CHAPTER 1

INTRODUCTION

1.1 GENERAL

Over the recent years, the objective of wind turbine systems development is to increase the output power continuously. The Doubly Fed Induction Generators (DFIG) is noted to be the current choice for multi-MW wind turbines. The DFIG system generally considered should be capable of operating over a wide wind speed range to achieve optimal efficiency by tracking the optimal speed ratio. Hence, the rotor of the generator should be able to operate at a variable rotational speed. The DFIG system has to operate both in sub and super synchronous modes with the speed of the rotor range in the order of the synchronous speed. Fundamentally, the stator circuit is directly connected to the grid while the rotor winding is connected through the slip rings to a three-phase converter. In case of variable-speed systems where the range of speed requirements is small, the DFIG is found to provide adequate performance and this is sufficient for the speed range required to be employed in case of wind resources.

Generally, grid codes worldwide require the wind turbines to supply the reactive power to the grid at the time of fault and as well after the fault, for supporting the voltage of the grid. In this scenario, the traditional crowbar system designed to protect the rotor side converter at the occurrence
of grid faults does not supply the required reactive power. Because in the case of the traditional crowbar system, the DFIG is noted to behave as a squirrel cage induction machine which absorbs more reactive power form the grid. This limitation has led to the development of the controllers which eliminate or completely avoid crowbar systems. Thus, the ultimate aim is to handle ride-through the fault without using any additional auxiliary hardware setup.

Considering the scale of the problem and the frequency with which the fault has to be handled, fault-ride through of the grid connected wind turbines along with DFIGs has become a major research area in the grid sector during the past few decades. Due to these facts, this work provides a better understanding of the need for Fault Ride-Through (FRT) of grid connected wind turbines and its importance in grid sector. The various methodologies employed for handling fault ride-through problem of grid connected wind turbines with their advantages and limitations as in the existing literature are outlined in this chapter. The importance and the need for the research contribution for designing controllers to handle FRT employing various proposed heuristic intelligent controllers are highlighted bringing the objectives for carrying out this research work.

1.2 LITERATURE STUDY ON THE DESIGN AND CONTROL OF DFIG

In this section, review on the various design modules and control systems developed with respect to DFIG in the past years is presented, so that the need for controllers with respect to DFIG is elucidated.

Vieira et al. 2009, carried out a work on a genetic algorithm based optimal controllers to the rotor-side converter of DFIG. The DFIG converter control action is performed by Proportional and Integral Controllers.
The presented approach improves transient stability margin of the power system and also has better global system dynamic behaviour during and after the fault period.

Bhatt et al. 2011, presented DFIG dynamic participation in automatic generation control, frequency response of the system is improved by frequency control support function and Craziness-based Particle Swarm Optimization (CRPSO) is utilized to obtain the optimal DFIG parameter, transient response of area frequency and tie-line power deviation.

Costa, JPd et al. 2011, suggested a novel robust controller in a stationary reference frame for grid-integrated DFIG based wind turbines. The voltage and flux equations in αβ coordinates used DFIG dynamic model design, the disturbances and uncertainties intrinsic to the system are accounted for as perturbation terms are included to the nominal model.

Dong et al. 2011, proposed an Artificial Neural Network based adaptive Proportional Integral (PI) controllers for DFIG driven based wind turbine to improve its transient performance in all wind speed conditions. Artificial Neural Network (ANN) is used to predict the optimal values of parameter and Adaptive PI controllers according to different wind speeds dynamically change PI gain values.

Ghadimi 2011, proposed a genetic algorithm based Proportional, Integral and Derivative (PID) controller coefficients adjustment for Wind Energy Conversion System (WECS) with DFIG. LIU, J et al. 2011 pointed out the DFIG speed controller based on the nonlinear intelligent model predictive control algorithm. Space Vector Modulation (SVM) is adapted to establish the
speed of DFIG and PSO is utilized to solve the rolling optimization, the forecasted error is used to form a closed-loop control.

Various computational intelligence based control of wind turbine generators such as PSO, Mean Variance Optimization, Adaptive critic design based adaptive control and shunt Flexible Alternating Current Transmission System (FACTS) devices are analyzed in Qiao et al. 2011.

Song, Y et al. 2011, dealt with multi-objective optimization control methodology of a DFIG considering the distorted grid voltage conditions. The four different control targets are proposed to restrain the harmonic components in stator/rotor current or the ripples in the stator output active/reactive power and electromagnetic torque.

Vinothkumar & Selvan 2011, carried out a work on a new enhancement of fault ride-through capability and subsequent betterment of rotor speed stability of doubly fed induction generator based wind farms. The wind turbine mechanical energy input is stored during the grid fault and at the moment of fault clearance it is utilized, hence the charging the Direct Current (DC)-link capacitor by grid side converter is relieved.

Numbi et al. 2012, presented PSO based reactive power control in grid-connected DFIG-based wind farm to optimize the power from Reactive Power Capability (RPC) of DFIGs in order to minimise the system active power loss.

Wang, L et al. 2012, proposed a Hybrid Particle Swarm Optimization (HPSO) algorithm for the DFIG optimum design in this work and the searching performance is improved by adapting the diversity-guided adaptive mutation and fitness-guided individual fuzzy inertia weight. An
optimal grid-integrated doubly fed induction generator design for wind turbine systems is developed in You et al. 2012. To maximize the torque per weight as well as to maintain the efficiency, the Kriging model based on latin hypercube sampling and genetic algorithm are utilized.

Amelian et al. 2013, carried out a work on a small signal stability improvement based on eigen value analysis of a wind turbine-based DFIG in a micro grid environment. The stability margin and damping ratio of critical modes are enhanced by using PSO algorithm.

An optimal Volt Ampere Reactive (VAR) expansion based on capability curve of DFIG wind farm has been proposed in El-Araby 2013. The proposed approach reduces the sum of the annual investment cost of the new VAR devices and the annual expected energy loss cost.

Sa-ngawong & Ngamroo 2013, proposed a design of adaptive controller using optimal fuzzy logic of DFIG wind turbine for standalone power system frequency control. The PSO is employed to adapt and optimize the fuzzy logic design membership function and the control rules.

Tang, Y et al. 2013, carried out a work on an optimal control of DFIG based wind generation adapting trajectory and frequency domain information based sensitivity analysis and PSO. The critical parameters, the Unified Dominate Control Parameters (UDCP) are identified using sensitivity analysis and PSO is utilized to obtain the control goal by searching the optimal values.

A fuzzy controller proposed in Beheshtaein 2014, is based on Fuzzy Adaptive Theta Particle Swarm Optimization (FAΘPSO). This
algorithm is used in DFIG to obtain Optimum values of membership functions and to run the machine at medium voltage.

A Load Frequency Control (LFC) of micro grids connected with main grids in a regulated and deregulated environment, the PSO tuned PI Controller gains has improved performance compared to the conventional PI Controller parameters is proposed in Dhillon et al. 2014.

Govindarajan & Raghavan 2014, pointed out an adaptive Neuro-Fuzzy inference system controller for DFIG based wind turbine. The presented approach control the current and voltage ripple with in 0.01pu as well as reduce the power loss.

Kong et al. 2014, proposed data-driven based modelling of DFIG wind turbine system adapting Neural Networks. The DFIG model is developed based on Neural Networks and Neuro-Fuzzy Networks by using large amount of input-output on-line measurement data from the selected months.

Wang, T et al. 2014, proposed an Rotor Side Converter (RSC) controller for DFIG based wind power generation system. The Stator Flux-Oriented (SFO) vector control based design is adapted and RSC controller for DFIG with double closed loop system such as rotor current control loop and power control loop designed with PI. WU et al. 2014, suggested combination of PSO and orthogonal method for wind turbines parameter tuning of DFIG.

A virtual resistance control approach for High Voltage Ride-Through of doubly fed induction wind generators is presented in Xie, Zhen & Li 2014, using particle swarm optimization. Zhang et al. 2015, pointed out design of additional impedance-based Sub-Synchronous Resonance (SSR)
damping controller for power system with DFIG wind turbine, which effectively suppresses the Resonance.

1.3 LITERATURE REVIEW ON FAULT HANDLING OF WIND TURBINES WITH DFIG

The literature study on the earlier works for fault ride-through of wind turbines with DFIG are presented here:

Zhou, L et al. 2015, proposed improvement in demagnetization control which is immune to system parameter variation to shorten the dynamic process. The investigation shows that the proposed method increases the probability of a successful ride-through at the recovery moment of balanced grid fault. The proposed method has been analyzed for the Low Voltage Ride-Through (LVRT) performance of a DFIG-based wind turbine under balanced grid fault.

Khezri & Bevrani 2015, proposed coordination between Automatic Voltage Regulator (AVR) and power system stabilizer. The performance of the designed fuzzy coordinator is demonstrated on the IEEE 10-machine 39-bus power system with different levels of DFIG-based wind farms contribution.

Saad et al. 2015, presented the modelling and control designs for WECS based on a real model of DFIG taking into account the effect of stator resistance. The non-linear control technique using Sliding Mode Control strategy is used to alter the dynamics of 1.5MW wind turbine system connected to the grid under severe faults of grid voltage.
Guo, W et al. 2015, evaluated the performance of three kinds of Bridge-Type Fault Current Limiters (BTFCLs) for enhancing LVRT capability. The performance of three kinds of BTFCLs is evaluated by simulation and experimental studies on a typical 1.5 MW wind turbine driven DFIG system and a 2 kW DFIG prototype. Chowdhury et al. 2015, reviewed the current research on the issue from two aspects. One is to describe the methods to improve the fault ride through capability and the other is to analyze its impact on transient stability of power systems. This review is done on DFIG wind turbines of the wind farm.

Huang et al. 2015, presented a novel Modulated Series Dynamic Braking Resistor (MSDBR) control strategy for enhancing the Fault Ride-Through (FRT). The simulation results demonstrate the satisfactory performance of the MSDBR with its preferred allocation for enhancing the FRT performance against both balanced and unbalanced faults. It is used to enhance the FRT of DFIG-based wind turbines.

Chen, L et al. 2015, suggested a modified flux-coupling-type Superconducting Fault Current Limiter (SFCL) to improve the FRT capability. The simulation model of a 1.5MW/690V, DFIG is integrated with the SFCL and the performance analysis is carried out. From the results, introducing the SFCL can effectively limit the fault currents across the DFIG’s stator and rotor sides, and when the stator side is selected as the installation site, the terminal voltage sag can be also improved, which helps prevent the disconnection of the DFIG from the power grid. Xie, Zhen & Li 2014, proposed a virtual impedance control strategy to enhance the High Voltage Ride-Through (HVRT) capability. The proposed optimization algorithm of virtual impedance is to improve the dynamic performance for grid connected DFIG.
Zhu et al. 2015, proposed a virtual damping flux-based LVRT control strategy. The effectiveness of the proposed strategies is examined by the simulation with a 2MW DFIG in MATLAB/Simulink and verified by the experimental results from a scaled-down 7.5kW DFIG controlled by a DSPACE1006. The proposed method finds application in the control of a DFIG-based wind turbine.

Huchel et al. 2015, presented a novel DC-link scheme for enhancing the FRT capability. Simulation studies were carried out to compare the performance of the solution with a DFIG based Wind Turbines (WT), equipped with the DC Chopper and Crowbar. The simulation results demonstrate the enhanced performance of the proposed approach in maintaining the DC-link voltage, transient rotor voltages, and currents within the permissible operating range during a bolted three-phase-to-ground fault. Safaei et al. 2015, investigated the effects of Static Volt Ampere Reactive Compensator (SVC) on DFIG operation during voltage drop and Crowbar protection. Results show that by using SVC the voltage drop of DFIG terminal during grid faults decreases. Therefore, the proposed method is used for FRT capability of DFIG.

Justo et al. 2015, presented an overview on various strategies applied to enhance the FRT capability. Typical case studies are presented to demonstrate and support the reviewed FRT schemes. In that case, using the simulation results from the MATLAB/Simulink software the effectiveness of each case study during network faults are analyzed and compared. The proposed method is used to enhance the FRT capability of the DFIG based WTs during transient-state.

Flores Mendes et al. 2015, proposed a modified resonant controller to improve the system response during voltage sags, and the
analysis of the Ride-Through Fault Capability (RTFC) based on the converter limits is carried out. The proposed method is used to enhance the RTFC or LVRT, which defines that the plants must not be disconnected from the grid at certain levels of voltage sags and also must contribute to network stabilization.

Mohammadpour et al. 2015, proposed a new method to improve LVRT using Gate-Controlled Series Capacitor (GCSC). To validate the effectiveness of the proposed method, extensive time-domain simulation is performed using MATLAB/SIMULINK on a 1.5 MW DFIG based WT. The proposed method is used to improve LVRT of the DFIG based WTs.

Sivasankar & Kumar 2015, presented a control strategy of a Dynamic Voltage Restorer (DVR) to improve the reliability in case of grid voltage fault. The proposed strategy is to use DVR to compensate the grid voltage disturbances. The DVR can compensate the faulty line voltage and aid the DFIG wind turbine for a stable operation as demanded in actual grid codes. The proposed method is used to improve the reliability of DFIG based WT in case of grid voltage fault.

Wei et al. 2014, proposed a mode switching scheme for the purpose of achieving LVRT for wind turbines. Analysis shows that the proposed Mode Switching Doubly-Fed Induction Generator (MSDFIG) scheme can ride through the complete low voltage and voltage recovery stages. The proposed method is used to achieve LVRT mode switching doubly fed induction generator for wind turbines.

Cai et al. 2013, 2015, proposed a novel rotor current controller to overcome strong nonlinearity of DFIG. The controller is designed on the back stepping method, and then the feedback of Extended State Observer (ESO) is used to eliminate the nonlinear factor. The proposed method is applied to
the DFIG in wind power generation systems. Zhang et al. 2015, investigated the multi-objective fuzzy optimization of Crowbar resistance for LVRT problem. The proposed approach has been evaluated on a 3 MW DFIG.

Wang, T et al. 2015, proposed a DFIG wind farm aggregation method based on the Crowbar. Simulation analysis is carried out to demonstrate that the proposed method can better reflect the changes of wind farm caused by the activation of Crowbar of DFIGs, compared with a single generator aggregated model.

Gkavanoudis and Demoulias 2015, proposed a new control strategy accomplished by a DVR and a Super Capacitor Energy Storage System, in order to ride-through symmetrical and asymmetrical faults. The proposed method is applied to a DFIG operating in an isolated power system. Niu, Y-g et al. 2015, proposed a Multiple Model Optimal Tracking Control (MOTC) design method using correlative measured technique. To illustrate the effectiveness of the proposed MOTC strategy, simulations on a Hybrid Wind Thermal Power (HWTP) system are performed. Comparing to the conventional PID control, transient stability, damping, and FRT capability of DFIG with the proposed MOTC design method have been improved effectively.

Xiong et al. 2013, proposed a new Crowbar resistance design method for reference in relevant engineering projects. An actual 10 kilo Watt DFIG is used for case study, the simulation results prove the accuracy of the expressions. This can provide solution to the LVRT issue problem of DFIG wind farm integration.

Duong et al. 2015, proposed the control system based on PI controller enables the LVRT capability of the wind turbines. The case studies
refer to a control system with hysteresis band for the Crowbar protection of a 3 Mega Watt (MW) doubly fed induction generator based wind turbine. The proposed method find application in Crowbar protection and voltage support, for wind turbines equipped with DFIG.

Huang, P et al. 2015, presented a novel Modulated Series Dynamic Braking Resistor (MSDBR) control strategy for enhancing the FRT. The proposed method is used for enhancing the FRT of DFIG-based wind turbines. Arribas et al. 2014, proposed a new control strategy that allows devices to withstand the effects of voltage sag while following the new requirements imposed by grid operators. The proposed method is used for DFIG to protect from grid faults such as voltage sags.

Gao et al. 2000, analyzed the transient characteristics of rotor voltage and current during the grid symmetric fault. With 2 MW DFIG as an example, the proposed fault ride-through control strategy was done by the simulation, which validated the feasibility and effectiveness of the proposed FRT control strategy.

Ling 2014, proposed a hysteresis controller in order to improve the performance of FRT of DFIG wind turbines when they are subjected to a dip of grid voltage. The FRT capability of DFIG-based wind turbines with the proposed scheme is validated by the simulation using the dedicated power system analysis tool PSCAD/EMTDC.

Liu, J-H et al. 2014, proposed a new LVRT operation scheme by combining of excitation control strategy with hardware devices. The simulation results showed that the proposed scheme not only improves the performance of rotor over current, but also deals with the grid voltage.
Mohammadi et al. 2014, proposed an efficient control strategy to improve the FRT capability during the symmetrical and asymmetrical grid faults. By applying the proposed strategy, negative effects of the grid faults in the DFIG system including the rotor over currents, electromagnetic torque oscillations and Direct Current (DC)-link over voltage are decreased.

Soares et al. 2010, presented comparative results between Proportional Integral controllers and Neural Networks based controllers for turbines operating under normal and under the occurrence of faults. The simulation results show that better dynamic characteristics can be obtained using Neural Network (NN) based controllers. The proposed method is used for nonlinear control of the DFIG in wind power systems.

1.4 REVIEW ON APPLICABILITY OF NEURAL NETWORKS IN DFIG CONTROL

The previous works carried out for design of controllers in DFIG employing Neural Network architectures are presented as follows:

Ro & Choi 2005, proposed a maximum power extraction of grid-connected wind turbine system using NN pitch controller, develop modelling and simulation of the horizontal axis wind turbine system. By controlling firing angles of the inverter switches and pitch angle of the wind turbine blades using NN pitch controller extract maximum power from wind and transfer the power to the grid.

Soares et al. 2009, suggested DFIG power flow control using NN controller. The pointed out strategy reduce the effect in the grid frequency and
voltage during normal and fault conditions, maximize the generated power and improve the dynamic characteristics compared to PI controllers.

Jalilvand et al. 2010, performed DFIG intelligent control using Adaptive Neural Controller and Genetic Algorithm is adapted to compute the PI controller parameters. Dong et al. 2011, suggested wind turbine driven DFIG adaptive PI control using Artificial Neural Network (ANN) and PI controller parameters were optimized using PSO and optimal values of parameters are predicted using NN controller.

Lan & Xuefei 2011, proposed Neural Network Inverse Control (NNIC) based excitation system for DFIG and Back Propagation Algorithm is used for training the NN. The pointed out approach supply the reactive power for grid independently and control the active power, to achieve better dynamic performance.

Lin, F-J et al. 2013, pointed out intelligent controllers for DFIG based on Probabilistic Fuzzy Neural Network (PFNN). In this case, DC-link voltage is maintained by Rotor Side Converter (RSC) and Grid Side Converter (GSC) field-oriented control. The result proves that under various working conditions DFIG system obtain better transient and steady state response.

Ruiz Riemann et al. 2011, carried out a work on a sliding mode discrete-time block controller for DFIG and Extended Kalman Filter (EKF) algorithm trained with Recurrent High Order Neural Network (RHONN) identifier is utilized to drive the mathematical model of generator. Xia et al. 2011, pointed out appropriate and fast response to wind speed fluctuations without anemometer or system pre-knowledge based Maximum Power Point Tracking (MPPT) and control approach for Permanent Magnet Synchronous
Generator. The presented approach is noted to be capable of updating parameters online with a shift of time-dependent turbine or generator.

Abdel-Khalik, AS et al. 2012, suggested power control method based on ANN in order to charge/discharge a Flywheel-Doubly Fed Induction Machine (FW-DFIM) storage system with constant power delivered to the grid. The wind generator delivered improved electrical power quality and thus avoided the overloading in the stator and rotor circuit. The effectiveness of the proposed method is evaluated using medium voltage of 10 Mega Joule/1000 horse power FW-DFIM.

De Santana et al. 2012, proposed Fast Fourier Transform (FFT) and ANN based fault identification system for DFIG. The dimensionality of the output data of FFT is minimized by Principal Component Analysis (PCA). The result reveals that the suggested approach achieve better performance, accuracy and reliability for DFIG fault identification.

Lin, FJ et al. 2012, carried out a work on a Proportional-Integral-Derivative Neural Network (PIDNN) based controller for stand-alone DFIG. The field-oriented control is also adapted for RSC and GSC in order to maintain the DC-link voltage magnitude. The steady state and transient response of DFIG under various working condition are improved by the presented PIDNN controller.

Rahim & Abido 2012, presented effective system transient control and recovery for DFIG based on adaptive Radial Basis Function (RBF) NN. The results prove that suggested controller restore the system to normal operation very fast.
Ruiz, R et al. 2012, pointed out DFIG discrete-time block controller based on NN and EKF algorithm is adopted to train the RHONN identifier.

Abdel-Khalik, A et al. 2013, performed ANN based power control strategy to charge/discharge a FW-DFIM storage system in order to maintain grid side power within the controllable limit. The effectiveness of the proposed approach is verified in medium voltage 1000hp FW-DFIM and the results prove that the suggested strategy obtained better wind generators electric power quality and avoid hysteresis power controller and overloading.

Chaiba 2013, performed a torque tracking technique for DFIG using Neuro-Fuzzy control. Membership functions of input and output parameters of the Fuzzy Logic Controller are adjusted by four layer NN which is trained by Back-Propagation Neural Network (BPNN) algorithm. The results prove that compared to the PI controller the suggested method obtain improved dynamic performance, robust and suitable for drive application.

Rahim & Abido 2012, suggested wind turbine driven with DFIG system pitch controller based on Differential Evolution (DE) incorporated with Adaptive Neural Network. The DE optimization method is found to generate input-output training data and these nominal weights are employed for the BPNN controller. The result confirms that the pointed out method obtain good damping profile and transfer the energy to the grid effectively.

Ruiz-Cruz et al. 2013, presented NN based real-time sliding modes control for a DFIG. RSC and GSC are controlled by Neural Network Discrete-Time Sliding Modes (NNDTSM) block control schemes. DFIG mathematical model is derived using higher order NN and the suggested
method is applied to 114 hp DFIG prototype in order to validate the effectiveness of the proposed approach.

Shojaei et al. 2013, carried out a work on a Recurrent Neural Network (RNN) based voltage control of DFIG in the power system. RNN is utilized here as RNN Controller (RNNC) and RNN Identifier (RNNI). The results show that the RNNC based voltage control of DFIG in the power system achieves improved voltage regulation.

Xiang et al. 2013, proposed Hopfield Neural Network (HNN) based primary reserve power and rotor kinetic energy control for DFIG and this is investigated in a two-area four-generator system using PSCAD/EMTDC. The results show that the presented technique obtains better frequency stability than other classical techniques.

Li et al. 2014, carried out a work on a wind turbine driven DFIG stator voltage oriented vector control using Neural Network PID (NNPID) technique. The result reveals that the suggested NNPID robust to the DFIG parameter variations is capable to capture the wind energy variation and is effective in the case of wind mutation change.

Niu, Y et al. 2014, presented wind turbine driven DFIG excitation control using decentralized coordinated neural control scheme which is composed of Neural Network Controller. The result confirm that the suggested approach achieve better hybrid power system transient stability, system damping and minimum computational cost.

Sharma et al. 2014, performed power system design with dynamic participation of wind turbine driven along with DFIG, Automatic Generation Control (AGC) and Regulators based on Least Squares-Support
Vector Machines (LS-SVM). Si & Zhang 2014, pointed out that WT based DFIG rotor side converter control adapts Neural Networks Internal Model Control (NN-IMC) strategy. The Network consists of inverse model of Neural Networks and positive model of Neural Networks and the control feature and its effectiveness are evaluated by simulation.

Boufounas et al. 2015, carried out a work on Adaptive Particle Swarm Optimization (APSO) algorithm based General Regression Neural Network Sliding Mode (GRNNSM) controller for DFIG driven by wind turbine. The uncertain model part is forecasted by GRNNSM and the weight of GRNNSM is trained by APSO algorithm; hence the chattering problems are avoided.

Doubly fed induction generator control scheme based on hybrid ANN with PI control for wind energy generation system and DFIG dynamic performance is analyzed under different conditions. The results prove that hybrid control method achieves better dynamic performance than PI and ANN based control.

Talebi et al. 2015, proposed a dynamic Recurrent Neural Networks based fault detection of Wind Energy Conversion Systems (WECS). The effectiveness of proposed scheme is validated and the results confirm that the fault detecting system detect the fault in a short time with less false alarms rate.

1.5 NEED FOR THE RESEARCH STUDY

From the above extensive literature study on design of controllers for FRT of wind turbines connected along with DFIG over the past decade, it is noted that the following problems are observed when performing control action on the grid side.
- Required reactive power not supplied to the grid
- Required additional hardware circuitry for grid control
- With conventional crowbar system, doubly fed induction generator acts as a squirrel cage machine
- Reactive power is noted to be absorbed from the grid
- Presence of a crowbar system
- Premature convergence of the already developed heuristic algorithms
- Varying controller parameters
- No guarantee on interpretability of the control system

Therefore there is a need to propose controllers which are adaptive, flexible and scalable. They should carry out necessary control action at the grid side by controlling the operations of WT connected along with DFIG. It is also necessary to give highest probability for obtaining effective control function with minimal mean square error and best fitness for the considered problem than that of the existing works due to the following:

- To eliminate the required additional hardware circuitry
- To supply the necessary reactive power to the grid
- To develop the faster convergence of the algorithms
- To locate the optimal solution
- To check the set constraints
- To provide Optimal coordination of DFIG converters
- To eliminate the over currents at the rotor windings
- To eliminate the over voltages at the DC side
- To avoid premature convergence
- To improve the exploration and exploitation capabilities of the search process
➢ To reduce the number of generations of the process and the mean square error of the controller model
➢ To improve the overall control action at the grid side

In general, this research is carried out to propose appropriate controller models to perform effective control action for the grid connected system. The contribution leads to the development of new controller models and novel stochastic algorithm for offering quality solutions involving Evolutionary Optimization, Neural Network architectures and Fuzzy approaches. In precise, this research work contributes in developing controller models by formulating effective and scalable approaches that are based on population based stochastic evolutionary algorithms, biological modelling of the human brain and reasoning capability using the fuzzy approach.

Commercially, to handle the fault-ride through in power companies; the power system and the generator are completely decoupled. The control of active and reactive power is completely determined by the converter, and can be performed even faster. The impact of power system voltage and frequency disturbances on the generator and mechanical drive train is negligible.

The commercial wind turbines use a DC braking chopper resistor in parallel with the DC-link capacitor inside the power converted. This resistor can dissipate any excess energy caused by temporary imbalances in the electrical and mechanical power during network fault conditions, when grid-side active power may temporarily need to drop to near zero. The instantaneous peak and continuous sustained fault currents produced by the grid side of the power converter are comparable to the rated current of the machine. This may be an advantage or disadvantage, depending on the conditions of the grid to which the wind farm is connected.
The proposed controller models are used to facilitate the control action with complete guarantee on constraints in a responsive and efficient way. The effectiveness based on the controller model is compared with few of the other existing and proposed algorithms based on the simulation results obtained for its proper validation.

### 1.6 OBJECTIVES OF THE RESEARCH WORK

The key objective of this research work is to develop heuristic intelligent controllers for improving the LVRT rate of grid connected wind turbines, which are connected along with DFIG. Basically, traditional controllers are found not to satisfy the desired requirement, since DFIG during the connection of Crowbar acts like a squirrel cage module and absorb the reactive power from the grid. This limitation at the grid side is taken care in this thesis by introducing heuristic intelligent controllers that removes the applicability of Crowbar and ensures that wind turbine system supply necessary reactive power to the grid during the occurrence of faults.

The Intelligent controllers are designed in this research work to enhance the DFIG converter during the grid fault and these proposed controllers were observed to take care of the ride-through the fault without employing any other hardware modules. This research is based on the applicability of the proposed evolutionary optimization algorithms, neural network architectures and fuzzy reasoning approach which had proven its efficiency to perform effective control action with complete control on the grid side. In this connection, the following are the major contributions of the research work:

- Development of Differential Evolution based Inertia Double Wavelet Neural Network (DE-IDWNN) controller to enhance the DFIG
converter during the grid fault and this controller takes care of the ride-through the fault without employing any other hardware modules.

- A new hybrid Particle Swarm Optimization (PSO)-Group Search Optimizer (GSO) based Spiking Neural Network (SNN) which improves the LVRT rate of grid connected wind turbines that are connected along with DFIG.

- A novel hybrid controller integrating fuzzy reasoning into SNN for performing control action of grid connected DFIG. The proposed Fuzzy Spiking Neural Network (FSNN) takes care on the active and reactive power component of the grid connected DFIG with a control on speed of the rotor at the time of fault.

- ELMAN NN is modelled employing Imperialist Competitive Algorithm (ICA) to handle the fault ride through of the grid connected wind turbines. This proposed ICA based ELMAN NN enhances the DFIG converter at the time of grid fault and this designed controller performs the ride-through the fault.

- A fuzzy controller module whose membership functions are optimized employing the developed variant of real coded genetic algorithm is proposed in this thesis to handle over voltage ride through of grid connected DFIG. This designed fuzzy controller activates with formulation of rule base to give signal along with the q-component of the rotor current.

Each one of the proposed approaches contributes in a distinct methodology for performing effective and efficient control action in a cooperative manner rather than a competitive manner. MATLAB mathematical software is employed for simulation of the proposed population-based stochastic evolutionary optimization algorithms, fuzzy reasoning approaches and neural network architectures. Simulations are carried out to analyze the performance and validity of all the proposed approaches. The
results computed employing the proposed controller models are compared with some of the existing methods to prove their level of accuracy and validity.

1.7 ORGANIZATION OF THE THESIS

The thesis is organized into seven chapters including this discussed chapter 1. An outline of the forthcoming chapters is given below:

Chapter 2 discusses the applicability and design of DFIG in wind turbines. The chapter presents a novel heuristic based controller module employing DE and NN architecture to improve the LVRT rate of grid connected wind turbines, which are connected along with DFIG. Further, the proposed work namely DE-IDWNN is presented in detail. The computed results are checked for its validity with the solutions available in the existing literature.

Chapter 3 summarizes the proposed novel hybrid PSO-GSO based SNN which improves the LVRT rate of grid connected wind turbines that are connected along with DFIG. The proposed algorithm is presented to depict their exploration and exploitation capabilities of PSO and GSO. The results of the proposed study for the considered problem are explained in detail.

Chapter 4 presents a proposed controller designed employing fuzzy reasoning into SNN for performing control action of grid connected DFIG. In this chapter, fuzzy processing carried out for the inputs that are to be presented for SNN and each input spikes representing a fuzzy input membership function is presented in detail. Simulation results computed prove the efficiency of the proposed controller in terms of the fitness function evaluated and other performance metrics than that of the earlier proposed controller modules existing in the literature.
Chapter 5 presents a controller designed by employing ICA based ELMAN NN to handle the FRT of the grid connected wind turbines, which are connected along with DFIG. The ELMAN NN is introduced in this chapter, wherein its weights are tuned optimally using the ICA model. The simulated results prove the effectiveness of the controller design in comparison to be better with that of the methods available in the literature and that of the other proposed controllers.

Chapter 6 proposes an intelligent controller employing Real Coded Genetic Algorithm (RGA) and Fuzzy approach to handle FRT of the considered electrical system. This fuzzy controller activates with formulation of rule base to give signal along with the q-component of the rotor current and eliminate the additional hardware circuitry required. The simulation results computed prove the effectiveness of the proposed RGA-fuzzy controller to be better in comparison with that of the methods available in the literature and as well that of the methods proposed earlier in this thesis.

Conclusion of the contributions made in the thesis work and suggestions for future scope are presented in the Chapter 7.

Appendix, list of references and a list of papers published based on this research work are given at the end of this research thesis report.

1.8 SUMMARY

This chapter presented an introduction to the need for FRT of grid connected wind turbine system and its importance to grid sector. It provides an in-depth justification about the motivation towards this research work and as well the need of proposed controller models based on heuristic intelligent techniques. It also discusses about the need for the research work
and an extensive literature review on various control system design adopted for grid connected wind turbine along with DFIG. This chapter deals about the major contributions towards the research problem undertaken in the area of FRT of grid connected wind turbines and sketches the details on the outline of this thesis.