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Mitigation of Power Quality Issues of Wind and Geothermal Power Generation System by using FACTS Devices

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Abstract: Renewable energy sources are alternative energy sources, can bring a new challenge when it is connected to the power grid system. As a promising alternative wind and geo-thermal is one of the significant sources of generation. When the wind and geo-thermal is connected to an electric grid it affects the power quality. There are many power quality issues pertaining when wind energy and geo-thermal is connected to the grid. For example reactive power, voltage sag, voltage swell, harmonics, flickers and electrical behavior of switching operation. In order to mitigate these issues, various techniques have been explained in this paper. In this proposed scheme a FACTS devices such as SVC, STATCOM, VSC, UPQC, and UPFC are commonly used to mitigate the power quality measurements. Consequently, with the development of the wind farms and geo-thermal power sources which are integrated into the grid, power quality could be better improved in the future. Recently, the most of wind conversion systems are equipped with a variable speed DFIG and geo-thermal power generation system equipped with high performance synchronous generators. The FACTS device control scheme for the grid connected wind and geo-thermal to improve the power quality standards is simulated by using MATLAB/SIMULINK environment. Results promise, and it seems that suggested idea is competitive with other renewable energy sources. Further studies are necessary to achieve more realistic results to start actual projects.

Keywords: power quality, Wind energy generation system and Geo-thermal power, FACTS device control and protection scheme, DFIG.

I.INTRODUCTION

Now a day’s power demand is increasing rapidly, due to the growth in population density and economic development in the world. Hence renewable energy resources must be developing in advance in order to meet the energy demand for increasing power utilization capacity. Wind power and geo thermal has becoming one of the leading renewable energy sources worldwide. The growth of wind power conversion technology and geo thermal power has been going on since 1970’s, and the rapid development has been seen from 1990’s. Most of the wind farms uses fixed speed wind turbine, its performance relies on the characteristics of mechanical sub circuits Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth’s surface, and the rotation of the earth. Wind energy systems convert this kinetic energy to more useful forms of power. Wind turbines transform the energy of the wind into mechanical power, which can be converted to electric power to generate electricity and Geothermal energy (“earth heat”) arises from the residual energy stored in the upper section of the earth’s thin crust after the formation of the earth, and from the continuing dynamism of the earth’s tectonic plates and crustal deformation. Heat stored in the earth crust can be used to generate electricity .Wind turbines can be used singly or in clusters called ‘wind farms’ Today, wind energy generating system and geo thermal power is connected into the power system to meet the consumers demand and to support the grid. However, the output power of wind generator is fluctuating and will effect operation of interconnected grid. Grid integration issues are a challenge to the expansion of wind power in some countries. The most common power quality issues provoke in grid connected system are, voltage sag, voltage swell ,flickers, harmonics, failure in voltage regulation, reactive power effects etc. are the power quality issues which are more harmful to wind generation and geo- thermal generation, transmission and distribution networks.

The devices used for mitigation of power quality problems are known as Customer Power Devices (CPDs). The generalized compensating devices are: Dynamic Voltage Regulator (DVR), Static VAR Compensator (SVC), and Static Synchronous Compensator (STATCOM), and Unified Power Quality Conditioner (UPQC), unified power flow

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controller (UPFC).For improving the power quality of wind and geo thermal power system a FACTS devices SVC, UPQC,UPFC based control technology has been proposed in this paper.

II. POWER QUALITY STANDARD ISSUES AND CONSEQUENCE

a) Voltage Variation: The voltage variation issue results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under: • Voltage Sag/Voltage Dips. • Voltage Swells. • Short Interruptions. • Long duration voltage variation. The voltage flicker issue describes dynamic variations in the network caused by wind turbine or by varying loads. Thus the power fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on grid strength, network impedance, and phase-angle and power factor of the wind turbines. It is defined as a fluctuation of voltage in a frequency 10–35 Hz. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly

b) Harmonics: The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution, as per the IEC61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

c) Reactive power effect: Certain situations in power system cause problems in reactive power flow which lead to system voltage collapse. In power systems, long lines with voltage uncontrolled buses at the receiving ends create major voltage problems during light load or heavy load conditions. In a power system, most of the parallel EHV networks are composed of radial transmission lines. Any loss of an EHV line in the network causes an enhancement in system reactance. Under certain conditions the increase in reactive power delivered by the line(s) to the load for a given drop in voltage, is less than the increase in reactive power required by the load for the same voltage drop. In such a case a small increase in load causes the system to reach a voltage unstable state. There may occur a disorganized combination of outage and maintenance schedule that may cause localized reactive power shortage leading to voltage control problems. Any attempt to import reactive power through long EHV lines will not be successful. Under this condition, the bulk system can suffer a considerable voltage drop.

III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT OF WTGS CONNECTED TO GRID

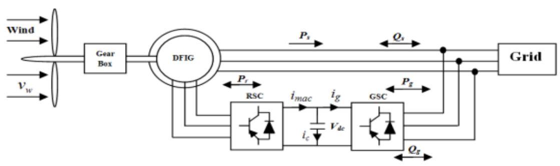

Fig: 1.DFIG control scheme with VSC

A typical configuration of a DFIG wind turbine is shown schematically in Figure 1. It uses a Wound Rotor Induction Generator (WRIG) with slip rings to take current into or out of the rotor winding and variable-speed operation is obtained by injecting a controlled voltage into rotor at slip frequency. The rotor winding is fed through a variable-frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSC) linked by a DC bus. The power converter decouples the network electrical frequency from the rotor mechanical frequency, enabling variable –speed operation for the wind turbine. The generator and converters are protected by voltage limits and an over current. A DFIG system can deliver power to the grid through the stator and rotor while the rotor can also absorb power, depending on the rotational speed of the generator.

a) **DFIG Control scheme**:

To guarantee stable operation and enable control of active and reactive power of the based feed-forward controller is developed dynamic model equations mentioned diagram is shown in Figure Fundamentally, controller is a vector controller, because reference frame in which the machine described is linked to the stator voltage space not to the stator or rotor flux vector, as is oriented controllers for drives.

Voltage control and reactive power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks, on an alternating current AC power system; voltage is controlled by managing production and absorption of reactive power. There are three reasons why it is necessary to

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manage reactive power and control voltage. First, both customer and power system equipment are designed to operate within a range of voltages usually within ±5% of the nominal voltage.

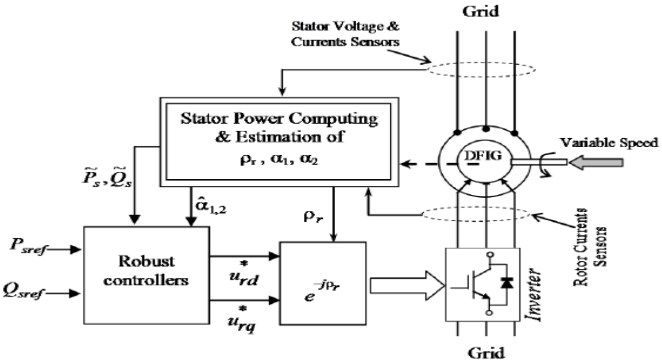

Fig: 2 DFIG angular control scheme

At low voltage, many types of equipment perform poorly, light bulbs provides less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at high voltages can damage equipment and shorten their lifetimes. Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transformed across a congested transmission interface. Reactive power flows must be minimized. Similarly, reactive power production can limit generators real power on the transmission system incurs real power losses. Both capacity and energy must be supplied to replace the losses.

b) UPQC SYSTEM FOR WTGS

The best protection for sensitive loads from sources with inadequate quality, is shunt-series connection i.e. unified power quality conditioner (UPQC) .Recent research efforts have been made towards utilizing unified power quality conditioner (UPQC) to solve almost all power quality problems for example voltage sag, voltage swell, voltage outage and over correction of power factor and unacceptable levels of harmonics in the current and voltage The basic configuration of UPQC is shown in figure The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance. Unified Power Quality Conditioner (UPQC) for non-linear and a voltage sensitive load has following facilities:

• It eliminates the harmonics in the supply current, thus improves utility current quality for nonlinear loads
• UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase, therefore, no additional power factor correction equipment is necessary.
• UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag.
• The voltage injected by UPQC to maintain the load end voltage at the desired value is taken from the same dc link, thus no additional dc link voltage support is required for the series compensator.

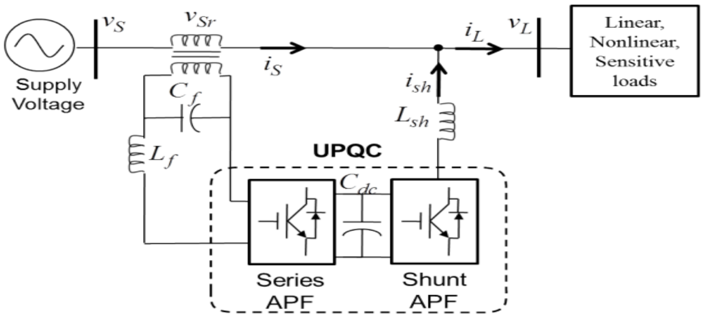

Fig: 3 UPQC systems for WTGS

V_S: Voltage at power supply V_{SR}: Series-APF for voltage compensation, V_L: Load voltage and I_{Sh}: Shunt-APF for current and VSR compensation.
Due to the voltage distortion, the system may contain negative phase sequence and harmonic components. In general, the source voltage in Figure can be expressed as:

$$Vs + V_{SR} = V_L$$

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c) DFIG WT S with UPQC

The reactive power improvement in wind farms can be achieved by UPQC device. In this work, the DFIG provided with UPQC unit Matlab/Simulink system. The dynamic compensation of voltage variations is performed by injecting voltage in series and active–reactive power in the (PCC) bus bar; this is accomplished by using an unified type compensator UPQC. The basic outline of this compensator; the busbars and impedances numbering is referred. The operation is based on the generation of three phase voltages, using electronic converters either voltage source type (VSI– Voltage Source Inverter) or current source type (CSI– Current Source Inverter). VSI converters are preferred because of lower DC link losses and faster response in the System than CSI. The shunt converter of UPQC is responsible for injecting current at PCC, while the series converter generates voltages between PCC and U1[11,12]. An important feature of this compensator is the operation of both VSI converters (series and shunt) sharing the same DC–bus, which enables the active power exchange between them. A typical configuration of a DFIG wind turbine is shown schematically in Figure 6. It uses a Wound Rotor Induction Generator (WRIG) with slip rings to take current into or out of the rotor winding and variable-speed operation is obtained by injecting a controllable voltage into the rotor at slip frequency.

The rotor winding is fed through a variable-frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSC) linked by a DC bus. The power converter decouples the network electrical frequency from the rotor mechanical frequency, enabling variable- speed operation of the wind turbine. The generator and converters are protected by voltage limits and an over- current 'crowbar'. A DFIG system can deliver power to the grid through the stator and rotor, while the rotor can also absorb power, depending on the rotational speed of the generator.

d) CONTROL MODELING OF DFIG WTS WITH UPQC

Reactive power and voltage compensation using series shunt (hybrid) topologies has been one of the effective techniques in improving the LVRT capability of the large scale of the wind farm level at the point of common coupling. The Unified Power Quality Conditioner (UPQC) demonstrates there may be a possible solution to the technical grid integration problems coming from the wind- driven FSIG. Fundamentally, UPQC which is an integration of series and shunt VSC have been commonly studied by many researchers as the ultimate device to improve voltage sag, voltage unbalance, harmonics, dynamic active and reactive power regulation and also the application of the UPQC systems to enhance low voltage ride-through capability of the FSIG-based wind turbine. The series VSC provides the lack of voltage to prevent over-speeding of the FSIG while the shunt VSC injects additional VAR required during the voltage reduction. However, the capital cost involved in the installation of this device is higher than any other solutions devices because of its use of two converters. A novel combination of resistive SFCL and UPQC illustrated in Fig.14, in order to improve power quality problems and fulfill grid code requirements. The SFCL not only reduce the volt-ampere rating of the UPQC, thereby reducing the installation cost, but also aid the. LVRT capability of the wind turbine and improves dynamic performance of the induction generator for additional support. Moreover, the feasibility of resistive SFCL incorporated in series with the dc-link inductance of the UPQC based on a current source converter is to limit excessive current in the event of the generator side fault (see Fig. 15) and increase voltage level at the generator terminal leading to compliance with international grid codes

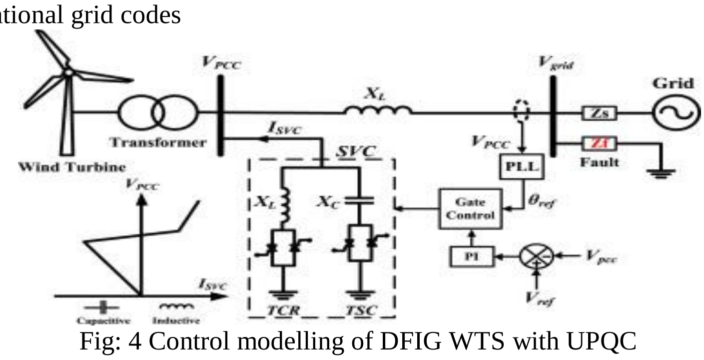

Fig: 4 Control modelling of DFIG WTS with UPQC

IV.TOPOLOGY FOR POWER QUALITY IMPROVEMENT OF GEOTHERMAL POWER CONNECTED TO GRID

A variety of energy conversion systems are used for the generation of geothermal power throughout the world. The single-flash steam plant is the mainstay of the geothermal power industry. In a single-flash power plant (Figure 2), the process consists of taking a two-phase mixture of liquid and steam that is produced by the well. The quality of this working fluid depends on the reservoir properties and the wellhead pressure. A steam separator is a device used to separate water from steam in a two-phase flow. This equipment creates a vortex that drives the heavy particles in the flow to one side due to centrifugal force This, in turn, produces a stream of steam that is used to drive the turbine.

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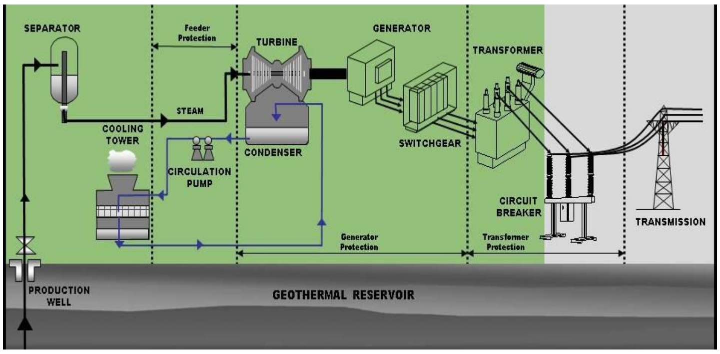

Fig: 5 geothermal power generation systems connected to grid

The turbine is the core unit of a geothermal power plant and the steam is the source that moves to the generator where the mechanical energy is transformed into electrical energy. This energy is created at a lower voltage level than the transmission voltage. Then a step-up transformer is used to inject the electrical energy into the transmission network. After developing the work on the turbine, the steam continues on to the condenser. The function of the condenser is to reduce the pressure at the turbine outlet and thus extract more energy from the steam flowing from the turbine. Based on this concept, this report will centre on the following pieces of electrical equipment: the generator, the unit transformer and the pumps. Also, it is important to note that the power system should operate in a safe manner at all times. Thus, it is necessary to provide a suitable protection system for all the equipments

a) **Control function for GTP through SCADA and Relay protection**

The protection system is active although the computer based control systems are not active and the respective equipment is operated in a local control mode. The protection relays used in these power plants for the electrical protection are modern numerical microprocessor-based relays. The relays have a serial connection for remote settings and indication of settings, measured values, event registers and disturbance records. For convenience, the trip groups have been divided into trip types to be able to define which piece of equipment the relevant protection functions will trip. These protection systems must trip different circuit breakers depending on the nature of the fault. Its number is largely dependent on the plant configuration the digital relays provide certain advantages, as they are usually programmed to execute the same functions on both relays; and this extra service is provided without adding any additional cost. Back up protection is also recommended to protect the main equipment in the power plant from the effects of faults that are not cleared because of failures within the normal protection scheme. The backup relaying can be applied to provide protection in the event of a failure at the power plant, on the transmission system or both

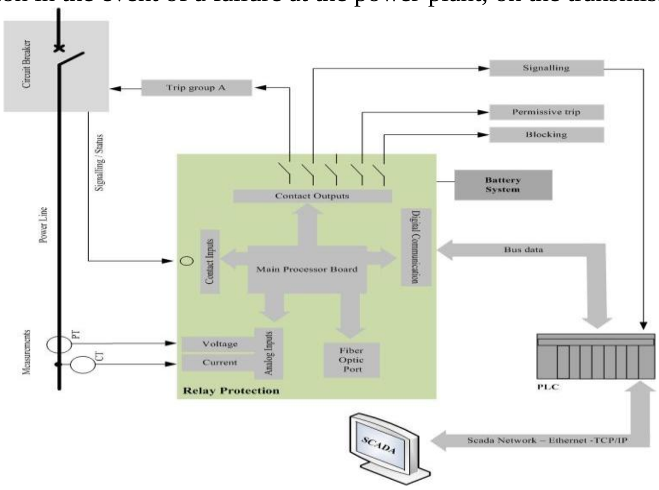

Fig: 6 GTP control and protection by SCADA and Relay system

V. POWER QUALITY IMPROVEMENT RESULT ANALYSIS OF WIND AND GEOTHERMAL POWER SYSTEM

a) SIMULATION MODEL OF WTGS

The wind turbine of the stand-alone hybrid system already presented in Fig. 2 [11], drives a multi-polar DFIG whose terminal voltage equations can be described by the following matrix expression

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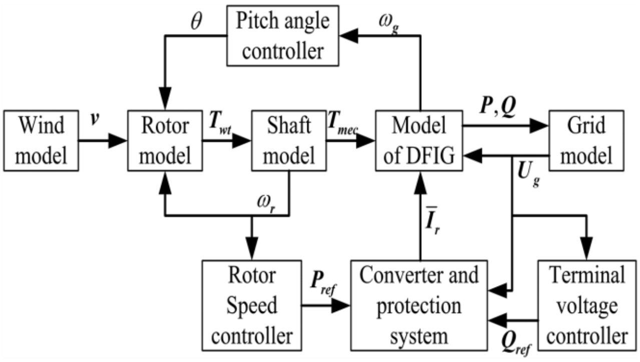

Fig:7 control modelling of WTGS

$V_{abc} = R_{sabc}\, i_{abc} + S\emptyset_{m\,abc}$ ---(1)

Where Rs is the stator phase winding resistance matrix, ϕm is the matrix of flux linked by the stator windings, and is the Laplace operator. Expressing this model in a rotor reference frame, (1) can be written as

$V_q = -R_s i_q - L_q S i_q - \omega_e L_q i_d + \omega_e \emptyset_m$ ----(2)

$V_d = -R_s i_d - L_d S i_d - \omega_e L_d i_q$ -----(3)

$T_e = \frac{3P(\emptyset_m i_q + (L_d - L_q) i_q i_d)}{4}$ -------(4)

Where L_q and L_d are the stator inductances in the d-q axes, ω_e=P ωm/2 is the electrical angular speed, and the number of poles. As it is shown in Fig. 2, the DFIG is linked to the dc bus through a diode bridge rectifier and a dc/dc converter. This configuration presents to the DFIG terminals a pure active power load whose value can be modified through the duty cycle (δ) of the converter. All controls of the hybrid distributed generation are conducted by the inverter control, not only in normal state but also in case of occurring of disturbances such as sags or swells; the wind generator performs only a role of maintaining the dcLink voltage in constant set point. Moreover, when any even happen in the distribution system, the DFIG Supplies power required from the local load through the shunt inverter

$i_q = -\frac{R_s}{L} i_q - \omega_e i_d + \frac{\omega_e \emptyset_m}{L} - \frac{\pi V_b i_q U_x}{3L\sqrt{3(i_q^2+i_d^2)}}$ ------- (5)

$\frac{V_s i_q}{\sqrt{i_q^2 + i_d^2}} = -R_s i_q - L_q S i_q - \omega_e L_q i_d + \omega_e \emptyset_m$ -------- (6)

$i_d = -\frac{R_s}{L} i_d - \omega_e i_q - \frac{\pi V_b i_d U_x}{3L\sqrt{3(i_q^2+i_d^2)}}$ ---- (6.1)

Then, assuming a full bridge topology for the dc/dc converter, the relationship between the voltage on the dc bus terminals (V_b) and V_s can be described by the following expression:

$V_s = \frac{\pi V_b U_x}{3\sqrt{3}}$ ----- (7)

Where U_x is a simple function of the dc/dc converter duty cycle δ , given for this configuration by U_x = Ktr/δ, with Ktr the winding ratio of the transformer included in the dc/dc converter. Thus, replacing (7) in (6) and operating, the latter can be rewritten as

$i_q = -\frac{R_s}{L} i_q - \omega_e i_d + \frac{\omega_e \emptyset_m}{L} - \frac{\pi V_b i_q U_x}{3L\sqrt{3(i_q^2+i_d^2)}}$ ---- (8)

$i_d = -\frac{R_s}{L} i_d - \omega_e i_q - \frac{\pi V_b i_d U_x}{3L\sqrt{3(i_q^2+i_d^2)}}$ ------ (9)

Assuming an ideal static conversion, the current injected by the wind subsystem in the dc bus can be readily determined equating the input and output power of the dc/dc converter. As it was previously said, this paper deals with the regulation of the output power of the system by focusing in the control of the wind subsystem. The control design of the photovoltaic subsystem is not under consideration here, so its operation is represented by a variable but measurable current i_f injected in the dc bus. Similarly, assuming an ideal voltage inverter, the load demand can be referred to the dc side as a measurable output current i_L Therefore, the current across the battery bank can be written as

$$i_o = \frac{\pi\sqrt{i_q^2 + i_d^2 U_x}}{2\sqrt{3}} \quad \text{-----(10)}$$

$$i_b = \frac{\pi\sqrt{i_q^2 + i_d^2 U_x}}{2\sqrt{3}} + i_f - i_L \quad \text{-------(11)}$$

Where i_F and i_L are measurable currents, and thus, assumed to be known currents. To complete the dynamic model of the system, it is necessary to outline the mechanical dynamic equation of the wind subsystem. Neglecting the friction term, this equation is given by (12)

$$\dot{\omega}_e = \frac{P\,(T_t - T_e)}{2J} \quad \text{------ (12)}$$

where is the inertia of the rotating system and T_t is the turbine torque. Thus, replacing (4) in (12) and considering that in radial flux DFIGs it holds L_d=L_q=L_s =L, (12) can be rewritten as

$$\dot{\omega}_e = \frac{P\left(\frac{T\Phi_t - 3\Phi_m i_q}{4}\right)}{2J} \quad \text{------ (13)}$$

$$\dot{\omega}_e = \frac{P\,(T_t - T_e)}{2J}$$

Therefore, considering (8), (11), and (13), and modelling the battery bank as a voltage source E_b connected in series with a resistance R_b and a capacitance C_b , a complete nonlinear dynamical model of the hybrid system may be written as

$$\frac{V_s i_d}{\sqrt{i_q^2 + i_d^2}} = -R_s i_d - L_d S i_d - \omega_e L_d i_q \quad \text{------- (14)}$$

$$\dot{\omega}_e = \frac{P\,(T_t - T_e)}{2J} \quad \text{---------- (15)}$$

$$\dot{V_c} = \frac{1}{C_b}\left(\frac{\pi}{2\sqrt{3}}\sqrt{i_q^2 + i_d^2 U_x} + i_f - i_L\right) \quad \text{------(16)}$$

$$\dot{V_c} = \frac{1}{C_b}\left(\frac{\pi}{2\sqrt{3}}\sqrt{i_q^2 + i_d^2 U_x} + i_f - i_L\right) \quad \text{----(17)}$$

Where V_c is the voltage in the capacitor C_b , and the voltage on the dc bus terminals is given by (18)

$$V_b = E_b + V_c + \left(\frac{\pi}{2\sqrt{3}}\sqrt{i_q^2 + i_d^2 U_x} + i_f - i_L\right) R_b \quad \text{---(18)}$$

Fig. 4 shows in the torque shaft speed plane, the turbine torque (Tt) developed by a horizontal shaft turbine parameterized in terms of the wind speed (dashed line) and the generator torque (Te) curves parameterized in function of Vs in solid line. It is interesting to note that for a given constant voltage in the DFIG terminals, there exists a minimum shaft speed below which the wind subsystem cannot generate

$$\omega_{elim} = \frac{V_S}{\emptyset_m} = \frac{\pi V_b U_x}{3\sqrt{3\emptyset_m}} \quad \text{--------(19)}$$

This lower limit arises naturally from the analysis of the phasor diagram depicted in Fig. 3, since it cannot be built for speeds that induce E_f smaller than V_s . Its expression is obtained in through the steady state analysis of a similar topology, and can be written for the electrical angular speed as given in above equation

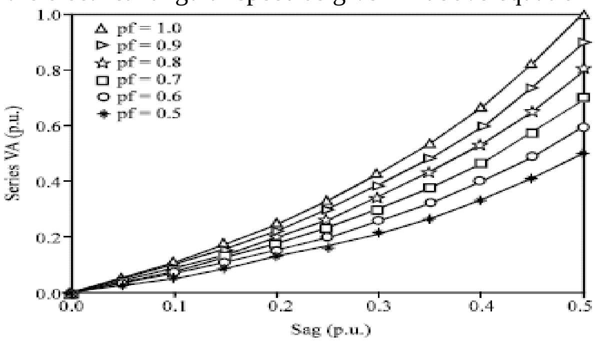

Fig: 8 VA loading of series inverter of UPQC for different power factor and p.u voltage sag values

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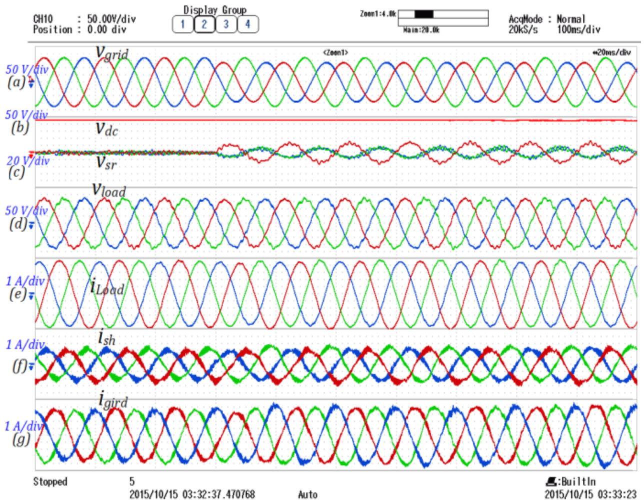

Fig: 9 Steady state performance of ten –switch of UPQC

b)Control and protection model analysis of Geo-thermal power

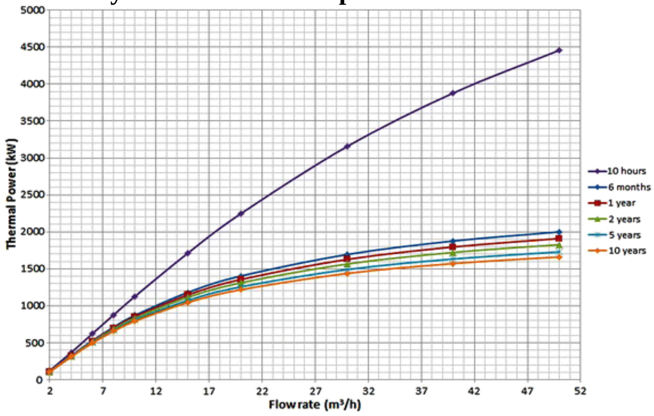

Fig: 10 GTP turbine control scheme

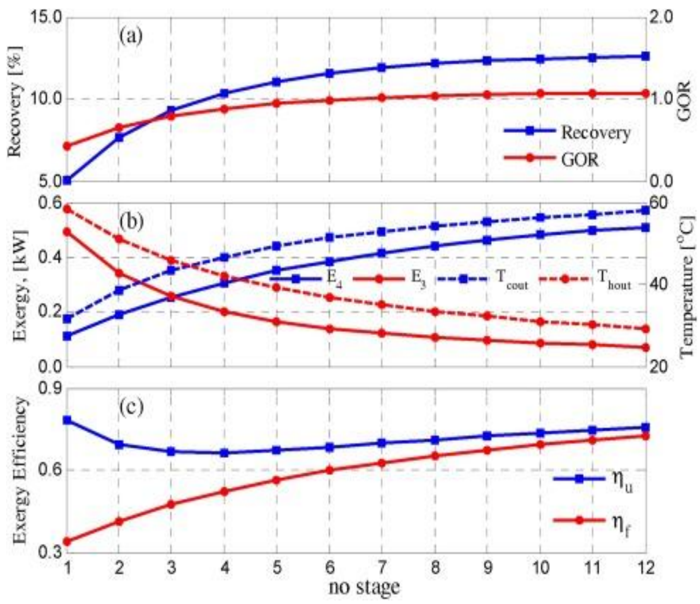

Fig: 11 GTP Temperature and Energy control analysis

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VI. CONCLUSION

In this paper we present the FACTS device (UPQC) -based control scheme for power quality improvement in grid connected wind generating system and with nonlinear load. The power quality issues and its consequences on the consumer and electric utility are presented. In power system transmission it is desirable to maintain the voltage magnitude, phase angle and line impedance. Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is applied. Modelling the system and studying the results have given an indication that UPFC are very useful when it comes to organize and maintain power system. The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with the transmission line. It was found that the UPFC regulates the voltage of the bus as well as regulates the active and reactive power of the buses and the lines within specified limits. Therefore the UPFC can fulfill functions of reactive shunt compensation, active and reactive series compensation and phase shifting. The UPFC controller mitigates the harmonic distortion that caused by the nonlinear load where all values of THD for voltage and current at all AC buses are decreased to values within allowable limits of IEEE standard The electrical protection system has a fundamental role in the reliability and security of the operation of a geothermal power plant. The protective relay is the control device of the protection system. Its main responsibility is to avoid the destruction of the interconnected equipment, which will impede the procurement of electrical energy. The system protection will isolate the faulty area in order to avoid the suspension of the generation of energy. In order to obtain high levels of availability in the operation of a geothermal power plant, special attention should be given to the protection scheme of the main equipment. The generator, transformer, and circulation and vacuum pumps are defined as the main equipment. The main equipment protection scheme should be designed with a backup. This is due to their high cost and lengthy installment; if they were ever to fail, it would cause the plant to become inactive for a long period of time.

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