CHAPTER 2
LITERATURE SURVEY

A method for the steady state analysis of self-excited induction generators using balanced terminal capacitors is presented. The operating characteristics are governed by the magnetic saturation in the machine. Saturation has been incorporated by the use of experimental data, which indicate the variation in magnetizing reactance with air gap flux. Operational and steady state equivalent circuits of the induction machine are employed to predict the steady state performance under different load conditions. The analytical procedure and the related computer program are described in this reference. Simulated results are presented and compared with corresponding results obtained experimentally and a reasonable correlation has been observed [21].

The capacitance requirements for isolated self-excited induction generators are discussed. It is concluded that the steady state as well as operational equivalent circuit methods give same value of the terminal capacitance required to maintain self-excitation under steady state operation. No load terminal capacitance requirements can be estimated by the analytical method proposed and give good agreement with the experimental measurements. Simplified no load model can be used to predict the performances of the self-excited induction generator with good accuracy. The influence of load impedances and its power factor on the terminal capacitance required to maintain self-excitation under steady state is also examined. The terminal capacitance required for a loaded machine is significantly higher than the corresponding no load values. It is affected by load impedance, its power factor and machine speed. The maximum power output from an isolated self-excited generator depends upon the terminal capacitances and the machine speed [22].

An accurate method of analysis is used to predict the steady state performance characteristics of a three-phase isolated induction generator with a single capacitor and feeding a single-phase load. It has been concluded that analytical equations are proposed to find the limiting values of the terminal capacitor and the
machine speed, below which an unloaded machine does not maintain self-excitation. For a loaded machine, there are also limiting values which determine the ranges of capacitance, voltage and the load impedance over which self-excitation can be maintained. These extreme values can be computed by following the proposed method of analysis. Capacitance, voltage and the load parameters affect the performance characteristics of a self-excited induction generator. Generally, the value of capacitance has a stronger influence on the performance characteristics and should be selected such that the terminal voltage is near its rated value while keeping capacitance close to its lower limiting value. The voltages and currents are unbalanced with relatively high losses with lower efficiency. Between the two configurations discussed, the delta-connected generator offers a higher current and lower terminal voltage and a wider range of excitation capacitance [23].

Investigation of behavior of grid connected induction generators driven by typical prime movers are presented with certain practical operational problems. Effects of variation in grid voltage and frequency input power and terminal voltage are studied. Analysis of self-excitation conditions on disconnection of supply has been carried out. The various practical aspects considered for study are:

a) The primary distribution network considered is having significant variations in voltage and frequency depending on loading and other conditions
b) Studies with both constant and input powers are carried out
c) Capacitors are connected to generator terminal for power factor improvement
d) The terminal capacitor may cause self-excitation and results high voltage under disconnection from the grid and over speeding of the turbine
e) Effects of system parameters [24].

Transient behavior of a wind driven induction generator after its disconnection from power grid is investigated. The variation of the terminal voltage, armature current, and the rotational speed of a wind driven induction generator after its disconnection from the power grid were presented. Suggestions for protection against self-excitation are made. However, in all cases, the generator was assumed to cover all active power that the local load has consumed [25].
A case study of fixed speed wind turbine induction generator of wind farm system consisting of 36 number of 600 kW fixed speed stall regulated wind turbines interfaced to 33 kV network is presented. This reference has described a comprehensive study of the application of a STATCOM to a wind farm. Several strategies for steady-state voltage and reactive power flow control of a wind farm equipped with a STATCOM were investigated [26].

To facilitate the investigation of the impact of a wind farm on the dynamics of the power system to which it is connected, an adequate model is required. In order to avoid the necessity of developing a detailed model of a wind farm with tens or hundreds of wind turbines and their interconnections, aggregated wind farm models are needed. The work focuses mainly on the development and specification of aggregated wind farm models. Proposed aggregated wind farm model consist of three models:

a) Wind speed model
b) Model of individual wind turbine
c) Specification of wind park layout

The various assumption made are the impedances of cables are neglected and only transformer impedance is considered. The wind speed can be split up in a fully deterministic and fully stochastic part. The fully stochastic part is different for each wind turbine and fully deterministic part is same for each wind turbine. The advantages and disadvantages of various wind turbines are presented [27].

The results of a case study concerning reliability evaluation of Ramgiri wind farm in Andhra Pradesh, India are discussed. It consists of several 250 kW wind electric generators connected to the grid. The failure and repair rates were presented. From each generating station the probability of the total generating capacity not exceeding a given power level were computed by using a computer software program. It has been concluded that the system availability for the given capacity is evaluated. This gives a measure of the reliability of the system [28].

In this reference the voltage variations associated with a 60 MW offshore wind farm being connected into an existing power network have been discussed. It
concludes that an SVC at the grid connection point can mitigate voltage problems. In addition to this, the instability that can occur in a wind farm due to network faults and the recovery from such faults has been discussed [29].

Various reactive power techniques are presented for improvement of the ride through capability of induction generators during disturbances on a 114 MW wind farm interconnected to 138 kV transmission systems. Voltage ride through capabilities during system disturbances with different reactive power compensation techniques are studied and compared. Effects of various types of reactive power compensation techniques on all voltages of wind farm terminals and nearby buses are studied. The various cases considered for simulation studies are:

1) System without any reactive power compensator
2) System with fixed capacitor banks and various generations as a percentage of total installed capacity
3) System with FC TCR for different wind generation as a proportional of total installed capacity

The proposed work is carried out by considering the various assumptions.

a) The compensation of SVC is assumed on power factor control mode.
b) All induction generators are assumed to operate at 0.85 leading power factor for the entire operation range.

It has been concluded that operation of wind farm at 0.95 leading, unity power factor does not survive after disturbance and the situation is better during disturbance at 0.95 lagging power factor and the performance of SVC is better than fixed capacitor on both steady state as well as dynamic stability [30].

A work is carried out in relation to the harmonic behavior of wind electric converter in grid-connected mode varying wind speed condition at Maharashtra energy development agency’s 1.84 MW demonstration wind power project at Gudhepanchgani in Maharashtra state (India) as a case study. The voltage and current waveforms are observed. Power quality is affected due to the variation of frequency, voltage, wave shape, asymmetry, transients, impulses, non-sinusoids etc. Power
quality variations are unavoidable as the wind parameters are continuously changing [31].

The measurements taken at wind power project and 220/33 kV substations in Satara district of Maharashtra state in India for the comparison of voltage harmonics generated by grid connected wind turbines are described. The parameters like voltage distortion factor, harmonics, and crest factor are monitored. It is concluded that the short circuit level of the grid network is very high than the wind power penetration into the network; the impact of wind turbines on power quality is not significant [32].

STATCOM based on voltage source converter (VSC) PWM technique rated at 50 Hz, 50 MVA is used to stabilize grid connected squirrel cage wind generator system. Fuzzy logic controller (FLC) is used as the control methodology of STATCOM, rather than conventional PI controller. The voltage sag and swell improvement of wind power generation system (WPGS) is compared with both fuzzy and PI controller where the simulations have been done by PSCAD/EMTDC. It is concluded that STATCOM equipped with FLC gives better performance than STATCOM equipped with conventional PI controller. Voltage sag and swell improvement of wind power generation system (WPGS) is compared with both fuzzy logic controller (FLC) and PI controller. The proposed work is carried out for small power system. It is necessary to investigate the WPGS connected with D-STATCOM to large power system and use of more intelligent controller for STATCOM and its interface to large power systems addressing various issues such as security, stability, voltage profile improvement and power quality. Effect of network strength at point of interface on rating and cost of STATCOM is not addressed [33].

A stability of wind farms rated at 60 MW based on fixed speed induction generators (FSIG) and investigates the use of SVC and STATCOM for wind farm are presented. Wind farm models based on FSIG and equipped with either SVC or STATCOM are developed in PSCAD/EMTDC. Stability of FSIG based wind turbine is highlighted using torque slip and reactive power slip characteristics. A detailed investigation is conducted on impact of SVC/STATCOM on system recovering after a network fault. Influence of SVC/STATCOM ratings and network strength on system
stability is considered. The performance of SVC and STATCOM is compared during disturbances on connected network. It was found that SVC and STATCOM considerably improves the stability during and after disturbances especially when network is weak. Compared to SVC, STATCOM give a much better reactive support to the network. The study is carried out for 60 MW wind farm. It is necessary to investigate the application of STATCOM for large size remote wind farms where load centers are far away from the point of connection [34].

A case study of 12-bus multimachine benchmark power system including a large wind farm rated at 360 MW is used. By using suitable software investigates the effects of the STATCOM and static synchronous series compensator (SSSC) devices on the 12-bus power system including a large wind farm by conducting simulation studies. STATCOM has been used to provide smooth and rapid steady state and transient voltage control at points in the network. SSSC has an excellent performance in damping low frequency power oscillations in a power network. It is concluded that FACTS devices provide an effective means of dynamic voltage control of wind farm, dynamic power control of the transmission lines, improving power oscillations damping and transient stability. It is necessary to extend the work for the large wind farms having DFIG, SFIG. The sizing of FACTS devices is not considered [35].

Solution for integration of large offshore DFIG based wind farms with common collection bus controlled by a STATCOM into the main onshore grid using line commutated HVDC connection are presented. The rated voltage of the offshore AC bus is 132 kV, rated HVDC power is 1000 MW (500 kV/2 kA) and STATCOM energy storage is 9 MJ. A design procedure is described and controlled system is validated using PSCAD/EMTDC simulations confirming high performance of the proposed control strategy in both normal operation condition and faults. Engineering issues related to STATCOM capacitor sizing and reduction of STATCOM rating are considered and effectiveness is confirmed. Reduction of STATCOM rating can be achieved by increasing the HVDC rectifier current loop band with or by utilization of reactive power capabilities of grid side converter controlling DFIG’s. The proposed control system can be satisfactory solution for integrating large offshore DFIG based
wind farms into existing AC networks. The proposed work focuses mainly on DFIG based offshore wind farms integration into existing AC network by using line communicated HVDC connections. It is necessary to study the power quality aspects and implementation of STATCOM for improvement of power quality [36].

A discrete-time sliding mode control of a VSC based STATCOM are used for wind farm connection to the grid. A sliding-mode controller has been used for currents while pole placement with a slower dynamic response has been used for DC bus voltage control. It is concluded that a discrete-time sliding mode control of a VSC based STATCOM show a small variation of DC bus voltage and a one-sample time step response for reactive power changes in case no voltage saturation occurs. If voltage saturates, a slightly slower response is obtained, but the good performance of the system is maintained. A good response to DC bus voltage disturbances has also been obtained. It is limited to current and voltage stability. The work is restricted to grid using ideal voltage source with its line resistances and inductances with VSC control. The various objectives are DC bus voltage regulation to its reference value and reactive power tracking at connection point. The considered network is small and effect of SCL at point of connection is not considered. It is necessary to extend the work for large network with non-ideal voltage source and effects of SCL at point of interface [37].

The analysis of a three-phase self-excited induction generator (SEIG) having a rating of 5 HP, 475 V, 15 A, 4 pole with STATCOM supported with battery energy storage system are described. The behavior of SEIG operating with STATCOM having constant DC link battery under open load condition is analyzed. A mathematical model of SEIG - STATCOM system has been developed. With the developed model equations a new equivalent circuit of the system has been arrived at and it has been simulated in MATLAB / Simulink environment. The effect of change in STATCOM modulation index “m” and relative phase angle “δ” between the fundamental components of STATCOM and SEIG voltage, on the SEIG terminal voltage and frequency and average SEIG and STATCOM active and reactive power flow, with given load and excitation capacitor, has been investigated. Variation in “δ”
changes both active power and reactive power flow at the SEIG terminals also simultaneously changing both terminal voltage and frequency of the SEIG. The proposed work does not covers the operational behaviors of SEIG with STATCOM used in wind farms interfaced to grid covering the various aspects such as stability, reactive power control, ride through during fault conditions and power quality management [38].

A case study of 2 MW, 690 V, and fixed speed machine connected to a simple weak network is presented. The short circuit level at point of connection was taken as 12 MVA. The ratio of SCL to wind farm apparent power is equivalent to the situation experienced by small wind farm connected to weak grid. Control techniques were developed for this hybrid unit and simulated by EMTDC/PSCAD simulation. The proposed techniques have been studied for 2 MW fixed speed induction generator interfaced to simple weak network and performance is evaluated for balance faults. The critical clearing time was studied for three cases without STATCOM BES and BR, with STATCOM BES and with STATCOM BES and BR. The simulation results confirm that STATCOM BES improves the stability margin of wind turbine by 300 % and a further 50 % improvement was achieved with the BR when compared with the wind farm operated alone. STATCOM BES can be used to eliminate power fluctuations. The cost effective sizing of STATCOM and battery energy storage is not evaluated. The entire mechanical aspects of the wind turbine was not modeled and work focuses mainly on use and control of the hybrid STATCOM rather than an obtaining precise values for wind turbine response. Cost effectiveness of use of alternate energy storage technologies is not considered. There is need to extend the work for large wind farms to evaluate performance of proposed techniques considering techno economic aspects for improvement of power quality and stability [39].

The performance analysis of STATCOM - based voltage regulator for isolated self-excited induction generators (SEIGs) having a rating of 22 kW, 400 V, 40 A, 6 pole machine supplying nonlinear loads are discussed. A simple mathematical model of the SEIG - STATCOM system under balanced and unbalanced three phases and
single phase nonlinear loads (controlled and uncontrolled rectifiers) is presented. The
SEIG is an isolated system, which is small in size and feeding nonlinear loads only. The
simulation results show that SEIG terminal voltage is maintained constant even
with nonlinear balanced and unbalanced load and free from harmonics using
STATCOM based voltage regulator. The work focuses only on a small SEIG operated
in isolated system feeding nonlinear loads only. Due to importance of energy
conservation the percentage of nonlinear loads is increasing at fast rate imposing
various power quality challenges. It is necessary to extend the application of
STATCOM for SEIG of higher ratings operated in large wind farms interfaced to grid
feeding linear and nonlinear loads. The use of STATCOM shall be considered for
stability improvement as well as improvement of power quality taking considering
 techno economic aspects [40].

A case study of 2 MW doubly-fed induction generator (DFIG) based wind
turbine connected to an infinite bus through a transformer are described. It was
analyzed by using PSCAD/EMTDC simulation. The reference presents the overview
of the operation and control of a DFIG. It is concluded that a 2 MW DFIG based wind
turbine connected to an infinite bus through a transformer was modeled using PSCAD/
EMTDC simulation. The functionality of DFIG arrangement and controls for
maximum power extraction and reactive power control has been discussed. The study
is restricted to single DFIG interfaced to infinite bus bar and doesn’t cover the reactive
power, voltage control issues when large number of DFIG are interfaced to grid
having faults level near to 20 times that of wind farm power rating. Ride through
capability of DFIG during faults condition is also not studied [41].

A case study of a 36 MW fixed speed wind farm composed of 40 squirrel cage
induction generators having rating of 0.9 MW is equipped with a STATCOM and a
 capacitor bank are discussed. The strength of grid is 800 MVA, which is 20 times the
power of wind farms. The wind farm is connected to HV network by means of 40
MVA, 20/220 kV transformer. A modified STATCOM controller with 0.95 leading
P.F. is analyzed by means of hybrid real time tests and offline simulations in
PSCAD/EMTDC for both in normal and fault conditions. Critical aspects like
STATCOM rating and control are analyzed. It is concluded that there is a great contribution of reactive power compensators to the transient behavior of fixed-speed wind farms. Also minimum rating of a power electronic compensation can be reduced to 50% of the wind farm nominal power with an appropriate control strategy. According to author, STATCOM helps to improve transient response of fixed speed wind farm during faults. The work is mainly focused on fixed speed wind farm and for improvement of ride through capability during fault conditions. The study is not extended to interfacing of wind farms to weak grids and effect of grid fault level at point of interface on sizing and cost of STATCOM [42].

It covers the wind power quality issues such as a) Wind turbine constructive parameters – nominal and reference power, active and reactive power. b) Wind power fluctuations – 1) Steady state – A flicker emission, long and short term emission. 2) Transient state – wind turbine cut in and cut out, voltage dips and drops. c) Imbalances and harmonics - current harmonics and inter harmonics. The possibilities of extrapolation from standards to grids and the issue of generalized grid code are addressed [43].

Various models of the induction generator in wind turbine under the transient using PSCAD/EMTDC software are discussed. In this reference, the simulated results under single line to ground fault are presented. The simulation is carried out at two values of grid frequency with same input conditions. It is concluded that the grid frequency has a distinct impact on the response of induction generator in transient fault [44].

This reference explains the modeling of the different elements in the wind farm to perform harmonics analysis. Potential parallel and series resonance problems that can occur in a large wind farm are analyzed. Solutions to mitigate harmonics problems are given like:
1) In the design stages, the size of substation capacitor banks can be adjusted to avoid the occurrence of resonance at certain frequencies.
2) Series filters are built by the addition of series reactors to the substation capacitor bank. Also the resulting impedances has series resonance will be shifted to a less problematic frequency.

3) The use of C type filters. These convert the substation capacitor bank into a shunt filter with damping. A case study on a 200 MW wind plant is used to explain the procedures of performing harmonics analysis. There is need to examine different harmonic mitigation solutions [45].

If the power network is not able to satisfy the wind farm reactive power requirement, the integration of the wind farm into the large power system would be limited and the overall energy losses in the distribution networks would be increased, even more voltage problems would also be caused. Tabu search algorithm and sensitivity analysis are applied to optimize the reactive power compensation for wind farms. An objective function composed of power losses, capacitor installations cost, and bus voltage and wind turbines output constraints are proposed. The reactive power optimization scheme is also presented and the optimization method is tested in a MATLAB based simulation model. It has been concluded that the proposed reactive power optimization method like SVC is simple and effective, and it can correct voltage deviation and reduce power loss [46].

When there is a fault in the power system on which the wind farm is connected having constant speed wind machine with SCIG. Simulation was done using standard 9-bus-3 generator systems. The output voltage fluctuation of wind farm will different according to the different types of wind machine. The voltage transient profile is different according to the different places where the wind farms are connected. It has been concluded that the local power system with wind farm connected is relatively weak; the short circuit capacity of the point at which wind farm connected is less. So the voltage problem is important during fault on power system [47].

Particle swarm optimization method (PSO) is used to solve the reactive power and voltage control (RPVC) problem in wind farm interfaced to grid. PSO is a stochastic optimization strategy from the family of evolutionary algorithms. With
significant increase of renewable energy sources contributing to the power generation mix, efficient online optimization techniques are required to ensure the successful integration of such sources. The PQ (where real and reactive power demand are known) and PX (where real power generated and nonlinear magnetizing reactance are known) wind turbine generator (WTG) models perform competitively when included as aggregated wind farm (WF) models in the IEEE 14-bus test system. Similar results for overall system reactive power losses were achieved for both models. Methods for calculating the reactive power consumption of each WTG is differed, causing an overall discrepancy between the two models in the reactive power consumption of the entire WF. Further improvements to the PX model could include calculating the magnetizing reactance as a (nonlinear) function of voltage for iteration, which may yield more accurate results. The fact that the PX model calculates its reactive power consumption from the previous load flow iteration’s. The impact of wind speed should be assessed with both of the models considered, as it would give a more realistic indication of the real power output of the WF. The particle swarm optimization (PSO) is an effective optimization strategy, which handles mixed-integer nonlinear optimization problems with ease [48].

A case study of wind farm connected to infinite bus to investing the benefits of a D-STATCOM on an AC network is used. This reference presents the design, control and analysis of a D-STATCOM when connected with a wind farm consisting fixed speed induction generators. The MATLAB software package is used to simulate the proposed compensation techniques. A vector control technique based on the decoupling of real and reactive power is implemented to eliminate wind power fluctuations. Super capacitors have been used as the energy storage technology as they are free from traditional battery problems of limited cycle life and limited charging rates. A methodology is presented to derive the required energy storage to achieve a certain level of flicker mitigation at the point of common coupling. It is concluded that use of STATCOM with energy storage provide real and reactive power flow also it has the ability to reduce power fluctuations generated by wind farm consisting fixed speed induction generators. Also wind farm’s fault ride through capability can be improved by using STATCOM with energy storage. The study is restricted to use of
only one type of energy storage and cost effective sizing of energy storage is not considered [49].

Power quality issues in the large-scale grid interfacing of wind electricity generators for reactive power consumption and various methods of mitigating the problems are discussed. This reference also described grid power quality issues, WEG side power quality issues and optimal size and placement of compensation devices. Author has proposed hybrid reactive power compensation system for wind farm system also develop an appropriate controller and control logic, which would meet all the challenges and requirements [50].

A new converter protection scheme presented for doubly-fed induction generators during disturbances. Fault ride-through capability is one of the basic requirements for a large-scale wind farm. There are two aspects to fault ride-through: to continue power supply without breaking any part of the system and to resume normal operation after clearance of the fault. The transients of the doubly-fed induction generator are analyzed. The safe operating area characteristics of the IGBT converter are also considered. The use of a high-power resistor as a traditional crowbar, DC-link braking resistor and a series dynamic resistor are discussed. From the discussion, a new protection control scheme, with a crowbar and a series dynamic resistor, is proposed. The new scheme is shown to reduce the rotor high current, maximize the working time of DFIG control then reduce the power, speed and torque fluctuations and protect it during disturbances [51].

A short-circuit current of wind turbines with doubly fed induction generator is discussed. The short circuit current contribution of wind turbines has not received much attention so far. This reference considers the short-circuit behavior, especially the short-circuit current of wind turbines with a doubly fed induction generator. Mostly, these wind turbines have a crowbar to protect the power electronic converter that is connected to the rotor windings of the induction generator. The maximum value of the short-circuit current of a conventional induction machine is determined. The differences between a crowbar-protected doubly fed and a conventional induction generator are highlighted and approximate equations for the maximum short-circuit
current of a doubly fed induction generator are determined. The values obtained in this way are compared to the values obtained from time domain simulations. The differences are less than 15% [52].

A performance study of a doubly fed wind-power induction generator under network disturbances is discussed. Transient performance of a 1.7 MW wind-power doubly fed induction generator (DFIG) under network disturbances is studied using a coupled field-circuit simulator. The simulator consists of the finite-element method model of a DFIG coupled with the circuit model of the frequency converter, a transformer, and a simple model of the network. The simulation results show the transient behavior of the DFIG when a sudden voltage dip is introduced. The field-circuit simulator is experimentally validated by full-power measurement [53].

The fundamental difficulty for the DFIG in ride-through is the electromotive force (EMF) induced in the machine rotor during the fault, which depends on the DC and negative sequence components in the stator-flux linkage and the rotor speed. The investigation develops a control method to increase the probability of successful grid fault ride-through, given the current and voltage capabilities of the rotor-side converter. A time-domain computer simulation model is developed and laboratory experiments are conducted to verify the model and a control method is proposed. Case studies are then performed on a representatively sized system to define the feasibility regions of successful ride-through for different types of grid faults [54].

Evaluation of current control methods for wind turbines using doubly-fed induction machines is discussed. Different rotor current control methods are investigated with the objective of eliminating the influence of the back electromotive force (EMF). It is found that the method that utilizes both feed-forward of the back EMF method to suppress the influence of the back EMF on the rotor current during voltage sag. The proposed method is robust and reliable [55].

The doubly fed induction generator (DFIG) is a variable-speed constant-frequency generator operating in either sub synchronous or super synchronous mode. The transient behavior of the doubly fed induction generator, symmetrically loaded,
during three phase short circuit is presented. Both speed and rotor excitation voltage and frequency remain unchanged during short circuit fault. The complete mathematical model of the transient state and experimental results are presented [56].

The issues of German grid codes relating to wind turbines are discussed. With the high utilization of wind power a simultaneous loss of several thousand MW wind generation becomes a problem. Main requirement becomes the fault ride through capability of wind turbines. Disconnection of wind turbines and wind farms above 15% nominal voltage at the grid connection nodes is not allowed. During network faults wind turbines have to supply a definite reactive current depending on the instantaneous voltage and must return quickly to normal operation. The frequency range wind turbines have to tolerate is about 47.5 to 51.5 Hz. German transmission grid operators large wind farms have to be treated in the future like conventional power plants [57].

Doubly-fed induction machine models for stability assessment of wind farms, is discussed. The increasing size of wind farms requires power system stability analysis including dynamic models of the wind power generation. Nowadays, the most widely used generator type units are above 1 MW is the doubly-fed induction machine. Doubly fed induction machines allow active and reactive power control through a rotor-side converter, while the stator is directly connected to the grid. Detailed models for doubly-fed induction machines are well known but the efficient simulation of entire power systems with hundreds of generators requires reduced order models. This reference presents a fundamental frequency doubly-fed induction machine model including a typical control system and discusses the accuracy of reduced order models under various operating conditions. The presented components were the doubly-fed induction generator, the grid-side converter, the rotor-side converter, the aerodynamic behaviour of the wind turbine and the pitch control system. For simulating power fluctuations, the wind speed variable must be fed from a measurement file, or stochastic wind models must be used. Possible model reductions making the model suitable for stability assessment in large power systems were presented and discussed. The models were implemented and tested in the power
system analysis package DIgSILENT power factory. Every reduced order model was validated against higher order models. The results of the test cases show that a third order induction machine model including crow bar protection together with a simplified model of the grid-side converter provides sufficient accuracy and the necessary computational efficiency for carrying out stability studies in large power systems with several hundreds of machines [58].

The design and implementation of a novel control scheme for a doubly fed induction generator is presented. It is shown that the controller provides a DFIG-based wind farm with operational and control compatibility with conventional power stations. The ability to contribute to voltage support and recovery following network faults. The ability to provide a power system stability capability with improved overall system damping, and the capability of contributing short-term frequency support following loss of network generation. A simple but realistic test network that combines synchronous and wind farm generation has been modeled and used to assess dynamic performance. Simulation results are presented and discussed that demonstrates the capabilities and contributions of the new DFIG controller to support network [59].

Dynamic modeling of doubly fed induction generator wind turbines is discussed. The requirement of accurate models of doubly fed induction generator wind turbines and their associated control and protection circuits is discussed. A dynamic model has been derived, which can be used to simulate the DFIG wind turbine using a single-cage and double-cage representation of the generator rotor with control and protection circuits. The model is suitable for use in transient stability programs that can be used to investigate large power systems. The behavior of a wind farm and the network under various system disturbances was studied using this dynamic model. The influence of the DFIG control on the stability of the wind farm was also investigated by considering different control gains and by applying network voltage control through both stator side and rotor side converters [60].

Modeling of the wind turbine with a doubly fed induction generator for grid integration studies is presented. Due to its many advantages such as the improved
power quality, high energy efficiency and controllability, the variable speed wind turbine using a doubly fed induction generator is becoming a popular concept. The modeling of the DFIG based wind turbine becomes an interesting research topic. Fundamental frequency models have been presented but these models are often complex. This reference develops a simple DFIG wind turbine model in which the power converter is simulated as a controlled voltage source, regulating the rotor current to meet the command of real and reactive power production. Traditional generator model was used for study. Interaction between the Arklow bank wind farm and the Irish national grid was simulated using the proposed model. The model performance and accuracy was also compared with the detailed model developed by DIgSILENT. Limitation and applicability of the model were also discussed [61].

A solution is described that makes it possible for wind turbines using doubly-fed induction generators to stay connected to the grid during grid faults. The key of the solution is to limit the high current in the rotor in order to protect the converter. A bypass for this current is provided via a set of resistors that are connected to the rotor windings. With these resistors, it is possible to ride through grid faults without disconnecting the turbine from the grid. Because the generator and converter stay connected, the synchronism of operation remains established during and after the fault. Normal operation can be continued immediately after the fault has been cleared. An additional feature is that reactive power can be supplied to the grid during long dips in order to facilitate voltage restoration. A control strategy has been developed that takes care of the transition back to normal operation. Without special control action, large transients would occur [62].

A control scheme that allows doubly fed induction wind generators to participate effectively in system frequency regulation. In this control approach, wind generators operate according to a reloaded optimum power extraction curve such that the active power provided by each wind turbine increases or decreases during system frequency changes. The control strategy defined at the wind generator for frequency regulation. A combination of control of the static converters and pitch control, adjust the rotor speed and the active power according to the optimum power extraction curve.
Results obtained in a small isolated system are presented to demonstrate the effectiveness of the approach [63].

A modeling and a control of doubly fed induction-generator-based variable-speed wind-turbine is illustrated. A detail dynamic model of a DFIG-based wind-turbine grid-connected system is presented in the $dq$-synchronous reference frame. Along with conventional control schemes for wind turbine, an innovative voltage control scheme is proposed that manipulates dynamically the reactive power from the voltage-source converter (VSC) with taking into account its operating state and limits [64].

An effect of sampling in an encoder-less vector-controlled induction motor drive with a digital controller is presented. The analysis focuses on the speed observer and the speed control loop which is executed at discrete instants. It is shown that the estimated speed can fluctuate between samples in the speed loop and cause a sustained resonance via feedback. The shaft inertia is not available to smooth the ripple of the estimated speed and the associated resonance could adversely affect the inverter and machine. An analytical model is proposed to evaluate the risk of such a condition in the design and on-site adjustment of control gains. The requirement for a smoothing filter in the speed loop is identified [65].

Direct power control of doubly-fed generator based wind turbine converters to improve low voltage ride-through during system imbalance is discussed. A novel control technique using direct active and reactive power control called direct power control (DPC) is discussed for low voltage ride through of DFIG based wind turbine converters. This controller eliminates the conventional current loops and uses delta modulation comparators, which yields a faster response. The new grid code requirements for wind power integration state that doubly fed induction generator (DFIG) controllers should be capable of overcoming temporary voltage disturbances. They should remain online instead of tripping due to low voltage [66].

The design of controllers that would keep the wind turbine in stable operation during an external fault that causes the voltage to drop up to 60% for two seconds is
presented. The focus is on the control of the grid-side converter. If the grid-side converter is capable of controlling power flow and maintaining DC bus voltage, then the DFIG will stay online during the disturbance. A fast acting controller eliminates the conventional current control and acts directly upon the real and reactive power of the system. As this control acts directly according to the error in the real and reactive power flows, this control is called direct power control. In DPC, the power required for the converter is commanded using the instantaneous voltages and currents whether they are balanced or not. A modified DPC algorithm is derived to reduce current harmonics that occur in the grid-side converter during disturbances. The controllers based on DPC and MDPC are fast acting; hence they are suitable for sudden grid and wind disturbances. Direct power control is capable of low voltage ride-through (LVRT) for wind turbines and can replace conventional current control schemes [67].

A Practical method for estimation of fault ride-through capability of wind power farms based on squirrel-cage rotor induction generator is used to present a practical method for estimation of fault ride-through capability of wind power farms composed by squirrel-cage rotor induction generators. Proposed method is based on the steady-state equivalent circuit of the induction generator and on the concepts of stable and unstable electrical-mechanical equilibrium points [68].

The use of STATCOM are discussed to improve the power quality like voltage fluctuations due to wind fluctuations and fault ride through capability of wind farm equipped with squirrel cage induction generators (SCIGs). The simulation studies have shown that STATCOM significantly reduces the voltage fluctuations and enhances the fault ride through capability of WTGs [69].

The analysis and simulation are been made to obtained the system stability from the point of load disturbances. A wind farm modeling and STATCOM usage are studied to increase the upper limits of induction generators dynamic stability in various distortion conditions in grid [70].

The power quality problems such as voltage flicker and harmonic distortion along with reliability issues of wind farm are discussed. Wind turbine connected to an
induction and synchronous generator is modeled to analyze power quality and reliability problems. STATCOM unit is developed to inject reactive power to mitigate power quality problems and to get stable grid operation [71].

Investigation of reactive power compensation strategies to mitigate voltage quality problem in power system such as flicker, sag, swell and unbalance is presented. This reference utilizes the principles of reactive power compensation, phase voltage differences and the negative component to design three controllers, namely balance controller, phase voltage unbalance controller and negative sequence controller [72].