iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** X **Month of publication:** October 2015

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

A Survey on Power Quality Improvement of Multi Machine Systems Using FACTS Devices

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Abstract—The power quality plays a vital role in industries as well as transmitting the generating power to the utility it is necessary to minimize the power quality issues such as power losses , harmonics , power factor , reactive power flow through the transmission line etc…In this paper mainly concerned with the power quality improvement in a multi machine system using a FACTS based STATCOM device with an wind turbine(WT) is connected to the grid this is helps to maintain the voltage stability and also improvement in the power factor and harmonic reduction in the source and load side.
Keywords - FACTS, STATCOM, SVC, Wind energy, Multi-machine.

I. INTRODUCTION

During past decades there is no consideration about the power quality issues and at that time there is no usage of the power electronic devices but nowadays it plays a vital role due to its simplicity and flexibility mostly in industries they are preferred to use the Intelligent Electronic Devices(IED'S) because of this impact there is a possibility of harmonics are generated in power system network to avoid this problem many research workers found that by means of using the proper designed filter, it can be avoided and also depends on the type of load it will tends to change the load angle it affects the power factor. In distribution side one of the most important affect is a flow of the reactive power through the transmission line it affects the system performance and it reduces the efficiency of the system. Injection of the wind power into an electric grid affects the power quality. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. 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. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme STATIC COMPENSATOR (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity . Today, more than 28 000 wind generating turbine are successfully operating all over the world. In the fixedspeed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During the normal operation, wind turbine produces a continuous vari- able output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower-shadow and of control system in the power system. Thus, the network needs to manage for such fluctuations.

The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag ,swells ,flickers, harmonics etc. However the wind generator introduces distur- bances into the distribution network. One of the simple methods of running a wind generating system is to use the induction gen- erator connected directly to the grid system. The induction gen- erator has inherent advantages of cost effectiveness and robust- ness. However; induction generators require reactive power for magnetization .When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compen- sate the fluctuation generated by wind turbine. A STATCOM- based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. The proposed STATCOM control scheme forgrid connected wind energy generation for power quality improvement has following objectives[1].

Unity power factor at the source side.

Reactive power support only from STATCOM to wind Generator and Load.

Simple bang-bang controller for STATCOM to achieve fast dynamic response.

II. CONTROL SCHEME FOR STATCOM

A distribution system suffers from current as well as voltage related power quality (PQ) problems, which include poor power factor, distorted source current, and voltage disturbances A DSTATCOM, connected at the point of common coupling (PCC), has been utilized to mitigate both types of PQ problems .When operating in current control mode (CCM), it injects reactive and harmonic components of load currents to make source currents balanced, sinusoidal, and in phase with the PCC voltages. In voltage control mode(VCM),the DSTATCOM regulates PCC voltage at a reference value to protect critical loads from voltage disturbance such as sag , swell and unbalances [2]. Rolling mill and electric arc furnace (EAF) are typical impact loads with capacities from several to hundred MVA. The reactive power may step from zero to their ratings within one or two cycles. Such strong reactive power impulses cause voltage fluctuations and voltage flickers, which make negative influences on the active power delivery to the loads. Poor power quality might degrade product quality, reduce equipment lifetime and increase power loss. To restrain the voltage fluctuations, Static Var Compensator (SVC) were developed in the late 1960s to provide dynamic reactive power compensation for large EAFs. Since SVC is a kind of thyristor based passive compensator, its response time is generally beyond one cycle and its reactive power output directly depends on the Point-of-Common-Coupling (PCC) voltage. Therefore, the dynamic performance of SVC has a ceiling in principle. Still, the control strategy of SVC may be improved to some extent [3].

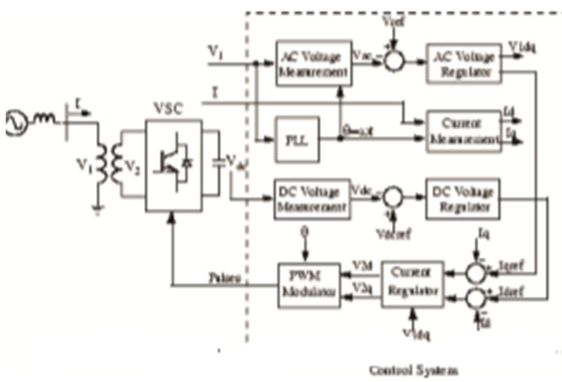

Fig 1.control scheme for a STATCOM [3].

The control system consists of:

A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the three-phase primary voltage V1. The output of the PLL is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltage and currents (labelled as Vd, Vq or Id, Iq on the diagram).

Measurement systems measuring the d and q components of AC positive sequence voltage and currents to be controlled as well as the DC voltage Vdc.

An outer regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator is the reference current Iqref for the current regulator (Iq = current in quadrature with voltage which controls reactive power flow). The output of the DC voltage regulator is the reference current Idref for the current regulator (Id = current in phase with voltage which controls active power flow).

An inner current regulation loop consisting of a current regulator. The current regulatory controls the magnitude and phase of the voltage generated by the PWM converter (V2d V2q)from the Idref and Iqref reference currents produced respectively by the DC voltage regulator and the AC voltage regulator (in voltage control mode). The current regulator is assisted by a feed forward type regulator which predicts the V2 voltage output (V2d V2q) from the V1 measurement (V1d V1q) and the transformer leakage reactance[4].

In olden days they preferred to use the capacitor banks to suppress the reactive power flow along the grid but nowadays people they are thinking to use STATCOM due to its merit by using capacitor banks it can't withstand huge inrush current in the grid it tends to fault in the banks but in the STATCOM depend on the load demand it can inject or suppress the reactive power.

III. THREE MACHINE NINE BUS SYSTEM

In many of the case studies of power quality they implemented only in the single machine system with respect to grid based wind energy system the main aim of this three machine nine bus system is to study the power stability under different faults. The wind turbine (WT) is connected to the system is to achieve the voltage stability with respect to the point of common coupling. Consider the nonlinear load i,e loads having constant impedance load based on this the power factor tends to vary, by connecting STATCOM at any of the buses with respect to PCC it may suppress the reactive power or it injects the reactive power based on the requirements To control the reactive power by means of maintaining all the bus voltages same.

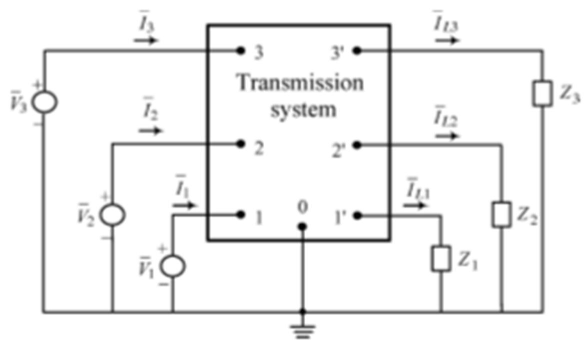

Fig 2. Multimachine system with constant impedance load.

IV. POWER SYSTEM STABILITY

It will actuate both generator and transmission network voltage regulators; the generator speed variations will actuate prime mover governors; and the voltage and frequency variations will affect the system loads to varying degrees depending on Power system stability is the ability of the system, for a given initial operating condition, to regain a normal state of equilibrium after being subjected to a disturbance. Stability is a condition of equilibrium between opposing forces; instability results when a disturbance leads to a sustained imbalance between the opposing forces.

The response of the power system to a disturbance may involve much of the equipment. For instance, a fault on a critical element followed by its isolation by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds; the voltage variations their individual characteristics. Further, devices used to protect individual equipment may respond to variations in system variables and thereby affect the power system performance. A typical modern power system is thus a very high-order multivariable process whose dynamic performance is influenced by a wide array of devices with different response rates and characteristics. Hence, instability in a power system may occur in many different ways depending on the system topology, operating mode, and the form of the disturbance.[5]. In order to determine the stability status of the power system for each contingency of any disturbance occurs in power system, many stability studies are defined. Power system stability analysis may involve the calculation of Critical Clearing time (CCT) for a given fault which is defined as the maximum allowable value of the clearing time for which the system remains to be stable. The power system shall remain stable if the fault is cleared within this time. However, if the fault is cleared after the CCT, the power system is most likely to become unstable. Thus, CCT estimation is an important task in the transient stability analysis for a given contingency. In this paper for the Transient Stability Analysis, an IEEE 9 Bus system is considered.

Critical clearing time (CCT) in a way measures the power systems Transient stability. It denotes the secure and safe time margin for clearing the contingency, usually three-phase ground-fault. The larger the value of CCT, the power system has ample time to clear the contingency. CCT depends on generator inertias, line impedances, grid topology, and power systems operating conditions, fault type and location. For a single machine infinite bus power system, CCT calculation is straightforward. While for the case of multi-

Volume 3 Issue X, October 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

machine power systems, CCT is always obtained by repeating time-domain simulations, and hence the evaluation of CCT can only be done off-line The Load Flow study and Transient Stability study is discussed and performed for the IEEE-9 Bus test system simulated on ETAP 7.5.1[6].

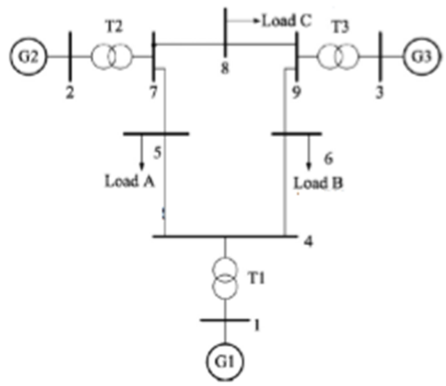

Fig 3.Three machine nine bus system.

The multi machine system was mainly concerned to study the system stability under various load condition depends on the load demand stability of the power system network varies at that time trip the load to maintain the voltage stability[7],by means of using facts based devices like shunt reactor, shunt capacitor, series capacitor it helps to improve the voltage stability of the system.

A. Shunt Reactors

Used to compensate the undesirable voltage effects associated with line capacitance limit voltage rise on open circuit or light load Shunt compensation with reactors increases effective Z_C reduces the effective natural load , i.e., voltage at which flat voltage profile is achieved They are connected either directly to the lines at the ends, or to transformer tertiary windings; conveniently switched as var requirements vary line reactors assist in limiting switching surges In very long lines, at least some reactors are required to be connected to lines.

B. Shunt Capacitors

Used in transmission system to compensate for I^2X losses and connected either directly to H.V. bus or to tertiary winding of transformers. Normally distributed throughout the system so as to minimize losses and voltage drops. Usually switched: a convenient means of controlling voltage Shunt capacitor compensation of transmission lines in effect decreases Z_C increases θ, i.e., electrical length Advantages: low cost and flexibility of installation and operating Disadvantages: Q output is proportional to square of the voltage; hence Q output reduced at low voltages Shunt capacitors are used extensively in the power factor correction and feeder voltage control.

C. Series Capacitors

Connected in series with the line used to reduce effective inductive reactance of line increases maximum power reduces I^2X loss series capacitive compensation in effect reduces both: characteristic impedance Z_C, and electrical length θ Reactive power produced increases with increasing power transfer self regulating typical applications improve power transfer compatibility alter load division among parallel lines voltage regulation.

V. STATCOM PRINCIPLE

The Static Synchronous Compensator is a shunt-connected reactive power compensation device that is capable of generating and/or absorbing reactive power at a given bus location and in which the output can be varied .It consists of a step-down transformer with leakage reactance , a three phase voltage source converter (VSC), and a DC side-capacitor. The AC voltage difference across the interface transformer leakage reactance XT produces reactive power exchange between the STATCOM local bus and the power system bus at the point of shunt interface.

Volume 3 Issue X, October 2015
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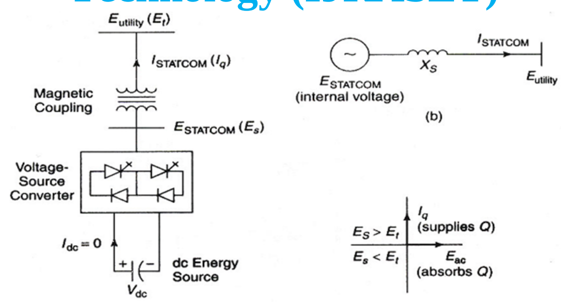

Fig 3.STATCOM principle diagram

The exchange of reactive Power Can be controlled by varying the amplitude of Es.If Es>Et, the reactive power flow from the VSC STATCOM to AC system (Capacitive Operation). If Es<Et, the reactive power flow from the AC System Bus to the Converter (Inductive Operation).If Es = Et, STATCOM is (floating non-active state) only P small flow. The net instantaneous power at the ac output terminals must always be equal to the net instantaneous power at dc-input terminals by neglecting switching losses .The converter simply interconnects the three phase terminals so that the reactive output phase currents can flow freely among them .Although the reactive current is generated by the action of the solid state switches. The capacitor is still needed to provide a circulating current path as well as act as voltage source storage .

VI. DFIG BASED WIND GENERATOR

DOUBLY-FED induction generator (DFIG) is, currently, the most employed wind generator due to its several merits. One of the advantages is the higher efficiency compared to a direct-drive wind power generation system with full-scale power converters since only about 20% of power flowing through power converter and the rest through stator without power electronics. Another advantage of a wind DFIG is the capability of decoupling control of active power and reactive power for better grid integration. However, by connecting stator windings directly to the power grid, a wind DFIG is extremely sensitive to grid faults. Moreover, wind energy is a kind of stochastic energy, implying that the output of OWF varies in a certain range due to unstable wind characteristic. Therefore, the operating point of the power system changes from time to time when the wind power is integrated with the power system. Several published papers have discussed how to reduce negative influence DFIG-based wind farms [7]–[11]. In [7], DFIG-based OWF connected to a power grid through a line-commutated high voltage direct current (HVDC) with a damping controller located at the rectifier current regulator of the HVDC link was proposed to contribute adequate damping to the OWF under various wind speeds and different disturbance conditions. But this control scheme was only suitable for the systems having a long distance from OWFs to onshore grids. In[8],a variable frequency transformer(VFT) was proposed to smooth the fluctuating active power generated by the OWF sent to the power grid and improve the damping of the OWF. These papers, however, just considered a power grid as an infinite bus that is not a practical power system. To study the performance of a practical power system, a multi-machine power system is generally employed to replace the single-machine infinite bus (SMIB) equivalent model. In [9], a DFIG-based wind power plant (WPP) was connected to a three-machine nine-bus system to compare voltage stability of the system at a point of common coupling when the system was with and without the WPP. The dynamic performance of DFIG-based wind turbines connected to multi-machine systems under three different configurations was presented in [10]. A new control strategy for improving fault ride-through capability of wind farms connected to a multi-machine power system was proposed in [11], while a small series dynamic braking resistor was located at the stator circuit of the DFIG along with a DC-chopper braking resistor. Especially, in- crease of wind-power penetration could lead to the problem of sudden disconnection of considerable amount of power generation in case of a transient fault occurred in the system, causing the system to be unstable from an otherwise harmless fault situation. In this case, a static synchronous compensator (STATCOM) is one of the good candidates for dynamic compensation of reactive power when the voltage is lower than the normal voltage range.
A STATCOM can generate more reactive power than other FACTS devices like static VAR compensator (SVC). This is due to the fact that the maximum capacitive power generated by a STATCOM decreases only linearly with the bus voltage but it drops off as square of the bus voltage for an SVC. In addition, the STATCOM normally exhibits a faster response as it has no significant time delay associated with thyristor firing (in the order of 4 ms for an SVC) [12]. In [13], a STATCOM was connected at the point of common coupling (PCC) to maintain stable voltage and to improve the power quality by protecting DFIG-based wind farm

connected to a weak grid from going offline during and after disturbances. As proposed in [14], a new control strategy using a full-power wind permanent-magnet generator (PMG) with a STATCOM to provide reactive power compensation can be used to improve stability of transient voltage. In [15], performance of a PMG-based wind energy system employing a dynamic voltage regulator (DVR) was compared to one of the system employing a STATCOM. It is recommended to use a STATCOM in systems with large loads where reactive power consumption from the grid could cause serious effects on connected loads. Also in [16], a STATCOM with a fuzzy logic controller (FLC) was used to enhance power stability of a two-area four generator interconnected power system. Co-operating a PI controller and an FLC applied to improve dynamic and steady-state performance of a speed controller based interior permanent-magnet synchronous motor was proposed in [17]. Simulation and experimental results were demonstrated that the superior performance of the proposed hybrid control over conventional fixed gain PI controller.

The tuning of the scaling factors of fuzzy PID-type controller with other fuzzy systems used in the excitation control of a synchronous power generator connected to an infinite bus through a transmission line was proposed in [18]. It was found that PID and fuzzy controller combinations can produce a better quality control. For the purpose of improving the damping of the studied power system for grid integration of an OWF, this paper proposes a STATCOM connected to the interconnected bus of a DFIG-based OWF fed to a three-machine nine-bus system for compensating reactive power and maintaining the voltage at the connected bus. The main contribution of this study is the hybrid PID plus FLC considered as a new damping controller which is designed to damp out oscillations of the studied system.

The most important part of electric power system from the point of view of its consumers is power distribution systems. In the recent years, however, the advances in power electronics and signal processing have led to the widespread usage of power electronic equipments which generally draw non-sinusoidal currents from the source leading to presence of harmonic currents in the system. In addition to that, unbalanced distribution of highly reactive linear loads on different phases of the three-phase power distribution system leads to problems such as high reactive power burden, load unbalancing, poor power factor etc. Due to the non-ideal nature of transformers, conductors, feeders and bus-bars used for power transmission and distribution, the voltages in the distribution systems also experience power quality problems such as poor voltage regulation, harmonics, unbalance, flicker, sag and swell etc.

In addition to the above mentioned problems, the presence of unbalanced and non-sinusoidal currents in three-phase four- wire power distribution systems mainly used for supplying single-phase low voltage loads, leads to significant neutral current. The presence of unbalanced voltages, which is very common in power distribution systems, aggravates the situa- tion due to the presence of zero sequence voltage leading to direct presence of zero sequence current even due to linear loads. Power factors below unity due to the presence of harmonics and reactive load currents not only degrade the power quality but also require the utility to generate more than the minimum volt-amperes necessary to supply the real power (watts).In this paper, by analysing the voltages inside a Zig-Zag transformer a novel neutral current compensation scheme is proposed to ensure exact zero source neutral current in the presence of unbalanced utility voltages. Also, a reduced rating DSTATCOM controlled using instantaneous symmetrical components theory is used for load balancing in the presence of unbalanced voltages**[**19**]**. Improvement of power quality is the greater concern in advanced power system element, it is essential to congregate the need of energy by employ the renewable energy generating sources like pv, fuel cell, biomass, wind, etc and utilizing many more applications like grid interconnected systems, power quality improvement. The situations like harmonic, reactive power exchanging, power factor correction, balancing the load & so on, due to greater effect on highly susceptible loads are to be encouraged in power distribution system. To enhance these circumstances, custom power appliances are used to achieve high grid stability. In that CHB based D-STATCOM is a meticulous power appliance for enhancing harmonic distortions from high power semiconductor switching device, exchanging the both active & reactive power, defend the gird stability by implementing DG technology, to regulate the PQ issues **[**20**].**

VII. CONCLUSION

This survey analyzes the stability of the system with different types of load connected at various buses from this system and helps to differentiate at which bus the reactive power flow is high. Using this study, if the STATCOM is connected at that particular bus there is a possibility of attaining a stable power system network, thereby reducing the harmonics and improving the power factor. By connecting an efficient STATCOM at the bus with respect to point of common coupling wind turbine grid issues can be avoided.

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Volume 3 Issue X, October 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)