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A Review of Power Quality Improvement Using Istatcom (Improved Statcom) With DFIG

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***Abstract*-Along with the increasing of electricity load type and capacity, the problems of the power quality, especially reactive power and harmonic, are a serious threat to the safe operation of power grid. Static synchronous compensator (STATCOM), as an important member of the FACT, has been widely used as the state-of the-art dynamic shunt compensator for controlling reactive power in transmission and distribution. It has attracted an extensive attention in domestic and foreign scientific and engineering fields with excellent performances of its smooth reactive power regulation and fast dynamic characteristics. Comparing with the traditional synchronous condenser. Static var compensator SVC, STATCOM which has a small size, a faster speed, a wide operation range has a great advantage in performance and can effectively compensate the reactive power, suppress harmonic current and provide voltage support for transmission system, it will be more and more widely used. This paper introduces the background, application status, challenges and development trend of STATCOM, pointing out that with the development of new technology and new power electronic devices and STATCOM in distribution network, STATCOM will occupy a very important position in the grid.**

***Keywords*-Transmission networks, FACTS, proportional-integral control, STATCOM, reactive power compensation, voltage stability.**

I.INTRODUCTION

The New and Renewable Energy resources are proposed by Ministry of New and Renewable Energy sources and Energy Development agencies to balance the need for the energy in the forthcoming years. The exploitation and development of various forms of energy and making energy available at affordable rates is one of the major thrust areas. Conversion of energy resources, environmental protection and sustainable developments are the three major changes of the world.

One important issue is to satisfy the energy needs of people without causing rapid depletion of natural energy resources and degradation of the environment. Now-a-days wind energy has the most exploitable potential of renewable energy and has attracted great interests in recent years. Large wind farms have been installed or planned around the world and the power rating of the wind turbines are increasing.

Wind generator is the crucial equipment to use wind energy. Generation of electricity has emerged as the most important application of wind energy worldwide. The concept is simple; blowing wind rotates the blades of a turbine and causes electricity to be produced in generator unit. It is environmentally benign and does not emit greenhouse gases. Induction generators are more commonly used in Wind Energy Conversion Systems (WECS). An induction generator is an induction motor operating above its synchronous speed. Due to its simple construction the induction generator is well suited for many industrial co-generation applications.The growing complexity of the modern power systems is largely due to the day-to-day changes in the system configuration in order to meet the ever-escalating demand of electrical energy, through the process of installation of new units of generation, interconnectivity of the transmission lines, extra high voltage tie line etc. Some major issues for consideration in modern power system are:

- Reactive power compensation
- Problems pertaining to stability of voltage (voltage fluctuations) and
- Oscillations of power consequent to faults or sudden disturbances in the load.

Increasing reliability and efficiency of the existing systems is an additional challenge to the engineers today. Improved infrastructure is required for the existing power systems in order to facilitate effective utilization, superior control mechanism, reliability in operation and commercial profitability. Several available sophisticated control technologies today, largely account for this possibility of enhanced utilization and better control. FACTS controllers are being extensively employed using advanced technology devices for effective utilization of the existing power system and for increasing power system's dynamic performance and stability[1]-[4].

II.POWER QUALITY

The accomplishment of the goals of the industry becomes possible, because the industries today extensively explore the innovative technologies which have evolved into technological developments. Continuous production can be ensured only when production optimization and getting maximum profits with minimized production costs are the projected objectives.

The modern equipments for production and process operate at high efficiency and require stable, fault-free and uninterrupted supply of power of high quality during the production process for the successful operation and functioning of their machines. Absolute precision in designing such machines which are sensitive to the slightest variations in supply of power must be ensured. Such category includes adjustable speed drives, devices of automation and the components of power electronics. Any failure in providing the necessary output of quality power may at times result in a total shutting down of the industries which in turn might lead to enormous financial losses to the industry concerned[6-7], [8]. But the utility itself cannot be blamed all the time for the degraded quality. Often, it has been observed that the industries themselves are guilty of generating conditions from within, which disrupt the process.

For instance, we can perceive that most of the non-linear loads result in transients capable of affecting the very reliability of supply of power. Some deviant electrical conditions causing process disruption at the utility as well as the customer end include [9]:

- Sags in Voltage
- Outages of Phase
- Interruptions in Voltage
- Transients resulting out of lighting loads, switching of capacitor, non- linear loads, electronic switching control devices etc.
- Harmonics

The above irregularities may cause extensive damage to the industries in the form of the outcome of burn-out motors, data loss on volatile memories, faulty robotic motion, needless downtime, enhanced costs in maintenance and burning of core materials particularly in plastic industries, semiconductor, plants and paper mills etc. The proposed solutions to the cited anomalies are known respectively as, 'utility-based solutions' and 'customer-based solutions'. FACTS devices (Flexible AC Transmission Systems) can be considered along with Custom Power Devices, which depend on power electronic components of solid state, as the best illustrations of these varieties of solutions. Utility normally controls FACTS devices while the customer operates, maintains and controls the Custom Power Devices after their installation at the premises of the customer.

III.STATCOM

Operating principle: STATCOM is a FACTS device, Voltage Source Converter (VSC)-based device, having a voltage source behind a reactor. STATCOM regulates voltage by generating or absorbing reactive power. During low system voltages, it acts as STATCOM capacitive by generating reactive power.

During high system voltages, it acts as STATCOM inductive by absorbing reactive power. Variation in reactive power is handled by the VSC which is connected to the secondary of a coupling transformer. The active power capability of STATCOM is very less because the VSC using GTOs or IGBTs synthesizes only the voltage source from a DC capacitor. But if an energy storage device is connected across the DC capacitor STATCOMs active power capability can be increased [9-13]. The performance of STATCOM is similar to that of SVC but if the system voltage is at lower voltage regulation range, STATCOM is able to generate large amount of reactive power than that of the SVC. Also the response time is less while using STATCOM because of the VSC, no delay is associated with the firing of thyristors. A model of STATCOM is given in Fig. 1.

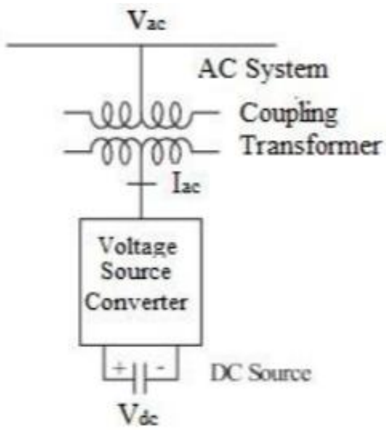

Fig.1STATCOM model.

The relation between the fundamental component of the converter ac voltage output and voltage across dc capacitor is given as

$$Vout = kVdc$$

Where k is coefficient that depends on the number of switching pulses, converter configuration and the converter controls. The fundamental component of the converter voltage output i.e. Vout is dependent on Vdc, can be controlled by varying the dc voltage across

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capacitor which can be done by varying the phase angle α of the converter switching. The direction of reactive power flow either from system to the coupling transformer or from coupling transformer to the system is decided by the difference between the converter voltage output and the ac system bus voltage. The dc capacitor is charged to a satisfactory dc voltage level by the real power supply into the converter.

During the course of each switching cycle, the capacitor is charged and discharged, but under steady state conditions, the average capacitor voltage remains unchanged. In steady state, the ac system power is used to replenish the switching losses. The ability of STATCOM to supply/absorb real power is determined by the size of dc capacitor and the active power switching losses. Whenever the dc capacitor and the losses are relatively small, the amount of real power transfer is also relatively small. This implies that the STATCOM's output ac current Iac, has to be approximately + 900 with respect to ac system voltage at its line terminals.

IV. TYPICAL APPLICATIONS OF STATCOM

Typical applications of STATCOM

- Effective voltage regulation and voltage control
- Reactive compensation of AC-to-DC converters and HVDC links
- Reduction of temporary over voltages
- Improvement of the capacity of steady-state power transfer
- Improvement of transient stability margin.
- Damping of power system oscillations
- Damping of the oscillations of sub synchronous power system
- Loading of individual phases in a balanced manner.
- Reduction of rapid voltage fluctuations (Flicker control)
- Improvement of Power quality
- Distribution system applications

STATCOM is defined as a Static synchronous generator operated as a shunt-connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage.

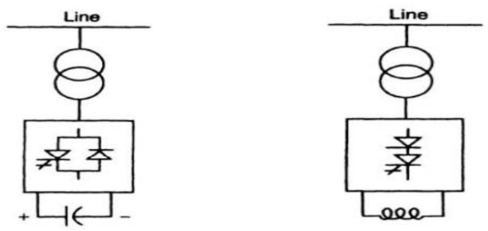

Fig. 2(a) STATCOM based on a voltage-sourced converter (b) STATCOM based on a current- sourced converter.

STATCOM is one of the most important FACTS controller used to improve the voltage stability. There are two types of STATCOM available: one is voltage sourced converter and other is current sourced converter. Figure a and Figure b show the STATCOM based on a voltage-sourced converter and STATCOM based on a current-sourced converter respectively. For voltage stability improvement voltage-sourced converters are more suitable and have preference from the overall cost point of view.

The AC output voltage in the voltage-sourced converter is controllable such that it is able to meet the required reactive current flow for any ac bus voltage. DC capacitor voltage is automatically adjusted as required to serve as a voltage source for the converter. The main objective of placing the STATCOM in power system is to increase the power transmission capability, with a given transmission network, without erecting the new transmission line by reducing the line loss and reactive power transfer.

Since STATCOM cannot generate or absorb real power (neglecting the relatively low internal losses of the SVC and assuming no energy storage for the STATCOM), the power transmission of the system is affected indirectly by voltage control. That is, the reactive output power (capacitive or inductive) of the STATCOM is varied to control the voltage at given terminals of the transmission network so as to maintain the desired power flow and voltage under steady state, dynamic, transient and contingency conditions.

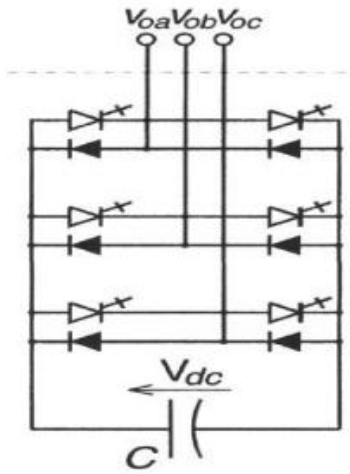

Fig 3 Voltage source converter used in STATCOM.

The STATCOM consists of a voltage-source inverter with a dc capacitor, (as shown in Figure 4.2) coupling transformer, and signal generation and control circuit. A multi level voltage source inverter is used in STATCOM to reduce the harmonic level of the output current. A 3-phase balanced voltage is generated by STATCOM on its terminal the magnitude and phase angle of the voltage can be controlled rapidly by using semiconductor switches.

STATCOM is the static equivalent of a synchronous compensator. Since it does not have any mechanical moving parts it can absorb or provide the reactive power in a short time. Further it offers better control flexibility in comparison with the synchronous machine.

It is used for both power systems static and dynamic compensation. The real and reactive power exchange between the network and STATCOM depends on voltage difference across the coupling transformer. The voltage magnitude of the bus at which the STATCOM connected is maintained through reactive power exchange. The DC voltage of the capacitor is controlled by real power exchange. Real power exchange is zero for steady state operation while neglecting the voltage source converter losses.

V. LITERATURE SURVEY

The literature survey presented reveals the utility of the FACTS devices to improve system performance. However, allocation of the unlimited FACTS devices to achieve one or two objectives without considering the cost of the devices cannot be justified. A cost effective objective function is proposed in this research work, for eliminating the problem and this is done by deciding the value of weight multiplier for each parameter in the objective function based on the real time cost of each parameter.

The literature survey also shows that most of the research carried out in the area of optimal placement of multiple type FACTS has utilized TCSC and SVC as multiple FACTS to improve system performance. Few papers utilized UPFC and SVC or STATCOM and TCSC combination for optimal placement of multiple type FACTS in power system.

The most important type of FACTS devices, namely, UPFC and STATCOM have been utilized in this thesis. The optimal placement and size of STATCOM, UPFC and combination of both STATCOM and UPFC are considered to improve voltage profile, obtain minimal total system loss, minimal reactive power transfer and maximum stability limit. The solution of stated optimization problem is obtained using PSO with cost effective objective function. The Basic Mat Lab program developed by Hadi Saadat (2002) to solve power flow analysis problem (Base case) is utilized in this research. Mat Lab program is developed for the proposed optimal placement of FACTS using PSO with cost effective objective function and tested in IEEE-30 bus system and Indian Utility - 66 bus system.

Liu Lingshun, Hu Yuwen and Huang Wenxin (2005) Suggested about the Optimal Design of Dual Stator Winding Induction Generator with Variable Speed based on Genetic Algorithm. The optimization theory of excited capacitors to minimize reactive power of control winding in the variable speed is discussed in this paper. Bansal R.C (2005) discussed about the comprehensive literature review on the important aspects of the SEIG such as the process of self-excitation and voltage buildup, modeling, steady state and transient analysis, reactive power control, and parallel operation.

MáriaImecs, Csaba Szabó, JánosJóbIncze (2007): Discussed about the Stator-Field-oriented Control of the Variable-excited Synchronous Machine. The paper deals with the modeling of the synchronous Machine with exciting and damper windings and its vector control system based on the stator-field orientation.

Soltani J, AbootorabiZarchi H, and Gh. R. Arab Markadeh (2009): Discussed the Stator-FluxOriented based encoderless direct torque control for synchronous reluctance machines using sliding mode approach.

Louze L et al (2009): Discussed a simple control structure based on the sliding mode algorithm for an isolated-loaded induction generator. Ali Ozturkand Kenan Dosoglu (2010) discussed the voltage stability of the bus load in various static and dynamic load systems that are fed by a wind farm. Paulo Fischer de Toledo (2005) proposed the analysis of a configuration consisting of a Wind Farm based on conventional fixed speed Induction Generator. The generator was magnetized with fixed capacitor banks for unit power factor operation during steady state conditions. The STATCOM was introduced to increase the transient stability conditions of the generator. Sharaf.M and Ismail H.Altas (2007) discussed the STATCOM controller for reactive Power compensation in distribution networks. This paper presented a multi loop dynamic error driven controller based on the d-q voltage and current tracking system.

Yuan-Rui Chen Norbert C. and Cheung JieWu(2004): Discussed about H∞ Robust Control of Permanent Magnet Linear Synchronous Motor in HighPerformance Motion System with Large Parametric Uncertainty. In this paper, the authors proposed to use an H∞ robust-controller to overcome the load uncertainty problem.

Tomonobu Senjyu (2007) Discussed about the Stabilization Control for Remote Power System by using H∞ Decentralized Controllers. This paper presented a methodology for controlling grid frequency and terminal bus voltage.

Kenichi Tanaka Toshihisa Funabashi, Tomonobu Senjyu (2009) Discussed about the balancing Control of PV Power and Dispersed Generators using H∞ Control. This paper proposed the control system to achieve balancing control and interconnection point power flow control by using fuel cell and ultra-capacitor based on H∞ control theory. Research in enhancement of voltage stability indicates a need to maintain stable voltage in wind power generation system for efficient operation.

Omidi et al (2009) have presented a technique to improve voltage stability margin of power system in contingency conditions based on reactive power generation management of shunt capacitors along with active and reactive power generation management of each unit. Chang et al (2009) have presented a procedure for application schemes for a coordinated control system of multiple FACTS controllers to enhance voltage stability.

Mehrdad Ahmadi Kamarposhti& Hamid Lesani (2010) have carried out studies about the application of STATCOM, TCSC, SSSC and UPFC for improving static voltage stability, and concluded that UPFC and STATCOM provide a better voltage profile and improved loadability.

HirotakaYeshida et al (2001) have proposed a method to expand the original PSO to handle a mixed-integer nonlinear optimization problem (MINLP) and determine an on-line Volt/VAR Control (VVC) strategy with continuous and discrete control variables.

Rashed et al (2007) have presented the application of GA and PSO techniques for finding out the optimal number, the optimal locations, and the optimal parameter settings of multiple TCSC devices to achieve maximum system loadability in the system with minimum installation cost of these devices.

Nagendra Palukuru et al (2014) have developed the steady state models of the Static VAR Compensators (SVC) and Thyristor Controlled Series Compensator (TCSC) with an integrated OPF program to investigate their effect on the voltage stability and proposed a Ê-network equivalent model with Optimal Power Flow (OPF) solution. Aarti Rai (2013) has applied the STATCOM and SVC in multi-machine power system to enhance the voltage stability and established that STATCOM gives better performance as compared to SVC.

Uma Mageswaran&Guna Sekhar (2013) have presented in their paper application of multiple STATCOM for reactive power control to reduce the voltage deviation and line losses.
Sang-Gyun Kang et al (2010) have presented a centralized control algorithm for power system performance in the Korean power system using FACTS devices with emphasis on voltage stability. Kalaivani& Kamaraj (2012) have proposed the application of PSO and GA to find the optimal location and rated value of SVC device to minimize the voltage stability index, total power loss, load voltage deviation, cost of generation and cost of FACTS devices, to improve voltage stability in the power system. A goal attainment method based on the GA has been presented to find optimum locations and capacity of FACTS devices (TCSCs and SVCs) in a power system using a multi-objective optimization function by Mohsen Gitizadeh& Mohsen Kalantar (2009).

EsmaeiliDahej et al (2012) have applied the hybrid binary GA and PSO algorithm in order to achieve optimal allocation of SVC and TCSC to improve the system performance by considering the costs of installation of these devices and operating cost of power system. A Coordinated Control of TCSC and SVC to improve Dynamic Stability of the Power System has been introduced by Rui Min et al (2013). The optimal location and size of SVC and STATCOM in an interconnected power system under N-1 contingency for voltage stability improvement using Cat Swarm Optimization (CSO) has been proposed by Naveen Kumar et al (2012).

Harmony search algorithm (HSA) and GA have been suggested by Parizad et al (2009) to optimally locate the UPFC, TCPAR and SVC to control voltage stability. Saoji& Vaidya (2013) have presented the Dynamic Programming approach based on Bellman's principle of optimality to find optimal location of SVC and TCSC devices for multi-objective function under normal and single line outage contingent condition. Jigar S. Sarda et al (2012) have presented an approach to find the optimal location of multi-types of FACTS devices using GA for improving loadability in power system.

Marcos Pereira & Luiz CeraZanetta (2013) have proposed a current based model of UPFC. This model has been developed by assuming the series converter as a variable. There is no much deference in the results obtained by current based model and power injection model of UPFC.

Enrique Acha& Behzad Kazemtabrizi (2013) have presented a new model of STATCOM for power flow solutions which allows a comprehensive representation of its ac and dc circuits. Effect of using new model of STATCOM tested by placing the devices at buses 10 and 24 in IEEE 30 bus system.

Prashant Kumar Tiwari &Yog Raj Sood (2013) have been proposed an efficient optimization technique for determining the optimal location and parameters of single TCSC in the power system. Only a single TCSC placement in large power system may not be sufficient to provide reactive power requirement of large power system.
Yan Xu et al (2013) have proposed a method for optimal placement of capacitor banks to distribution transformer for power loss reduction in radial distribution systems. A single objective has been considered to solve the optimal placement of capacitor. The coordination of wind generator's reactive power with other reactive sources for

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voltage stability enhancement has been presented by Seshadri Sravan Kumar et al (2014).

Hasan Mehrjerdi et al (2013) have discussed a coordinated control strategy to reduce the voltage deviation under load varying conditions using neighborhood compensation. If any region is getting a lower voltage due to over load and unable to meet the reactive power demand, the possibility of reactive power supply from the neighboring region is considered. But reactive power cannot be transmitted over a long distance due to line loss. So large power systems require a larger number of compensating devices for secure and economical operation.

Xuan Wei et al (2005) have established that in UPFC by circulating the power from the shunt Voltage Source Converter (VSC) to the series Voltage Source Converter, the transfer capability can be increased. In this present research work the power always transferred from the shunt VSC to the series VSC so as to get maximum power transfer capability and consequently voltage stability.

C. Boonmee, et.al (2009) Analysed the system performance of a PVgrid-connected system installed in Thailand with the help of a monitoring system. The monitored data are installed by acquisition software into a computer. This paper has given all details about system components, monitoring system and monitored data.

Michael E. Ropp and Sigifredo Gonzalez (2009) Developed and experimentally tested a MATLAB/Simulink model of a single-phase gridconnected PV inverter. The development of the PV array model, the integration of the MPPT with an averaged model of the power electronics and the Simulink implementation were described. It was experimentally demonstrated that the model works well in predicting the general behaviours of single-phase grid-connected PV systems. This paper has concluded with a discussion for a full gradient-based MPPT model, as opposed to a commonly used simplified MPPT model.

Marcelo Gradella Villalva, et. al (2009) proposed a method of modelling and simulation of photovoltaic arrays. The main objective was to find the parameters of the nonlinear I–V equation by adjusting the curve at three points: open circuit, maximum power and short circuit. With the parameters of the adjusted I–V equation, one can build a PV circuit model with any circuit simulator by using basic math blocks. In the first pages, the reader will find a tutorial on PV devices and will understand the parameters that compose the single-diode PV model. The modelling method was then introduced and presented in details. The model is validated with experimental data of commercial PV arrays.

Amirnaser Yazdani and Prajna Paramita Dash (2009) proposed a control strategy for a single-stage, three-phase, PV system that was connected to a distribution network. A modal/sensitivity analysis had been conducted on a linearized model of the overall system, to characterize dynamic properties of the system, to evaluate robustness of the controllers and to identify the nature of interactions between the PV system and the network/loads. The results of the modal analysis confirm that under the proposed control strategy, dynamics of the PV system were decoupled from those of the distribution network and therefore, the PV system did not destabilize the distribution network. It was also shown that the PV system dynamics were not influenced by those of the network.

H. ValizadehHaghi, et. al (2010) described an integration study of photovoltaics and wind turbines, distributed in a distribution network, based on the stochastic modelling and Archimedean copulas as a new efficient tool. A comprehensive case study for Davarzan area in Iran was presented after reviewing Iran's renewable energy status. This study has shown an application of the presented technique when large datasets, assuming 10-min interval between data points of PV, wind and load profiles, were involved where a deterministic study is not trivial.

A. Coronado-Mendoza, et. al (2011) described the usage of the dynamic phasors methodology to develop an extended model for the boost converter as a device to be integrated with a PV array and transfer the energy produced to the load. This method has needed less computational effort than other methodologies.

VI. CONCLUSION AND FUTURE WORK

In most of the literatures, various STATCOM control models have been discussed and also PI controller applications are included. The control parameters of the PI controller has to be adjusted for the optimal performance of STATCOM at a given or different operating points. An adaptive PI control model can be preferred, that can selfadjust the controller gain parameters dynamically under disturbances thereby the performance of the entire system always matches the desired response, regardless of the change of operating conditions. This work can be applicable under various operating conditions, such as different initial control gains, change of the transmission network, different load levels, consecutive disturbances and a severe disturbance. Future work can be carried with the investigation of multiple STATCOMs, because the interaction among different STATCOMs may affect each other. Also, the extension to other power system control problems can be explored.

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