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A Survey on Power Quality Improvement of Grid Connected Wind Energy Systems using FACTS

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ABSTRACT

The wind energy generation, utilization and its grid penetration in electrical grid are increasing worldwide. The wind generated power is always fluctuating due to its time varying nature and causing stability problems. This weak interconnection of wind generating source in the electrical network affects the power quality and reliability. The influence of the wind turbine in the grid system concerning the power quality measurements are the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national international guidelines. This paper's objective is to analyze modern techniques used for mitigation of power quality issues that arise due to the penetration of wind energy into the distribution grid.

Keywords--- FACTS, STATCOM, DVR, SSSC, SVC, TCSC, UPFC

I. INTRODUCTION

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government's incentives have further accelerated the renewable energy sector growth. Long transmission lines are one of the main causes for electrical power losses. Therefore emphasis has increased on distributed generation networks with integration of renewable energy systems in to the grid, which lead to energy efficiency and reduction in emissions.

In recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impacts. Wind energy conversion systems are the fastest growing renewable source of electrical energy having tremendous environmental and social benefits. To increase the system efficiency, high efficiency devices based on power electronics equipments have been increasingly used in many applications[1][5]. This causes increasing harmonic levels on power systems and concerns about the future impact on system capabilities. So, if there is any fault in the subsystems there will be disturbances, disruptions and the other effects, which decrease the power quality in the system. The power-transfer capability of long transmission lines are usually limited by large signals ability. Economic factors, such as the high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. On the other hand, the development of effective ways to use transmission systems at their maximum thermal capability has caught much research attention in recent years. Fast progression in the field of power electronics has already started to influence the power industry. The ability to control power flow in an electric power system without generation rescheduling or topology changes can improve performance using the power system performance using controllable components. Flexible ac transmission systems (FACTS) technology is the ultimate tool for getting the most out of existing equipment via faster control action and new capabilities. The most striking feature is the ability to directly control transmission line flows by structurally changing parameters of the grid and to implement high-gain type controllers based on fast switching. The application of FACTS devices to power system security has been an attractive ongoing area of research. In most of the reported studies attention has been focused on the ability of these devices to improve the power system security by damping system oscillations and minimal attempts have been made to investigate the effect of these devices on power system reliability. The opportunities arise through the ability of FACTS controllers to control the interrelated parameters that governs the operation of transmission systems including series impedance and shunt impedance, current, phase angle and damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome otherwise, while maintaining the required system stability, by mechanical means without lowering the useable transmission capacity. By providing added flexibility, FACTS controller can enable a line to carry power closer to its thermal rating. Mechanical switching needs to be supplemented by rapid-response power electronics. The FACTS technology can certainly be used to overcome any to the stability limits, in which case the ultimate limits would be thermal and dielectric.

II. POWER QUALITY STANDARDS AND ISSUES

A. Power quality characteristics of wind turbines

Power injection from grid-connected wind turbines affects substantially the power quality. The procedures for the measurement and assessment of the main parameters involved in the power quality characteristics of a wind turbine are described in the IEC 61400-21standard. The tests are designed to be as non-site-specific as possible, so that power quality characteristics measured with the wind turbine connected at a test site can also be considered valid at other sites.

According to the standard there are seven parameters compromising [4]

- Active and reactive power characteristics
- Flicker in continuous operation and due to switching operations
- Current harmonics, current interharmonics and higher frequency current components
- Active Power controls
- Reactive Power controls
- Response to voltage dips
- Grid Protection and Reconnection time

B. IEC Guidelines

The International standards are developed by the working group of Technical Committee-88 of the International Electro technical Commission (IEC), IEC standard 61400-21, describes the procedure for determining the power quality characteristics of the wind turbine. [3] The standard norms are specified.

1) IEC 61400-21: Wind turbine generating system, part-21. Measurement and Assessment of power quality characteristic of grid connected wind turbine.

2) IEC 61400-13: Wind Turbine—measuring procedure in determining the power behaviour.

3) IEC 61400-3-7: Assessment of emission limits for fluctuating load.

4) IEC 61400-12: Wind Turbine performance.

The data sheet with electrical characteristic of wind turbine provides the base for the utility assessment regarding a grid connection. For the specification of measurements IEC 61400-21 refers to further IEC standards e.g. consequently, flicker measurements have to take into account IEC 61000-4-15, harmonics measurements are based on IEC 61000-4-7.

C. Wind power quality issues

A big challenge arises when trying to convert the mechanical energy from the wind, which presents a stochastic behaviour into useful electric energy. [6] Wind Speed varies a lot and consequently the torque applied into the electrical machine connected to a wind turbine will vary too, leading to various issues.

i). Power Coefficient and Peak Power Tracking

This wind speed variation not only can make it difficult to ensure good power quality but also implies in a variation of the power coefficient Cp. The power coefficient is the ratio of the mechanical power obtained by the wind turbine and the mechanical power related to the wind.

$$P_{mech} = C_p P_{wind} \quad (1)$$

The power coefficient is not a constant; it depends on the wind speed, aerodynamic factors and possibly on the blade pitch angle if the wind turbine is pitch-controlled. For most turbines the power coefficient is zero for low wind speeds, which make wind turbine control even more difficult. Wind's mechanical power may be defined as:

$$P_{wind} = \frac{1}{2} \rho A V^3{}_{wind} \quad (2)$$

Along with the wind speed variation comes the tower shadow effect, which is a consequence from the spatial distribution of the horizontal axis wind turbine. The tower shadow effect introduces more uncertainty into the power coefficient. Since one blade will eventually be shaded by the wind turbine tower, it will not transfer as much power as it would on other positions. This wind power variation can affect the active power output, reactive power consumption and voltage output of an induction machine. It will also affect the power and voltage output of a synchronous generator. When the wind speed varies, there is also a change in the power coefficient. It is of our interest to keep the power coefficient as high as possible (unless under extremely high wind speeds that can damage the turbine or the electric machine connected to it). Many techniques known as Peak Power Tracking or Maximum Power Point Tracking are used in order to maximize the power coefficient. These techniques aim to find an optimum rotor speed where the mechanical coefficient is maximized.

ii). Induction Generators Self-Excitation

Due to its relative low cost, low need for maintenance and simple operation many wind power plants have adopted the induction asynchronous generator as the device responsible for the electromechanical energy conversion. When using an induction generator, the voltage and frequency are determined by the balancing of the system. The induction machine needs reactive power in order to produce active power, thus it is a common technique to compensate that reactive power with a shunt capacitor. As the grid fault occurs, self-excitation of the induction generator may occur causing voltage and frequency to variate. This situation is extremely undesirable since it can damage several types of equipments including the wind turbine and high voltages produced may be a threat to human life.

iii). Voltage Transients

Some capacitor banks use mechanical switches in order to provide the right amount of reactive power to induction generators. These mechanical switches can introduce large voltage transients into the wind energy generation grid very frequently. Frequent occurrences of voltage transients can damage sensitive electronic equipment used in wind energy control systems [19].

iv). Voltage Unbalance

When large unbalanced loads are present in the distribution grid negative sequence currents flow into induction machines, causing them to overheat. This implies in a shorter life time for the machine and the need of it to be de-rated. takes place when voltage fluctuates in a range of frequency between 10-35Hz, it may produce light disturbances to the human eye through incandescent lamps, which can trigger epileptic attacks of photosensitive persons and also damage sensitive equipment. This document presents energy storage techniques that can be used in order to avoid flicker due to wind speed variations.

v) Harmonic Distortion

Voltage Total Harmonic Distortion may be defined as follows:

$$\mathrm{THDv} = \sqrt{\sum_{h=2}^{N} \frac{Vh^2}{V1^2}} \qquad (3)$$

Where Vh is the voltage rms value for the harmonic of order h. Current Total Harmonic Distortion may be defined analogously:

$$\mathrm{THDi} = \sqrt{\sum_{h=2}^{N} \frac{Ih^2}{I1^2}} \qquad (4)$$

Harmonic Distortion can cause reduction in equipments lifetime, malfunctioning of sensitive equipment, power losses, heating of transformer cores and many other issues. Sub harmonics, voltage or current components that present a frequency less than 50Hz are also a big issue in power quality and can damage generators due to its low frequency of oscillation. It is common practice to rectify the electric power from a wind power plant and feed it into an inverter, in order to control the injected current phase and total harmonic distortion. This is possible due to the improvement in power electronics converters.

III. FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

FACTS is the acronym for Flexible AC Transmission Systems and refers to a group of resources used to overcome certain limitations in the static and dynamic transmission capacity of electrical networks. The IEEE defines FACTS as “alternating current transmission systems incorporating power-electronics based and other static controllers to enhance controllability and power transfer capability.” The main purpose of these systems is to supply the network as quickly as possible with inductive or capacitive reactive power that is adapted to its particular requirements, while also improving transmission quality and the efficiency of the power transmission system[7][9].

Now and in the future the inevitable globalization and liberalization of energy markets associated with growing deregulation and privatization are increasingly resulting in bottlenecks, uncontrolled load flows, instabilities, and even power transmission failures. Power supplies are increasingly dependent on distributed power plants with higher voltage levels, a greater exchange within meshed systems, and transport to large load centers over what are often long distances. This type of power transmission must be implemented safely and cost effectively with a view to the future. Implementing new transmission systems and components is a long-term strategy for meeting these challenges. Over the short and medium term, modern transmission technologies can be employed at comparatively little expense to rectify or minimize bottlenecks and substantially improve the quality of supply. Often, this makes it possible to postpone investing in new plants and, as a result, to achieve critical advantages over the competition – especially important in de-regulated energy markets in which power supply companies are subject to extreme pricing pressure.

A .Static Var Compensators (SVC):

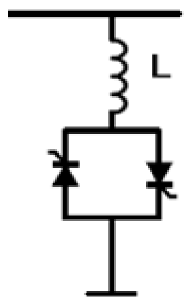

Fig 1: TCR

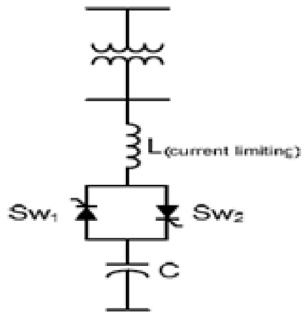

Fig 2: TSC

The compensator normally includes a thyristors controlled reactor (TCR), thyristor-switched capacitors (TSCs) and harmonic filters. It might also include mechanically switched shunt capacitors (MSCs), and then the term static var system is used. The harmonic filters (for the TCR-produced harmonics) are capacitive at fundamental frequency. The TCR is typically larger than the TSC blocks so that continuous control is realized. Other possibilities are fixed capacitors (FCs), and thyristor switched reactors (TSRs).The transmission side voltage is controlled, and the Mvar ratings are referred to the transmission side [8].

• TSC (Thyristor Switched Capacitor) is a capacitor switched using thyristor. Systems of this type consist of one or more cooperating three-phase sections of TSC, where each section includes capacitors, thyristor switches that are switched on or off depending on the total reactive power supplied by the entire device.

• TSR or TCR: TSR and TCR are systems with induction components only. They consist of a TSR (Thyristor Switched Reactor) or TCR (Thyristor Controlled Reactor) section; TSR includes thyristor switched reactors, whereas TCR are reactors with thyristor controlled induction. A TSR-type compensator is composed of several three-phase TSR sections whose thyristor switches are switched on or off (discrete control) depending on reactive power that is to be received by the entire device from the system. A TCR-type compensator has a similar structure, but the basic difference between these devices lies in the fact that TCR has no ability to provide smooth control of inductance.

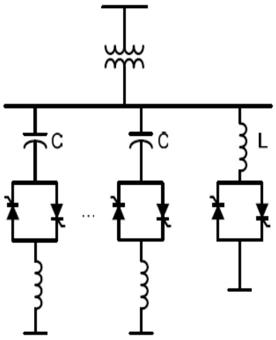

Fig 3 : Combined TSC and TCR Configuration

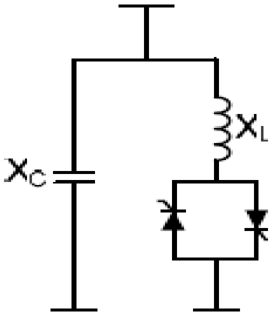

Fig 4: TCR-FC configuration

• TCR-FC: These devices consist of two types of components. The first one is a TCR module that receives reactive power, and the second is FC (Fixed Capacitor), which include also higher harmonic filters. They are an essential element when it comes to the work of TCR. FC is a source of reactive power.

• TCR-TSC-FC: These compensators consist of three groups of components. The first group consists of thyristor controlled reactors. The second group consists of TSC, which is the primary source of reactive power. The third group is higher harmonic filter (treated as fixed capacities – FC), which is an additional source of reactive power. Their presence in this system is necessary due to the need to eliminate the interferences caused by TCR.

• TSR-TSC. Compensators of this type consist of two groups of elements. The first group consists of thyristor switched inductors, while the second group consists of TSC. The system may provide only discrete control [13].

B. Thyristor Controlled Series Compensation

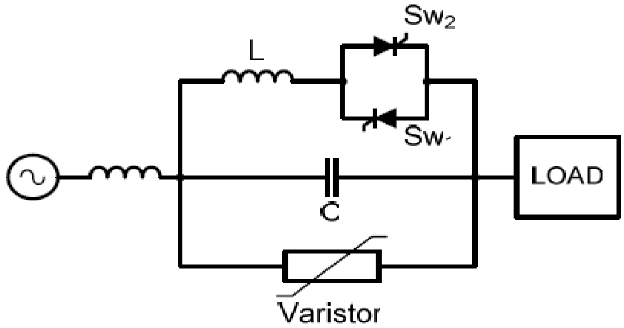

Fig 5: Thyristor Controlled Series Compensator (TCSC)

Figure 5 shows a single line diagram of a Thyristor Controlled Series Compensator (TCSC). TCSC provides a proven technology that addresses specific dynamic problems in transmission systems [8]. TCSC's are an excellent tool to introduce if increased damping is required when interconnecting large electrical systems. Additionally, they can overcome the problem of Sub synchronous Resonance (SSR), a phenomenon that involves an interaction between large thermal generating units and series compensated transmission systems.

There are two bearing principles of the TCSC concept. First, the TCSC provides electromechanical damping between large electrical systems by changing the reactance of a specific interconnecting power line, i.e. the TCSC will provide a variable capacitive reactance. Second, the TCSC shall change its apparent impedance (as seen by the line current) for sub synchronous frequencies such that a prospective sub synchronous resonance is avoided. Both these objectives are achieved with the TCSC using control algorithms that operate concurrently. The controls will function on the thyristor circuit (in parallel to the main capacitor bank) such that controlled charges are added to the main capacitor, making it a variable capacitor at fundamental frequency but a "virtual inductor" at sub synchronous frequencies.

For power oscillation damping, the TCSC scheme introduces a component of modulation of the effective reactance of the power transmission corridor. By suitable system control, this modulation of the reactance is made to counteract the oscillations of the active power transfer, in order to damp these out.

C. Static Synchronous Compensator (STATCOM)

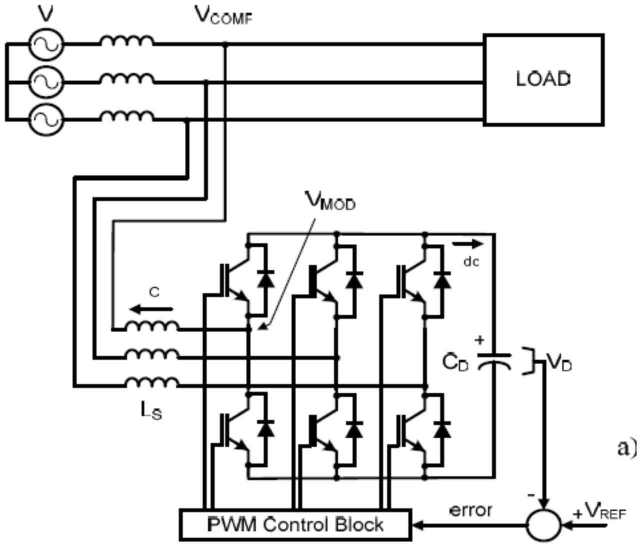

Fig 6: Static Synchronous Compensator

With the commercial breakthrough of high power gate turn-off devices, the road is paved for an additional step forward in flexibility of AC transmission and distribution systems: STATCOM, or the Static Synchronous Compensator. The name is an indication that STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost and lower operating and maintenance costs. A STATCOM can be seen as a voltage source behind a reactance [10]. It provides reactive power generation as well as absorption purely by means of electronic processing of voltage and current waveforms in a Voltage Source Converter (VSC). This means that capacitor banks and shunt reactors are not needed for generation and absorption of reactive power, giving a compact design[11].

With the advent of STATCOM, still better performance can be reached in areas such as:

• Dynamic voltage control in transmission and distribution systems

• Power oscillation damping in power transmission systems

• Transient stability improvement

• Ability to control not only reactive power but, if needed, also active power (with a DC energy source available).

STATCOM also brings further benefits like
• A small footprint, due to the replacing of passive banks by compact electronic converters
• Modular, factory built equipment, reducing site works and commissioning time
• Use of encapsulated electronic converters, which minimizes environmental impact on the equipment.

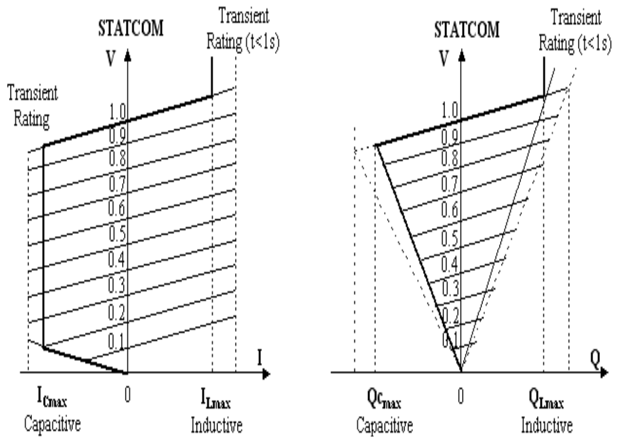

Fig 7: V-I and V-Q characteristics

From V-I and V-Q characteristics [8] it is possible to conclude that:
1) The STATCOM can be operated all over its full output current range even at very low system voltage levels. In other words, the output current can be maintained independently from the a.c. system voltage.
2) The maximum VAr generation or absorption changes linearly with the a.c. system voltage.
3) The independence of STATCOM output from equivalent system impedance means that the voltage regulator controlling the STATCOM output can be designed for a faster response rate and can provide stable regulation over the range of system contingencies.

D. The Static Synchronous Series Compensator (SSSC)

SSSC is a series connected FACTS controller based on VSC and can be viewed as an advanced type of controlled series compensation, just as a STATCOM is an advanced SVC.

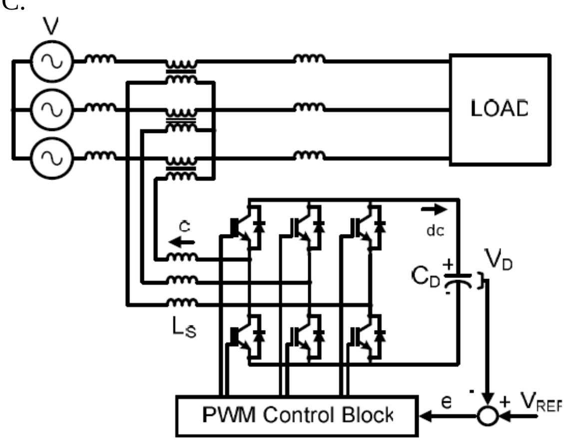

Fig 8: Static Synchronous Series Compensator

A SSSC has several advantages over a TCSC such as
(a) Elimination of bulky passive components (capacitors and reactors)
(b) Improved technical characteristics
(c) Symmetric capability in both inductive and capacitive operating modes
(d) Possibility of connecting an energy source on the DC side to exchange real power with the AC network.

The SSSC when operated with an appropriate DC supply (an energy source and/or sink, or a suitable storage) can inject a component of voltage in anti-phase with the voltage developed across the line resistance, to counteract the effect of the resistive voltage drop on the power transmission. The capability of the SSSC to exchange both active and reactive power makes it possible to compensate for the reactive and resistive voltage drops, maintaining a high effective X/R ratio independently of the degree of series compensation [12].

E. Dynamic Voltage Regulator (DVR)

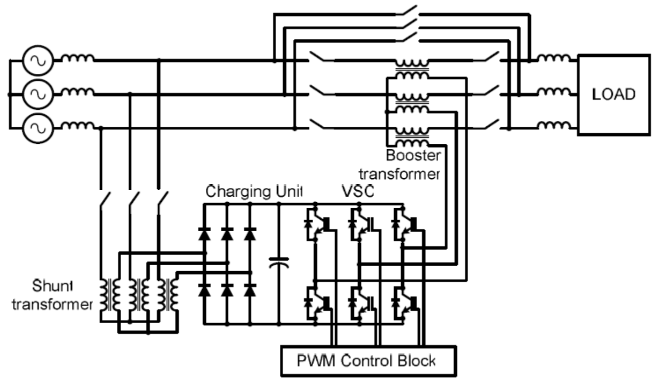

Fig 9: Dynamic Voltage Regulator

DVR is used at the consumer premises to protect the critical loads. The dynamic voltage restorer (DVR), one of the aforementioned devices, is used for improving the PQ of the load terminal voltages against voltage sags, swells, transients, and harmonic distortions in the source voltages. A DVR is a voltage-source converter (VSC)-based power electronics device connected in series between the supply and the critical loads, which are to be protected from the supply side voltage quality problems, other than outages, by injecting the required compensating voltage through DVR into the distribution line [14][15]. A DVR can restore a balanced sinusoidal load voltage of desired amplitude even when the source voltage is unbalanced and/or distorted. The voltage injected by self supported DVR is in quadrature with the feeder current; hence, it does not need any active power during steady state. However, its disadvantage is that, in case of the voltage sag/swell, the restored voltage may not be in phase with the presag/preswell voltage [16].

F. Unified Power Flow Controller (UPFC)

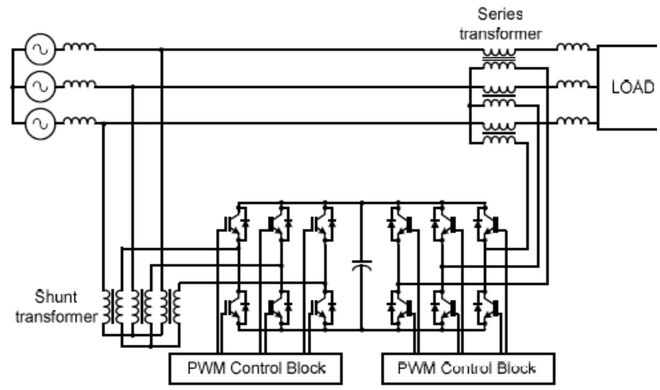

Fig 10: Unified Power Flow Controller

The unified power flow controller (UPFC), shown in Fig. 10, consists of two switching converters operated from a common dc link provided by a dc storage capacitor. One connected in series with the line, and the other in parallel [17]. 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 inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal. The series converter of the UPFC injects via series transformer, an ac voltage with controllable magnitude and phase angle in series with the transmission line. The shunt converter supplies or absorbs the real power demanded by the series converter through the common dc link. The inverter connected in series provides the main function of the UPFC by injecting an ac voltage Vpq with controllable magnitude ($0 \le Vpq \le Vpqmax$) and phase angle ρ($0 \le \rho \le 360^{\circ}$), at the power frequency, in series with the line via a transformer. The transmission line current flows through the series voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal, that is the terminal of the coupling transformer, is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter. The basic function of the inverter connected in parallel (inverter 1) is to supply or absorb the real power demanded by the inverter connected in series to the ac system (inverter 2), at the common dc link. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can 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 inverter 1 and back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by inverter 2 and therefore it does not flow through the line. Thus, inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by inverter 2.

G. Distributed power flow controller (DPFC)

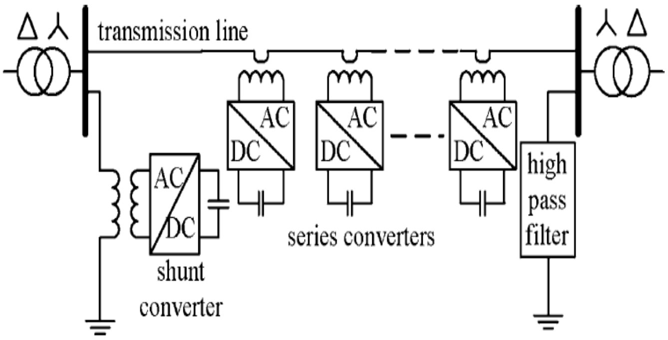

Fig 11: Distributed power flow controller (DPFC)

DPFC is a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig 11.The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [18].

In comparison with UPFC, the main advantage offered by DPFC is eliminating the huge DC-link and instate using 3rdharmonic current to active power exchange.Within the DPFC, the transmission line is used as a connection between the DC terminal of shunt converter and the AC terminal of series converters, instead of direct connection using DC-link for power exchange between converters. The method of power exchange in DPFC is based on power theory of non-sinusoidal components [9]. Based on Fourier series, a non-sinusoidal voltage or current can be presented as the sum of sinusoidal components at different frequencies. The product of voltage and current components provides the active power. Since the integral of some terms with different frequencies are zero, so the active power equation is as follow:

$$P=\sum_{i=1}^{\alpha} Vi * Ii\ Cos\phi i \qquad (5)$$

Where Vi and Ii are the voltage and current at the ith harmonic, respectively, and ϕi is the angle between the voltage and current at the same frequency. Equation (3) expresses the active powers at different frequency components are independent. Based on this fact, a shunt converter in DPFC can absorb the active power in one frequency and generates output power in another frequency.

The DPFC in comparison with UPFC has some advantages, as follows:

• High Control Capability - The DPFC similar to UPFC, can control all parameters of transmission network, such as line impedance, transmission angle, and bus voltage magnitude.

• High Reliability - The series converters redundancy increases the DPFC reliability during converters operation. It means, if one of series converters fails, the others can continue to work.

• Low Cost - The single-phase series converters rating are lower than one three-phase converter. Furthermore, the series converters do not need any high voltage isolation in transmission line connecting; single-turn transformers can be used to hang the series converters.

V. CONCLUSION

Wind energy has the ability to provide cheap and clean electric power. Wind energy is one of the fastest growing renewable energy technologies in the world. The variation of output power with the variation of wind can cause significant power quality issues, even in a network that is connected to a weak grid, with dynamic and nonlinear loads. It is found that; when the FACTS devices is connected to the wind system introduce a significant enhancement to the network operation.

REFERENCES

[1] J. Manel, “Power electronic system for grid integration of renewable energy source: A survey,” IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1014, 2006, Carrasco.

[2] S.W.Mohod, M.V.Aware,“ Power quality issues & its mitigation technique in wind generation, ”Proc. of IEEE Int. Conf.on Harmonics and Quality of Power (ICHQP) , pp. 1-6, Sept. 2008.

[3]IEC-61400-21 Ed. 2.0 (2008). Wind turbine generator systems. Part 21: Power quality requirements for grid connected wind turbines.

[4]Emanuel.H,Schellschmidt.M, Wachtel.S,Adloff.S, "Power quality measurements of wind energy converters with full-scale converter according to IEC 61400-21"10th International Conference on Electrical Power Quality and Utilisation, September 2009.

[5]A. Larsson, "Power Quality of Wind Turbine Generating Systems and their Interaction with the Grid," Department of Electric Power Engineering, Chalmers University of Technology, Goteborg, Sweden, Tech. Rep. No. 4R, 1997.

[6] Abrantes.A "Overview of power quality aspects in wind generation" North American Power Symposium (NAPS), 2012.

[7] R. Grünbaum, M. Noroozian and B. Thorvaldsson,“FACTS – Powerful Systems for Flexible Power Transmission”, ABB Review, May 1999, pp. 4-17.

[8] Narain Hingorani & L. Gyugi, Understanding FACTS, Concepts and Technology of Flexible AC ransmission Systems, IEEE Press, 2000.

[9] Information materials, Power Transmission and Distribution, Discover the World of FACTS Technology, Technical Compendium, SIEMENS AG Power Transmission and Distribution High Voltage Division, No. E50001-U131-A99-X-7600

[10]Information materials: ABB STATCOM For flexibility in power systems, ABB Power Systems AB, A02-0165E, acquired on: July 2010.

[11] S. W. Mohod and M. V. Aware, “A STATCOM control scheme for grid connected wind energy system for power quality improvement,” IEEE, System Journal,vol.2,issue 3,pp.346-352,Sept.2010.

[12] L. Gyugyi, C. D. Schauder, and K. K. Sen, “Static synchronous series compensator: a solid-state approach to the series compensation of transmission lines,” IEEE Trans. Power Delivery, vol. 12, no. 1, Jan.1997, pp. 406-417.

[13] L. Morán, P. Ziogas, G. Joos, “Analysis and Design of a Synchronous Solid-State VAR Compensator,” IEEE Trans.Industry Applications, vol. IA-25, No.4, pp. 598-608, July/August 1989.

[14] Neil H. Woodley, “Field Experience With Dynamic Voltage Restorer Systems”, IEEE Power Engineering Society Winter Meeting 2000, Singapore.

[15] Saha, Tapan K. and Nguyen, P. T. (2004) Dynamic Voltage Restorer Against Balanced and Unbalanced Voltage Sags: Modelling and Simulation, IEEE Power Engineering Society General Meeting, 6-10 June, 2004, Denver, Colorado, USA.

[16] X. Wei, J. H. Chow, B. Fardanesh, and Abdel-Aty Edris,“A Common Modeling Framework of Voltage-Sourced Converters for Load Flow, Sensitivity, and Dispatch Analysis”, IEEE Transactions on Power Systems, Vol. 19,No. 2, May 2004, pp. 934-941.

[17]L.Gyugi,T.R.Reitman,A.Edris,C.D.Schauder,D.R Torgerson,S.L Williams "The Unified Power Flow Controller: A New Approach To Power Transmission Control" IEEE Transaction on Power Delivery,Vol.10,No.2 April 1995.

[18] Zhihui Yuan, Sjoerd W.H de Haan, Braham Frreira and Dalibor Cevoric “A FACTS Device: Distributed Power Flow Controller (DPFC)” IEEE Transaction on Power Electronics, vol.25, no.10,October 2010.

[19] M. G. Sugirtha and P. Latha, “Analysis of power quality problems in grid connected wind power plant,” Recent Advancements in Electrical, Electronics and Control Engineering (ICONRAEeCE), 2011 International Conference pages 19-24, 2011.