# Power quality control by WECS & Power electronics by voltage & frequency control

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***Abstract:*** This paper deals with controlling of both voltage and frequency for standalone wind power generating systems. The proposed controller has bidirectional active and reactive power flow capability along with battery energy storage system by which it controls the system voltage and frequency with variation of consumer loads and speed of wind. The proposed system is modelled and simulated in MATLAB using simulink .The proposed controller has additional capability of harmonic elimination and load balancing and hence power quality can be improved. The global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. The production, distribution and the use of the energy should be as technological efficient as possible and incentives to save energy at the end-user should be set up. The deregulation of energy has lowered the investment in larger power plants, which means the need for new electrical power sources may be very high in the near future. Two major technologies will play important roles to solve the future problems. One is to change the electrical power production sources from the conventional, fossil (and short term) based energy sources to renewable energy resources. The other is to use high efficient power electronics in power systems, power production and end-user application. Wind power production has been under the main focus for the past decade in power production and tremendous amount of research work is going on renewable energy, specifically on wind power extraction. Wind power provides an ecofriendly power generation and helps to meet the national energy demand when there is a diminishing trend in terms of non-renewable resources. This paper reviews the modeling of Wind Energy Conversion Systems (WECS), control strategies of controllers and various Maximum Power Point Tracking (MPPT) technologies that are being proposed for efficient production of wind energy from the available resource.

Keywords: Battery energy storage system, isolated Wind energy, Conversion systems, Induction generator, Permanent magnet, Wind turbine

## INTRODUCTION

Some of the areas are remote so that it is very difficult for those areas to access main power grid. So it is necessary to meet the demand of remote areas. Wind is the most prominent source of energy available. We can easily exploit by using asynchronous generator .Squirrel cage induction are low cost, robust and simple in its construction. Wind speed and load are varying, so in order to maintain voltage and frequency here employing a voltage and frequency controller for standalone winds power generating systems.

### 1.1 Voltage and frequency controller

The proposed voltage and frequency controller is having bidirectional active and reactive power flow capability by which it controls the system voltage and frequency with variation of consumer loads and wind .It has additional capability of harmonic elimination and load balancing .The performance is demonstrated using standard MATLAB software. This paper is organised as follows: Section I gives the importance of wind generating system and a controller. Section II is helpful to understand the configuration of an isolated wind energy system. Section III explains the control strategy .Section IV deals with modelling of control scheme. .Section V deals with the analysis and design of controller. Section VI deals with the simulation results and its discussion for various loads and last section VII concludes the paper followed by references. In classical power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centers over long distance transmission lines. The system control centers monitor and control the power system continuously to ensure the quality of the power, namely the frequency and the voltage.

### 1.2 DG & PV

However, now the overall power system is changing, a large number of dispersed generation (DG)units, including both renewable and non-renewable sources such as wind turbines, wave generators ,photovoltaic (PV) generators, small hydro, fuel cells and gas/steam powered Combined Heat and Power (CHP)stations, are being developed and installed. A wide-spread use of renewable energy sources in distribution networks and a high penetration level will be seen in the near future many places. E.g. Denmark has a high penetration (> 20%) of wind energy in major areas of the country and today 18% of the whole electrical energy consumption is covered by wind energy.

### 1.3 Effect of Renewable energy sources

The main advantages of using renewable energy sources are the elimination of harmful emissions and the inexhaustible resources of the primary energy. However, the main disadvantage, apart from the higher costs, e.g. photovoltaic, is the uncontrollability. The availability of renewable energy sources has strong daily and seasonal patterns and the power demand by the consumers could have a very different characteristic. Therefore, it is difficult to operate a power system installed with only renewable generation units due to the characteristic differences and the high uncertainty in the availability of the renewable energy sources. The wind turbine technology is one of the most emerging renewable technologies. It started in the 1980'es with a few tens of kW production power to today with Multi-MW range wind turbines that are being installed.

**Voltage and Frequency Controller**

The voltage and frequency controller is having bidirectional active and reactive power flow capability by which it controls the system voltage and frequency with variation of consumer loads and wind .It has additional capability of harmonic elimination and load balancing.

**2.1 Performance in MATLAB**

The performance is demonstrated using standard MATLAB software. To achieve high efficient energy conversion on these drives different control strategies can be implemented like direct torque control (DTC), field oriented control (FOC) .The FOC using PI controller has linear regulation and the tuning becomes easier. The wind turbine electrical and mechanical parts are mostly linear and modeling will be easier. The blade aerodynamics of the wind turbine is a nonlinear one and hence the overall system model will become nonlinear. The wind energy conversion system which will be modeled may not be optimal for extracting maximum energy from the resource and hence various optimization techniques are used to achieve the goal.

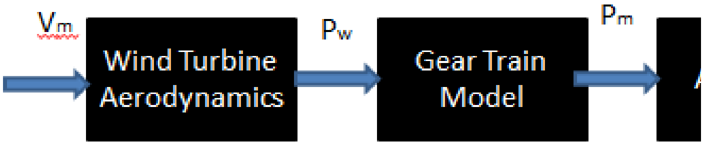


Fig. 1.1 Block Diagram

**2.2 MODERN POWER ELECTRONICS AND SYSTEMS**

Power electronics has changed rapidly during the last thirty years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. For both cases higher performance is steadily given for the same area of silicon, and at the same time they are continuously reducing the price.

The complete off grid stand-alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/ unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Fig.1. The proposed controller includes three-phase insulated gate bipolar junction transistor (IGBT) based voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor [1]. The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller.

**2.3 Stand-alone System with Asynchronous Generator**

The complete off grid stand-alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Fig.1. The proposed controller includes three-phase insulated gate bipolar junction transistor (IGBT) based voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor [1] . The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller.

**2.4 Blade**

Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power. The number of blades is normally three. As the blade tip-speed typically should be lower than half the speed of sound the rotational speed will decrease as the radius of the blade increases. For multi-MW wind turbines the rotational speed will be 10-15 rpm.

SYSTEM CONFIGURATION

The complete off grid stand -alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/ unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Fig.1. The proposed controller includes three-phase insulated gate bipolar junction transistor (IGBT) based voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor [1]. The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller.

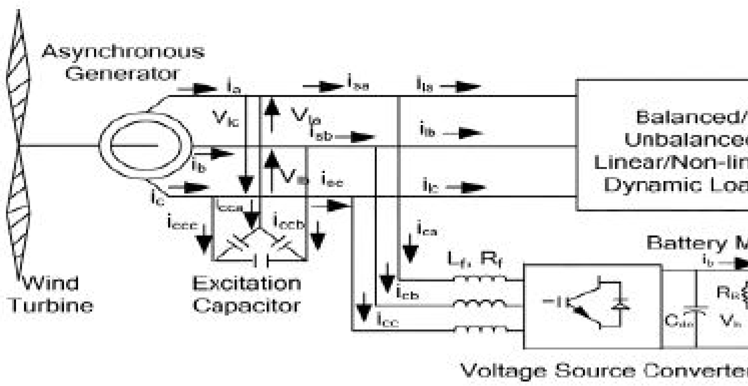


Fig.1. Schematic diagram of the proposed isolated wind energy system.

3.1 This wind energy system includes:

A .EXCITATION CAPACITOR BANK

Autonomous induction generators are cheap, simple and robust. However, while they are capable to generate active power, they are unable to produce the reactive power needed for their own excitation. The classical solution to this problem is to connect capacitors across its stator terminals of the externally driven three-phase squirrel cage induction machine Due to the three-phase capacitor bank connected to the induction generator an emf is induced in the machine windings due to the self-excitation provided by the capacitors. The magnetizing requirement of the machine is supplied by these capacitors. For self-excitation to occur, the following two conditions must be satisfied:

i.) The rotor of the machine should have sufficient residual magnetism.

ii.) The three-phase capacitor bank should be of sufficient value.

If an appropriate capacitor bank is connected across the terminals of an externally driven squirrel cage induction generator, and if its rotor has sufficient residual magnetism emf will be induced in the machine windings due to the excitation provided by the capacitors. This phenomenon is known as "capacitor self-excitation". If the induced emf is sufficient, leading currents through the capacitors will circulate. The magnetic flux produced due to these currents would assist the residual magnetism in magnetizing the iron core of the induction generator. This would increase the machine main magnetic flux and larger emf will be induced. This in turn will increase both the currents and the flux. The induced voltage and the current will continue to rise until the reactive power supplied by the capacitors is balanced by the reactive power required by the induction machine, a condition which is essentially decided by the saturation of the magnetic cores. This process is thus cumulative and the induced voltage keeps on rising until saturation is reached.

B.BATTERY ENERGY STORAGE SYSTEM

The proposed voltage and frequency controller is realized using IGBT (Insulated Gate Bipolar Junction Transistor) based voltage source converter (VSC) along with battery energy storage system (BESS) at its DC link. The proposed controller is having bidirectional flow capability of reactive and active powers because of which it can control the magnitude and frequency of the generated voltage under different electrical and mechanical dynamic conditions.

Accordingly the principle of frequency regulation for generating constant frequency at fixed speed, the total generated power should be consumed by the applied load (consumer load battery) otherwise additional generated power might be stored in the revolving component of the machine and it increases the machine speed which in turns increases the system frequency. On the other hand when there is variation in wind speeds and corresponding variation in the machine speed, the battery and consumer loads absorb such amount of power by which desired frequency of the generated voltage can be achieved.

In proposed control scheme, the frequency controller is used for extracting active component of the source current. When there is deficiency in the generated power, the battery supplies the additional required load demand through process of discharging and maintains the constant frequency along with providing the functions of load levelling.

While there is an excess generated power it starts charging and consumes additional generated power which is not consumed by the consumer loads.

C.CAPACITOR BANK

The main drawback of the autonomous squirrel cage induction generator having a three-phase capacitor bank is the lack of ability to control the terminal voltage and frequency under non-constant load and speed conditions. Therefore, capacitor excited induction generators have poor voltage and frequency stability. To regulate the voltage of an autonomous induction generator with changing load and speed, the capacitors may be replaced or supplemented with an active external source of reactive power. Such a so-called solid-state synchronous voltage source is based on a dc-ac converter (or inverter), which is able to generate leading or lagging reactive power. Thus, inverters can be used as reactive power compensators for squirrel cage induction generator.

**WIND ENERGY CONVERSION & Control Strategies**

Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power. The number of blades is normally three. As the blade tip-speed typically should be lower than half the speed of sound the rotational speed will decrease as the radius of the blade increases. For multi-MW wind turbines the rotational speed will be 10-15 rpm. The most weight efficient way to convert the low-speed, high-torque power to electrical power is using a gear-box and a standard fixed speed generator as illustrated in Fig. 4. The gear-box is optional as multi-pole generator systems are possible solutions. Between the grid and the generator a power converter can be inserted. The possible technical solutions are many and Fig. 5 shows a technological roadmap starting with wind energy/power and converting the mechanical power into electrical power. It involves solutions with and without gearbox as well as solutions with or without power electronic conversion. The electrical output can either be ac or dc. In the last case a power converter will be used as interface to the grid. In the following sections, some different wind turbine configurations will be presented and compared.

**4.1 FIXED SPEED WIND TURBINES**

The development in wind turbine systems has been steady for the last 25 years and four to five generations of wind turbines exist. It is now proven technology. The conversion of wind power to mechanical power is as mentioned before done aerodynamically. It is important to be able to control and limit the converted mechanical power at higher wind speed, as the power in the wind is a cube of the wind speed. The power limitation may be done either by stall control (the blade position is fixed but stall of the wind appears along the blade at higher wind speed), active stall (the blade angle is adjusted in order to create stall along the blades) or pitch control (the blades are turned out of the wind at higher wind speed). The wind turbines technology can basically be divided into three categories: the first category is systems without power electronics, the second category is wind turbines with partially rated power electronics (small PE converter in Fig. 5) and the last is the full-scale power electronic interfaced wind turbine systems (large PE converter in Fig. 5). Fig. 6 shows different topologies for the first category of wind turbines where the wind turbine speeds is fixed.

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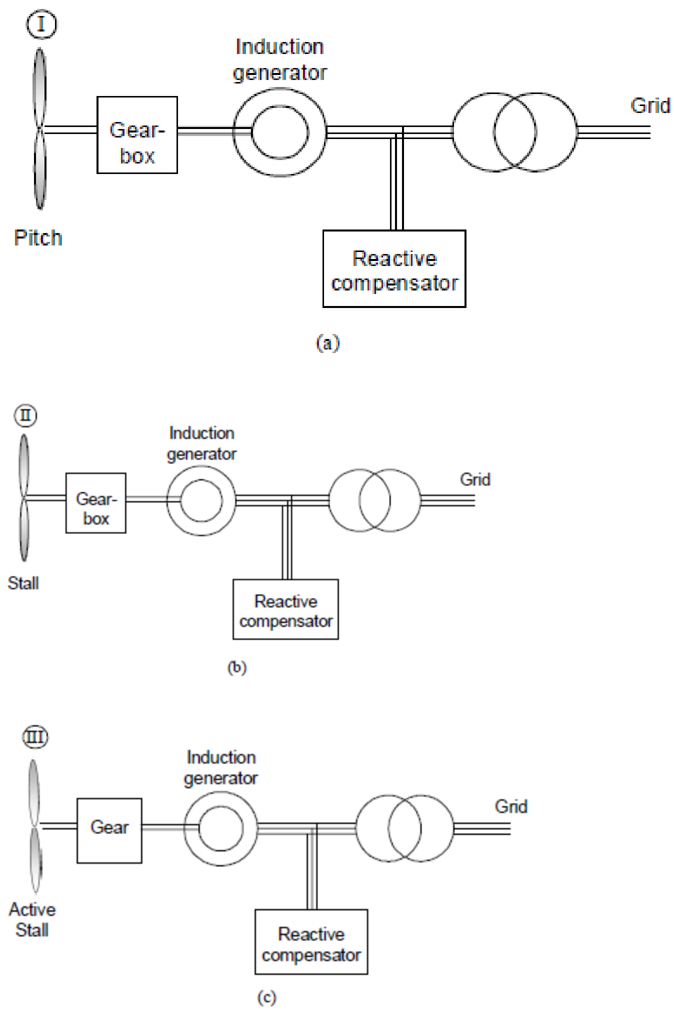


**Fig. 6. Wind turbine systems without power converter but with aerodynamic power control.**

**a) Pitch controlled (System I) b) Stall controlled (System II) c) Active stall controlled (System III)**

The wind turbine systems in Fig. 6 are using induction generators, which almost independent of torque variation operate at a fixed speed (variation of 1-2%). The power is limited aerodynamically either by stall, active stall or by pitch control. All three systems are using a soft-starter (not shown in Fig. 6) in order to reduce the inrush current and thereby limit flicker problems on the grid. They also need a reactive power compensator to reduce (almost eliminate) the reactive power demand from the turbine generators to the grid. It is usually done by continuously switching capacitor banks following the production variation (5-25 steps). Those solutions are attractive due to cost and reliability but they are not able very fast (within a few ms) to control the active power. Furthermore wind-gusts may cause torque pulsations in the drive-drain and load the gear-box significantly.

Fig. 7 shows that by rotating the blades either by pitch or active stall control it is possible precise to limit the power while the measured power for the stall controlled turbine shows a small overshoot. This depends a lot on the final aerodynamic design.

## MODELING OF THE CONTROL SCHEME

Basic equations of the control scheme of the proposed controller are as follows.

### *5.1 A. COMPUTATION OF ACTIVE COMPONENT OF REFERENCE SOURCE CURRENT*

Active component of reference source current is estimated by dividing the difference of filtered instantaneous load power ( *Lfilter P* ) and output of the PI frequency controller ( *C P* ) to the terminal voltage ( *tm V* ). The load power ( *L P* ) is estimated as by taking three-phase to two-phase transform

Instantaneous active power is estimated as

It is filtered to achieve its dc component (*P* Lfilter ). The frequency error is defined as

where is reference frequency (50 Hz in present system) and "*f* ref " is the frequency of the voltage of an asynchronous generator. The instantaneous value of " *f*" is estimated using phase locked loop (PLL).

At the th sampling instant the output of frequency PI controller (P*c* ) is as

Where and are the proportional and integral gain constants of the frequency proportional integral (PI) controller. Then active component of reference source current (I*dm*) is calculated as

The instantaneous line voltages at the terminals of an asynchronous generator ( *la v* , *lb v* and *lc v* ) are considered sinusoidal and their amplitude is computed as

The unity amplitude templates are having instantaneous value in phase with instantaneous voltage ( *la v* , *lb v* and *lc v* ), which are derived as

### *B. COMPUTATION OF REACTIVE COMPONENT OF REFERENCE SOURCE CURRENT*

Instantaneous values of in-phase components of reference source currents are estimated as

*irda = Idmida, , irdb = Idmidb , irdc = Idmidc*

The ac voltage error at the *n* th sampling instant as

*Ver(n ) = Vtmref(n) – V tm(n )*

Where V *tmref(n)* is the amplitude of reference ac terminal voltage and V *tm(n)* is the amplitude of the sensed three-phase ac voltage at the terminals of an asynchronous generator at *n* th instant.

The output of the PI controller (*Iqm(n)* ) for maintaining constant ac terminal voltage at the *n* th sampling instant is expressed as

*Iqm(n)=Iqm(n-1)+Kpa {Ver(n) –Ver(n-1) +Kia Ver(n) }*

Where K *pa* and K *ia*are the proportional and integral gain constants of the voltage proportional integral (PI) controller (values are given in Appendix ). V *er(n )*and V *er(n-1)* are the voltage errors in *nth* and *(n-1)th*instant and is the amplitude of quadrature component of the reference source current at *(n-1)* thinstant.The instantaneous quadrature components of reference source currents are estimated as

*I rqa = I qm i qa, ,Irqb =I qm i qb ,I rqc = I qm i qc*

where*q a , q b and q c* and are another set of unit vectors having a phase shift of 900 leading the corresponding unit vectors , and which are computed as follows:

### *C. COMPUTATION OF REFERENCE SOURCE CURRENT*

Total reference source currents are sum of in-phase and quadrature components of the reference source currents as

*irsa= i rqa + i rda*(18)

*irsb= i rqb + i rdb*(19)

*irsc= i rqc + i rdc*(20)

*D. PWM SIGNAL GENERATION*

Reference source currents (*irsa, irsb and irsc*) are compared with sensed source currents (*isa*, *i sb*and *i sc*). The current errors are computed as

*irsaerr=irsa-isa*(21)

*irsberr=irsb-isb*(22)

*irscerr=irsc-isc*(23)

These current errors are amplified with a gain (K ) and the amplified signals are compared with fixed frequency (10 kHz) triangular carrier wave of amplitude to generate gating signals for IGBTs of VSC of the controller.

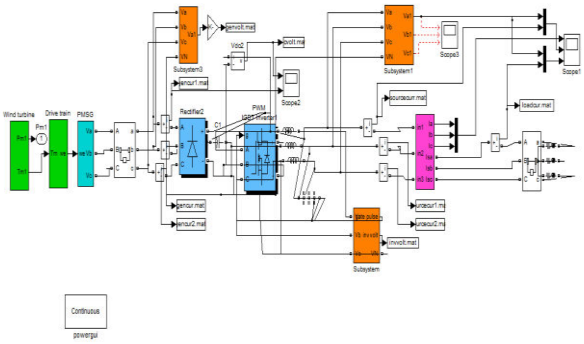

Fig. 5.1 Wind pencyower plant for volatgage&frequ

**5.2 ANALYSIS AND DESIGN**

***A.DESIGN OF THREE LEG VFC***

Parameters of VFCs are designed for a 22-kW, 415-V, 50-Hz asynchronous generator-based standalone WECS. It is reported that for feeding reactive power in the case of 0.8-pf lagging reactive loads, an IAG requires 140–160% of the reactive power of the rated generated power. Therefore, the VAR rating of the VFC required for 22 kW (*PA*) generator is around 30 kVAR.

Then, the apparent power *SA* is given as

*SA* = √(*PA*)2 + (*QA*)2 = √(22)2 + (30)2 = 37 kVA.

So the current rating of VSC is √3*V C I* = 37 kVA

∟ *C I* = 51.7 A.

The amplitude of the current is *C I* (*pk*) = 73.19 A.

The average current is *Iavg*= 0.9 × 51.7 A = 46.53 A.

On the basis of earlier current rating, the peak-to-peak current ripple (considering 5% of the peak current) through the filter inductor can be estimated as

**RESULTS AND DISCUSSION**

Model with voltage and frequency control is modelled using MATLAB for linear- balanced and unbalanced, nonlinear- balanced and unbalanced loads. The results are given below and we can see distortion is very much reduced.

***A. PERFORMANCE OF THE CONTROLLER FEEDING LINEARLOADS***

Similarly Fig.6.1. Demonstrates the performance of the controller with 0.8 pf lagging reactive loads (balanced and unbalanced respectively) at fixed wind speed. At 1 s load is given and at 1.2 s one phase of the load are opened and the load becomes unbalanced but voltage and current at the generator terminals remain balanced

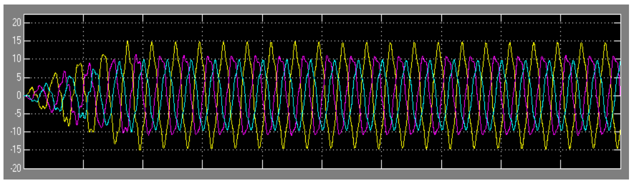

**Fig. 6.1 Demonstrates the performance of the controller with 0.8 pf lagging reactive loads**

***B. PERFORMANCE OF THE CONTROLLER FEEDING NONLINEARLOADS***

Fig.6.2 demonstrates the performance of the controller with nonlinear load at fixed wind speed. A three-phase rectifier load with resistive element is applied and the generator terminal with minimal harmonic distortion which show the load balancing aspects of the controller. At 0.95 s one phase and later on at 1.1 s another phase of the load are opened and the load becomes unbalanced but voltage and current at the generator terminals remain balanced.

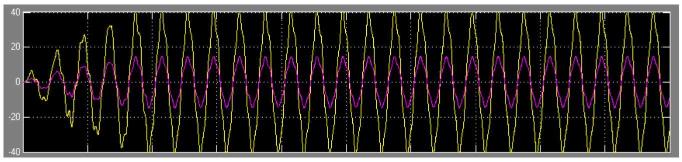

**Fig.6.2 demonstrates the performance of the controller with nonlinear load at fixed wind speed**

***C. PERFORMANCE OF THE CONTROLLER UNDER VARYING WIND SPEED***

Fig.6.3 shows the performance of the controller with varying wind speeds at constant applied consumer load. At 0 s when the wind speed is 4 m/s, a consumer load (18 kW) is applied at the generator terminals. Due to insufficient power generation at low wind speed, an additional load power is supplied by the battery to regulate the frequency. At 0.25 s as the wind speed is increased from 4 m/s to 10 m/s here also the controller provides the load levelling and control of the frequency of the generated voltage.

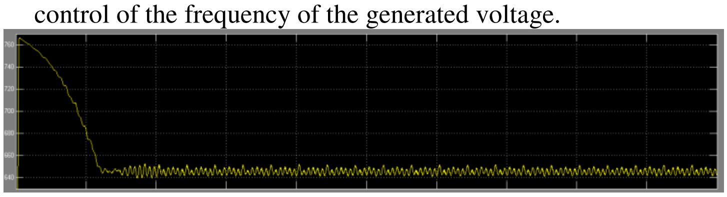

**Fig.6.3 shows the performance of the controller with varying wind speeds at constant applied consumer load**

As it can be seen the wind farms have interesting features in order to act as a power source to the grid. Some have better abilities than others. Bottom-line will always be a total cost scenario including production, investment, maintenance and reliability. This may be different depending on the planned site.

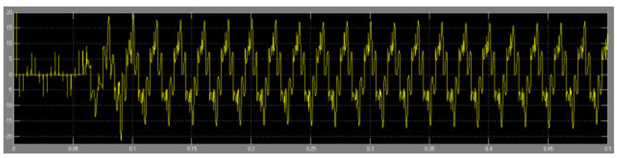

**Fig. 6.4 wind farms have interesting features in order to act as a power source**

**6.1 WIND POWER TRENDS**

The installed power in wind energy has grown rapidly in many years. Today more than 45000 MW are installed globally with recently an annual market of 8000 MW. This is illustrated in Fig. 13. Fig. 13. Annually installed and accumulated wind power globally. (Source: Risoe National Laboratory, Denmark) The expectations for the future are also very positive as many countries have progressive plans. Table IV gives an estimate for the installed wind power in 2010 based on official statements from different European countries. It can be seen that many countries will increase their wind power capacity in large scales. In Denmark the installed capacity is expected to approach saturation as the problems of a too high capacity compared to the load level are appearing. However, energy cost rise can change this. The power scaling has been an important tool to reduce the price pr. kWh. Fig. 14 shows the average size of the installed wind turbines in Denmark as well as their produced energy pr. m2 swept area pr. year. It can be seen that the technology is improving and it is possible to produce more than 900 kWh/m2/year. This depends of course on location and from experience off-shore wind-farms are able to produce much more energy The influence on the power scaling can also be seen at the prices pr. kWh for different wind-turbine sizes in two different landscape classes and it is shown in Fig. 15. The key to reduce price is to increase the power and today prototype turbines of 4-5 MW are seen around the world being tested. Finally, the development of wind turbines is illustrated. It is expected 10 MW wind turbines will be present in 2010.

**CONCLUSION**

The performance of the proposed controller has been demonstrated for an isolated wind energy conversion system. Simulation results have verified the performance of the controller under different electrical (varying consumer loads). It has been observed that the proposed controller has been found to regulate the magnitude and frequency of the generated voltage constant in isolated wind power application. The proposed voltage and frequency controller has also been found capable to function as a harmonic compensator, a load balancer and a load leveller. The paper discusses the applications of power electronic for the wind turbine technology. The development of modern power electronics has been briefly reviewed. The applications of power electronics in various kinds of wind turbine generation systems and offshore wind farms are also illustrated, showing that the wind turbine behavior/performance is very much improved by using power electronics. They are able to act as a contributor to the frequency and voltage control by means of active and reactive power control. Also it can be concluded the power scaling of wind turbines is important in order to be able to reduce the energy cost. An attempt has been made in this paper to discuss the most-recent research trends in the field of wind energy conversion systems. From the study, it can be concluded that in case of generators and converters, most system adopts DFIG with back-to-back converter due to their less weight and cost. However, for the large capacity wind turbines where efficiency and reliability plays a major role has been utilizing PMSG's even though it has more weight and increased installation cost. Moreover, WECS based on the multibrid concept, will become more attractive alternative technology in the future. Regarding the controllers for the WECS, is still the most important and challenging topic of research as there are various controllers had been proposed by various researchers has been discussed in this paper. As there are lot of ongoing developments takes place at various stages of WECS, it is noted that the most suitable (optimized) solutions to extract maximum power of the installed system is ad-hoc, rather than generalized solution. The overview of this information highlights the current research progress in the field of wind energy conversion system and this will be helpful for the new researchers to focus on the above area.

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