Journal of Naval Science and Engineering
2010, Vol. 6 , No.2, pp. 166-185

EVALUATING THE IMPACTS OF WIND FARMS ON POWER SYSTEM OPERATION

Ph.D.Özgür Salih MUTLU, Lt.
Ministry of National Defence,
İzmir Construction & Estate Regional Authority
Konak, İzmir, Turkey.
ozgurmutlu@yahoo.com

Abstract

This paper presents evaluation methods to study the impacts of wind energy conversion systems on power system operation Detailed information is given about the parameters which has essential significance in further operation of the wind farm in the power system and their influence on each other. The objective of this study is to determine the methodology for studies about power system- wind energy interconnections.

GÜÇ SİSTEMİ ÜZERİNDE RÜZGAR SANTRALLERİNİN ETKİLERİNİN DEĞERLENDİRİLMESİ

Özetçe

Bu makalede rüzgar enerjisi dönüşüm sistemlerinin, güç sistemi üzerindeki etkilerinin değerlendirme metotları üzerinde durulmaktadır. Güç sistemindeki rüzgar çiftliğinin daha da iyi çalştırılması üzerindeki hayati öneme haiz parametreleri ve birbirlerine olan etkileri hakkında detaylı bilgi sunulmaktadır. Bu çalışmanın amacı güç sistemi - rüzgar enerjisi bağlantıları hakkındaki çalışmalar için metodolojiyi belirlemektir.

Keywords: Wind Energy Conversion Systems, Power System, Grid Codes.
Anahtar Kelimeler: Rüzgar enerjisi dönüşüm sistemleri, güç sistemi, Grid kodları.

1. INTRODUCTION

Sources of energy for the production of electricity are many and varied. Wind power is being used as a clean and safe energy resource for electricity generation for nearly a hundred years. The early established wind farms had relatively smaller power rated generators with respect to conventional power stations. But nowadays, large power rated offshore wind farms are being installed to control power system data instead of conventional ones.

The wind farms have different impacts and functions on the performance of the grid than conventional power plants, because of variation of wind speed in time. Doubly fed and squirrel cage induction generators are widely used in wind energy conversion systems. These generators are usually grid-coupled via power electronic converters in order to control the voltage, frequency and power flow during the variation of wind speed. As a consequence, wind turbines affect the dynamic behaviour of the power system in a way that might be different from hydrolic or steam turbines[1].

The increasing percentage of wind energy conversion systems in electrical power production has amplified the need to address grid integration concerns. Power system operators or transmission system operators(TSO) need simulation tools and scientific practices before wind power-power system integration to guarantee reliable operation of the system with wind power. Power system reliability consists of system security and adequacy.

In order to assure reliable operation, TSO demanded high short-circuit power capability at wind farm connection buses, like at least 20 times greater than the wind farm nominal power. These regularities impede further penetration of wind power because of power system operational precautions.

There are guidelines, recommendations and requirements which deal with the technical data needed to assess the impact of wind turbines on power system and discuss the requirements to be met by networks to which wind turbines are to be connected. Research groups are founded by goverments, universities, manufacturers, wind farm owners and power system operators to develop grid codes for wind farm-grid integration. In the last years the trend has moved from installations including few wind turbines to planning of large wind farms with capacity over hundreds of MW. Figure 1.1 shows impacts of wind power on power systems, divided in different time scales and width of area relevant for the studies.

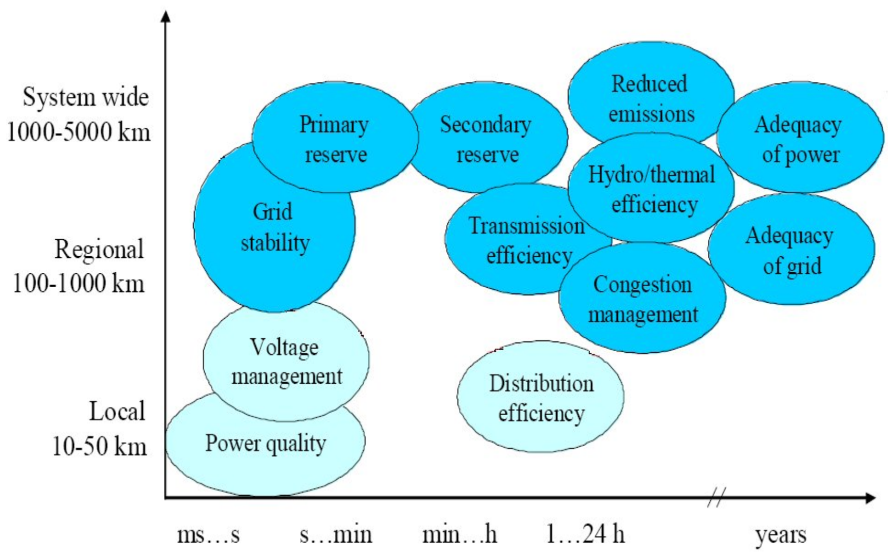

Figure 1.1 Impacts of wind power on power systems, divided in different time scales and width of area relevant for the studies[2].

At the time of developing the standard IEC 61400-21:"Measurement and assessment of power quality characteristics of grid connected wind turbines", the wind turbines were mainly connected to the distribution grid, and the basic concern was their possible impact on the voltage quality and not on power system operation. This has changed with the development of large power rated wind farms that may form a significant part of the power system. In consequence, today's wind turbines are able to control the power (active and reactive) delivered both in transient and steady state, they can cope with power ramp requirements and they have low voltage ride through(LVRT) capability. They may even contribute to the primary frequency control, but then on the cost of dissipating energy.

2. POWER SYSTEM, DISTRIBUTED GENERATION, WECS CONNECTION ISSUES AND GRID CODES

The interconnected power system is often referred to as the largest and most complex machine ever built by humankind. This may be hyperbole, but it does emphasize an inherent truth: there is a complex interdependency between different parts of the system. The aim of this complex machine is to produce and deliver to the consumers electric energy of defined parameters, where the main quantities describing the electric energy are the voltage and frequency. It has to be operated to ensure a continuous supply at the consumers terminals. The voltage should be a sinusoidal wave with nominal amplitude and a frequency[3,4]. The power system can be separated into three major subsystems: generation system, transmission system, and distribution system.

The vast majority of generation is carried out by synchronous generators. The source of the mechanical power, commonly known as the prime mover, are hydraulic turbines, steam turbines or alternate sources. Hydraulic turbines operate with low speed and their generators have salient type rotor with many poles. Steam turbines operate relatively high speeds and coupled with cylindrical rotors. The purpose of the electric transmission system is the optimal high voltage interconnection of the electric energy producing power plants or generating stations with the loads. A three-phase AC system is used for most transmission lines. The distribution system is the part of electric power system between the bulk power source and the consumers' service switches. It operates in low and medium voltage levels and includes subtransmission systems; distribution substations; distribution lines; and appropriate protective and control equipment[5].

2.2 Power System Connection Issues of Wind Energy Conversion Systems

The wind farms have different impacts and functions on the performance of the grid than conventional power plants, because of variation of wind speed in time. Many studies have been performed on grid connected wind farms and related power system issues. Different techniques and models have been used for determining problems; the impacts of wind farms on technical and operational characteristics of power systems and technical requirements for wind farm-grid connections were analyzed. The doubly fed and squirrel cage induction generators are widely used in wind energy conversion systems. These generators are usually grid-coupled via power electronic converters in order to control the voltage, frequency and power flow during the variation of wind speed. As a consequence, wind turbines affect the dynamic behaviour of the power system in a way that might be different from hydrolic or steam turbines. The factors that cause these affects will be analyzed in this section.

2.2.1 Location of the Wind Farm in the Electric Power System

The point of common coupling(PCC) of wind farms and the power system, including the parameters of the power system, the parameters of wind farm and the structure of the grid are of essential significance in further operation of the wind farm in the power system and their influence on each other. The size and the location of the considered wind farm and the parameters of the grid in that region highly influences the appropriate PCC.

Wind farms must be located in the regions that have favourable wind conditions. These regions can be shorelines and islands where the power network in these regions can be named as “weakly developed”. A part of power grid can be named as “weak” when it is electrically far away from the infinite bus of the interconnected power system. The weak grids have lower short circuit power than strong grids relatively. The short circuit power level in a given point in the electrical network represents the system strength.

Figure 2.1(a) illustrates an example of one line diagram of wind farm connection to a grid and (b) shows phasor diagram.

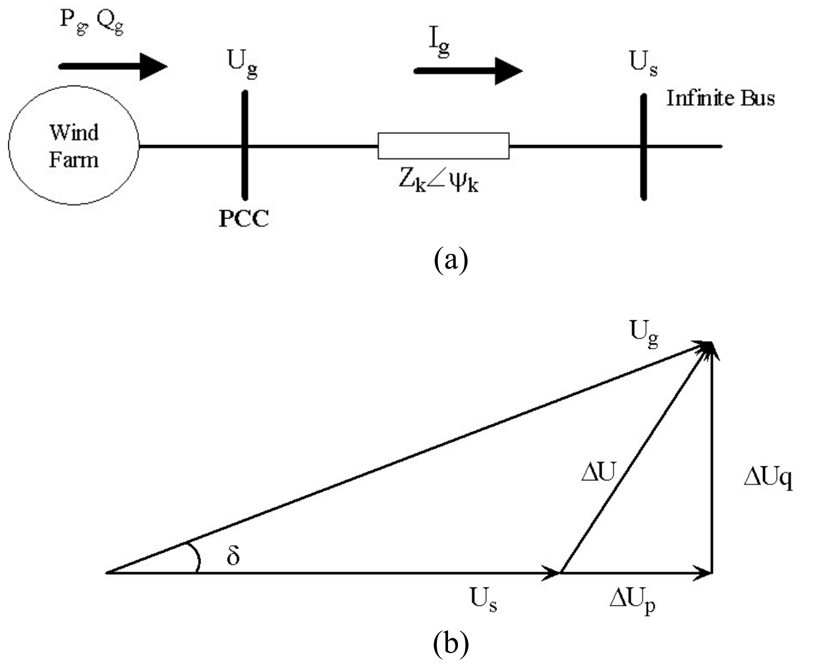

Figure 2.1 (a) One line diagram of wind farm connection to a grid, (b) Phasor diagram

Wind farm is connected to the network with equivalent short circuit impedance, Z_k. The network voltage at the assumed infinite busbar and the voltage at the PCC are U_s and U_g, respectively. The output power and reactive power of the wind farm are P_g and Q_g, which corresponds to a current I_g.

$$I_g = \left(\frac{S_g}{U_g}\right)^* = \frac{P_g - jQ_g}{U_g} \tag{2.1}$$

The voltage difference, ΔU, between the infinite system and the PCC is given by

$$U_g - U_s = \Delta U = Z_k . I_g = (R_k + jX_k)(\frac{P_g - jQ_g}{U_g}) \tag{2.2}$$

$$\Delta U = \frac{R_k P_g + X_k Q_g}{U_g} + j\frac{P_g X_k - Q_g R_k}{U_g} = \Delta U_p + j\Delta U_q \tag{2.3}$$

The short circuit impedance, the real and reactive power output of the wind farm determines the voltage difference. The variations of the generated power will result in the variations of the voltage at PCC. When the impedance Z_k is small, then the grid can be named as strong and when Z_k is large, then the grid can be named as weak. Since strong or weak are relative concepts, for a given electrical wind power capacity P, the ratio,

$$R_{sc} = \frac{S_{sc}}{P} = \frac{U_s^{\ 2}}{Z_k . P} \tag{2.4}$$

stated as the measure of the strength, where S_{sc} is short circuit power. The grid may be considered as strong with respect to the wind farm installation if R_{SC} is above 20. It is obvious from (2.4) that for large wind farm-grid connections, the PCC voltage level have to be as high as possible to limit voltage variations[6].

Local wind farms are the most typical forms of distributed generation. Although distribution systems are planned for unidirectional power flow from transmission system to the consumers, the amount of distributed generation located at the distribution level of electrical networks is showing rapid growth worldwide. Issues such as new energy sources, efficiency of local energy production and modularity of small production units are promoting this growth. On the other hand, large power rated wind farms connected directly to the transmission level do not actually meet the definition of distributed generation since those are named as the members of generation system[7].

In case of wind farm installations on islands and offshore platforms the underwater transmission of power to the mainland power system has to be performed by cable. For long distance transmission, the transmission capacity of cables may be mainly occupied by the produced reactive power, therefore ac transmission will meet difficulties. In this situation high voltage direct current (HVDC) transmission techniques may be used. Figure 2.2 shows different wind farm connections to grid.

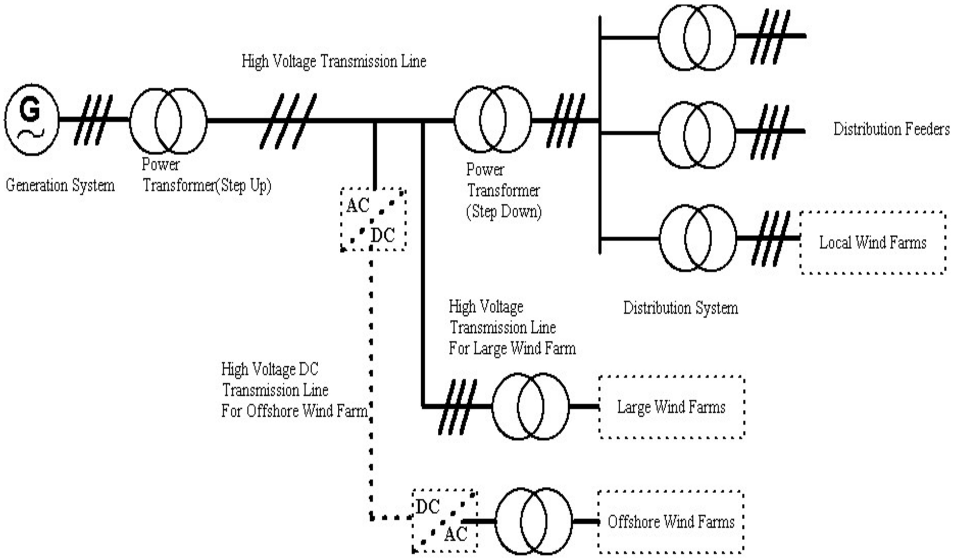

Figure 2.2 Different wind farm connections to a grid.

2.2.2 Impacts of Wind Farms on Power Quality

The currently existing power quality standard for wind turbines, issued by the International Electrotechnical Commission (IEC), IEC 61400-21: "Measurement and assessment of power quality characteristics of grid connected wind turbines", defined the parameters that are characteristic of the wind turbine behavior in terms of the quality of power, and also provides recommendations to carry out measurements and assess the power quality characteristics of grid connected wind turbines. Although the standard mainly describes measurement methods for characterizing single wind turbines, there are methodologies and models developed that enable, for well pre-defined conditions, to extrapolate the single turbine unit parameters to the typical quality characteristics of wind farms.

Since voltage variation and flicker are caused by power flow changes in the grid, operation of wind farms may affect the voltage in the connected network. On the local level, voltage variations are the main problem associated with wind power. This can be the limiting factor on the amount of wind power which can be installed. If necessary, the appropriate methods should be taken to ensure that the wind turbine installation does not bring the magnitude of the voltage at PCC outside the required limits.

2.2.3 System Stability

Stability analysis of the power system is a large area that covers many different topics. A formal definition of power system stability is provided by “IEEE/CIGRE Joint Task Force on Stability Terms and Definitions” as the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

Tripping of transmission lines, loss of production capacity and short circuits are named as power system faults which are related to system stability. These failures affects the balance of both real and reactive power and change the power flow. Though the capacity of the operating generators may be adequate, large voltage drops may occur suddenly. The unbalance and re-distribution of real and reactive power in the network may force the voltage to vary beyond the boundary of stability. A period of low voltage may occur and possibly be followed by a complete loss of power. Many of power system faults are cleared by the relay protection of the transmission system either by disconnection or by disconnection and fast reclosure. In all the situations the result is a short period with low or no voltage followed by a period when the voltage returns. A wind farm nearby will see this event. In early days of the development of wind energy only a few wind turbines, named earlier as local wind turbines, were connected to the grid. In this situation, when a fault somewhere in the lines caused the voltage at the PCC of local wind turbines to drop, local wind turbines were simply disconnected from the grid and were reconnected when the fault was cleared and the voltage returned to normal.

Because the penetration of wind power in the early days was low, the sudden disconnection of a wind turbine or even a wind farm from the grid did not cause a significant impact on the stability of the power system. With the increasing penetration of wind energy, the contribution of power generated by a wind farm can be significant. If a large power rated wind farm is suddenly disconnected at full generation, the system will loss further production capability. Unless the remaining operating power plants have enough "spinning reserve", to replace the loss within very short time, a large frequency and voltage drop will occur and possibly followed by a blackout. Therefore, the new generation of wind turbines is required to be able to LVRT during disturbances and faults to avoid total disconnection from the grid. In order to keep system stability, it is necessary to ensure that the wind turbine restores normal operation in an appropriate way and within appropriate time. This could have different focuses in different types of wind turbine technologies, and may include supporting the system voltage with reactive power compensation devices, such as interface power electronics, SVC, STATCOM and keeping the generator at appropriate speed by regulating the power etc[6].

2.3 Grid Codes for Wind Energy Conversion Systems

Modern MW wind turbines currently replace a large number of small wind turbines and there is a significant attention to offshore wind farms, mainly because of higher average wind speed and no space limitations. Large power rated wind farms are started to operate in superior power systems and more large power rated wind farms are in construction or in the planning stage all over the world. However, in order to achieve objectives as continuity and security of the supply, a high level of wind power into electrical network posses new challenges as well as new approaches in operation of the power system. Therefore countries started to issue dedicated "grid codes" for connecting the wind turbines/farms to the electrical network addressed to transmission and/or distributed system.

These requirements have focus on power controllability, power quality, LVRT capability and grid support during network disturbances. Grid code regulations often contain costly and demanding requirements for wind farm operators due to the increase in share of wind farms in power production. Large wind farms connected at the transmission level have to act as a conventional power plant and participate in primary (local) and secondary(system level) frequency/power control.

The current status of grid codes in Turkey is presented in [8] and discussed with following headlines;

- Low Voltage Ride Through(LVRT) Capability,
- Reactive Power and Voltage Variations,
- Frequency Range, Control of Frequency and Active Power,
- Signals, Control and Communications.

3. TECHNICAL FEATURES OF WIND POWER PLANTS

The wind turbine generator system operation is permanently determined by the speed and variations of the wind. The following four basic operating states can be distinguished: Standstill of the turbine – as a result of the wind speed value falling below the cut-in wind speed $v < v_{cut\text{-}in}$. Partial load – operation with maximum energy extraction from the wind, when the wind speed v is within the range $v_{cut\text{-}in} \leq v \leq v_n$, where v_n is the rated wind speed. Wind turbine generator generates the rated power at the rated wind speed. Full load – operation with constant and rated load when the wind speed is higher than the rated wind speed $v_n < v \leq v_{cut\text{-}out}$ and simultaneously lower than the maxiumum one. The cut-out wind speed is usually $v_{cut\text{-}out}$ = 25 m/s. Standstill of the turbine – because of too high wind speed v > $v_{cut\text{-}out}$.

These operating states of the wind turbine are usually presented in the form of the power versus wind speed characteristics of the wind turbine. An example of such a characteristic is shown in Figure 3.1[4]. The dashed line shows the power in the wind and the continuous line shows the power that the wind turbine can convert to the grid. The vertical axis is the ratio of power generated P_G, to the rated power of the wind turbine P_n, and the horizontal axis is the wind speed.

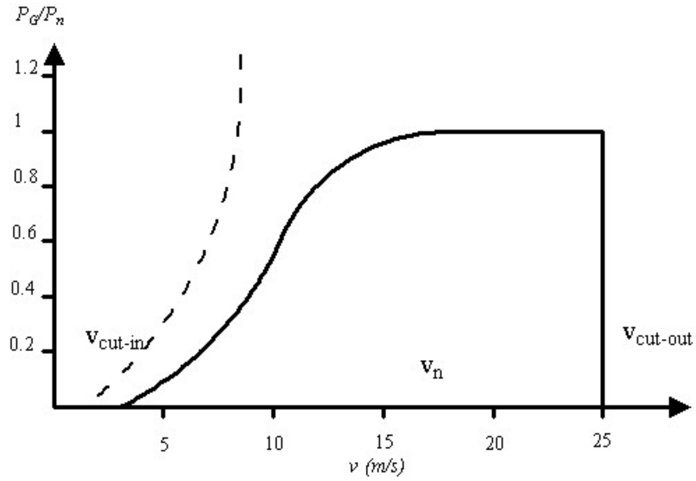

Figure 3.1 Power versus wind speed characteristics of a wind turbine.

The power of an air mass that flows at speed *v(m/s)* through an area *A* can be calculated as follows;

$$Power\ in\ wind(watts) = \frac{1}{2}\rho A v^3 \tag{3.1}$$

where, ρ is air density in *(kg/m*^{3}*)*. As seen from (3.1) the *power in wind* is proportional to the air density, the intercepting area(the area of the wind turbine rotor), and the speed to the third power.

The *power in wind* is the total avaliable energy per unit of time. The power in the wind is converted into mechanical-rotational energy of the wind turbine rotor, which results in a reduced speed in the air mass.

Capacity factor, given in (3.2), of a wind farm is relatively lower; 0,25 for low wind speed locations and 0,40 for high wind speed locations, than conventional power plants. This implies that in order to obtain the same energy production from a conventional power plant and a wind farm, the installed wind farm capacity must be significantly larger than the capacity of the conventional power plant[9].

$$Cap.Fac. = \frac{W(Annual)}{P_{rated}.8760} \tag{3.2}$$

where *W(Annual)* is the sum of the energy produced by the wind farm for a year in *(kW/h)*.

4. MODELLING AND SIMULATION OF WIND FARMS FOR POWER SYSTEM STUDIES

Wind turbine generators, control systems, power factor correction equipments, transformers, wind farm substation, inner loops for connections and transmission lines can be listed as wind farm sections that shold be modelled for power system studies. The models of the grid and the wind farms have to comply with common requirements of the simulation platforms for getting accurate results. Computer simulation makes it possible to investigate a multitude of properties in design and application phase. The correctness of a computer simulation depends on the quality of the built-in models and of the applied data. In order to investigate the effects of wind energy conversion systems on power system and vice versa; it is necessary to develop accurate models of both systems. When the aim is to investigate grid integration of wind turbines, there are three main interests; steady-state voltage level influence, rapid voltage fluctuations(flicker), and response to grid disturbances.

4.1 Steady-State Voltage

The voltage difference between the infinite system and the PCC of the wind farm is given by (2.2) and (2.3). The voltage difference, ΔU, is related to the short circuit impedance, the real and reactive power output of the wind farm.

Infinite system (or busbar) represents interconnected grid, where voltage never changes from the designed value. So it is an important decision for us that at which feeder in the model voltage never changes. Power system components between the infinite system and the PCC of the wind farm; transmission lines/cables and transformers, have to be modelled exactly in the simulation. Otherwise the effect of system X/R ratio(ratio between grid reactance and grid resistance) on wind farm terminal voltage can not be modelled correctly.

The first term and real part of the voltage difference ΔU, which is given in (2.3), is ΔU_p:

$$\Delta U_p = \frac{R_k P_g + X_k Q_g}{U_g} \tag{4.1}$$

The effect of system X/R ratio on the voltage difference can be examined by monitoring the magnitudes of the two terms on the nominator of ΔU_p. No-load power factor correction, which means that the wind-farm reactive power consumption will be zero at no load, must be set for a clear examination. With a relatively low X/R value, the first term of ΔU_p predominates, and voltage rises over the loading range. When X/R value is relatively high, the second term of ΔU_p, which goes negative with increasing reactive consumption, predominates at higher active power generation.

4.2 Flicker

There are two types of flicker emissions associated with wind turbines. In order to predict the rapid power fluctuations from fixed-speed turbines, there is a need to represent the wind field arriving at the turbine, since the flicker emission during continuous operation is mainly caused by fluctuations in the output power due to wind speed variations, the wind gradient and the tower shadow effect.

Switching operations like start, stop and switching between generators or generator windings, also produce flicker. When the limits of the flicker emission are given, the maximum allowable number of switching operations in a specified period can be examined by appropriate models in simulations. Model of a single wind energy conversion system must take into consideration soft starter, capacitor group, pitch control, and wind speed variations.

4.3 Grid Disturbances

When the response to grid disturbances is of interest, it is mainly the generator description that affects the response of the turbine. For assessing the stability margin of the wind farm-grid integration, small-signal dynamic model of the system must be formed in simulation platforms.

Wind speed, pitch control and input torque to generator are usually assumed constant for transient analysis, since mechanical system time steps are too larger than time constant of electrical system. The worst case scenario must be defined, like maximum wind speed and minimum load conditions.

4.4 Aggregated Modeling

Representing a wind farm, which consists of many relatively small power rated wind turbines, by one or few large power rated wind turbines by addition of power ratings of the small power rated wind turbines, can be stated as "aggregated modeling". When the effect of a wind farm on power systems is studied, the behavior of the wind farm at the PCC to power system can be represented by an equivalent model derived from the aggregation of wind turbines into an equivalent wind turbine, instead of the complete model including the modelling of all the wind turbines . The structure of an aggregated wind farm model should be such, that maximum user friendliness is achieved while keeping the results as close to reality as possible[10].

The advantage of an aggregated model is that it eliminates the need to develop a detailed model of a wind farm with tens or hundreds of wind turbines and their interconnections, and to specify the wind speed at each individual wind turbine within the wind farm.

Groups of wind turbines with similar winds can be aggregated by an equivalent model which results representing a large power rated wind farm by a few large wind turbines. An example of such representation for a fictitious wind farm is shown in Figure 6.1. There are three sections with identical wind turbines facing similar wind speeds. Power ratings of representative wind turbines are according to the addition of the wind turbines inside the sections;1, 2, and, 3. The effective value of the wind is reduced per row of the wind turbines because of shadowing and generation of turbulence in the wind farm. Aggregating just the electrical system of variable speed wind turbines, including electrical controls and the electrical part of the generators and to model the mechanical system of each individual turbine and generator is another option for modelling. This model maintains the nonlinear characteristics, but it reduces calculation speed considerable compared to a fully detailed, non-aggregated wind farm model[11].

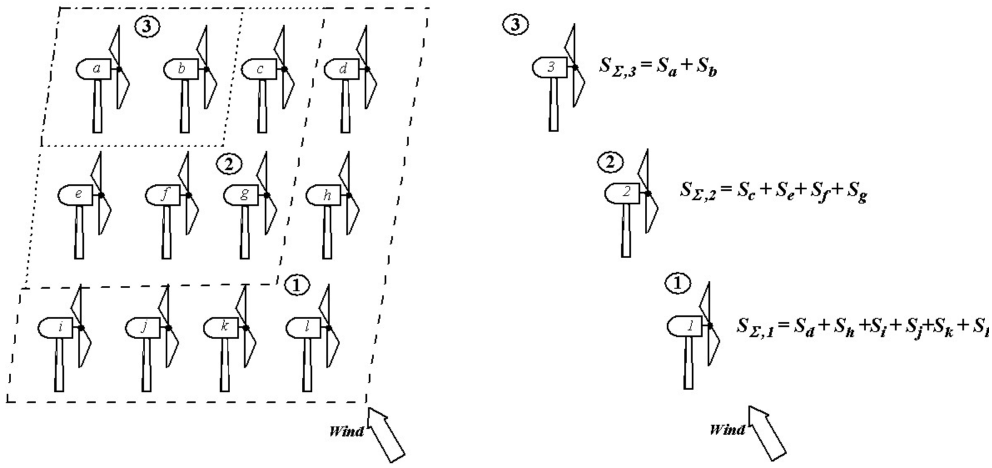

Figure 6.1 Aggregated modelling of a wind farm by a few large wind turbines.

4.5 Validation Procedure of Wind Farm Models

Models of grid connected wind farms can be validated with field measurement results to represent correct prediction of wind farm behavior. The response of the aggregated and the detailed models have to show a high degree of similarity, both during normal operation as well as during disturbances for model validation. Field measurements for validation and data acquisition requires simultaneous electrical and wind speed measurements. The SCADA systems are usually used by wind farm operators to acquire data for operation conditions.

However substation-load conditions and different power system faults may not be observed by this way. External measurement system which is capable of aquiring reliable data with optimum equipment should be used for additional measurements. Additional measurement points also can cause synchronization and data storage problems for both wind farm operators and study groups.

4.6 Case Study Results

A case study had been performed according to given information and results were presented[1]. The simulation model of the grid connected wind farm was developed in power system analysis tool, PSCAD/EMTDC. The grid and the electrical components of the wind farm were built with standard electrical component models from PSCAD/EMTDC library. The models of the wind, the aerodynamic and control components of the wind turbine were built with custom components developed in PSCAD/EMTDC. Simulations were performed to analyze the mutual effects of the wind farm with the grid.

The case study has given benficial outputs about a grid connected wind farm. Field measurements were used for PSCAD/EMTDC complete model verification process of the wind farm. PCC of the wind farm is a 34.5 kV substation feeder which was chosen as the electrical measurement point. Grid and load conditions could not be controlled or measured during electrical measurements. Wind speed measurement results, related to the same period of the electrical measurements, were obtained from early installed wind speed anemometer in the wind farm. The control algorithm of wind turbine was not provided by the system operators for the wind farm considered.

Models for the wind farm were given as Generator Modelling, Control System Model, Turbine Model, Model of Wind, Substation and Power System(Grid). Wind farm simulation results with PSCAD/EMTDC were presented with field measurement results[1].

4.6.1 Aggregated Model of the Wind Farm

Aggregated model of the wind farm and aggregated model PSCAD/EMTDC simulation results were presented in [12,13] and the effect of main parameters on steady-state stability margin was evaluated and discussed by the help of aggregated wind farm model results. The results helped to understand the steady-state stability phenomena in wind farms eqquipped with wound rotor induction generators. The studied parameters were; power system components, rotor resistance control and substation voltage level. The developed aggregated model of the wind farm was used for simulation studies in PSCAD/EMTDC.

Presented simulation results showed that the PCC voltage reduction caused reduction in the maximum mechanical torque that could be applied to the generator. That meant that the voltage reduction at the PCC in case of high wind speeds(full power output of the wind farm) could result as losing rotor speed stability and cut out of the wind turbine as a consequence.

Also PSCAD/EMTDC simulation results of the developed aggregated wind farm model were compared with the PSCAD/EMTDC simulation results of complete wind farm model for verification. The effectiveness of the aggregated model to represent the collective response of the wind farm was demonstrated by comparing the simulation results of aggregated and complete models both during standart operation and grid disturbance.

5. CONCLUSIONS

The wind farms have different impacts and functions on the performance of power system than conventional power plants, because of variation of wind speed in time. Power system operators have to be sure about the reliability of the system after wind energy integrations. As a result; accurate models of wind farms and power system are needed for accurate analysis.

Detailed information is given about the parameters like; location of the wind farm in the electric power system, steady-state voltage level influence, aggregated modeling and model verification which have essential significance about the integration studies of wind farms in power systems.

The case study has given benficial outputs about a real system. The combination of measurements and simulation model makes it possible to estimate power quality and stability margin of the system that would otherwise be difficult to predict and to measure. With the experiences and results acquired from these integration and modelling studies, future research will be much more detailed. Other existing simulation results, models, and scenarios can be examined with given headlines.

REFERENCES

[1] Mutlu, Ö.S., Akpınar, E. and Balıkcı, A. *Power Quality Analysis of Wind Farm Connected to Alaçatı Substation in Turkey.* Renewable Energy 34 (2009) 1312–1318.

[2] Holttinen,H., Meibom, P., Orths, A., Hulle F.V.,Ensslin C., Hofmann L., McCann J., Pierik J., Tande J.O., Estanqueiro A., Söder L., Strbac G., Parsons B., Smith J.C., Lemström B.(2006). Design and Operation of Power Systems with Large Amounts of Wind Power, First Results of IEA Collaboration. Global Wind Power Conference, Adelaide, Australia-2006.

[3] Venkatasubramanian, M., & Tomsovic, K. (2004). Power System Analysis. In W. Chen, (Ed.). The Electrical Engineering Handbook (761-768). U.S.A. : Elsevier Academic Press.

[4] Lubosny, Z. (2003). Wind Turbine Operation in Electric Power Systems. Berlin : Springer-Verlag.

[5] Gönen, T. (2004). Power Distribution. In W. Chen, (Ed.). The Electrical Engineering Handbook (749-759). U.S.A. : Elsevier Academic Press.

[6] Chen, Z. (2005). Issues of Connecting Wind Farms into Power Systems. Proc. of IEEE/PES Transmission and Distribution Conference & Exhibition 2005 : Asia and Pacific-China.

[7] Mäki, K., Repo, S., & Järventausta, P. (2006). Network Protection Impacts of Distributed Generation –A Case Study on Wind Power Integration. Proc. Nordic Wind Power Conference 2006, Espoo, Finland.

[8] Mutlu, Ö.S. and Akpınar, E. Assessing the Grid Codes For Wind Power Plants in Turkey. Proc. of 9th World Wind Energy Conference 15-17 June 2010 Istanbul-Turkey.

[9] Manwell, J. F., McGovan, J. G. , & Rogers A.L. (2002). *Wind Energy Explained:* Theory, Design and Application. Great Britain : J.Wiley & Sons Ltd.

[10] Slootweg, J. G. & Kling, W. L. (2002). Modeling of Large Wind-farms in Power System Simulations, Proc. IEEE Power Engineering Society Summer Meeting. 503-508

[11] Pöller, M., & Achilles, S. (2003) Aggregated wind park models for analyzing power system dynamics. 4th International workshop on large-scale integration of wind power and transmission network for off-shore wind-farms, Billund, Denmark.

[12] Mutlu, Ö.S.(2009). Effects of Wind Turbines on Power System Operation. Ph.D. Thesis. Dokuz Eylül University.

[13] Mutlu, Ö.S. ve Akpınar, E. Elektrik Güç Sistemine Bağlı Rüzgâr Enerjisi Dönüşüm Sistemlerinin Bütünleşik Modellenmesi. 5. Yenilenebilir Enerji Kaynakları Sempozyumu.Haziran 2009. Diyarbakır-Turkiye. S.90-97.