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Fuzzy based STATCOM for Reactive Power Compensation in Grid Connected Wind Farm

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Abstract: *In modern electrical distribution systems harmonic distortions are created from a number of sources such as variable frequency drives, lighting, computers and nonlinear loads. Such harmonic distortions produce a variety of undesirable side effects ranging from poor power factor, motor failure to overloading of transformers and conductors. Now a days increasing number of renewable energy systems such as solar and wind turbine generators are connected to the existing power system in order to reduce the negative environmental impact of fossil fuel based conventional electric power generation schemes. But power quality of an electric grid is affected by the penetration of intermittent wind power into it. This paper analyses the harmonic distortion problem, which arises due to the integration of fixed speed induction generator based wind energy conversion system with electric grid which is already incorporated with nonlinear load. In the proposed scheme STATic COMpensator (STATCOM) is connected at Point of Common Coupling (PCC) to provide dynamic reactive power compensation required by grid connected wind farm for maintaining voltage within prescribed limits as well as harmonic mitigation endow with grid codes. Mamdani based fuzzy logic controller has been designed for controlling STATCOM. The viability and effectiveness of the proposed fuzzy control strategy in steady state is verified and proved by creating a simulation model of a small grid connected wind farm with nonlinear load in MATLAB/SIMULINK. It is clearly presented that STATCOM with FLC reduces Total Harmonic Distortion (THD) of source current in power system connected with fixed speed wind farm and nonlinear load.*
Keywords: *Fixed speed wind farm, fuzzy logic, STATCOM, Harmonic distortion, Reactive power compensation*

I. Introduction

Recently, renewable wind energy has become an important green electricity source to replace polluting and exhausting fossil fuel.But winds do not blow strongly enough to produce electricity all the time, power derived from wind energy is considered as intermittent only. Connecting induction generator based wind farm to the grid has an undesirable effect of reactive power absorption from grid, especially when wind velocity reduces. Reactive power management of grid connected wind farms is a major concern to maintain voltage stability of connected power system network [1].Wind power is now an undisputed pillar of the electricity supply in many parts of the world. 370 Gigawatt of wind power installed worldwide can now contribute close to 5 % of the global electricity demand. Several countries, including Denmark, Spain, Portugal, Ireland, the United Kingdom and Germany, have now reached 10% or more of their power coming from wind [2].Improvements in wind generation technologies will continue to encourage the use of wind energy in both the grid-connected and stand-alone systems. Owing to the random nature of the wind, the wind generators behave quite differently from the conventional generators. Therefore, it is important for the power system planners and engineers to carefully consider the reliability issues [3] associated with the wind energy sources.

The need to integrate renewable energy resources like wind energy into power system to make it possible to minimize the environmental impact of conventional power plants has been introduced by A. Sannino, et.al. The integration of wind energy into existing power system presents technical challenges and that requires consideration of voltage regulation, stability, power quality problems[4].Basics of wind energy conversion, and issues dealing with conversion of wind energy into electrical energy, integration with local grid, standalone generation and consumption, and hybrid power systems, were discussed by Bhadra S.N.et.al [5].Wind energy can be integrated with other energy sources such as solar energy or diesel generators to provide reliable and continuous of electrical energy supply.

Juan Manuel Carrasco, et.al [6] analyzed a new technology in the wind power market introducing variable-speed working conditions depending on the wind speed in order to optimize the energy captured from the wind. The advantages of variable-speed turbines are that their annual energy capture is about 5% greater than the fixed-speed technology, and that the active and reactive powers generated can be easily controlled. There is also less mechanical stress, and rapid power fluctuations are scarce because the rotor acts as a flywheel (storing energy in kinetic form). In general, no flicker problems occur with variable-speed turbines. Variable-speed turbines also allow the grid voltage to be controlled, as the reactive-power generation can be varied. As disadvantages, variable-speed wind turbines need a power converter that increases the component count and make the control more complex. The overall cost of the power electronics is about 7% of the whole wind turbine. Variable-speed operation can only be achieved by decoupling the electrical grid frequency and mechanical rotor frequency.

A sharadW.Mohodet.al [7] analyzed the traditional wind turbine which is equipped with induction generator. Induction Generator is preferred because they are inexpensive, rugged and requires little maintenance. Unfortunately induction generators require reactive power from the grid to operate. The interactions between wind turbine and power system network are important aspect of wind generation system.

When wind turbine is equipped with an induction generator and fixed capacitors are used for reactive compensation then the risk of self-excitation may occur during off grid operation. Thus the sensitive equipment may be subjected to over/under voltage, over/under frequency operation and other disadvantage of safety aspect.

Hingorani N.G.et.al [8] provides various merits and demerits of the shunt compensation devices. The importance of selecting an adequate size SVC and STATCOM is also discussed. This is an important issue as far as voltage stability is concerned, as these devices suffer voltage control problems at the limits. The impact of static synchronous compensator (STATCOM) to facilitate the integration of a large wind farm (WF) into a weak power system is studied by Chong Han, et.al [9].

Research by J.V.Milanovic and Y.Zhang [10] highlighted the benefits resulting from FACTS device installation include local mitigation of voltage sags and, to some extent mitigation over wider part or over the entire network. Fengquan Zhou et.al [11] proposed the detailed wind energy conversion system and the full order induction generator model to analyze the voltage stability in a weak connection wind farm. María Isabel et.al [12] proposed Strategies for extracting the three-phase reference currents for shunt active power filters and evaluated their performance under different source and load conditions. Various interfacing topologies to get wind turbine power within the norms specified in IEC 61400-21 were analyzed by S.W. Mohod, et.al [13].

M.F. Fariaset.al [14] analyzedVoltage sag conditions, whichmay lead to wind farm outage ininduction generator based wind farms; due to lack of reactive power to restore the internal magnetic flux once the fault is cleared. So, its behavior limits the low voltage ride–throughcapability in this type of generators.

Generally, PI controller is used to control the DC bus voltage. The PI controller based approach requires precise linear mathematical model which is difficult to obtain. Also, it fails to perform satisfactorily under parameter variations, non-linearity, and load disturbances [15]. Recently, fuzzy logic controller has generated a great deal of Interest in various applications and has been introduced in the power electronics field [16] .The advantages of fuzzy logic controllers over the conventional PI controller are that they do not need an accurate mathematical model, they can work with imprecise inputs, can handle nonlinearity, and may be more robust than the conventional PI controller.Sharadw.mahod et.al [17] proposed wind energy extraction scheme with batteries energy storage system with interface of current controlled mode for exchange of real and reactive power support to the load.

This paper presents the fuzzy basedSTATCOMfor power quality improvement in grid connected wind generating system and with nonlinear load. The operation of the control system developed for the STATCOM is simulated in MATLAB/SIMULINK for maintaining the power quality. First, the wind generation system is simulated with nonlinear load and no STATCOM control and the THD of source and load currents are obtained. Next, the control system in STATCOM is included in wind generation system and again simulated. Now, the THD values of source current is noted to check whether the control scheme in STATCOM has cancelled out the harmonics part and leave the sources current harmonic free. The THD value should obey the IEC norms.

II. Power Quality issues in grid connected windfarm

The aim of electric power system is to generate electrical energy and deliver it to the end-user equipment at an acceptable voltage for reasonable cost. The term power quality is applied to a wide variety of electromagnetic phenomena on the power system. The increasing application of electronic equipment and distributed generation has heightened the interest in power quality in recent years, and this has been accompanied by the development of a special terminology to describe the phenomena [18]. Any power problem manifested in voltage, current, or frequency deviations that result in failure or disoperation of customer equipment. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment."

All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems. Today wind-generating system is connected into the power system to meet the consumer's demand. The connection of wind turbine to the grid affects the electric grid power supply quality. Therefore it is necessary to maintain the power quality norm at the interface of the grid from the disruptive effect caused by wind turbine such as voltage fluctuation, switching operation, voltage dips, and reactive power & harmonics distortion on the grid.

Grid power quality problems that affect the WEG (Wind Electric Generator) are mainly concerned with the quality of voltage that is being supplied by the utility. The supply of "Good" quality voltage is utility responsibility. Some of the parameters (attributes) of voltage are 1) Voltage magnitude and its limits (the steady state & short time voltage must be within specified limits), 2) Frequency and its limits,3) Voltage Unbalance and its limits (the unbalance on the voltage must be within specifications),4) Voltage distortion & limits (the distortion/ harmonics on voltage must be within specified limits)The harmonic current drawn by the WEG (during motoring – soft starting) could itself be a problem, as these current harmonics would appear as voltage harmonics, as the fault levels at WEG terminals are quite low. Apart from this the system could itself have voltage harmonics created by non-linear loads connected elsewhere. Voltage harmonics cause over heating of transformer and generators. These also cause an increase in currents through shunt capacitors thus leading to failure of such capacitors. Harmonics in addition to the fundamental current cause additional losses in the cables, fuses and also the bus bars.

Some of the power quality aspects associated with WEG operation, that affect the grid power quality are as follows: 1) Reactive power consumption: Reactive power consumption in a wind farm is mainly due to the use of induction generators for energy conversion. The basic principle of Induction generators is that they consume reactive power (to set up the excitation / magnetic field) in order to generate real power. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. This reactive power consumption leads to increased Transmission and Distribution losses, poor voltage profile (and reduced voltage stability margins) over loading of Transmission and Distribution equipment and blocked capacity and over loading and reduction in life of Transmission and Distribution equipment.

2) Generation of current harmonics: Current harmonics are generated due to soft starting of induction generators during motoring mode. Due to the large generators concentrated at small geographic locations and large series impedance (low fault levels) associated with wind farms, these current harmonics get reflected ad voltage harmonics. This distorts the voltage on the line and affects all the consumers connected to the line.

Current harmonics also causes over heating of transformers and capacitors and could lead to premature failure of capacitors. The possibility of a resonance / harmonic amplification also exists, with dangers of catastrophic failures.

3) Injection of fluctuating power: Power (energy) in wind by nature is not steady and is characterized by annual, monthly, daily and hourly variations. This results in generation and injection of a power (current) that is fluctuating. This leads to operational problems, especially if the grids are weak and the portions of such fluctuating sources are more than certain limits (25%) [19].

III. Simulated Wind farm Topology

FACTS (Flexible AC Transmission Systems) controllers play a critical role in power systems to provide controlled, stable, reliable, economic and high quality power. Different kinds of highly versatile, effective FACTS controllers exist in emerging power systems. STATCOM is one of the second generation FACTS controller and based on non thyristor devices like Gate Turn Offs (GTOs) and Insulated Gate Bipolar Transistors (IGBTs).STATCOM is defined as a shunt connected reactive power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system [8].

In general, at the Point of Common Coupling STATCOM provides voltage support without using external reactors or capacitor banks. Power electronic based converters distort voltage and current waveforms in a power network and introduce power quality issues. STATCOM is also a power electronics converter in which staircase type wave is synthesized from its dc input voltage with appropriate combinations of converter switches. If STATCOM staircase ac line voltage approaches ideal sinusoidal waveform then harmonic contents will be greatly reduced. The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling as shown in Fig.1. The grid connected system consists of fixed speed induction generator based wind energy conversion system with STATCOM and nonlinear load.

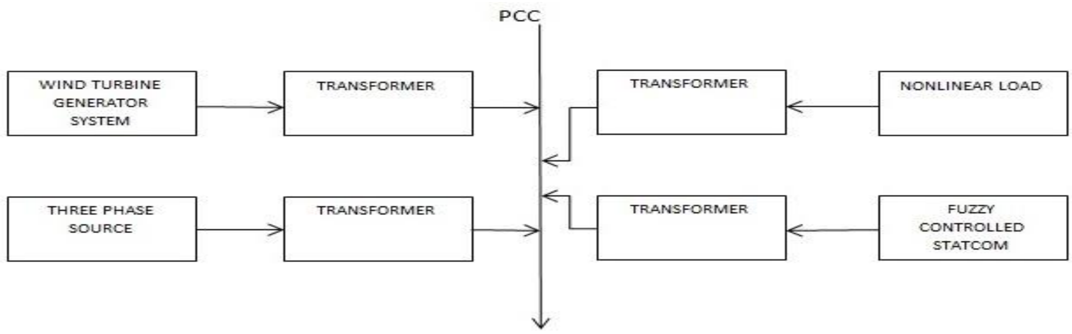

Fig.1.Simulated windfarm Topology

The wind turbine mechanical power Pm as a function of generator speed, for different wind speeds, and for initial blade pitch angle is illustrated in Fig.2.

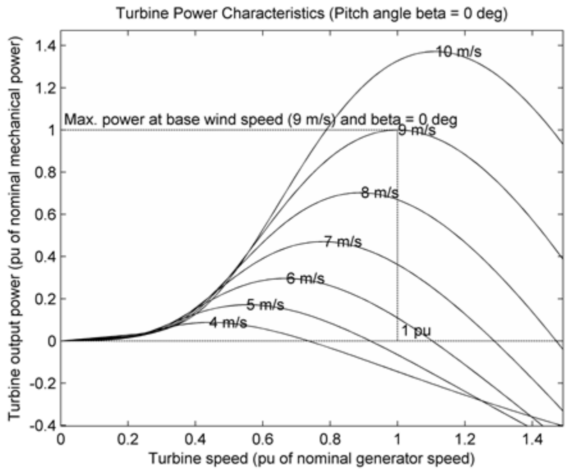

Fig.2.PowerCharacteristics of Wind Turbine

IV. Fuzzy Logic Controller

The concept of Fuzzy Logic Controller (FLC) was proposed by Professor Lotfi Zadeh in 1965, at first as a way of processing data by allowing partial set membership rather than crisp membership. Soon after, it was proven to be an excellent choice for many control system applications. Fuzzy control is based on a logical system called fuzzy logic. It is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays, Fuzzy logic Controllers (FLCs) has been introduced in various applications of power electronics. Comparing to the conventional PI controllers, FLCs do not need an accurate mathematical model and are more robust. FLCs can work with imprecise inputs, can handle nonlinearity. The general structure of a fuzzy logic control system is shown in Fig.3. The assumptions generally made in FLC are (1) The plant is observable and controllable and input output variables are available for observation and measurement or computation. (2)A solution exits not necessarily the optimum. (3) The controller is designed to the best of our knowledge.

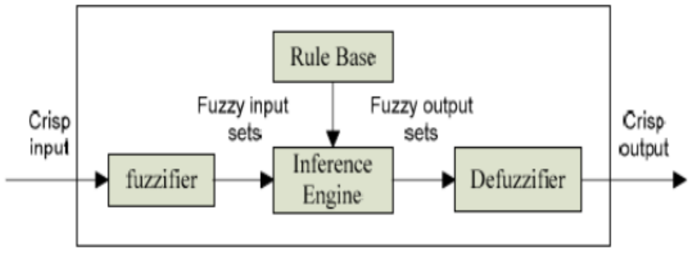

Fig.3.General architecture of fuzzy logic system (FLS)

The Mamdani type of FLC is used for the control STATCOM. Fig.4. shows the structure of control circuit.

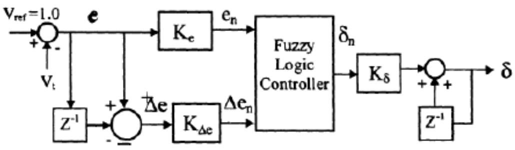

Fig.4. Control circuit for STATCOM

The fuzzy controller is characterized as follows: 1) Five fuzzy Membership Functions (MF) for input and output.2) Trapezoidal membership functions for simplicity.3) Fuzzification using continuous universe of discourse.4) implication using Mamdani's min operator.5) Defuzzification using the center of gravity method.

Table-1Fuzzy Rule Base

$I_{ref}\backslash I_f$	VL	L	N	H	VH
VL	OFF	OFF	ON	ON	ON
L	OFF	OFF	ON	ON	ON
N	ON	ON	OFF	OFF	0FF
H	ON	ON	OFF	OFF	OFF
VH	ON	ON	OFF	OFF	OFF

V. Simulation Results and Discussions

Fixed speed induction generator based wind energy conversion system is connected with an electric power grid which is having a nonlinear load. The operation of wind generation system is deliberated with a constant speed, pitch controlled turbine.

The performance of the system is studied and analyzed by switching on the STATCOM at time t=0.3 s. When STATCOM is switched on, it starts to inject current to fulfill reactive power demand as well as mitigate harmonic current. Variation of load current and source current are shown in Fig.5 (a) and 5(b) respectively.Fig.5(c) shows current generated from wind turbine induction generator at PCC.Current injected into the system by STATCOM is depicted in Fig 5(d).

In general, nonlinear elements connected with the power system introduces harmonic distortions because of the nature of drawing distorted current wave farm that contain harmonics. From the simulation results, it is observed that the source current on the grid is affected due to the effects of nonlinear load as well as penetration of intermittent wind power.

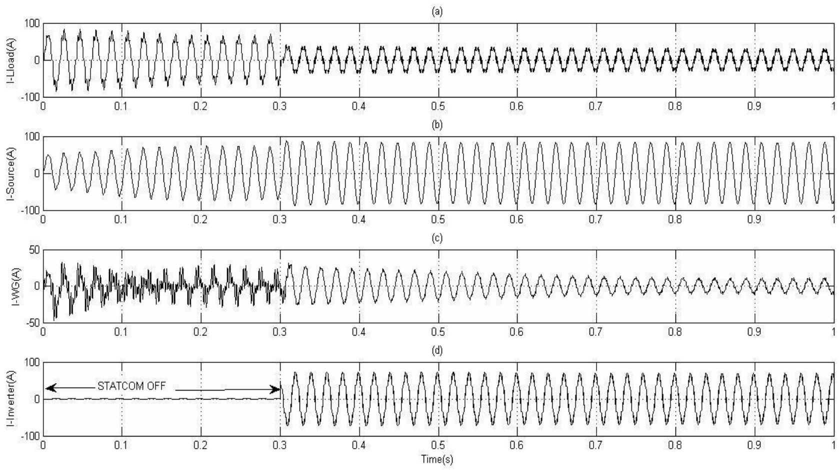

Fig.5. (a) Load Current. (b)Source Current. (c)Current from Wind turbine Induction Generator.(d) Inverter Injected Current

Analysis of the source current before and after STATCOM compensation is carried out.FFT analysis of source current waveform without STATCOM at PCC is given in Fig 6.In Fourier analysis of source current waveform it was found that THD of source current at PCC without STATCOM operation is 4.70% which is above the power quality standards.

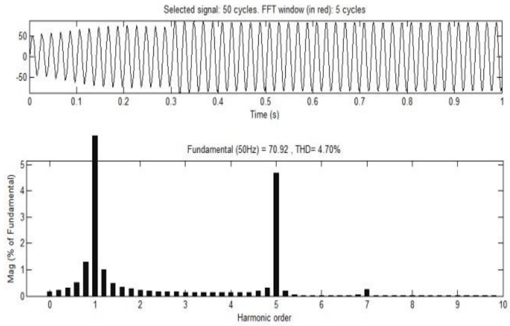

Fig.6.FFT of source current without STATCOM

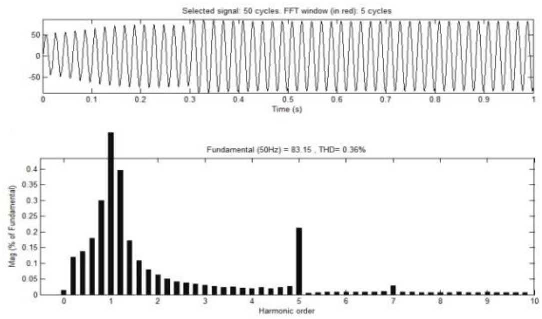

Fig.7.FFT of source current with STATCOM

Power quality improvement (i.e.) harmonic distortion reduction is observed at PCC when STATCOM is on as shown in Fig 7. THD is reduced considerably to 0.36% which is within norms prescribed by grid code.

VI. Conclusion

Fuzzy based STATCOM for reactive power compensation and harmonic mitigation in grid connected fixed speed wind power generation system with nonlinear load is analyzed in this paper. The fuzzy control scheme for STATCOM to maintain power quality is developed and simulated in MATLAB /SIMULINK. From the observation of simulation results it was found that STATCOM supports the reactive power demand for both wind generator and load at PCC of grid system and enhances utilization factor of transmission line. Also, a fuzzy logic controltechnique of STATCOM is proposed to identify reference currents and PWM to generate gating signals. These performances are related to the current reference quality. This method is very important because it allows harmonic current and reactive power compensation simultaneously. The simulation results assure that the regulation performance for the fuzzy controller is better compared to the PI controller .Simulation results showthat the fuzzy controller is robust against parameter variation and rule uncertainty. The current THD is reduced from 4.70% to 0.36% which confirms the good filtering quality of harmonic currents and a perfect compensation of reactive power which improves the power quality.

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