac-to-ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters, and each converters can independently generate (or absorb) reactive power at it's own ac output terminal.

VSC2 provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an insertion transformer. This injected voltage acts essentially as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and real power exchange between it and the ac system. The reactive power exchanged at the ac terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted in to dc power which appears at the dc link as a positive or negative real power demand.

The basic function of VSC 1 is to supply or absorb the real power demanded by VSC 2 at the common dc link to support the real power exchange resulting from the series voltage injection. This dc link power demand of VSC 2 is converted back to ac by VSC1 and coupled to the transmission line bus via a shunt connected transformer. In addition to the real power need of VSC2 2, VSC 1 can also generate or absorb controllable reactive power, if it is desired, and there by provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed direct path for the real power negotiated by the action of series voltage injection through converter 1and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by VSC 2 and therefore does not have to be transmitted by the line. Thus, VSC 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by VSC 2.Obviously there can be no reactive power flow through the UPFC dc link.

3. SIMULATION RESULTS

Case 1.A transmission line of a simple power system with parameters as given in Table I is considered. UPFC is placed in series with the transmission line at the sending end. Voltage, active power, reactive power and current variations in the transmission line with UPFC and without UPFC are studied and compared. It is observed that when the transmission line is without UPFC, the sending-end and receiving end power and current is shown in fig. 7 & 9 respectively. When UPFC is placed across the same transmission line, transmission line, the active and reactive power and current flow is improved as shown in fig 8 & 10 respectively.

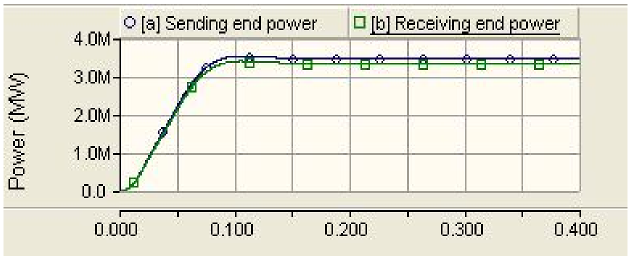

Fig. 7 : Sending end and receiving end active power without UPFC

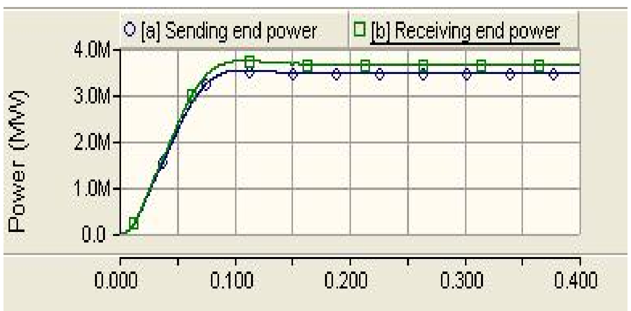

Fig. 8 : Sending end and receiving end active power with UPFC

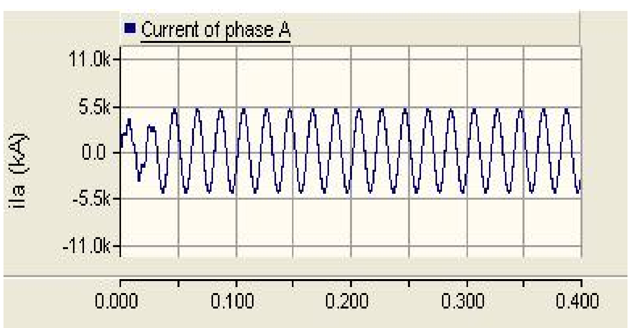

Fig 9 : Current of phase 'A' without UPFC

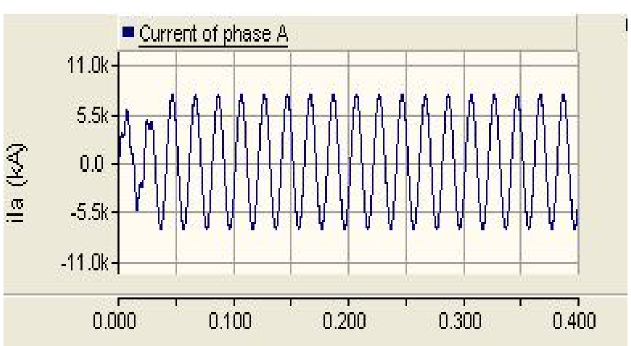

Fig 10 : Current of phase 'A' with UPFC

Case 2. Performformance of the same transmission line is checked for harmonic compensation. It is observed that when the transmission line is without UPFC, voltage of the line is distorted and harmonic content measured is 45% . However when UPFC is placed across the same transmission line, voltage waveform is improved and THD of line voltage is improved to 5% as shown in fig 11.

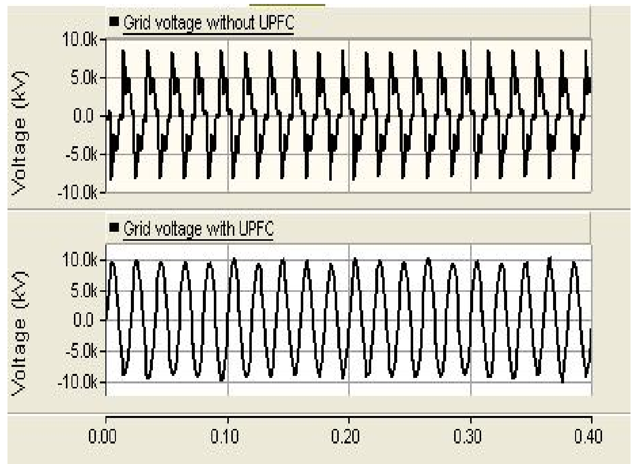

Fig 11: Grid voltage without UPFC and with UPFC

4. CONCLUSION

Within this paper, conventional and FACTS-based aspects of voltage control and reactive power compensation are compared. Benefits of applying power electronics-based devices are clearly depicted within grid integration aspects of the wind energy conversion system. The FACTS-based solution prevents large deviations of bus voltage magnitude induced by variable WECS injected power to penetrate through the distribution network. With the UPFC operated, the WECS voltage control and reactive power compensation problems are alleviated by simultaneous regulation of the bus voltage magnitude and series reactive power flow at the point of the WECS connection to the network. It is expected that presented results would help find another increasingly interesting possibility of FACTS implementation within grid integration aspects of wind energy conversion systems.

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