# ENHANCEMENT OF POWER QUALITY AND SAFE OPERATION OF DFIG BASED WIND TURBINE SYSTEM USING ANFIS CONTROLLER

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**Abstract- In this paper doubly fed induction generator (DFIG) based wind energy conversion system (WECS) integration with the grid is presented. DFIG facilitates a wide range of speed variations with constant frequency, due to its controllable excitation given to rotor through a back to back connection. DFIG has a better output profile compared to other generators due to its controllable input given to rotor separately. DFIG control has two controllers one is stator/grid side control (GSC) and another is the rotor side controller (RSC). UPFC provides fast acting reactive power compensation on the grid. The UPFC is controlled by the PWM signals generated by the fuzzy logic controller contribute to the enhancement of power quality. ANFIS can reduce deviations present in system response for a change in input wind speed, short grid faults and system parameter variation. Implemented ANFIS control has involved in grid side control and rotor side control, than these combinations gives better performance. The first part of this paper describes the improvement in power quality using fuzzy and the second part describes safe operation by overcoming fault in wind energy system. The system is modeled using MATLAB / Simulink software for the Fuzzy Logic Controller (FLC) and Adaptive Neuro-Fuzzy Inference System (ANFIS) implementation.**

***Keywords*** -Adaptive Neuro fuzzy inference system (ANFIS), FLC, Wind energy conversion system, Rotor side control, Grid side control and Doubly fed induction generator.

## I INTRODUCTION

In renewable energy sector wind Energy has been the major source in country. Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind power system is the fastest growing and most promising renewable energy resources among them due to both technically and economically viable [1]-[3]. Many applications of wind power can be found in a wide power range from a few kilowatts to several megawatts [4]-[5]. The wind power can be found in small scale off-grid standalone systems or large scale grid-connected wind farms. Due to lack of control on active and reactive power, this type of distributed generation causes problems in the interconnection system.

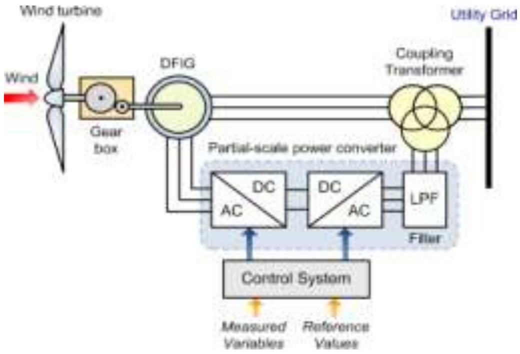
Throughout the 20th century parallel paths developed small wind plants suitable for farms or residences, and larger utility-scale wind generators that could be connected to electricity grids for remote use of power. The wind genetic phenomenon from many causes; atmospheric pressure, temperature difference and rotation force of earth. These are the reasons which produce the wind speed and power. Now a days, utilization of wind energy is increased due to clean, friendly for environment, free and reusable resource. Wind turbines convert the wind energy into electrical energy. Kinetic energy form of wind is converted into mechanical energy by using mechanical equipment for utilization[3] . However, there are many unsolved problems in wind energy.

The conventional controller as well as newly enhanced advanced controllers for horizontal, Variable – speed wind turbines proposed. Basically wind turbines are of two types one is fixed speed and the other one is a variable speed wind turbine. Among this variable speed wind turbine (VSWT) can facilitate a wide range of power generation. The doubly fed induction generator (DFIG) based wind farms have high efficiency and it is having a high fault ride through capability. The back-to-back conversion set was included in the design of DFIG based WECS in between the rotor of DFIG and grid. Due to variable speed wind turbine utilization, frequency is the effecting factor. This can be overcome by controlling the excitation of rotor by controlling back to back set firing pulses [6]. This can give a constant frequency of the variable speed machine. Block diagram of the DFIG based WECS is shown in fig1.

Variable wind turbines are using two controlling methods to extract maximum power from available wind speeds; one is tip speed ratio control (TSR) and pitch angle control. Pitch angle control can adjust the blade to change the angle of attack to extract maximum energy.

With combination of these reactive power controls are used to monitor power generation.

Fig 1 Block diagram of the WECS




## II Doubly-Fed Induction Generator Wind Turbines

In WTs with DFIG, the stator of the induction generator (IG) is directly connected to the grid and the wound rotor is connected to the grid through an ac-dc-ac converter system as shown in Fig. 3. The ac-dc-ac converter system consists of two voltage source converters: rotor side converter (RSC) and grid side converter (GSC) [7]. A line inductor and shunt harmonic ac filters are used at the GSC to improve power quality. A crowbar is used to protect the RSC against over current and the dc capacitor against overvoltage. During crowbar ignition, the RSC is blocked and the IG consumes reactive power. To avoid the crowbar ignition during faults, the dc resistive chopper is used to limit the dc voltage. DFIG converters are controlled using vector control techniques. The RSC operates in the stator flux reference frame and the GSC operates in the stator voltage reference frame. Both RSC and GSC are controlled by a two-level controller[9]. The slow outer control calculates the reference dq-frame currents and the fast inner control allows controlling the converter ac voltage reference [8].

### *A. Rotor Side Converter Control*

The q- and d-axis currents of the RSC are used to control the active power output and terminal voltage of the DFIG, respectively. The outer loop equations of the RSC are

$$i'_{dr} = (K_v)(1 + \Delta V'_{dfig} - V_{dfig}) + (V_{dfig}/X_m)$$
$$i'_{qr} = (K_{PP} + K_{IP}/s)(P'_{dfig} - P_{dfig})$$

where the subscript r stands for rotor, *vK* is the voltage regulator gain, *K pp* and *K ip* are the power regulator PI parameters. The reference values *dfig V* dfig and *dfig P* dfig are given by the WPC and the MPPT control, respectively.

### *B. Grid Side Converter Control*

The GSC maintains the dc bus voltage *dcV* at its nominal value and operates at unity power factor during normal operation. The outer loop equations of the GSC are

$$i'_{dg} = (K_{Pdc} + K_{Idc}/s)(V'_{dc} - V_{dc})$$
$$i'_{qg} = 0$$

where the subscript g indicates grid, *Pdc K* and *Idc K* are the dc voltage controller PI parameters.

### *C. EMT MODEL*

The EMT model of the WP consists of an aggregated DFIG WT, an aggregated DFIG transformer, a PI circuit that represents the equivalent MV collector grid, and the HV/MV WP transformer[9]. The aggregated DFIG WT model per unit (pu) parameters are the same with the single DFIG WT pu parameters in aggregation when

$$S_{agg} = N\, S_{WT}$$

where *SWT* is the single WT base power, *N* is the number of WTs in aggregation and *Sagg* is the base power for the aggregated WT. The parameters for the equivalent MV collector grid are calculated on basis of active and reactive power loss in the feeder for the rated current flow from each of the WTs.

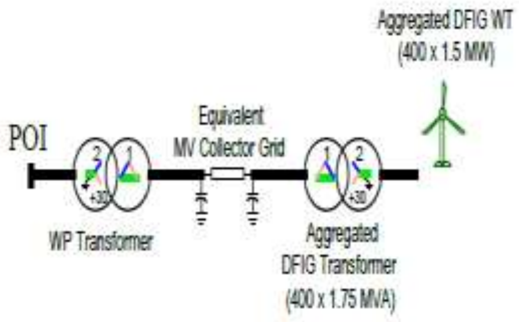



Fig 2 Wind park EMT model

### *D. Wind Park Model Used In Eigenvalue Analysis*

The series capacitor compensated transmission line, the wind farm transformer, the equivalent collector grid and the aggregated DFIG transformers are represented with a single RLC branch. All shunt branches (except the DFIG aggregated harmonic filters) are disregarded. This simplification results a difference in the impedance seen from the DFIG terminals. However, this difference is not significant around series resonant frequency. The series resonant frequency is around 30.7 Hz in EMT model and around 30.6 Hz in simplified linearized model[8,9]. The state space representation of the IG, electrical network, choke filter, DC bus and torsional dynamics can be found. The linearized model of the electrical system is in d-q reference frame. It disregards the DFIG input measuring filters and the PLL dynamics. The limitations of this systems are

1. Large discrepancies between eigen value analysis and EMT simulations results. Mathematical approach and more complexity.
2. DFIG control sampling frequency introduces a strict limit for the highest possible filter cut-off frequency.
3. High order filter usage should be avoided.

## III PROPOSED SYSTEM

The power quality issues can occur either from source side or from load side. Source side power quality problems can be given as Voltage sags, Voltage variations, Interruptions Swells, Brownouts, Blackouts, Voltage imbalance. The power quality problems[12] arise from the load side due to widespread use of electronic equipment led to a complete change of electric loads nature. These loads are simultaneously the major causes and the major victims of power quality problems[11]. Due to their non-linearity, all these loads cause disturbances in the voltage waveform. In this paper, a DFIG system is controlled by using Fuzzy Logic Controller along with Unified Power Flow Controller (UPFC). The Fuzzy logic controller is designed for the power quality improvement. This paper presents a fuzzy logic based PWM current control technique and ANFIS which performs well under unbalanced and variable load conditions since the controller do not need an accurate mathematical model; it can work with imprecise inputs and can handle nonlinearity.

The fuzzy controllers are used to perform error controlling action. To increase DFIG performance one new control technique is proposed which is better than fuzzy i.e., an Adaptive Neuro fuzzy system (ANFIS) [10]. It is a rule based training system, it uses a sugeno type of rule base system. ANFIS with sugeno combination can give better performance than conventional methods .The ANFIS system has been utilized to execute the proposed model .To start with, it utilizes the training data information to build the fuzzy system in which membership functions are adjusted [10]. The system will take grid parameters as a reference for integration of DFIG with grid. Grid voltage is taken as reference during synchronization, from this phase angle and frequency is measured. The controller can take DFIG voltage, phase angle and frequency, then the reference and measured parameters are compared. The error between these two are given to ANFIS, it will reduce error near to zero. By these the pulse generation to control DFIG inverter output is same as grid. In a grid failure, system goes to islanded mode of operation, In this case the loads are operated up to 60% without using battery storage system. In islanding mode load parameters are taken as a reference parameter.

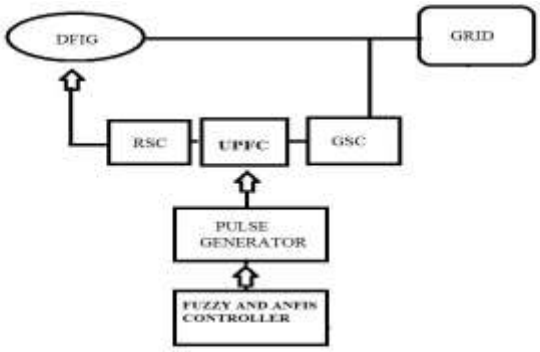



Fig 3 Block diagram of the proposed ANFIS and based PWM generator

### *A. Unified Power Flow Controller (UPFC)*

The unified power flow controller (UPFC) is one of the most widely used FACTs controllers[14] and its main function is to control the voltage, phase angle and impedance of the power system thereby modulating the line reactance and controlling the power flow in the transmission line. The basic components of the UPFC are two voltage source inverters (VSIs) connected by a common dc storage capacitor which is connected to the power system through a coupling transformers. One (VSIs) is connected in shunt to the transmission system through a shunt transformer, while the other (VSIs) is connected in series to the transmission line through a series transformer[15]. Three phase system voltage of controllable magnitude and phase angle (Vc) are inserted in series with the line to control active and reactive power flows in the transmission line. So, this inverter will exchange active and reactive power with in the line.

The UPFC has many possible operating modes.

(1) VAR control mode:-The reference input is a simple var request that is maintained by the control system regardless of bus voltage variation.

(2) Automatic voltage control mode:-The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value with a defined slope characteristics the slope factor defines the per unit voltage error per unit of inverter reactive current within the current range of the inverter. In Particular, the shunt inverter is operating in such a way to inject a controllable current into the transmission line. The figure 1 shows how the (UPFC) is connected to the transmission line.

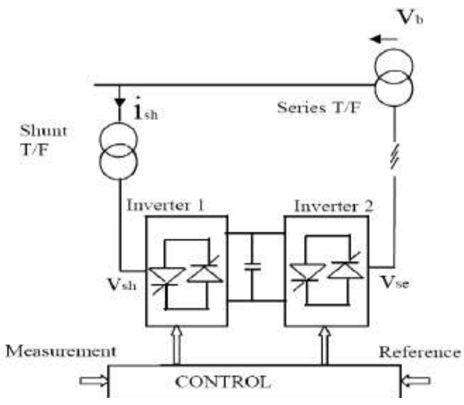



Fig 5 UPFC system

As the UPFC consists of two converters that are coupled on the DC side, the control of each converter is explained below:

There are two operating (control) modes for a STATCOM or the shunt converter. They are,

1. VAR control mode where the reactive current reference is determined by the inductive or capacitive VAR command. The feedback signals are obtained from current transformers (CT) typically located on the bushings of the coupling (step down) transformer.

2. Automatic voltage control mode where the reactive current reference is determined by the output of the feedback voltage controller which incorporates a droop characteristic (as in the case of a SVC or a STATCOM)[16,17]. The voltage feedback signals are obtained from potential transformers (PT) measuring the voltage V1 at the substation feeding the coupling.

### B. *ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM*

In recent years, fuzzy logic control has played an increasing and significant role in the development and design of real-time control applications. However, membership function type, number of rules and correct selection of parameters of fuzzy controller are very important to obtain desired performance in the system. Determination of membership function type and rule number of fuzzy controller and selection of parameters is made by means of trial and error method and by using the specialization knowledge [19,20].

Adaptive Neuro-Fuzzy Inference System is the integration of artificial neural networks and fuzzy inference systems. ANFIS is formulated on three main elements: auxiliary, compatible and integrative [21]. ANFIS is also expressed as functional adaptive networks unit equivalent to fuzzy inference system. ANFIS is the combination of neural networks and fuzzy system to determine parameters of the fuzzy system. The main purpose of using the Neuro-Fuzzy approach is to automatically realize the fuzzy system by using the neural network methods. In ANFIS control system, Fuzzy Sugeno models are involved in framework of adaptive system to facilitate the learning and adaptation studies [19]. ANFIS permits combination of numerical and linguistic data. Besides, Neuro-Fuzzy systems have the ability to obtain fuzzy information from numerical data. [22,23].

In the adaptive neuro-fuzzy model, two basic learning algorithms are required. One of them is the structural learning algorithm to find suitable fuzzy logic rules and the second one is the parameter learning algorithm to adjust the membership functions and other parameters according to desired performance from the system. [22].

In this context, the designing has been accomplished with the sugeno type technique that lines out the input characteristics to input membership functions. In some sort of designing conditions, it may not be easy to analyze the data of the membership functions, it should be more correlated with the membership functions directly. A network- type design same as a neural network system has been adopted to strengthen and improvise the input/output map in such a way that it will evaluate the input units through the regular membership functions of input/ output parameters that are linked with the membership functions which can be altered through the learning procedure[25]. In the process of calculation, the variable parameter changes are supplemented with a gradient vector, which has been used as reference to the FIS to measure the input/output data in correspondence with the pre-determined parameters. The controller takes measured values as inputs to do a particular task. To maintain DFIG synchronism with grid, the voltage, phase angle and frequency are same for these two. This can be achieved by comparing measured values with reference value. The measured DFIG voltages and currents are compared with reference values, then the error between these two and change in error taken as an input to ANFIS controller. ANFIS can reduce error in two stages, one is rule base action. In this case the ANFIS can check error value range[24].

Based on this, output can generate with a range closer to reference, and then this output is given to trained system. Further the error is reduced based on this trained parameters, it will make the system outputs closer to reference values [10,18]. The vector control performance of proposed ANFIS controller is contrasted with a vector control utilizing fuzzy logic controllers. The wind speed is set at 6 m/s in accordance with a angular speed of 78 rad/s

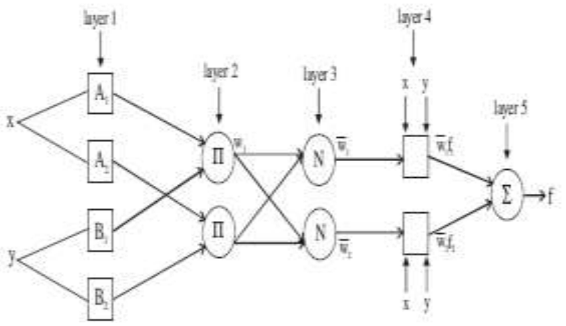



Fig Architecture of ANFIS

**Layer 1 (L1):** Each node produces the membership grades of a linguistic label. An example of a membership function is the generalised bell function:

$$\mu(x) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}$$

where {*a*, *b*, *c*} are the parameters. By changing the values of the parameters, the shape of the bell-shaped function varies. Parameters in that layer are called premise parameters.

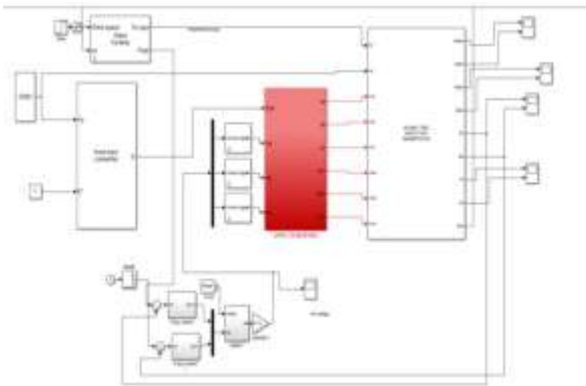
**Layer 2 (L2):** Each node calculates the firing strength of each rule using the min or prod operator. In general, any other fuzzy AND operation can be used.

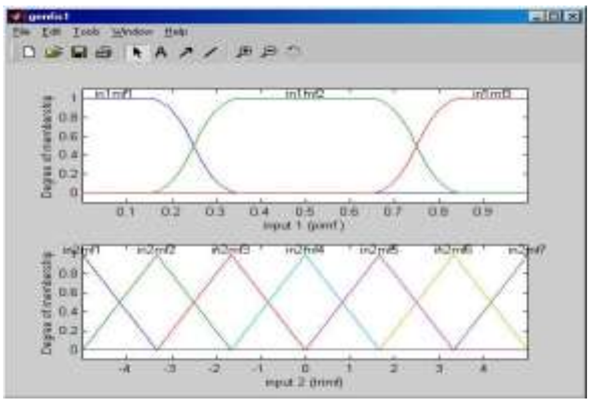
**Layer 3 (L3):** The nodes calculate the ratios of the rule's firing strength to the sum of all the rules firing strength. The result is a normalised firing strength.

**Layer 4 (L4):** The nodes compute a parameter function on the layer 3 output. Parameters in this layer are called consequent parameters.

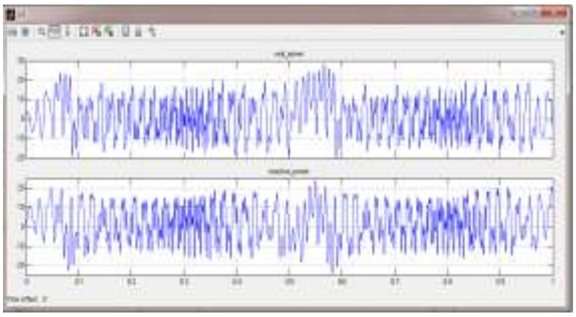
**Layer 5 (L5):** Normally a single node that aggregates the overall output as the summation of all incoming signals

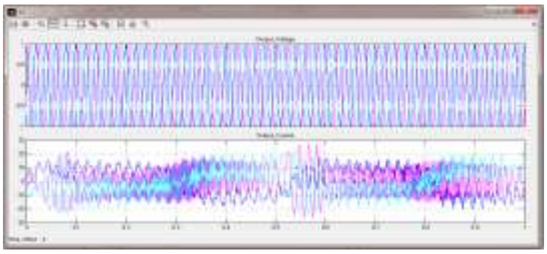
## IV SIMULATION AND RESULTS



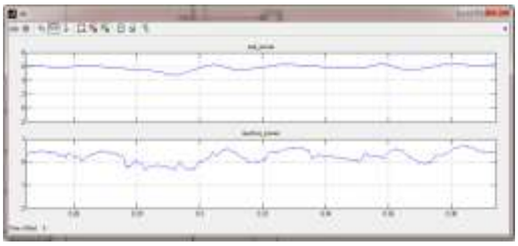


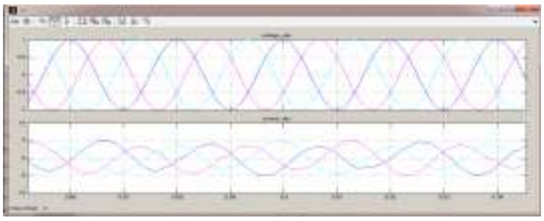
Existing system





Proposed system





## V CONCLUSION

This paper has described the control scheme of doubly-fed induction generator (DFIG) wind energy conversion system using FLC and ANFIS approach. The wind turbine driven by doubly- fed induction generator is a part of distributed generation which feeds ac power to the distribution network. The system is modeled and simulated in the Simulink Matlab software in such a way that it can be suited for modeling of all types of induction generator configurations. The real and reactive powers increase with the increase in angle of injection. Simulation results show the effectiveness of UPFC to control the real and reactive powers, while fuzzy controller has strong robustness to control system whose parameters varied. The results show that fuzzy controller has better performance than PI controller. The simulation results are highly consistent with theoretical analysis and verify correctness of the proposed simulation system. The model makes use of rotor reference frame using dynamic vector approach for machine model. All power system components and the adaptive neuro-fuzzy controller are simulated in Matlab Simulink software. The future work of this paper includes the detailed work of DFIG under fault conditions using ANFIS controller.

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