PERFORMANCE EVALUATION OF WIND DIESEL HYBRID STANDALONE SYSTEM

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **PERFORMANCE EVALUATION OF WIND-DIESEL HYBRID STANDANLONE SYSTEM** in partial fulfillment of the requirements for the award of the degree **Master of Technology** with specialization in **Power systems engineering,** to the **Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee** is an authentic record of my own work carried out during a period from July 2007 to June 2008 under the supervision of Dr. **E.Fernandez** of the Department, Electrical Engineering Department, Indian Institute of Technology Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

S.K.

(S.KISHORE KUMAR)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

This thesis studied the performance of the Wind-Diesel hybrid system. Power systems utilizing renewable energy such as wind and solar require control methods to maintain stability due to the real time variation of input energy and load, while maximizing the use of renewable resources. Wind-Diesel power system (WDPS) have been accepted and widely used as electricity generating systems for remote areas. In such cases, the WDPS serves an entire isolated load and is responsible for maintaining frequency and voltage stability (dynamic performance). Voltage of the hybrid system is controlled by the excitation system of the synchronous condenser such that voltage of the system is maintained at nominal values. The frequency is regulated by using Discrete Frequency Regulator block. This controller uses a standard three-phase Phase Locked Loop (PLL) system to measure the system frequency. The random power disturbances at the output of wind turbine generators can cause relatively large frequency voltage fluctuations. In a large grid, these fluctuations can have little effect on the overall quality of the delivered energy. However, with weak autonomous networks, these power fluctuations can have a marked effect, Hence control of voltage and frequency of isolated Wind-Diesel hybrid system is more challenging than grid connected systems. This project studied asynchronous wind generator short-circuits regime transients at rated power for variable and fixed wind speeds.

Reliability of Wind-Diesel hybrid system plays vital role in performance of hybrid systems, Reliability evaluation of hybrid system helps system planner and utility administrators to evaluate, upgrade, size and optimize their hybrid systems. The Diesel generators in hybrid systems plays vital role in Reliability evaluation. In these Thesis Reliability indices of any Wind-Diesel hybrid system is evaluated by utilizing discrete wind speed frame analysis. Expected Energy Not supplied (EENS), EIR(Energy Index of Reliability), LOLE(Loss Of Load Expectation) were evaluated to study the hybrid system performance such that to ensure reliable power supply.

Simulink is the tool that was selected for carrying out the simulations of this project. It has been developed by Mathworks and it works with its main product (Matlab)

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CHAPTER 1
INTRODUCTION

In a remote area there used to be two general solutions for its electrification making a connection to the closest grid or using diesel generation to get self-sufficiency. Both methods are incredibly expensive and that is the origin for the hybrid systems, which means the combination between that dispatchable diesel source and a renewable one.

Wind energy has received considerable public attention since the last decade, and has since been the fastest growing energy source. The global installed wind capacity is expected to grow much more rapidly in the next decade as many jurisdictions around the world have implemented or are in the process of implementing policies such as Renewable Portfolio Standard (RPS). Acceptance of the RPS is a commitment to produce a specified percentage of the total power generation from renewable sources within a certain date. Most of this renewable energy will come from wind as other renewable sources are not very suitable for bulk power generation. Wind energy is non-depleting, site-dependent, non-polluting, and a potential source of the alternative energy option. Many countries (with average wind speeds in the range of 5–10 m/s) are pursuing the option of wind energy conversion systems (WECS),

Diesel generators also know as Gensets, provide reliable power when properly maintained. The initial cost of a complete diesel power system is also relatively low. They can be easily transported and are low-tech which aids in their reliability and ensures ease of operation. The high price of diesel fuel is aggravated in many cases by additional transportation costs. Diesel generators need regular maintenance and so do the fuel storage tanks. Diesel engines burn fossil fuel which releases harmful emissions into our atmosphere and depletes the earth limited stored resources. Even with the recent advances in reduced emission diesel engines they are still the worst polluters in the decentralized power generation market. Their CO_2, NOx, SO2 emissions are amongst the highest with only CO emissions being around par [1]. Hybrid systems come in many shapes, sizes and complexity. In some areas of the world where wind power is not abundant other forms of

Renewable energy such as solar and hydro power can be used and in some cases the diesel generator has been done away with all together. Hybrid systems range in size from a few Kw to several Mw of power. The variable nature of most renewable energy sources means that hybrid systems often have to have extensive control systems so that demand can met and power quality assured.

Power systems utilizing renewable energy such as wind, solar and micro-hydro require control methods to maintain stability due to the real time variation of input energy and load, while maximizing the use of renewable resources. Wind-Diesel power system (WDPS) have been accepted and widely used as electricity generating systems for remote areas. In such cases, the WDPS serves an entire isolated load and is responsible for maintaining frequency and voltage stability (dynamic performance). The main focus in WDPS design is to secure both fuel saving of diesel generator unit and reliable power supply to load. Using, diesel generator installed capacity is sized to meet the peak power demand, but is used in practice to supply power only when the wind power output is insufficient to meet the load demand [1].

Reliability of Hybrid system is required to evaluate for maintain reliable power supply for remote areas, Reliability evaluation help system planner and utility administrators to evaluate, upgrade, size and optimize their hybrid power systems. Power system reliability is the measure of the ability of the system to deliver electricity as demanded to various points of utilization within acceptable standards. A quantitative measure of system reliability can be represented by numerical values using various reliability indices. The primary function of a power system is to ensure economic and reliable supply of electrical energy to its customers. Power system reliability evaluation provides a measure of the overall ability of the system to perform its intended function. Power system reliability evaluation is an important part of various facilities planning, such as generation, transmission and distribution networks. The evaluation of sufficient system facilities is essential in providing adequate and acceptable continuity of supply.

CHAPTER2

LITERATURE REVIEW

Many in recent past have carried out research in Wind-Diesel Hybrid systems. *H.S.Ko, T.NJImur, K.Y.Lee* [2] described an intelligent controller based on a neural network for a wind-diesel power system equipped with a stall regulated wind turbine run as induction generator. The goal for the wind-diesel power system is to design an intelligent controller to maintain a good power quality under varying wind and load conditions. *Iosif szeidert* [3] had presented a comparative study regarding the control (using an adaptive neuro-fuzzy controller and a PD controller) based on the simulation of wind energy conversion systems functioning. The practical problems in the grid integration of windmill represented special cases of design and analysis of energetic systems [4-6]. *Farid Katiraei, Chad Abbey* [7] introduced an energy-flow model developed for performance analysis and unit sizing of an autonomous wind-diesel Microgrid. The model is employed to analyze the interaction of wind and diesel power plants in order to identify alternative unit sizing approaches that improve wind-energy absorption rate of the wind plant, and overall efficiency of the diesel plant. *X.Liu , S.Islam* [8] has discussed a new analytical approach of reliability evaluation for wind-diesel hybrid power system with battery bank for power supply in remote area. The proposed approach is developed on the basis of the discrete speed frame analysis of the weibull wind speed distribution. By employing wind speed frame analysis, an analytical model of wind-diesel hybrid system is developed, which deals with system outage as a result of a component failure and wind speed fluctuation. This model computes power output of wind turbine generators for each discrete wind speed frame, which is created by splitting the Weibull wind speed distribution curve. The battery bank model is combined with that of the wind-diesel system. The reliability analysis of the overall system is conducted by combining power outputs of the wind and diesel generation units with battery throughout all wind speed frames to obtain the reliability indices, Loss of Load Probability (LOLP) and Expected Energy Not Supplied (EENS), which reflect a long term performance of the hybrid power system. *R.Sebastian, J Quesada* [9] has proposed distributed control system (DCS) by analyzing the control requirements for frequency control in different modes of operation and described the actuation of its sensor and actuator nodes. A power system for WO mode consisting of a wind turbine generator (WTG), A synchronous machine (SM), the consumer load, a battery based energy storage system (ESS) and the discrete dump load (DL) along with the associated DCS have been simulated. By means of a 400 Hz reference power message that establishes the active power necessary for frequency regulation and a prescribed active power sharing between the ESS and DL actuators, graphs for frequency, voltage and active powers for consumer load and wind speed changes are presented. The DCS solution presented could constitute a proposal for the standardization of the control for WO mode in high wind penetration WDHS which rely on a SM to generate the voltage waveform in that mode. *R.Sebastian, F.Yeves, M.Castro,J.V.Miguez*[10] has proposed Distbributed Control System (DCS) based on the CAN (Controller Area Network) bus is proposed for Diesel Generators (DGs) scheduling in DO mode, for active power control in WD mode, for frequency control in WO mode and for reactive power control in the three operation modes. Finally they specified a complete DCS solution for the control of WDHS based on two CAN buses, one high speed CAN bus with the nodes involved in the real time tasks and other low speed CAN bus which links the nodes taking part in the DGs and controllable loads scheduling task. *P.A.Stott, M.A.Mueller.*[11] has given a new topology for a fully variable speed hybrid wind/diesel power system modeled in Matlab Slimulink. Use of the variable speed diesel generators is shown to increase the fuel savings over a constant speed generator in a hybrid system. The load matching capabilities of the variable speed diesel generator to wind speed drops in the hybrid system are then assessed. Finally integration of a variable speed wind turbine and new variable speed diesel generator through the DC-link stage of an AC/DC/AC power converter has been simulated to establish compatibility. *Chun-Lung Chen, Sheng-Chuan Hsieh, Tsung-Ying Lee, Chia-Liang Lu*[12] has developed a software for a Wind-Diesel coordination generation scheduling (WCGS) for appropriate assessment of the added cost to cover the unpredictable wind generator output variations. The developed WCGS software is also a useful tool for the system planner to predict the energy cost and the fuel saving from the expected new wind-diesel systems. Several technique constraints are applied to determine the optimal proportion of wind generator capacity that can be integrated into the existing system. A simple benefit cost ratio (BCR) is used in this study to evaluate the investment effectiveness of the installation of wind farms for an isolated hybrid system. Numerical experiments are also included to understand the wind generator output variations in system operating cost analysis and to assess the impact and economic benefits of the installation of wind farms.

J.K.Kaladellis [13] has focused on presenting a detailed mathematical model describing the operational behavior of the basic hybrid system components, along with the representative calculation results based on the developed mathematical model. Accordingly, an integrated numerical algorithm is build to estimate the energy autonomy configuration of the hybrid system under investigation. This proposed methodology was equally well be applied to any other remote consumer and wind potential type, in order to estimate the optimum wind-diesel hybrid system configuration that guarantees long-term energy autonomy. *R.C.*Bansal [14] has presented an artificial neural network (ANN) based approach to tune the parameters of the static Var compensator (SVC) reactive power controller over a wide range of typical load model parameters. The gains of PI (proportional Integral) based SVC are optimized for typical values of the load voltage characteristics (n_q) by conventional techniques. Using the generated data, the method of multi layer feed forward ANN with error back propagation training is employed to tune the parameters of the SVC. An ANN tuned SVC controller has been applied to control the reactive power of a variable slip/speed isolated wind-diesel hybrid power system. It has been shown that initially synchronous generator supplies the reactive power required by the induction generator and/or load, and the latter reactive power is purely supplied by the SVC.

CHAPTER 3
HYBRID SYSTEMS

3.1 INTRODUCTION

Power systems using multiple generation sources can be more accurately described by the term *'hybrid power systems'* and can incorporate different components such as production, storage, and power conditioning and system control to supply power to the remote community. Hybrid power systems range from small systems designed for one or several homes to very large ones for remote island grids or large communities.

The rapid depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to cater to the present day demands. Alternative energy resources such as solar, wind, ocean thermal and tidal have attracted energy sectors to generate power on a large scale. However, solar and wind energy systems are being considered as promising power generating sources due to availability and the topological advantages in local power generation. It is prudent that neither standalone wind energy system nor solar system can provide a continuous supply of energy due to seasonal that combine solar and wind generating units with battery backups are implemented to satisfy the load demand. A great deal of research and has been carried out on hybrid energy systems with respect to performance, optimization, integration with diesel /biomass systems and other related parameters of significance.

Hybrid systems by definition contain a number of power generation devices such as wind turbines, photovoltaic, micro-hydro, diesel generators. Hybrid power systems are seen as a way to provide power to the many remote communities in the developing world where as the costs for large scale expansion of electrical grids is prohibitive and the transportation costs of diesel fuel are also very high. The current global scenario, regarding power generation, faced by electric utilities is characterized by many challenging problems among the most important are: aging of main equipment at power plants, financial investment uncertainty for new plant construction, competition among independent power producers to satisfy the energy demands of end users, and pressure to meet stringent government requirements to maximize the use of natural resources and to minimize environmental impact. The advantage of hybrid power systems is the combination of the continuously available diesel power and locally available pollution-free wind energy. With the hybrid power system, annual diesel fuel consumption can be reduced and pollution can be minimized at the same time. Hybrid systems can guarantee the certainty of meeting load demands at all times at reasonable cost, for certain latitudes and escapes of the total dependency of the resources of the hydrocarbons and the economic viability of some other energetic alternatives.

3.1.1 ADVANTAGES OF THE HYBRID SYSTEMS

1. Optimum utilization of renewable energy sources in a remote area
2. The certainty of meeting load demands at all times is greatly enhanced by the hybrid system using more than one power source
3. Most hybrids use diesel generator with P.V. or wind, since diesel provides more than one power source.
4. In some hybrids, batteries are used in addition to the diesel generator, the Batteries meet the daily load fluctuation, and the diesel generator takes care of the long term fluctuations.
5. Designed for easy to operate, service and maintenance when required.
6. Most eco friendly and clean source of power
7. Long life span for SPV modules and Modular design
8. No pollution and no recurring costs, Highly reliable and consistent power supply and very good quality power output with steady output and Frequency
9. Simple installation can be mounted on roof-top or on the ground.
10. Very few moving parts negligible maintenance is required.
11. Environmental pollution is controlled thus improving health.
12. Lower total system cost, contribution of solar and cost effective electric Power for remote application. Wind is beneficial even on low wind sites and smoothens out seasonal wind fluctuations.
13. Laying of the expensive grid line, transmission and distribution losses can be eliminated

14. Eliminates any associated expensive electricity bills.
15. The hybrid systems provide more consistent year round renewable energy production. These systems are modular and can be expand easily.

3.1.2 TYPES OF THE HYBRID SYSTEMS

1. Solar and wind Hybrid system
2. Wind and Diesel Hybrid system
3. Solar and Diesel Hybrid system
4. Wind and Diesel and Fuel cell Hybrid system
5. Wind and micro-Hyde Hybrid system

3.2 DESIGN CONSIDERATIONS OF HYBRID ENERG SYSTEMS

The design of hybrid energy systems involves the following steps

1. Selection of the energy resources to be used (this will depend on the of potential of different renewable energy resources in the area).
2. Choice of the system configuration.
3. Load profile determination of the area to be served (Seasonal/monthly/yearly)
4. Sizing of the system components and switchgear, distribution networks etc. taking into consideration reliability of power delivery in bleak periods etc.
5. Economic analysis of the project (payback, NPV etc)
6. Environmental/socio-economic evaluation for sustainability
7. Provision for expansion, land costs and environmental clearances.
8. Testing of the system design through simulation exercises.
9. Modification of the system configuration on the basis of the simulation feedback.

Once the main considerations have been finalized, the system is ready for the implementation stage. The subsequent performance of the system will then be governed by appropriate system management strategies, which can promote local employment, conservation and high efficiency.

3.3 OBJECTIVE OF THESIS

The main objective of this thesis to study the performance of Wind-Diesel hybrid system. These combines two types of studies, Dynamic performance of Wind-Diesel hybrid system is studied in Matlab/Simulink environment, in this study WDPS serves an entire isolated load and is responsible for maintaining frequency and voltage stability (dynamic performance). Voltage of the hybrid system is controlled by the excitation system of the synchronous condenser such that voltage of the system is maintained at nominal values. The frequency is regulated by using Discrete Frequency Regulator block. This controller uses a standard three-phase Phase Locked Loop (PLL) system to measure the system frequency.

In these Thesis Reliability indices of any Wind-Diesel hybrid system is evaluated by utilizing discrete wind speed frame analysis. Expected Energy Not supplied (EENS), EIR(Energy Index of Reliability), LOLE(Loss Of Load Expectation) were evaluated to study the hybrid system performance such that to ensure reliable power supply. Reliability of Wind-Diesel hybrid system plays vital role in performance of hybrid systems, Reliability evaluation of hybrid system helps system planner and utility administrators to evaluate, upgrade, size and optimize their hybrid systems. The Diesel generators in hybrid systems plays vital role in Reliability evaluation.

CHAPTER4

WIND ENERGY

4.1 INTRODUCTION

Wind mills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. The use of windmills to generate electricity can be traced back to the late 19^{th} century with the 12kw DC windmill generator constructed by Brush in the USA. However much of 20^{th} century there was little interest in using wind energy other than for battery charging for remote dwellings. In Denmark the 200KW 24m diameter Gedser machine was built in 1956 while France tested a 1.1 MW 35m diameter turbine in 1963. Improved turbine designs and plant utilization have contributed to a decline in large-scale wind energy generation costs from 35cents per kWh in 1980 to less than 5 cents per kWh in 1997 in favorable locations.

Major factors that have accelerated the wind –power technology development are as follows:

1. High-strength fiber composites for constructing large low-cost blades.
2. falling prices of the power electronics
3. Variable-speed operation of electrical generators to capture maximum energy.
4. Improved plant operation, pushing the availability up to 95 percent.
5. Economy of scale, as the turbines and plants are getting larger in size.
6. Accumulated field experience improving the Capacity factor.

4.2 WIND TURBINES

Wind turbine is a machine that converts the kinetic energy in wind into mechanical energy. If the mechanical energy is used directly by machinery such as pumping or grinding stones, the machine is called a windmill

4.2.1 TYPES OF WIND TURBINES:

1. HORIZONTAL AXIS
2. VERTICAL AXIS.

HORIZONTAL AXIS

Horizontal-axis wind turbines (HAWT) have the wind rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, which large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable for generating electricity. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes titled up a small amount.

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds, the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Because turbulence leads to fatigue and reliability is so important, most HAWTs are upwind machines.

VERTICAL AXIS

Vertical-axis wind turbines (VAWTs) have the main rotor shaft running vertically. Key advantages of this arrangement are that the generator and gearbox can be placed at the bottom, near the ground, so the tower doesn't need to support it, and that the turbine doesn't need to be pointed into the wind. Drawbacks are usually pulsating torque that can be produced during each revolution and drag created when the blade rotates into the wind. It is also difficult to mount vertical-axis turbines on towers, meaning they must operate in the often slower, more turbulent air flow near the ground, resulting in lower energy extraction efficiency.

4.3 WIND TURBINE PERFORMANCE

The performance of a wind turbine can be characterized by the manner in which the three main indicators—power, torque and thrust vary with wind speed. The power determines the amount of energy captured by the rotor, the torque developed determines the size of the gear box and must be matched by whatever generator is being driven by the rotor. The rotor thrust has great influence on the structural design of the tower. It is usually convenient to express the performance by means of non-dimensional, characteristic performance curves from which the actual performance can be determined regardless of how the turbine is operated, e.g., at constant rotational speed or some regime of variable rotor speed. Assuming that the aerodynamic performance of the rotor blades does not deteriorate the non-dimensional aerodynamic performance of the rotor will depend upon the tip speed ratio and, if appropriate, the pitch setting of the blades. It is usual, therefore, to display the power, torque and thrust coefficients as functions of tip speed ratio.

$C_P - \lambda$ performance curve

The usual method of presenting power performance is the non dimensional C_P-λ curve. The first point to notice is that the maximum value of C_P is only 0.47, achieved at a tip speed ratio of 7, which is much less than the Betz limit. The discrepancy is caused, in this case, by drag and tip losses but the stall also reduces the C_P at low values of the tip speed ratio. Even with no losses included in the analysis the Betz limit is not reached because λ the blade design is not perfect.

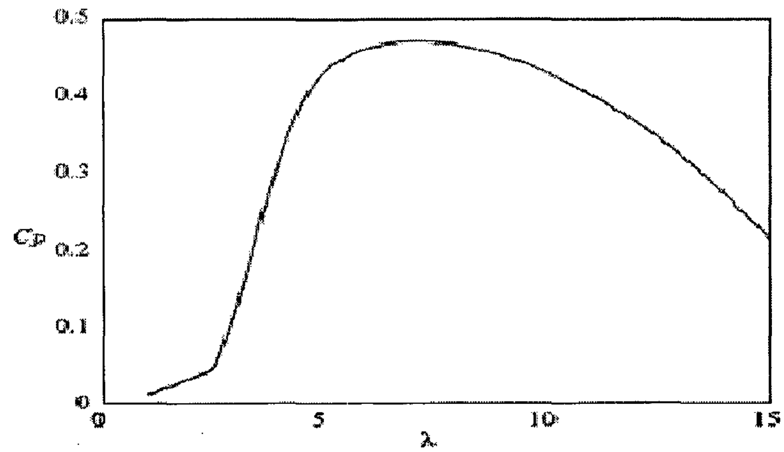

Fig 4.1 Cp- **λ performance curve of 3 blade Turbine**

4.3.1 Variable Speed Operation

If the speed of the rotor can be continuously adjusted such that the tip speed ratio remains constant at the level which gives the maximum C_P then the efficiency of the turbine will be significantly increased. Active pitch control is necessary to maintain a constant tip speed ratio but only in the process of adjustment of rotational speed; the pitch angle should always return to the optimum setting for highest efficiency. Pitch control regulation is also required in conditions above the rated wind speed when the rotational speed is kept constant.

4.3.2 Wind Turbine Field Testing

Wind-turbine field testing is undertaken in the main for two different reasons. First, as part of the development of new designs, manufacturers and researchers under take a wide range of measurements to check on the operation of a given machine and in some instances to validate wind turbine models used in the design process. The second, and perhaps the most common, reason for testing is to establish the performance of a given wind turbine for commercial reasons. Because in the second case the objectives are better defined and since many of the problems are common to both sorts of tests, there will be a concentration on performance measurement. Performance measurement is also the area best covered by agreed standards and recommendations, although some difficulties and inconsistencies still remain. It should be mentioned that testing is also increasingly undertaken, in a commercial context by the operators, to verify the manufacturer's performance warranty. Such tests will tend to follow the agreed performance testing methodology although the context is often more demanding, involving possibly complex terrain and also the influence of adjacent turbines. There are other specialized tests that are of importance, such as for determining the acoustic emission characteristics, and the assessment of noise at a given site. Other areas such as the evaluation of fatigue, including the associated mechanical loads, and power quality can involve direct measurement.

This section will provide an overview of field testing, and in particular will

1. describe the reasons for undertaking field testing,
2. identify recognized testing procedures,
3. examine practical aspects of transducers and data loggers,
4. discuss the difficulties associated with aerodynamic performance assessment
5. looks at errors and uncertainty

4.4 WIND TURBINE PERFORMANCE MEASUREMENT

Wind-turbine performance is concerned with the estimation of long-term energy production expected on a given site. The wind resource is described by the probability distribution (usually annual) of 1h (sometimes 10 min) mean wind speeds. To calculate the average energy production for a given probability distribution of wind speeds a relationship between wind speed and wind power is needed, this is the power curve of the wind turbine. As dynamic effects are not of interest for long-term performance, averaging of the measured wind speed and wind turbine power is carried out which improves the correlation between them and attenuates the effects of wind turbulence. This is not to say that site turbulence is irrelevant a point which will be dealt with later. It is also important to note the power from the wind turbine which is of relevance here is the net power, defined as the power available from the wind turbine less power needed for control, monitoring, display or maintaining operation. In other words it is the power available to the user and is measured at the point of connection to the network.

4.4.1 Wind-speed measurement

Wind speed is the most critical parameter to be measured so considerable emphasis should be placed on its accuracy. According to the IEA (1982) the anemometer should have an accuracy of 5 percent or better over the range of relevant wind speeds and according to the revised IEA recommendation (1990) it should be accurate to 0.1m/s or less for wind speeds between 4 and 25 m/s. Finally the IEC have opted to eschew a stated precision, and require instead calibration against a traceable instrument. The instrument should be calibrated, before and after the test, so as to establish that its accuracy has been maintained throughout the test(MEASNET have documented a specified calibration procedure). To avoid problems, it is advisable to run in a new anemometer for a period of about 2 months before use, to allow the bearings to ease. Another characteristic of an anemometer is its distance constant, which the IEC states should be 5 m or less. The distance constant is an indication of the response of the anemometer and is defined as the Length of wind run which must pass the anemometer for its output to reach $\left(1-\frac{1}{e}\right)^{\frac{1}{4}}$=0.63 of its final value. Large distance constants can give rise to a significant over speeding effect because the cup anemometer responds more quickly to increases in wind speed than decreases, and this is the reason for the 5 m cut off in the standard. Some believe that, even with a distance constant of 5 m, the instrument should be assessed to evaluate the likely over-speeding error, and a correction applied if necessary. The IEC allow this as the accuracy can be shown to be improved. The wind speed that is measured should be as representative as possible of wind which would have been present in the plane of the rotor in the absence of the wind turbine. The desired velocity never exists and so a suitable upstream velocity is selected instead. The anemometer location is generally chosen so as to minimize any interference from the wind turbine rotor itself whilst maintaining a reasonable correlation between the measured wind speed and the output from the wind turbine. Between 2 and 4 rotor diameters from the wind turbine is stated in the IEC standard, which recommends 2.5 diameters as the optimum. This compares with the 2 and 6 diameters recommended by the IEA. If the anemometer were placed significantly nearer than 2 diameters, correction for the velocity deficit caused by the rotor would have to be made. Although corrections can in theory be made to take account of wind shear for anemometers not at hub height, this is discouraged and whenever possible the wind speed should be measured at the same height (relative to ground level) as the hub of the wind turbine rotor. The IEC specify a height within 2.5 percent of the turbine hub height. As already mentioned, the anemometer must not be located in the wake of the turbine, or other significant obstacles on the site, including of course other wind turbines, operating or otherwise. Poor location of the anemometer on the tower has recently been identified as a potential cause of error and for the first time with the IEC standard, precise guidelines exist. These reflect the need to avoid mast wake effects and any significant blockage in the vicinity of the instrument. An ideal location is on a vertical tube clear of the top of the meteorological mast. To speed up the experimental assessment it is common to use more than one meteorological mast, arranged so that at least one anemometer is free of any exclusion zone at any given time

4.4.2 WIND TURBINE MODEL IN SIMULINK

The output power of the turbine is given by the following equation.

$$P_m = c_p(\lambda, \beta)\frac{\rho A}{2}v_{wind}^3 \qquad (1)$$

Where

P_m mechanical output power of the turbine (w)
C_p performance coefficient of the turbine
P air density (kg/m^3)
A Turbine swept area (m^2)
V_{wind} Wind speed (m/s)
λ tip speed ratio of the rotor blade tip speed to wind speed
β blade pitch angle (deg)

The Simulink model of the wind turbine is illustrated in the following figure4.2. The three inputs are the generator speed (ωr_pu) in pu of the nominal speed of the generator, the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in pu of $\lambda_{\_nom}$ is obtained by the division of the rational speed in pu of the base rotational speed and the wind speed in pu of the base wind speed. The output is the torque applied to the generator shaft.

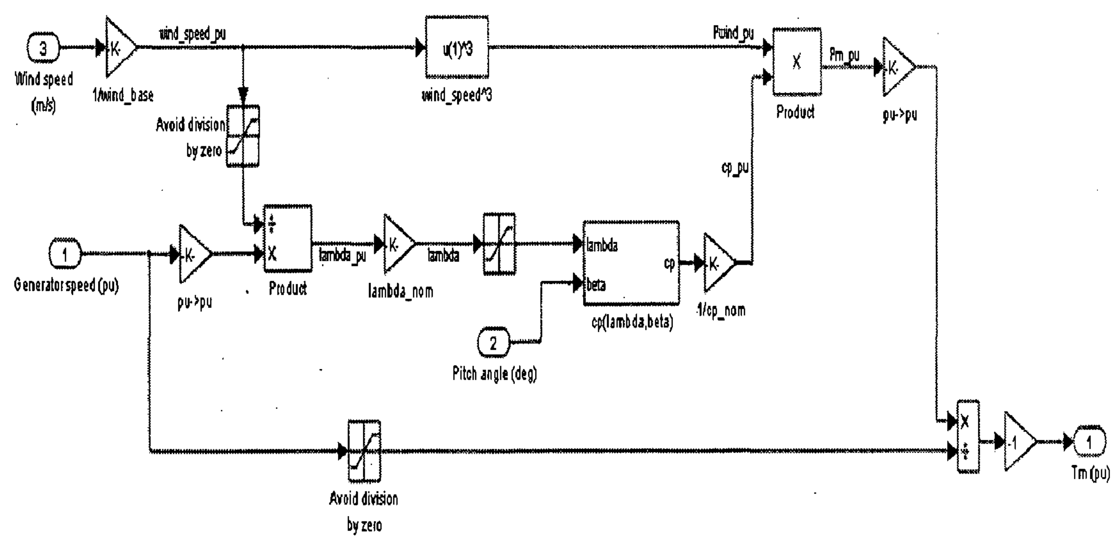

Fig 4.2 Simulink model of the wind turbine

The mechanical power P_m as a function of generator speed, for different wind speeds and for blade pitch angle $\beta = 0$ degree, is illustrated below. This figure is obtained with the default parameters (base wind speed = 12 m/s, maximum power at base wind speed = 0.73 pu ($k_p = 0.73$) and base rotational speed = 1.2 pu).

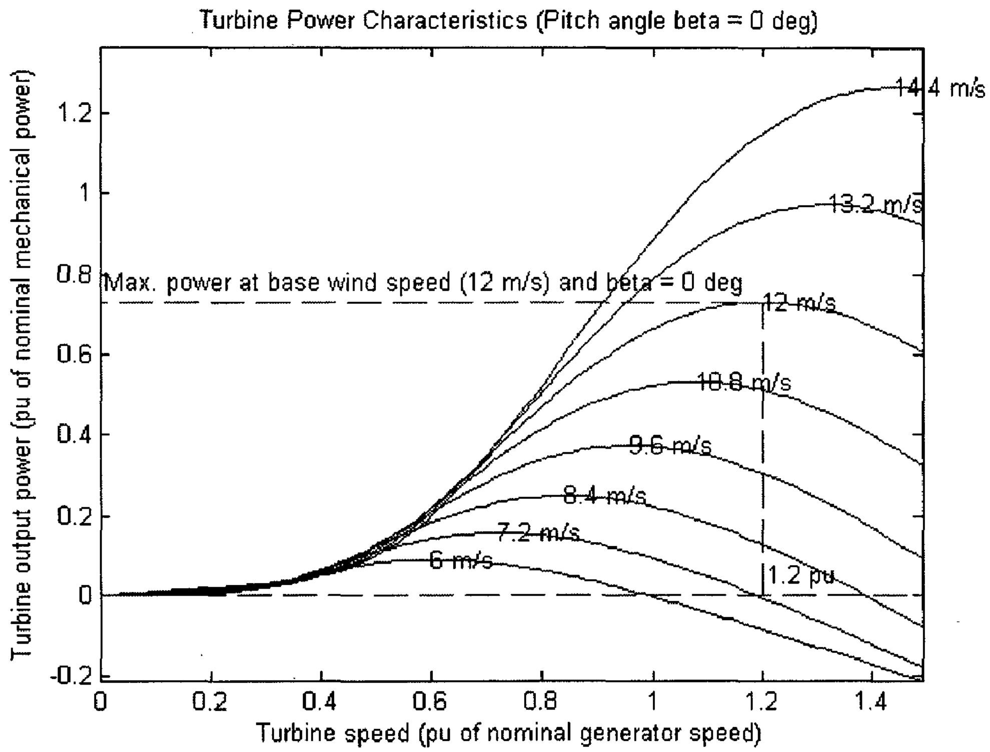

Fig 4.3 Turbine power characteristics

4.5 WIND SPEED AND ENERGY DISTRIBUTIONS

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over year.

4.5.1 Speed and Power Relations

The kinetic energy in air of mass "m" moving with speed V is given by

$$\text{Kinetic Energy} = \frac{1}{2} \times m \times v^2 \text{ joules.} \quad (2)$$

The power in moving air is the flow rate of kinetic energy per second therefore

$$\text{Power} = \frac{1}{2} \times mass\ flow\ rate\ per\ second \times v^2 \quad (3)$$

If we let P= mechanical power in the moving air in watts

ρ = air density Kg/m^3

A= area swept by the rotor blades, m^2

v= velocity of the air, m/s

Then, the volumetric flow rate is A.V, the mass flow rate of the air in kilograms per second is ρ, A.V, and the power is given by the following.

$$P = \frac{1}{2} \times (\rho A v) \times v_2 = \frac{1}{2} \times (\rho A v_3) \text{ Watts} \quad (4)$$

Rotor Swept Area

The output power of the wind turbine varies linearly with the rotor swept area. For the horizontal axis turbine, the rotor swept area is given by:

$$A = \frac{\pi}{4D^2} \quad (5)$$

Where

D is the rotor diameter.

For the vertical axis machine, determination of the swept area is complex, as it involves elliptical integrals. However approximating the blade shape as a parabola leads to the following simple expression for the swept area

$$A = \frac{2}{3} \times (Maximum\ rotor\ width\ at\ center) \times (Height\ of\ the\ rotor) \quad (6)$$

The wind turbine efficiently intercepts the wind energy flowing through the entire swept area even though it has only two or three thin blades with solidity between 5 to 10 percent. The solidity is defined as the ratio of the solid area to the swept area of the blades.

Air Density

The wind power varies linearly with the air density sweeping the blades. The air density ρ varies with pressure and temperature in accordance with the gas law;

$$\rho = \frac{P}{RT}$$

where, p=air pressure T=temperature on the absolute scale

R= gas constant.

The air density at sea level, one atmospheric pressure and 60oF is 1.225 kg/m3. Using this as the reference, ρ is corrected for the site specific temperature and pressure. The temperature and the pressure both in turn vary with the altitude. Their combined effect on the air density is given by the following equation, which is valid up to 6,000 meters of the site elevation above the sea level:

$$\rho = \rho_o \times \varepsilon^{-\left\{\frac{0.297 \times Hm}{3048}\right\}} \quad (7)$$

Where,

H_m is the site elevation in meters.

4.5.2 WIND SPEED DISTRIBUTION:

Having the cubic relation with the power, the wind speed is the most critical data needed to appraise the power potential of a candidate site. The wind is never steady at any site. It is influenced by the weather system, the local land terrain, the height above the ground surface. The wind speed varies by the minute, hour, day, season, and year. The wind-speed variations over the period can be described by a probability distribution function.

Weibull Probability Distribution

The variation in wind speed are best described by the Weibull probability distribution function 'f' with two parameters, the shape parameter 'k', and the scale parameter's'. The probability of wind speed being v during any time interval is given by the following:

$$f(v) = \frac{\beta}{\eta} \times \left(\frac{v}{\eta}\right) \times \beta^{-1} \times \exp\left(-\left(\frac{v}{\eta}\right) \times \beta\right) \qquad (8)$$

where f *(v)* is the probability of observing wind speed v, Basically the scale parameter, η indicates how 'windy' a wind location under consideration is, whereas the shape parameter, β, indicates how peaked the wind distribution is (i.e. if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and be very peaked).

Once the mean, v¯ and the variance, σ^2 of the data are known then approximation is done to calculate the weibull parameters c and k.

$$\beta = (\sigma/v^{\wedge}-)^{1.086} \qquad (9)$$

$$\eta = \frac{v^{-}}{\tau\left(1+\frac{1}{\beta}\right)} \qquad (10)$$

By studying the wind speed records, the shape parameter β and scale parameter η of the Weibull distribution are computed as 3 and 11m respectively.

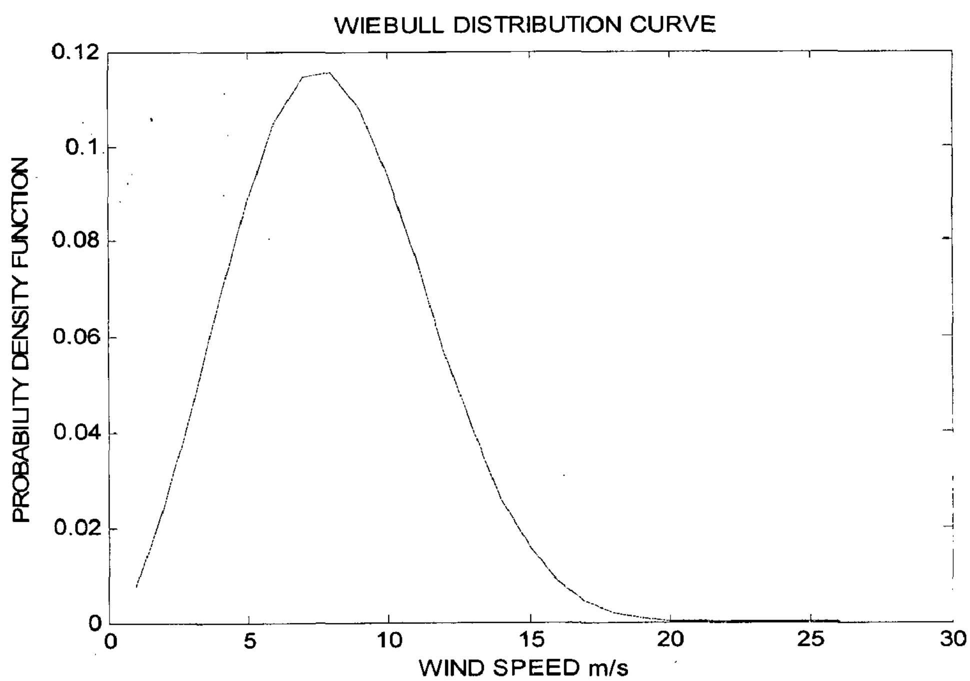

Fig.4.4 Weibull distribution curve.

The Weibull distribution curve applied for the most of the test sites is shown in figure4.4

4.6 POWER QUALITY APPLIED ON WIND TURBINES

When it comes to power quality from wind turbines only some specific voltage irregularities are of interest. A conventional wind turbine, equipped with an induction generator connected directly to the grid, gives a fluctuating active power output and has a reactive power demand. This may lead to slow voltage variations.

Inverters do inject harmonic currents into the grid and will, due to the grid impedance, cause harmonic voltages. As a result, voltage harmonics are the most interesting type of irregularity when converters are used. A simple converter may due to current harmonic content and reactive power demand, make the power quality worse. Using an advanced converter makes it possible to control the reactive power. An advanced converter can also operate as an active filter [15-16]

VARIABILITY OF WIND

The variability of the wind is a crucial factor in the exploitation of wind energy and in the design of a wind turbine. Knowing such information on an area's mean wind speed, the decision for the selection of size of a wind turbine can be determined.

The variability of the wind is acknowledged in the design ranges of commercial wind turbines. It is common to offer tower height and rotor diameter variations around a particular core design to suit specific site conditions.

4.7 WIND TURBINE SIZES

Wind turbines can have ratings from hundreds of watts to thousands of kilowatts. Turbines in the range several kilowatts are for battery charging applications such as remote telecommunications, electric fences and domestic systems. Large wind turbines in the range of hundreds to thousands of kilowatts are used commercially for power stability and distribution. Examples of large sized wind turbines are given below

1. Enercon E30(200 kw), E40 (500 kw) and E66 (1.5 Mw)
2. Lagerwey LW45/750 (750 kw)
3. Aeolus III (3 MW)

4.8 OFFSHORE WIND FARMS

The largest offshore wind farm in the world is the 17 MW Dronten wind farm in the Netherlands (based on 600 kW units). This farm is, however, only offshore in the sense that it has its foundations in the water of an inland sea. According to various studies, larger machines of several MW need to be used to reduce generation costs. The first offshore wind turbine was installed in 1990 by Wind World in Sweden. Since then four other projects have been installed, two in Denmark and the other two in the Netherlands. In total there are 45 wind turbines with a total capacity of 23.57 MW. All of these offshore projects are installed relatively close to the shoreline, between 1-5 km. One of the major challenges offshore lies in the logistics of maintenance and repair, daily monitoring and control of offshore installations. Some of the reasons for off-shore wind farms include higher average wind speeds (~15%), and little to no visual or environmental impacts.

CHAPTER5

DIESEL ENGINES AND GENERATORS

5.1 DIESEL ENGINES

Diesel engines are a common part of our everyday lives and they widely used in automobiles and other applications. Diesel prime-movers are attractive for applications requiring fast responding backups at the time of peak load demands, or where local demand for additional power necessitates augmentation of power source. Since the response of the prime mover itself is fast, it is imperative that control techniques that are fast converging, and involve low computational burden, be employed. An important feature of the diesel prime-mover, that distinguishes it from other power systems where adaptive control may be an attractive possibility [17-18], is the presence of an input dead-time between the actuator oil-injection and the production of mechanical torque. The dead time of the diesel engine is non-linear function of operating conditions, and also of the engine speed. This significantly degrades the performance of the prime mover under disturbances. Although certain PID schemes presently in use give acceptable performance.

5.1.1 SPEED CONTROL OF THE DIESEL ENGINES

Speed control of power generation plants driven by diesel prime-movers is difficult because of the presence of a dead time and changes in parameters. This results in slow plant dynamics. Self tuning PID controller based on indirect estimation of the dead time is proposed resulting in fast response at the startup and quick recovery, when a disturbance occurs. By using indirect estimation of the dead time and recursive least squares parameter estimation, an explicit estimate of the plant parameters and dead time is obtained.

Typical diesel engine model describes the fuel consumption rate as a function of speed and mechanical power at the output of the engine. It is usually modeled by a simple first order relating the fuel consumption (fuel rack position) to the engine mechanical power [19]. The power output of the engine and the generator has to be varied with the changing load to meet the consumer demands. The task of the governor is to adjust the fuel flow and then regulate the input of the engine and the generator so as to provide the required power to meet changing in the load.

The presence of dead-time between the actuator fuel injection and the production of mechanical torque is very important characteristic of the diesel engine. There are also system parameter uncertainties which together with the varying dead time significantly degrade the performance of the prime mover, especially in case of a load. A diesel engine is a nonlinear system together with a nonlinear, time-varying dead time between the injection and production of the mechanical torque. It is commonly controlled with a PI controller to prevent steady-state error in speed.

5.1.2 METHODS OF SPEED CONTROL OF DIESEL ENGINES

1. An adaptive speed controller method
2. Combination of neural network and fuzzy logic approaches
3. An H_∞ controller for diesel engine systems.
4. Comparison of a k-predictive adaptive controller

5.1.3 MODELING OF DIESEL ENGINE

There are many methods for modeling diesel engine, with comparison of those a k-predictive adaptive controller method is used most widely. The general structure of the fuel actuator system is usually represented as a first order phase lag network, which is characterized by gain K_2 and time constant τ_2 the fig 5.1 shows the actuator and the current driver constant K_3. The output of the actuator is the fuel-flow φ.

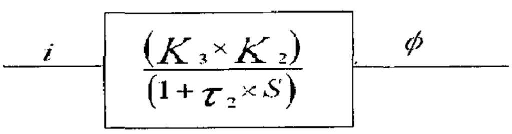

Fig 5.1 The Actuator Model and the current driver constant.

The fuel flow then converted to mechanical torque q after time delay τ_1 and the engine torque constant K_1 which can be represented by the model of the diesel engine as shown in fig 5.2

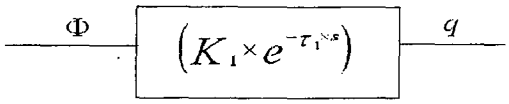

Fig5.2 Diesel Engine Model.

The governor can be defined as a mechanical or electromechanical device for automatically controlling the speed of an engine by relating the intake of the fuel. Several types of governors exist as mechanical-hydraulic, direct mechanical type, electro hydraulic, electronic, and microprocessor based governors. The integrator is added between the reference signal and the engine actuator to eliminate the speed droop in steady operation. The flywheel represents the complex dynamic effects of engine inertia, the angular speed of flywheel, the viscous friction coefficient ρ and the loaded alternator. It can be essentially assumed to have an integrator with flywheel acceleration constant J and serves to filter out a large proportion of the disturbance and noise effects. The values K_3 and K_2 can be considered to be constant for a particular engine setup. K_3 is a factor that determines the amount of the mechanical torque obtained per unit of fuel flow. K_3 depends on the operating point of the prime mover.

The parameter estimation algorithm, which is based on the exponential weighted sequential least squares method, is chosen to estimate the parameters. Self tuning PID controller based on indirect estimation of the dead time is proposed for control system.

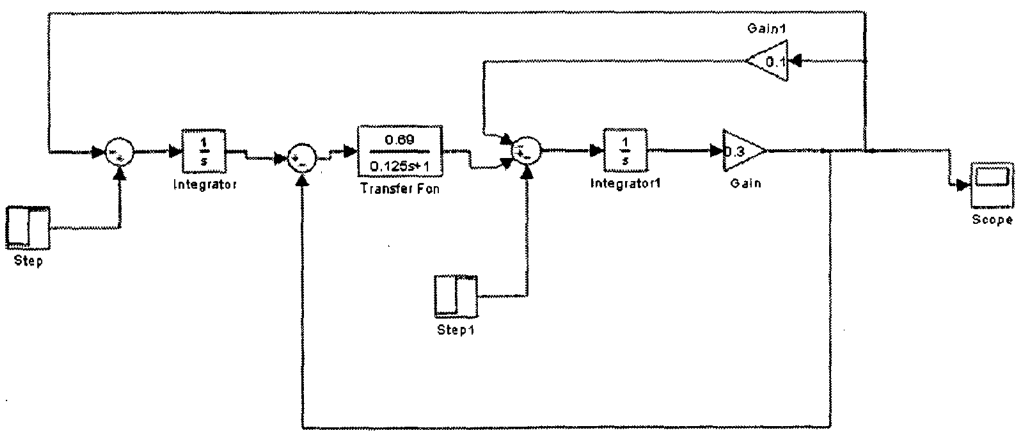

Fig 5.3 Simulink diagram of the Diesel engine system

The gain value 0.3 in the fig.5.3 is the flywheel acceleration constant, the gain1 value 0.1 in the fig 5.3 is viscous friction coefficient, and transfer function in fig.4 combines both the actuator and the diesel engine model. The speed loop control study involves two types of changes in the performance conditions, startup and load disturbances. For the purpose of performance studies, the diesel prime movers with self tuning PID controller have been simulated. In the startup condition unit step of signal was applied at t=0 and after 25 second another unit step signal was injected as load disturbance to see how the controller responded.

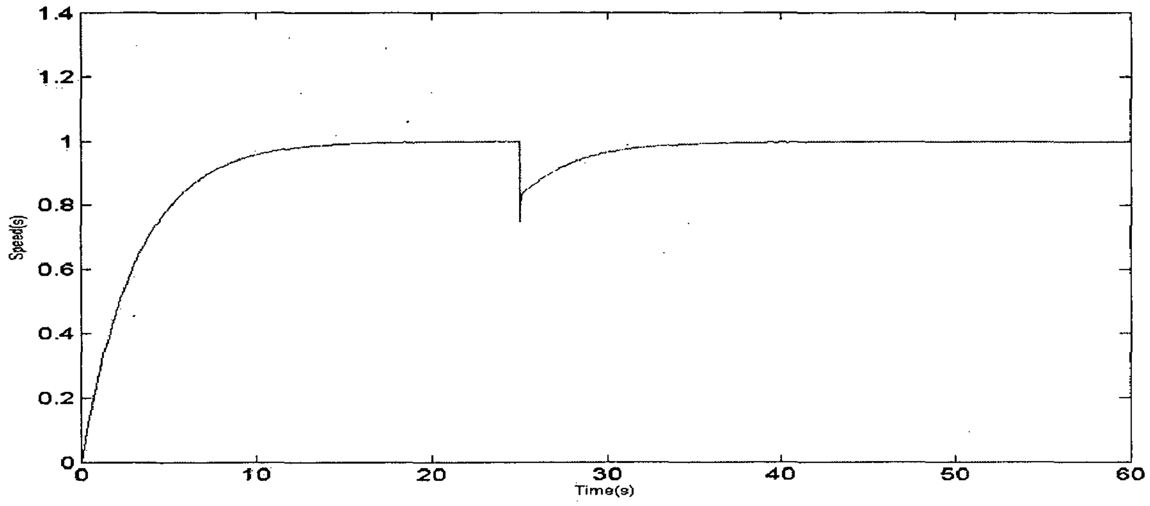

Fig 5.4 Speed Characteristics of Diesel engine for K_I=0.9, τ_2 =0.05

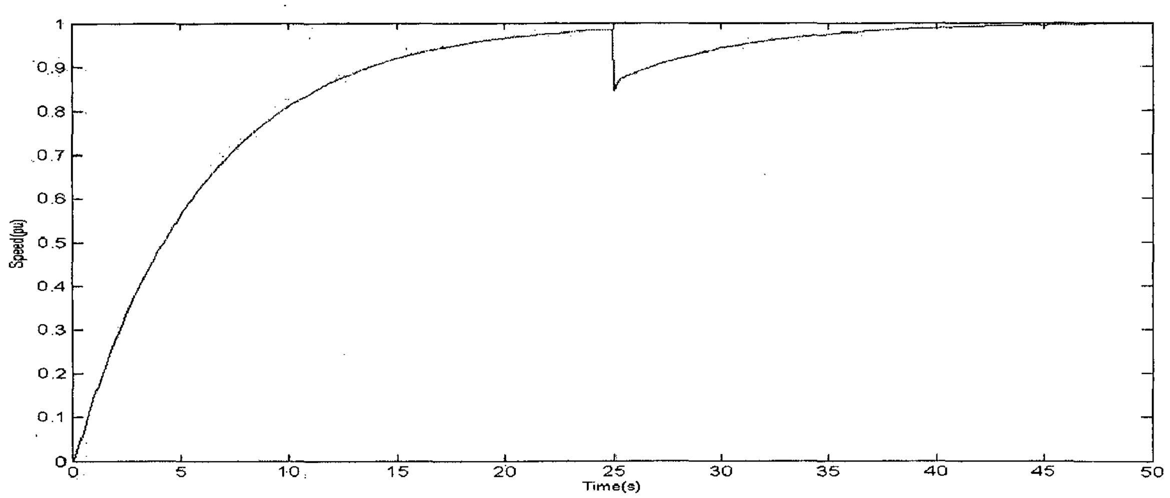

Fig 5.5 Speed Characteristics of Diesel engine for K1=0.7, τ_2 =0.1

5.2 DIESEL GENERATORS

Diesel generators also know as Gensets, provide reliable power when properly maintained. The initial cost of a complete diesel power system is also relatively low. They can be easily transported and are low-tech which aids in their reliability and ensures ease of operation. So far they sound like the ideal solution for the given application but where they fall down is in the environmental and running costs.

Standard diesel generators are fitted with synchronous generators and consequently are controlled to run at a constant speed to guarantee constant electrical frequency. Due to the poor efficiency at low load, most of the engine manufacturers recommend their plants be operated no lower than 40% of rated capacity in order to prolong diesel engine lifetime. To achieve this dump loads may need to be installed at extra cost to the consumer. The fuel consumption rate per Kw of power is increase at lower loads and fuel consumption at no load is still 15-30% of the full load value. At low loads the speed of the generator will be reduced ensuring the engine is running optimally in terms of fuel economy. Due to the above considerations the variable speed diesel generators were recommended, the main push for the variable speed revolution is the inherent problems of fixed speed minimum operating load and poor efficiency at low load. Permanent magnet synchronous generator is used as variable speed diesel generator for most of the applications.

Recent advancements in power electronics and control strategies have made it possible to regulate the voltage of the Permanent Magnet Synchronous Generator (PMSG) in many different ways. This has resulted in renewed interest in PM synchronous generators, particularly in the remote areas with diesel engines, small-scale power generation with small hydro heads and wind power. Fig 5.6.shows the schematic diagram of diesel engine with Permanent Magnet Generator where K in the fig is equal to $K_1 \times K_2 \times K_3$. Typical values of system parameters were given in Appendix A.

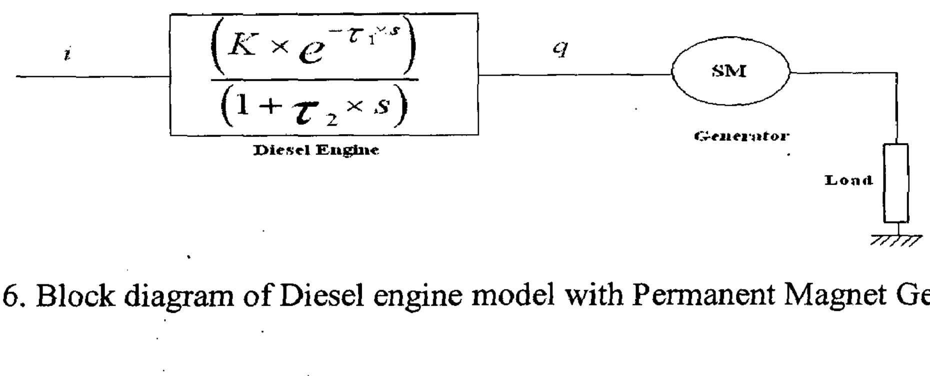

Fig 5.6. Block diagram of Diesel engine model with Permanent Magnet Generator

CHAPTER6

WIND-DIESEL HYBRID SYSTEMS

6.1 INTRODUCTION

In the last several years, interest in medium to large scale (100kw to multi-MW) wind-diesel hybrid power systems for rural electrification has grown enormously among energy officials and utility planners in the developing countries. Only a small fraction of researchers and engineers working in the wind power industry, which is relatively small itself, are involved in hybrid systems for off-grid applications. There is therefore relatively little information available on the technical issues involved in implementing a wind-diesel power system.

It is tempting to view the addition of wind turbines to a diesel mini-grid or isolated system as a straight forward task, only slightly more complicated than a conventional grid-connected installation, requiring only a few ancillary components at a relatively modest cost. This is true for low penetration wind-diesel hybrid systems, for high penetration systems much more sophisticated controllers and more extensive components in addition to the wind turbines are required. This thesis focuses to some of the control challenges faced by developers of wind-diesel systems, system stability and long term performance.

Since 1995, the National Wind Technology Center (NWTC) at NREL has been researching wind-diesel hybrid power systems. Areas of study have included optimal diesel dispatch strategies, the value of energy storage, village mini-grid optimization, power converter efficiency, and economic modeling.

6.2 PRIMARY TASKS OF A HYBRID POWER SYSTEM

1. Automatic dispatch of the diesel generators to ensure proper loading and good operating efficiency.
2. The most critical tasks of the system are to provide good frequency and voltage
3. Performance data logging to facilitate troubleshooting and maintenance.

4. Management of the secondary loads to ensure that excess power is directed where it is most needed.

6.3 MAIN PRINCIPLE

In periods with sufficient wind power to supply the electrical system and necessary water production or heating the diesel engine(s) are disconnected from the generator by means of a magnetic clutch and shut down in order to save fuel. In these periods the power system is solely supplied from the wind turbine(s) (100% wind power penetration) and there is no idle fuel consumption of the diesel engine(s). The standby diesel engine shall be preheated in order to facilitate a fast startup.

6.3.1 FREQUENCY CONTROL

Control of the hybrid power system frequency is maintained by the fast control of the power balance between the fluctuating wind power, the dump load bank (electrical heating elements) and the consumer load. In periods where the diesel engine is in operation the frequency is controlled by the diesel engine governor. In periods with 100% wind power, the frequency is controlled by absorbing the surplus wind energy in a dynamic variable dump load or load bank.

6.3.2 VOLTAGE CONTROL

Control of the wind-diesel hybrid system voltage is maintained by the Automatic Voltage Regulator (AVR) of the synchronous generator - also supplying reactive power for energizing the induction generators in the wind turbines. At increasing load or decreasing wind power, thus the wind power is not able to supply the complete consumption the diesel genset is automatically started supplementing the wind power.

6.4 OPERATION OF A HYBRID SYSTEM

The power output from wind turbines varies during the day according to the variations in wind speed. In a large grid these variations and fluctuations in wind power are absorbed by the strong grid, thus controlling frequency and voltage. In a small and isolated grid the power balance between production and consumption has to be continuously maintained in order to keep frequency and voltage of the small grid within predefined limits. As the wind power does not supply constantly, the power balance between the consumption, the fluctuating wind power and the diesel power must be maintained by regulating the power output of the diesel generator or in periods with surplus wind power (wind power larger than the consumption) regulating the load by means of a dump load or load bank. The installed capacities of energy producing units in isolated grids are typically made up of smaller units. These small units provide flexibility in regulation of the power output, e.g. a modern diesel generator can be started up, synchronized and connected to the grid in less than 2 seconds. Furthermore, during operation the fast automatic governor of a modern diesel generator reacts to changes in grid frequency and voltage so, that the resulting fluctuations are negligible.

6.5 ECONOMICS OF THE WIND-DIESEL SYSTEM

As the level of system penetration increases the complexity of the power system also increases and subsequently so does the cost. Therefore, the optimal level of system penetration increases complexity of the power system also increases and subsequently so does the cost. The optimal level of wind penetration depends on the relative cost difference between increasing the penetration of wind and difference between generation using wind and diesel technology. If excess energy from the wind can be used in place of other expensive fuels to provide additional services, such as heating, the economics of using alternative sources also improve.

6.6 ENERGY STORAGE OF WIND-DIESEL HYBRID SYSTEMS

An additional design consideration for hybrid systems is the use of energy storage device. The amount of storage influences the system's ability to cover short-term fluctuations in wind energy and/or the village load. The addition of energy storage into a high-penetration wind-diesel system can increase the fuel savings and reduce the diesel generator operating hours and number of starts. These factors affect the wear on the diesel machines and resulting maintenance and overhaul costs. However, the storage equipment is expensive and difficult to ship, install and maintain, and their useful lifetime is generally limited to 5-15 years. In low penetration systems, storage is not required since the wind does not provide enough power to allow the diesels to be shut off. Storage is also not required in medium and high-penetration systems if an adequate dump load and synchronous condenser are provided to maintain voltage and frequency stability. This preliminary analysis investigates the potential of low to high penetration systems with no storage. The costs and benefits of adding battery storage systems will be considered at a later time. In a system without energy storage, a dispatchable Energy source (the diesel engine in this case) must be used to cover the difference between the power required by the community (the village load) and power being supplied by the wind turbine. This difference is usually called the instantaneous net load. The net load fluctuates due to changes in the village load and changes in power from the wind turbine due to changes in the wind speed. In order to cover any anticipated increases in the net load, an operating reserve must be maintained. In this analysis a reserve equal to 20% of the wind power output was used. The no-storage system can include a dump load to absorb any excess electricity generated and to maintain system frequency. Systems may also include active load control to shut off non-critical loads in time of power storage. At least one diesel is always in operation to provide reactive power and maintain system voltage.

6.7 ADVANTAGES OF WIND-DIESEL HYBRID SYSTEMS

In the small isolated grids the cost per unit energy is much higher than in the main grids. Typically the electrical powers in the small isolated grids are generated by means of combustion engines (diesel generator sets). Compared to the relative energy costs (price per kWh energy) of conventional power plants in the main grids, the price of energy produced by diesel generators are often seen to be much higher -especially when adding the costs for transportation of fuel. Alternatively, renewable power such as wind or solar can be utilized. However, a major drawback of the renewable sources is its irregularity in generating power. With a combined wind diesel system, fuel savings and system reliable can be achieved. Fuel savings means lower operating costs. The system will minimize the pollution regarding emissions of noise, exhaust gases and other waste, as the diesel generator will turn off for periods when wind generated power is sufficient. Lesser diesel operation means a longer life or less maintenance for the diesel generator, thus further reducing costs.

6.8 APPLICATIONS OF WIND-DIESEL HYBRID SYSTEMS

The worldwide potential for conventional wind turbines in isolated grids is extremely large. In remote locations the cost of electricity is very high due to the extreme costs of transmission lines or fuel for local generating plants. Based on the high costs of electricity incentives are present for the search for efficient and sustainable energy generating concepts. Due to the high energy costs in remote areas these locations may be viable for implementation of wind diesel systems - even if the wind conditions are moderate and not sufficient when compared with grid connected wind farms and energy costs in main grids. This means that areas with wind regimes lower than these normally feasible for wind farms may be interesting for wind-diesel plants.

In some areas the main problem for the survival of the community or the development of local initiatives is the lack of freshwater or heating. In these situations a wind diesel system utilizing all waste and surplus energy for the main purpose of fresh water production or heating is very applicable.

Based on the above, the following subjects are in favor of the implementation of wind-diesel systems:

1. Remote areas without any connection with main grids and without any electrification plan for main grids.
2. Islands with more than a few kilometers to nearest grid connection point.
3. Areas with lack of fresh water or sufficient heating.
4. Environmentally sensitive areas where reduction of emissions are essential.
5. Areas with high kWh price and high fuel price.
6. Areas with moderate to high wind potential.

CHAPTER 7
RELIABILITY STUDIES

7.1 INTRODUCTION

A Power system serves one function only and that is to supply customers both large and small, with electrical energy as economically and as reliably as possible. Due to random system failures the reliable power cannot be supplied all the times. The probability of customers being disconnected can be reduced by increased investment during the planning phase, operating phase or both. Although system may reliable the economic constraint is also necessary to be considered. The determination of the required amount of system generating capacity to ensure an adequate supply is an important aspect of power system planning and operation. The static capacity area is the long term evaluation of the overall system requirement. The probability techniques are used to evaluate the static capacity problem. This method provides an analytical basis for capacity planning which can be extended to cover partial or complete integration of systems. A large number of papers which apply probability techniques to generating capacity reliability evaluation have been published in the last 40 years. At present time it appears that the Loss of Load Probability or Expectation method ,Expected Energy Not Supplied is the most widely used probabilistic techniques for evaluating the adequacy of a given generation configuration.

7.2 PROBABALISTIC APPROACH

Power system behaves stochastically and it is rational to assess system reliability based on techniques that respond to the random system behavior in various scenarios. Probabilistic techniques have been developed to overcome the limitations of deterministic techniques and to provide quantitative measure of system reliability. Many utilities around the world have adopted probabilistic techniques for system risk evaluation at the Hierarchy Level (HL-I) level. The LOLE index is the most widely used index for system reliability evaluation at the HL-I level. The North American Electric Reliability Council (NERC) has provided LOLE index of 0.1day/year as a guideline for system planning at the HL-I level. This criterion requires that the generation system be designed such that the system load does not exceed the total generation for a long-term average value of 0.1 days in a year. Many utilities use this LOLE criterion in generation planning. Few utilities use the energy-based index such as the Loss of Energy Expectation (LOEE) or the Expected Unused Energy (EUE). Probabilistic techniques can be categorized under analytical and simulation techniques that can be useful in obtaining various statistical system risk indices.

1 ANALYTICAL TECHNIQUE

The system is represented by a mathematical model in an analytical technique, which provides direct numerical solutions. The majority of existing techniques are based on analytical methods.

2 SIMULATION TECHNIQUES

Simulation techniques are the other type of probabilistic methods used in power system reliability evaluation. Unlike analytical technique, this technique simulates the actual system process on a computer to evaluate various risk indices. The advancement in computing facility has made simulation process faster. Monte Carlo Simulation (MCS) process is based on random variable generator and it may provide different numerical solution every time the simulation is repeated. These techniques use chronological load variation for system risk evaluation.

MCS process can be mainly used in two ways, random and sequential. The random approach simulates the basic duration of the system lifetime by choosing intervals randomly. The sequential approach simulates the system interval chronologically [20]. This approach is very essential to analyze the system for which one basic interval has significant effect on the next interval. Simulation techniques can be very useful in system risk evaluation at the HL-1 level. Simulation techniques require large computation time and memory space. Slightly different results are usually obtained when a simulation process is repeated. These techniques are normally not used when direct analytical techniques are available. A crucial requirement in the reliability evaluation of a power System containing wind energy is to accurately simulate the hourly wind speed. Wind speed varies with time and sites and at a specific hour is related to the wind speeds of previous hours. An autoregressive moving average (ARMA) time series [21] was used as the wind speed model. The general expression is as follows

$$Y_t = \emptyset_1 \times y_{t-1} + \emptyset_2 \times y_{t-2} + \cdots + \emptyset_n \times y_{t-n} + \alpha_t - \theta_1 \times \alpha_t - \theta_1 \times \alpha_{t-1} - \theta_2 \times \alpha_{t-2} - \cdots - \theta_m \times \alpha_{t-m} \quad (11)$$

Where Y_t is the time series value at time t, $\emptyset_i\{i = 1,2,3,\ldots\ldots n\}$ and $\emptyset_j\{j = 1,2,3,\ldots\ldots M\}$ are the auto regressive and moving average parameters of the model respectively. $\{\alpha_t\}$ is a normal white noise process with zero mean and a variance of $\sigma^2 i.e. \alpha_t \in (0, \sigma_a^2)$ where "normally independently distribution is denoted NID.

The hourly wind speed SW_t at time t is obtained from the mean wind speed μ_t, its standard deviation σ_t and the time series value y_t as shown

$$SW_t = \mu_t + \sigma_t y_t \quad (12)$$

7.3 GENERATION SYSTEM ADEQUACY EVALUATION

The basic HL-I system model can be represented by the model shown in Fig 7.1 The overall system generation is denoted as G, which provides power supply to the system load. The basic approach to system reliability evaluation at the HL-I level can be represented by Fig 7.2 the evaluation process consists of three parts: a) generation modeling b) load modeling and c) risk modeling.

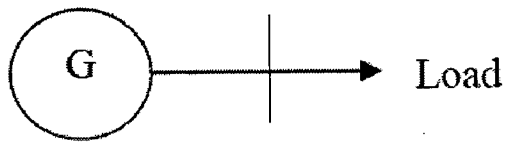

Fig.7.1 Basic Hierarchical Level-1

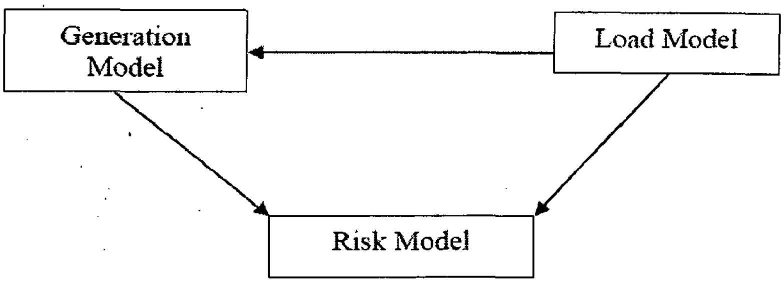

Fig.7.2 Basic concepts of Hierarchical Level-1 adequacy system

7.4 FORCED OUTAGE RATE:

The basic generating unit parameter used in static capacity evaluation is the probability of finding the unit on forced outage at some distant time in the future. This probability was defined in *Engineering Systems* as the unit unavailability, historically in power system applications it is known as the unit forced outage rate (FOR).The forced outage rate (FOR) is an important parameter in generation system modeling.. The FOR of a generating unit can be calculated using Equation 13

$$FOR = \frac{\sum[downtime]}{\sum[downtime] + \sum[uptime]} \tag{13}$$

Where

Downtime = expected failure rate.

Uptime= expected repair rate

The generating unit capacity ratings and the corresponding FOR are the important data inputs that are used to create a capacity outage probability table (COPT)

CAPACITY OUTAGE PROBABILITY TABLE

The generation model required in the loss of load approach is sometimes known as capacity outage probability table. It is a simple array of capacity levels and the associated probabilities of existence. If all the units in the system are identical, the capacity outage probability table can be easily obtained by using the binomial distribution. The COPT can be formed by using the recursive algorithm shown in Equation 14

$$P(x) = \sum_{i=1}^{n} p_i \times p'(x - C_i) \qquad (14)$$

Where

P'(X) and P(X) = the cumulative probabilities of the capacity outage state of X MW Before and after the unit is added respectively.

n = The number of outage states with C_i MW on outage with a probability of p_i.

The above algorithm is initialized by setting P'(X) = 1 for X ≤ 0 and P'(X) = 0, otherwise. Generating unit may partially fail and reside in derated state

7.5 LOAD DURATION CURVE

The load model represents the variation in the system load with time within a certain period. The basic period used in system planning and reliability study is a calendar year. It can also be presented in per unit of time. The system load can also be represented in per unit of the peak load. There are a number of load models, which can be used to produce different risk indices. The Load Duration Curve (LDC) are widely used load models in analytical evaluation. The Daily Peak Load Variation Curve (DPLVC) is a model that represents the variation in the daily peak loads in the descending order. The resultant cumulative load model is known as the LDC when the individual hourly load values are used. Fig.7.3 shows a simple load model.

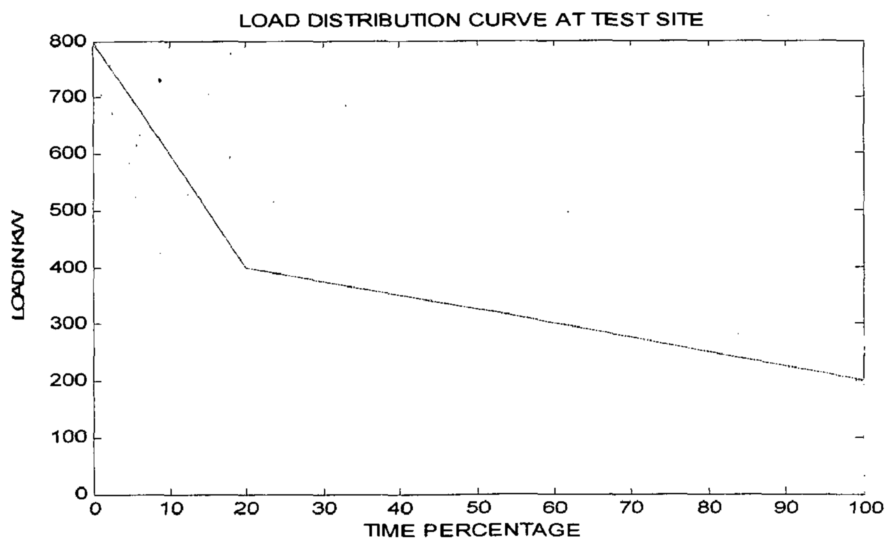

Fig 7.3 Load duration curve of test site

7.6 LOSS OF LOAD INDICES

The generation system model can be convolved with an appropriate load model to produce a system risk index. There are number of possible load models which can be used and therefore there are a number of risk indices which can be produced. The simplest load model and one that is used quite extensively is one in which each day is represented by its daily peak load. The individual daily peak loads can be arranged in descending order to form a cumulative load model which is known as the daily peak load variation curve. The resultant model is known as the load duration curve when the individual hourly load values are used, and in the case the area under the curve represents the energy required in the given period.

In this approach, the applicable system capacity outage probability table is combined with the system load characteristic to give an expected risk of loss of load. The units are in days if the daily peak load variation curve is used and in hours if the load duration curve is used. The individual daily peak loads can be used in conjunction with the capacity outage probability table to obtain the expected number of days in the specified period in which the daily peak load will exceed the available capacity. The index in this case is designated as the loss of load expectation (LOLE).

$$\mathrm{LOLE} = \sum_{i=1}^{n} p_i (C_i - L_i) \text{Days/period} \tag{15}$$

Where

C_i= available capacity on day i.

L_i= forecast peak load on day i.

If the time is in per unit of total time period, the above equation gives the Loss of Load Probability (LOLP) in lieu of the LOLE. The unit of LOLE is in days per year when using a DPLVC, and in hours per year when using a LDC load model.

The area under the LDC represents the total energy demand in a year by the system. Fig.6 is a LDC, the shaded area (E_k) corresponds to an energy curtailment due to capacity outage O_k with a probability of P_k. Each outage state in the COPT is superimposed on the LDC to calculate the total energy curtailed. The energy based index Loss of Expected Energy (LOEE) can be calculated using Equation 14. This index is also known as the Expected Unsupplied Energy (EUE).

$$\mathrm{LOLE} = \sum_{k=1}^{n} E_k \, t_k \tag{16}$$

7.6.1 EXPECTED ENERGY NOT SUPPLIED

The most popular technique at the present time for assessing the adequacy of an existing or proposed generating capacity configuration is the Loss of Load Probability or Expectation method [22] in this basic form this technique has been in existence for over thirty years. Another technique which has been in existence for almost as long is the Loss of Energy Approach. In this technique the capacity outage probability model is convolved with the period load duration curve to calculate the expected energy not supplied due to unit forced outages. The basic simplicity of this approach can be best illustrated by a simple numerical example. Consider the load duration curve (LDC) shown in fig.7.4 and the generating unit capacity data given in table.1

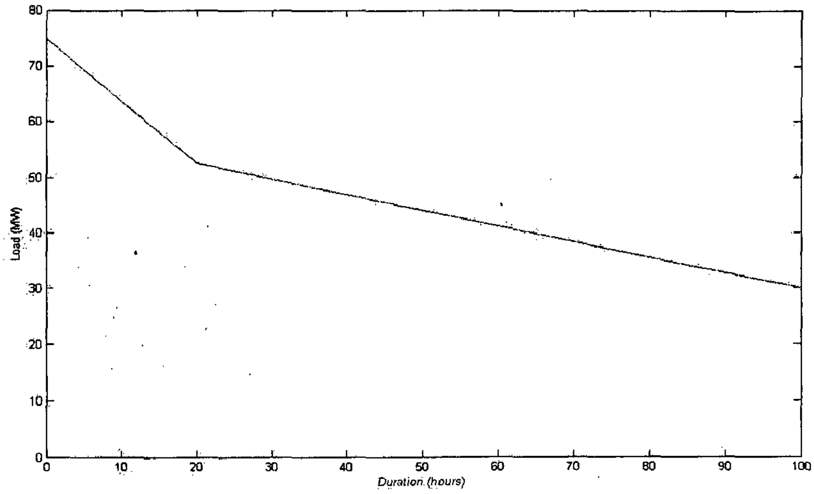

Fig 7.4. Load Model

Table 7.1 Generation Data

Unit No.	Capacity (MW)	Probability
1	0	0.05
2	15	0.30
3	25	0.65

The total required energy in this period is 4575 MWh i.e. the area under the LDC in fig 7.4 if there are no units in the system then expected energy not supplied ($EENS_0$) would be 4575 MW. The EENS for the above given schedule of the unit can be calculated as shown in table

Table 7.2 Calculation of EENS of 25MW unit.

Capacity out of service (MW)	Capacity in Service (MW)	Probability	Energy Curtailed (MWh)	Expectation (MWh)
0	25	0.65	2075.0	1348.75
10	15	0.30	3075.0	922.50
25	0	0.05	4575.0	228.75

$EENS_1$=2500MWh

The expected energy produced by the unit

= $EENS_0$-$EENS_1$

=4575-2500 =2075.0 MWh

The Expected Energy Not Supplied in the above system is 2075 Mwh. This can be expressed in terms of the energy index of reliability (EIR)

$$EIR=1-(EENS_1/EENS_0).$$

CHAPTER 8

RELIABILITY OF WIND-DIESEL SYSTEM

8.1 INTRODUCTION

With increasing introduction of wind generators in wind-diesel systems, system stability is becoming a crucial issue to the power company. Due to the intermittent characteristics of wind energy the most difficult issue is to assess the capacity adequacy of the hybrid system in addressing the electricity Demand of the consumers. However the well developed techniques applied to conventional generation system reliability evaluation, associate fixed capacity outputs to generating units and cannot readily extended to include wind energy sources that have highly fluctuating capacity levels[23].

A number of authors reported a variety of models to deal with this issue. All these models can be roughly classified by their techniques into two categories; the Monte Carlo simulation and the analytical method. The application of the Monte Carlo simulation to wind energy generation system utilizes prediction techniques to obtain time series wind speed data and integrate this fluctuant attribute with generation unit indices[23-26], In this method, the most critical step is the estimation of wind speed data, which requires historical wind speed data and a wind speed prediction model [27]. A well designed wind speed prediction model in the Monte Carlo simulation can lead to very reliable results coming from large amount calculation time on sequential simulation.

In[28] the authors demonstrate a model of constrained wind generation output below a certain ratio of system load considering conventional generation and load at the same time. In the time frame approach [29], discrete wind speeds are applied to wind turbine power output function with the probabilities of discrete speeds based on the Weibull distribution to model wind turbine generator (WTG). A short term system reliability index can then be obtained by associating this model with load duration curves within each discrete frame. The typical hybrid system configuration is illustrated in Fig 8.1

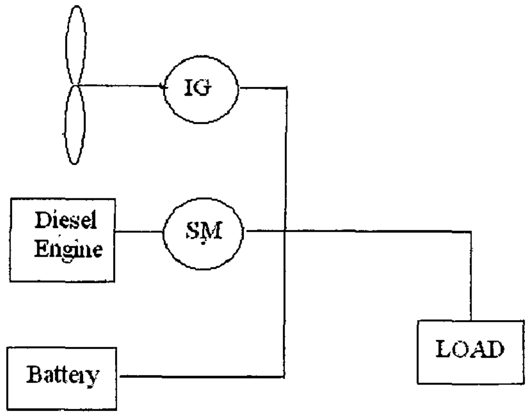

Fig.8.1 A typical wind-diesel power system

The approach proposed in this paper studies the performance of wind-diesel hybrid power system in discrete wind speed frames on the Weibull wind speed distribution to obtain long term reliability indices. The wind turbine generator modeling procedures deal with the single turbine or multiple turbines (wind farm). For wind turbine generators, assume that the outage events are independent of each other and have no correlation with wind speed.

Power Curve of Wind Turbine Generator

The Power curve gives a quantitative relationship between wind speed and wind turbine power output. It describes the operational characteristics of a wind turbine generator. Thus, to any power output, a corresponding wind speed can be found on this curve. A typical curve is shown in fig 8.2

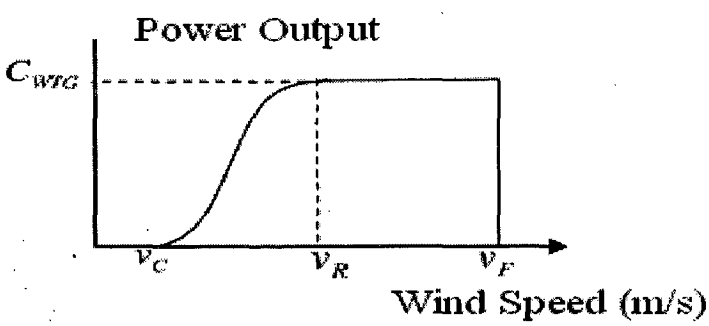

Fig 8.2 A typical power curve of wind turbine generator

Where

V_c is the cut-in speed

V_R is the rated speed

V_F is the cut-out speed

C_{WTG} is the rated Power output.

This curve comes available from the wind turbine manufacturer or plotted by polynomial curve fitting technique using recorded wind speed and corresponding power output data.

8.2 The Weibull Wind Speed Distribution

It is widely accepted that the Weibull distribution fits actual wind speed distribution quite well. Like many other studies, the Weibull distribution is utilized to describe the principle wind speed variation in this study. Its probability density function is given by:

$$f(v) = \frac{\beta}{\eta} \times \left(\frac{v}{\eta}\right) \times \beta^{-1} \times exp\left(-\left(\frac{v}{\eta}\right) \times \beta\right) \qquad (17)$$

Where

v is the wind speed (m/s)

β is the shape parameter and

η is the scale parameter (m/s)

8.2.1 Wind speed frames and wind turbine power output

Some of the earlier developed models use discrete wind speed points to describe the fluctuating characteristic of wind speed in time sequence, which means that turbine power output are studied one speed point after another. This requires a large amount of computation time to conduct calculation for numerous time intervals. However, by observing the Weibull wind speed distribution curve, it is not difficult to find that wind speed profile can be easily depicted by a series of speed frames and their probabilities. Fig 8.3 shows the wind speed frame on the Weibull distribution curve.

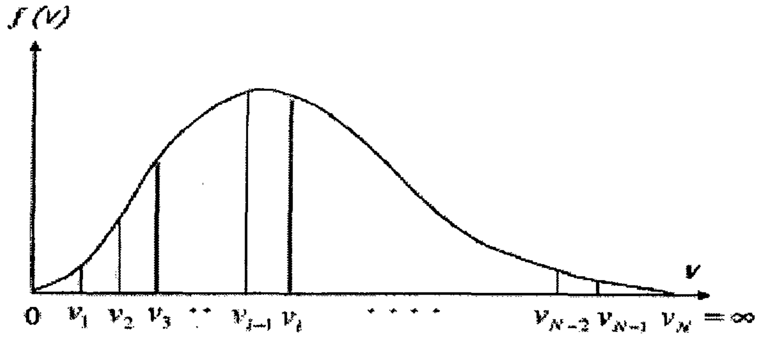

Fig 8.3 Wind speed frame on the weibull distribution

The Weibull distribution can be split along the horizontal axis into N equal frames. The first frame and last frame are from 0 to V_1 and from V_{N-1} to V_N respectively, with V_N equal to ∞. The value of frame interval Δ_V around 1m/s is sufficiently small.

T_i is the duration of i[th] speed frame

$$T_i = T\int_{V-1}^{V} f(v)\,dv \tag{18}$$

T is the whole study period.

P_{wi} is the availability of the i[th] speed frame.

$$P_{wi} = \int_{V-1}^{V} f(v)\,dv \tag{19}$$

P_{WTGji} is the average power output of j[th] wind turbine generator operating with i[th] wind speed frame,

$$P_{WTGji} = \frac{\int_{V-1}^{V} P_{WTGj}(v)f(v)d}{\int_{V-1}^{V} f(v)dv} \tag{20}$$

8.2.2 Wind farm modeling

Hybrid system may contain m wind turbines generators. If the Forced Outage Rate of the wind turbine is FOR_{WTG}. The availability rate can be represented by

$$A_{WTG} = 1 - FOR_{WTG} \tag{21}$$

If 'h' wind turbines out of 'm' wind turbines were operating in i[th] speed frame, the wind farm remaining capacity can be given by

$$C_{RWTGi} = P_{WTGi} \times h \quad (22)$$

Where

P_{WTGi}= average power output of any identical turbine generator operating within i-th speed frame

The Probability of the 'h' identical turbines available in calculated according to the Binomial distribution

$$P_{WTG} = \binom{m}{h} A_{WTG} (1 - A_{WTG})^{m-h} \quad (23)$$

Where

A_{WTG}= availability of any identical wind turbine Generator

The above procedure for calculating capacity and probability applies when all the turbines are of same rating. When there are different ratings the corresponding probability can be obtained by utilizing convolution algorithm.

8.2.3 Diesel Units modeling

Hybrid generation system modeling is conducted by incorporating wind model with diesel model. Diesel (conventional) unit is always described as two-state model.

If the Forced Outage Rate of the Diesel generator is FOR_D its available rate cane be represented by:

$$A_D = 1 - FOR_D \quad (24)$$

If g out of n Diesels are available. If all these Diesels belong to same type, the remaining capacity of the system can be given by

$$C_{RD} = P_D \times g \quad (25)$$

Corresponding probability can be given by

$$P_D = \binom{n}{g} A_D^g (1 - A_D)^{n-g} \quad (26)$$

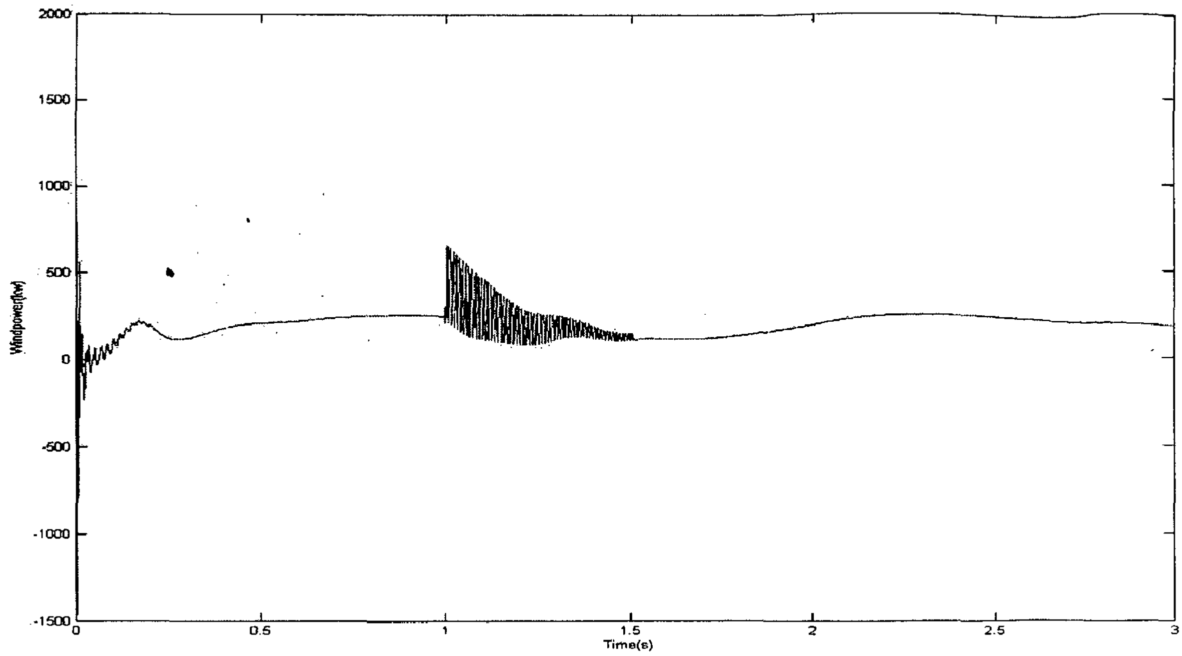

Fig 9.5 Wind power output (kw) for single-phase fault conditions

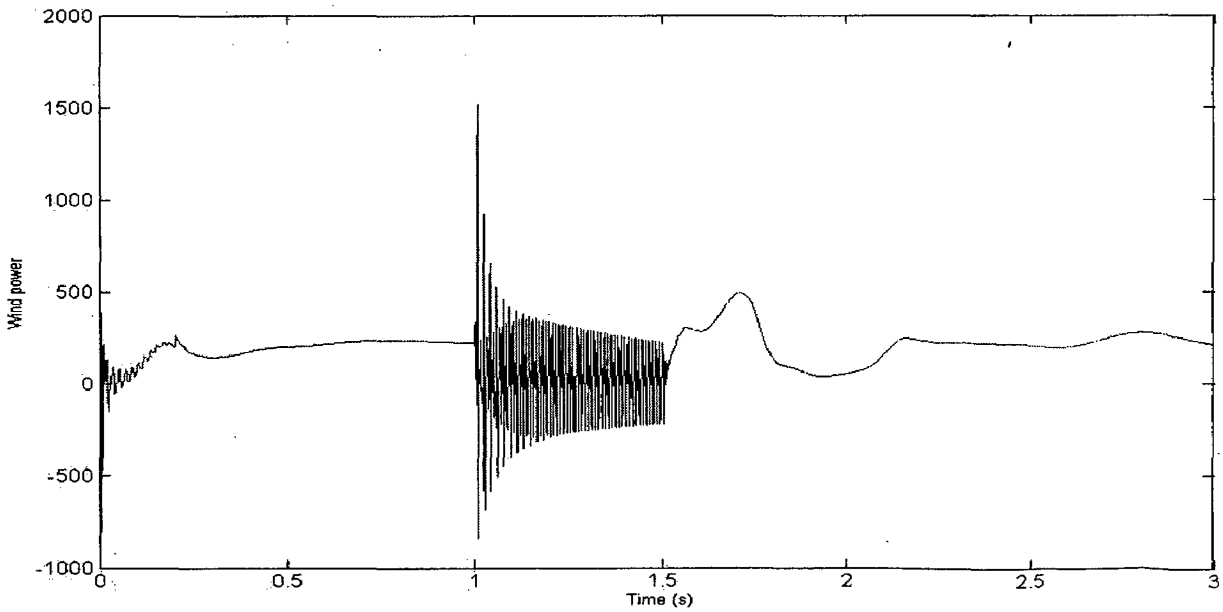

Fig 9.6 Wind Power output (kw) for two-phase fault conditions

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$$C_{RWTGi} = P_{WTGi} \times h \tag{22}$$

Where

P_{WTGi}= average power output of any identical turbine generator operating within i-th speed frame

The Probability of the 'h' identical turbines available in calculated according to the Binomial distribution

$$P_{WTG} = \binom{m}{h} A_{WTG} (1 - A_{WTG})^{m-h} \tag{23}$$

Where

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If g out of n Diesels are available. If all these Diesels belong to same type, the remaining capacity of the system can be given by

$$C_{RD} = P_D \times g \tag{25}$$

Corresponding probability can be given by

$$P_D = \binom{n}{g} A_D^g (1 - A_D)^{n-g} \tag{26}$$

8.2.4 Hybrid System Modeling

Hybrid system model can be easily obtained by combing the turbine model and the diesel model. After obtaining the wind turbine model and Diesel model the hybrid system capacity and corresponding probability can be given by

$$C_{RWDi} = C_{RD} + C_{RWTGi} \tag{27}$$

And

$$P_{Dwi} = P_D \times P_{WTGi} \times P_{wi} \tag{28}$$

8.3 RELIABILITY EVALUATION OF HYBRID SYSTEM

After wind turbine, Diesel generator has been modeled, the next thing is the evaluation of the reliability indices of the whole system. The main reliability indices are LOLE and EENS and EIR.

8.3.1 Expected Energy Not Supplied

The loss of energy when g available diesel generators and h available wind turbines operating within i^{th} speed frame can be denoted by the area E_i the expected energy not supplied throughout N_{speed} frames, $EENS_{gh}$ can be given by.

$$EENS_{gh} = \sum_{i=1}^{N} P_i\, E_i \tag{29}$$

The above equation can be generalized that for any 'x' available diesel generators and 'y' available wind turbines operating throughout the whole range of N wind speed frames, the corresponding expected energy not supplied can be represented by $EENS_{xy}$. so the EENS of the hybrid system can be obtained by

$$EENS = \sum_{x=0}^{n} \sum_{y=0}^{m} EENS_{xy} \tag{30}$$

8.3.2 Energy Index of Reliability (EIR)

$$EIR = 1 - \frac{EENS}{\text{Energy Demand}} \qquad (31)$$

8.3.3 Loss of Load Probability (LOLP)

After 'g' available diesel generators and 'h' available wind turbines operate through whole range of N speed frames, by repeating the above procedure N times the cumulated loss of load probability can be calculated by

$$LOLP_{gh} = \binom{n}{g} A_D^g (1 - A_D)^{n-g} \times \binom{m}{h} A_{WTG}^h (1 - A_{WTG})^{m-h} \times \sum_{i=1}^{N} \frac{P_{wi} \times t_i}{100} \qquad (32)$$

Generalizing (32) it can be obtained that for any x available diesel generators and y available wind turbines operating throughout whole range of N wind speed frames, the loss of load probability can be represented by $LOLP_{xy}$. Therefore the cumulated loss of load probability of the hybrid system consisting of n diesel generators and m wind turbines can be calculated as

$$LOLP = \sum_{x=0}^{n} \sum_{y=0}^{m} LOLP_{xy} \qquad (33)$$

CHAPTER 9

RESULTS AND DISCUSSION

9.1 The Asynchronous Generator's short-circuit regime transients

The specific regime can occur in the case of an autonomous or grid connected windmill. The short-circuit regimes can be total or partial (1,2,3,-phase short-circuit). The study of these transients reveals the mechanic stress of the energy conversion line. These regimes can lead to severe system failures. The study of this specific transients are important in order to implement safety procedures that prevent the malfunction of the energy conversion line or of the grid connected consumers. In this study case, there is considered the case of partial short circuit (one-phase short-circuit) that occurred at 1 seconds. The short-circuit acts for 0.50 seconds, afterwards at 1.50 seconds the short-circuit is removed. The simulation interval is set to 3 seconds. The wind speed is considered constant and present to 10(m/s). In fig.9.1 is represented the evolution of 3-phase voltage system. In fig 9.2 is represented the evolution of 3-phase voltage system under two-phase to ground fault conditions. In fig 9.3 it was shown There can be spotted that on the phase where the short-circuit occurred the voltage is obviously zero, but on the other two phases there occurs an over voltage effect, that drops to the nominal value after the short-circuit removal, due to the control system action. Similarly in fig 9.4 there can be also noticed that after the short-circuit removal the frequency advances towards the nominal value. In fig 9.5 represented the wind power output under single-phase to ground fault conditions. Similarly in fig 9.6 represented the wind power output under the two-phase to ground fault conditions. The load power output is presented in fig 9.7. There can be noticed that in the highly stressing regimes (short-circuit regimes). Thus there can be concluded that in the case of a short-term short-circuit the windmill's control structure succeeds to stabilize and to operate conversion in the range of nominal operating conditions.

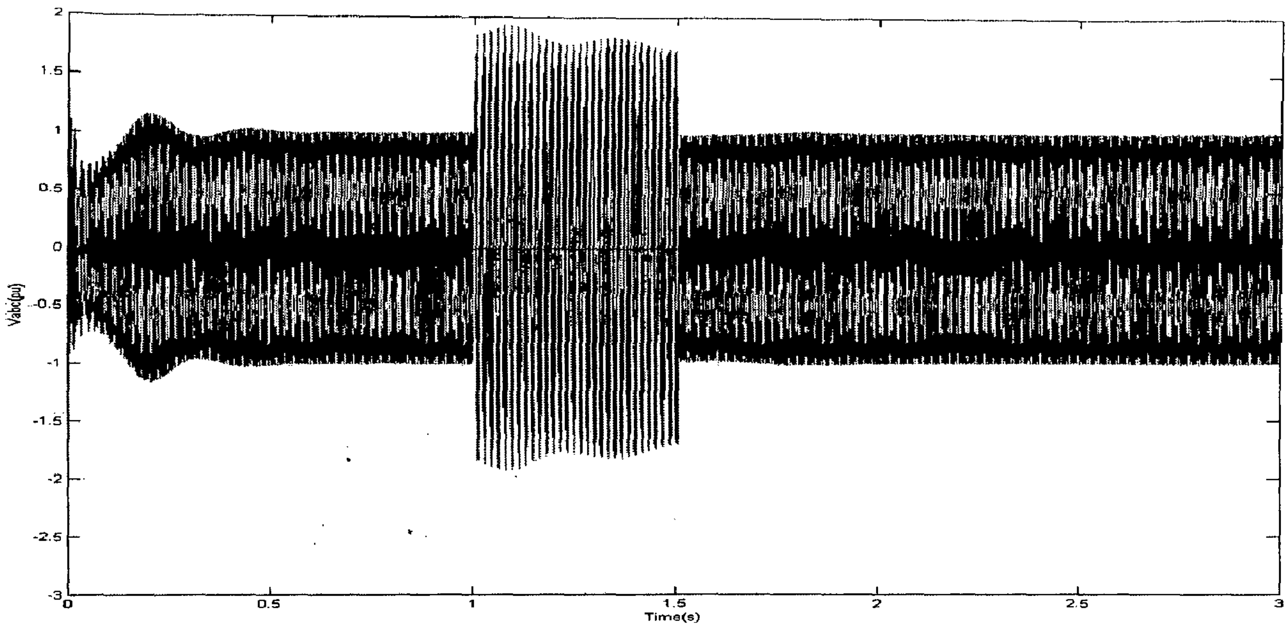

Fig.9.1 3-phase voltage(V_{abc}) for single phase fault condition

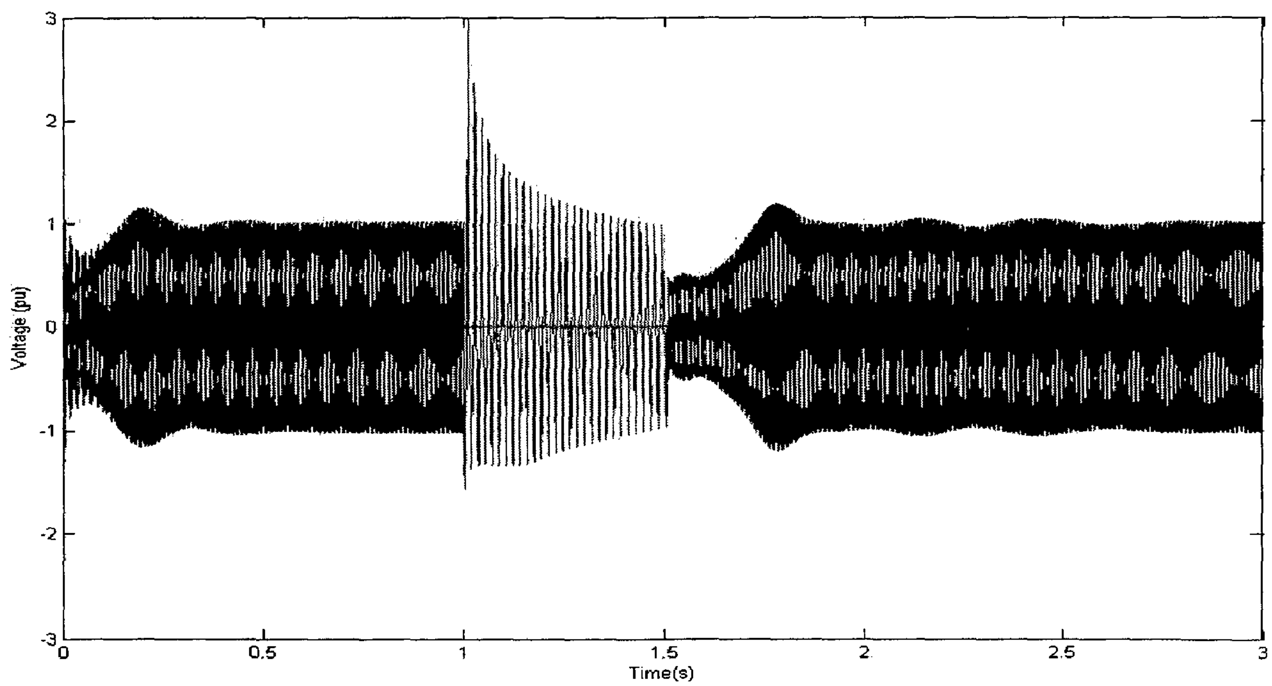

Fig 9.2 3-phase voltage (V_{abc}) under two-phase to ground fault conditions

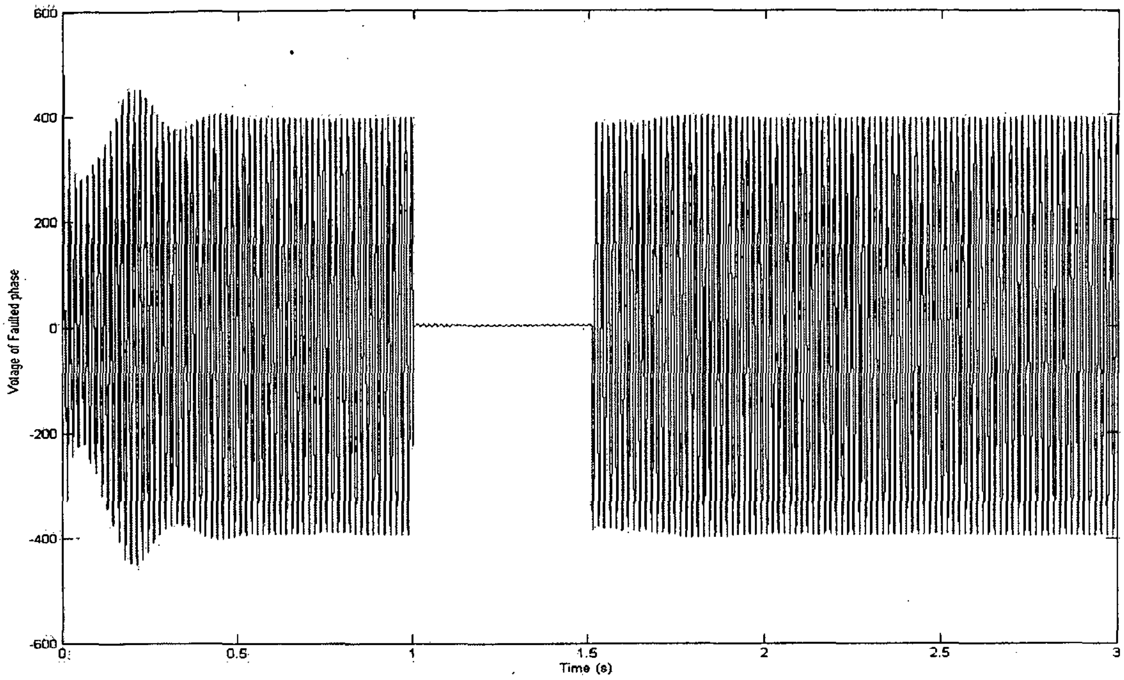

Fig 9.3 Voltage of faulted phase

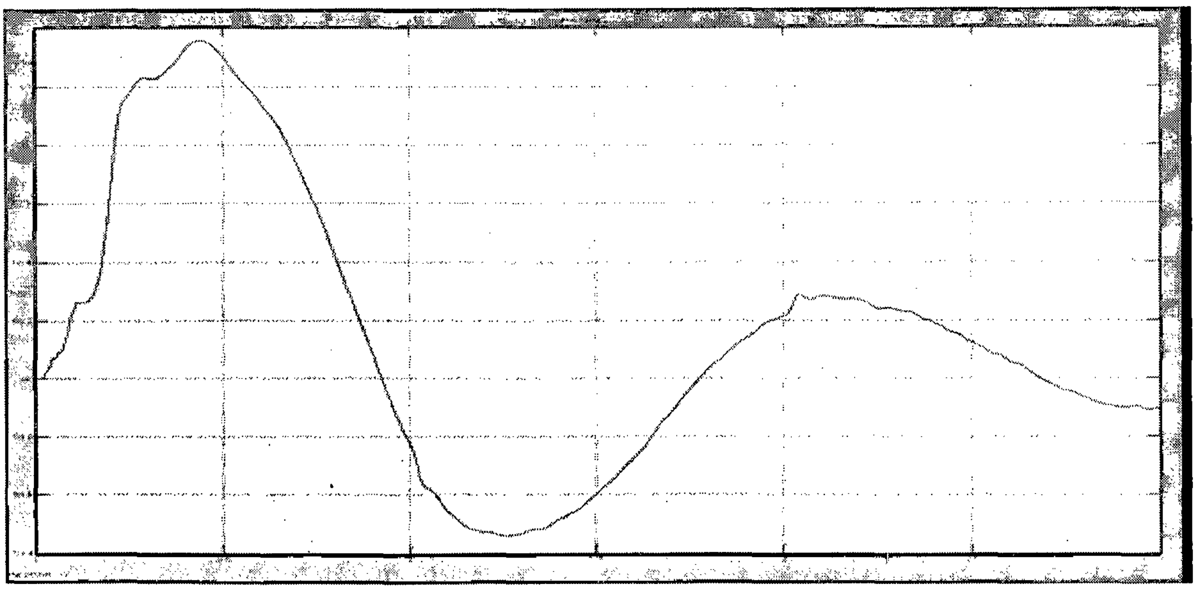

Fig 9.4 Frequency of the Wind mill (Hz)

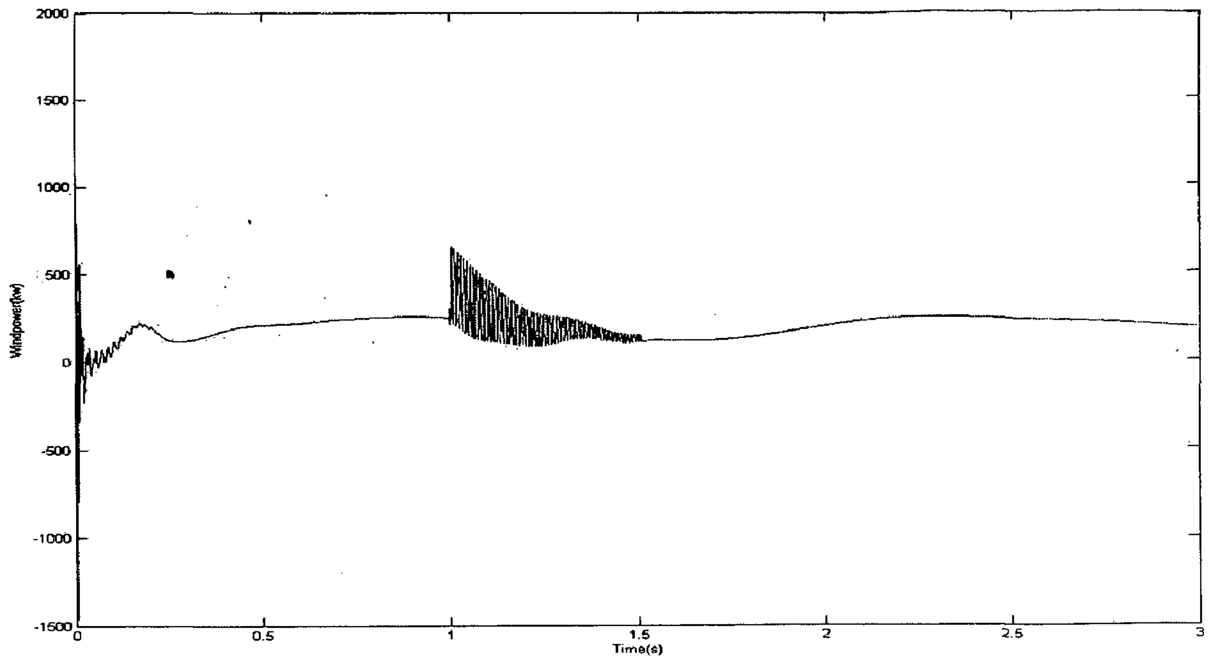

Fig 9.5 Wind power output (kw) for single-phase fault conditions

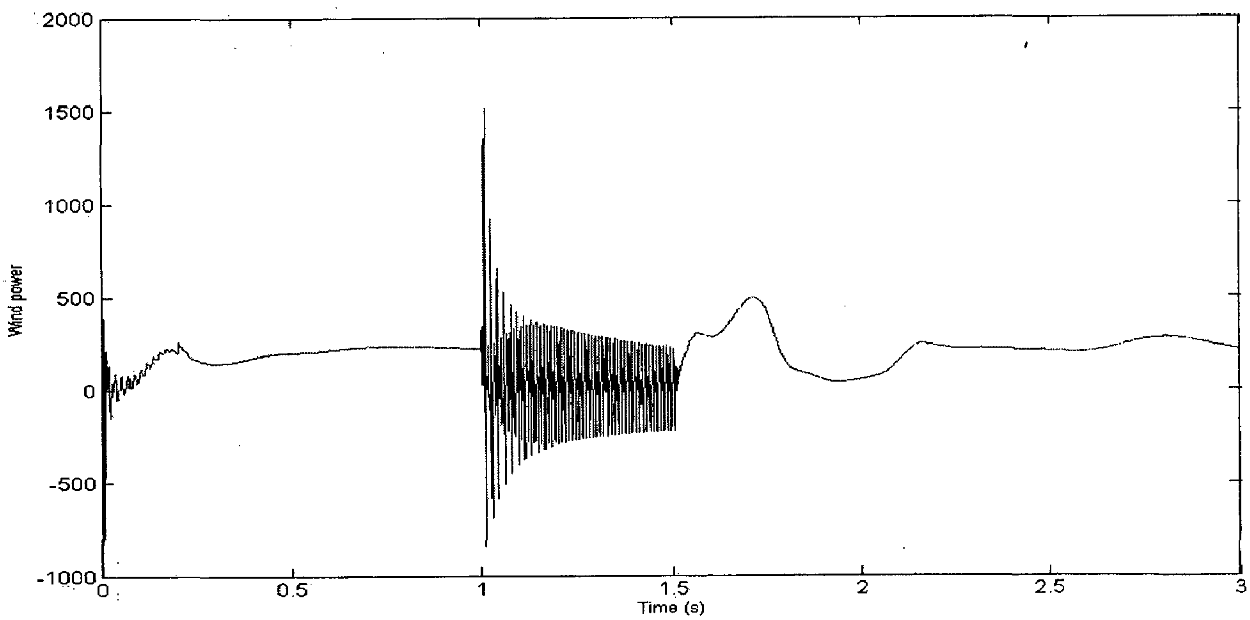

Fig 9.6 Wind Power output (kw) for two-phase fault conditions

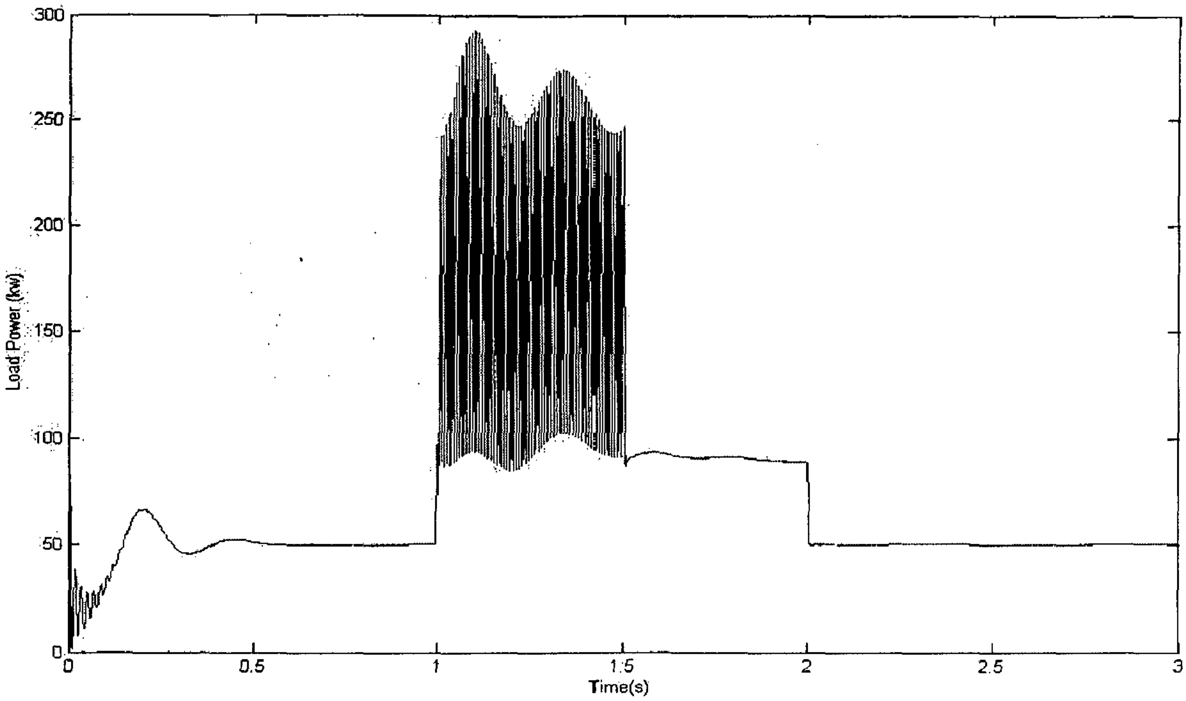

Fig 9.7 Load Power output of Wind mill (kw)

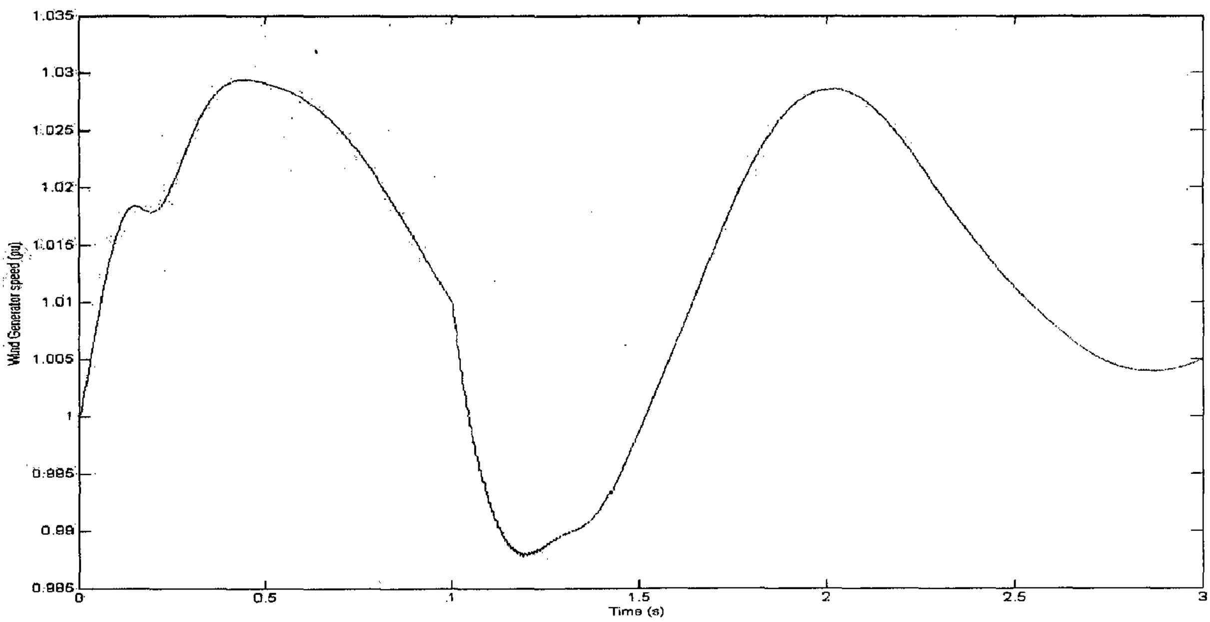

Fig 9.8 Asynchronous machine speed in (pu)

9.2 The asynchronous generator's nominal functioning regime at rated power

The wind speed is considered having the average value of 10 (m/s) during the entire simulation time period. The simulation interval is set to 0...3 seconds. Initially, there is connected only a main consumer of 50kw at 1 seconds there is also connected a secondary consumer with nominal power of 40kw. At 2 seconds the secondary consumer is disconnected. This fact can be noticed in the fig 9.9 which represents the evolution of the considered load power.

In fig.9.10 shows the frequency profile of the wind mill. It can be noticed the fact that in the spite of continuous wind speed variation and of a variable load power (consumer) the entire windmill control structure succeeds to control the network voltage's frequency varies between 59.5 Hz and 60.6Hz. In fig 9.11 is represented the asynchronous machine speed (rpm) in pu (per unit) units. There can be noticed that the rotation speed is slightly over the synchronous speed because the machine operates in generating mode. The wind turbine's power evolution (kw) is represented in pu units. It can be concluded that considered windmill's control structure presents good overall control performance.

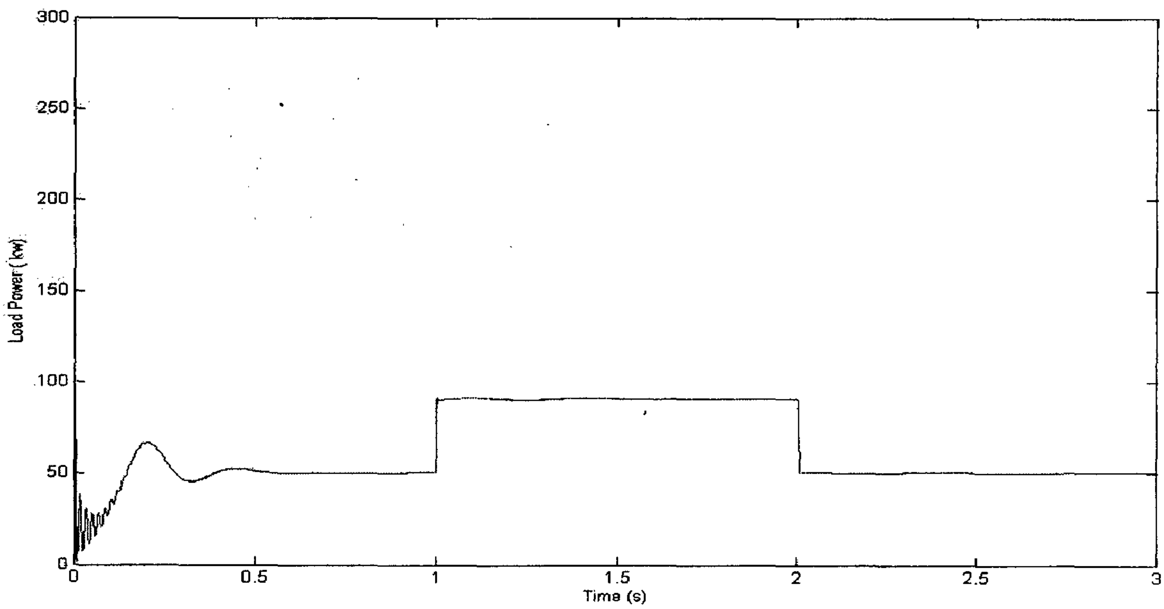

Fig 9.9 Load power Output at constant wind speed(kw)

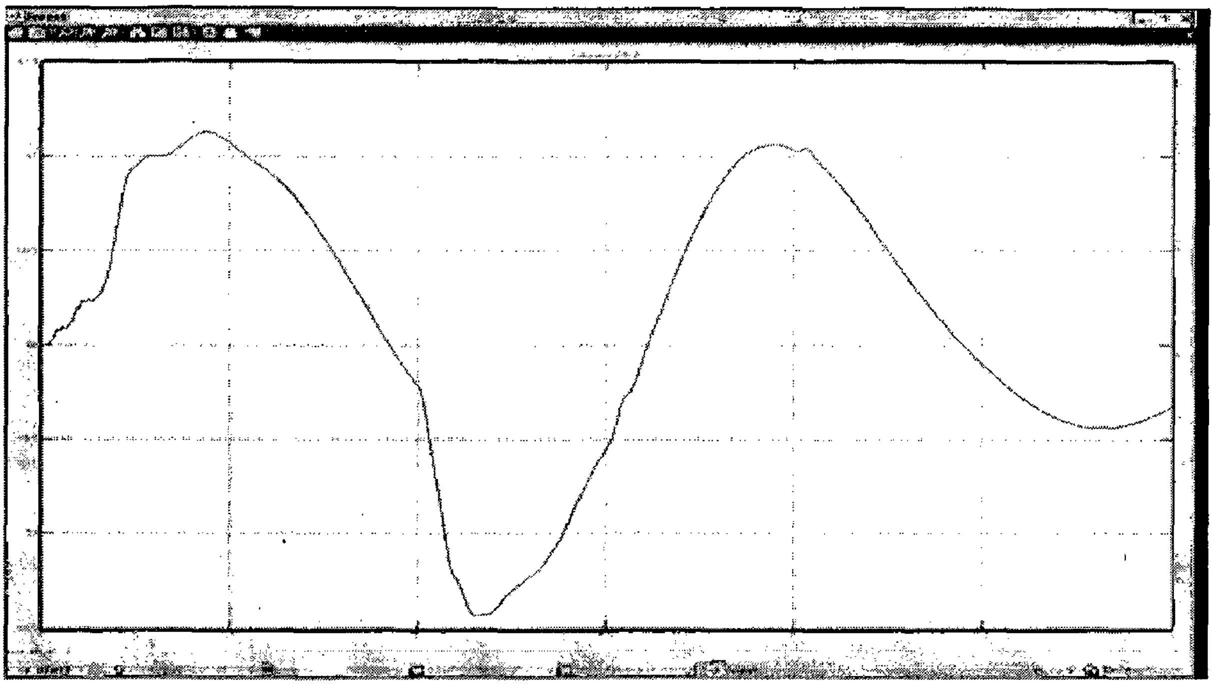

Fig 9.10 Load Frequency at constant wind speed in (Hz)

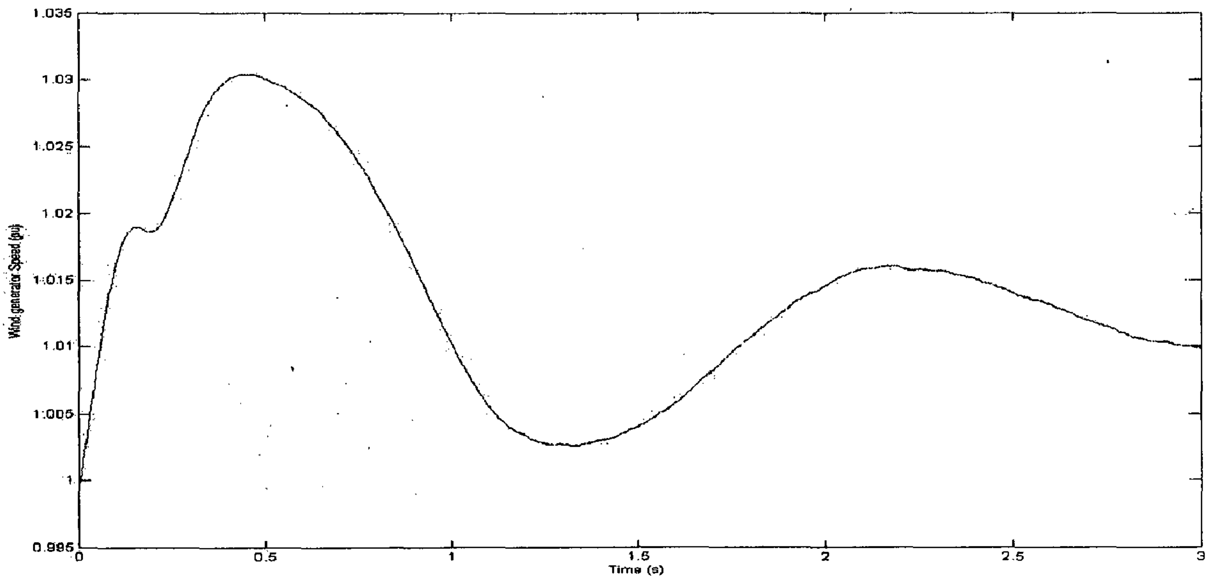

Fig 9.11 Asynchronous machine speed (pu)

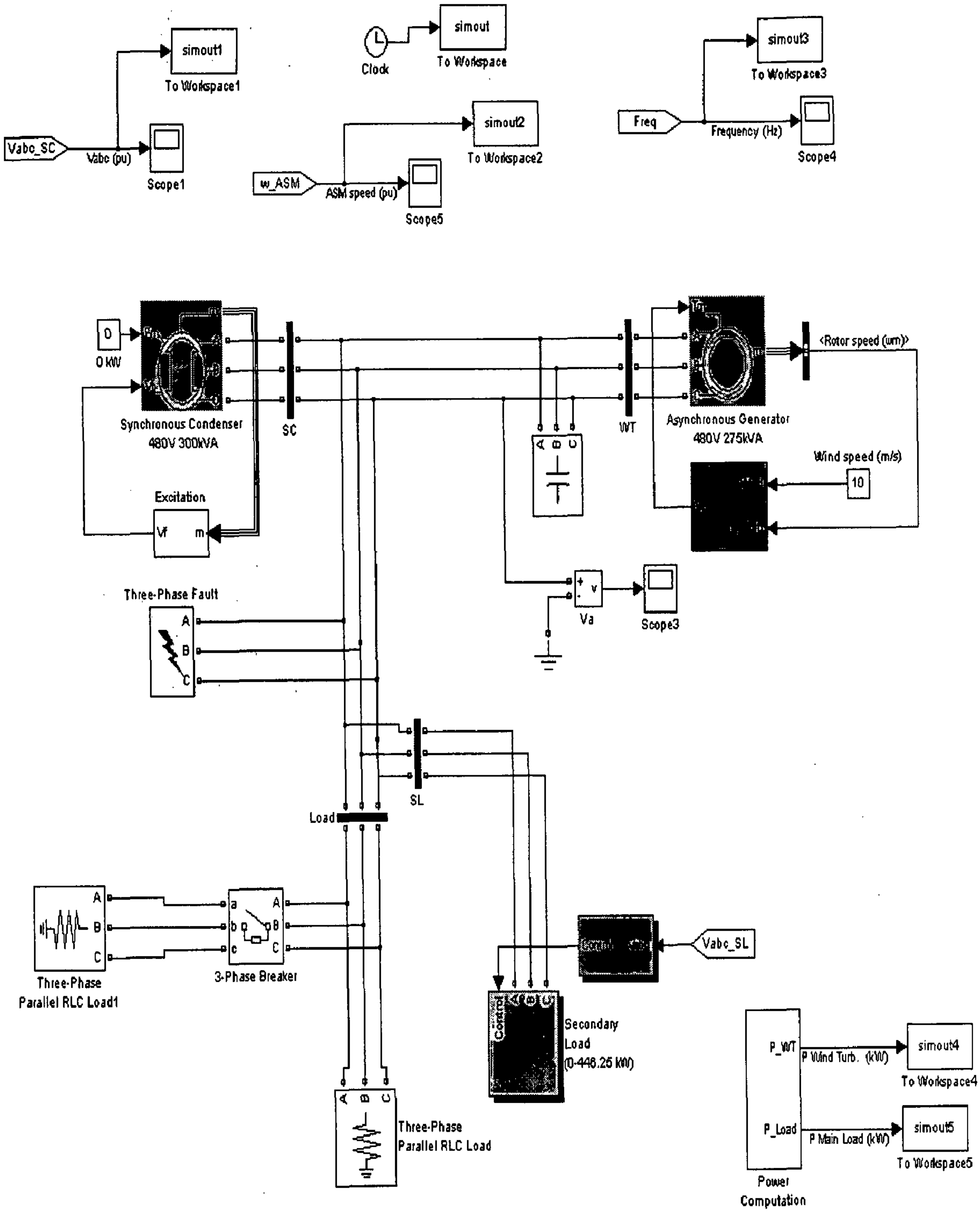

FIG 9.12 SIMULINK MODEL OF WIND TURBINE

9.3 WIND-DIESEL HYBRID SYSTEM TRANSIENT REGIMES

The Asynchronous machine model is based on park dq equations in this thesis. The input to the machine is represented by mechanical energy (torque) and the output is represented by the electrical energy (voltage, frequency, currents). There occurs the necessity to adjust the rotor speed in relation to the changing wind speed in order to maintain the aerodynamic efficiency at a maximum possible value. the considered wind turbine is modeled as a controlled mechanical torque source that supplies the asynchronous generator. The frequency regulator input is represented by the voltage's frequency. There is used a three Phase Phased Locked Loop (PLL) system to measure the frequency of the 3-phase voltage of the network. Therefore the measured frequency is compared to the reference frequency 60 (Hz) in order to obtain the frequency error. Afterwards, this error is integrated in order to obtain the phase. The analog signal is afterwards converted to 8-bit signal that commands the switching elements from the dump load. The dump load is used to dissipate the excess power produced by the wind turbine and simultaneously to maintain constant the frequency. The diesel engine Simulink model contains Actuator which sense the load changes accordingly it control the fuel inlet such that the mechanical power output is changed it simultaneously control the frequency of the system. Typical diesel engine model describes the fuel consumption rate as a function of speed and mechanical power at the output of the engine. It is usually modeled by a simple first order relating the fuel consumption (fuel rack position) to the engine mechanical power [19]. The power output of the engine and the generator has to be varied with the changing load to meet the consumer demands. The task of the governor is to adjust the fuel flow and then regulate the input of the engine and the generator so as to provide the required power to meet changing in the load.

The presence of dead-time between the actuator fuel injection and the production of mechanical torque is very important characteristic of the diesel engine. There are also system parameter uncertainties which together with the varying dead time significantly degrade the performance of the prime mover, especially in case of a load. A diesel engine is a nonlinear system together with a nonlinear, time-varying dead time between the Injection and production of the mechanical torque. It is commonly controlled with a PI controller to prevent steady-state error in speed.

Diesel engine model in modeled in Simulink/Matlab environment by K- predictive adoptive controlled method Fig 9.13 shows the Diesel engine and excitation block developed in Simulink. The reference speed and terminal voltage was taken as 1pu. The governor and diesel engine was also modeled in Simulink environment by k-predictive adoptive controlled method.

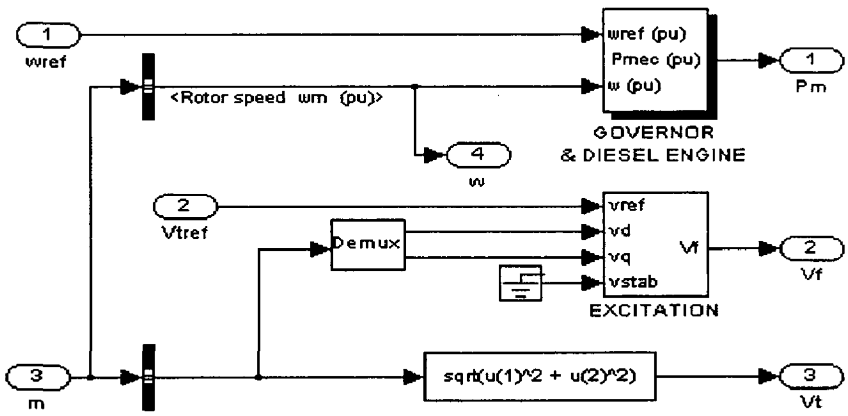

Fig 9.13 Diesel Engine and Excitation Block

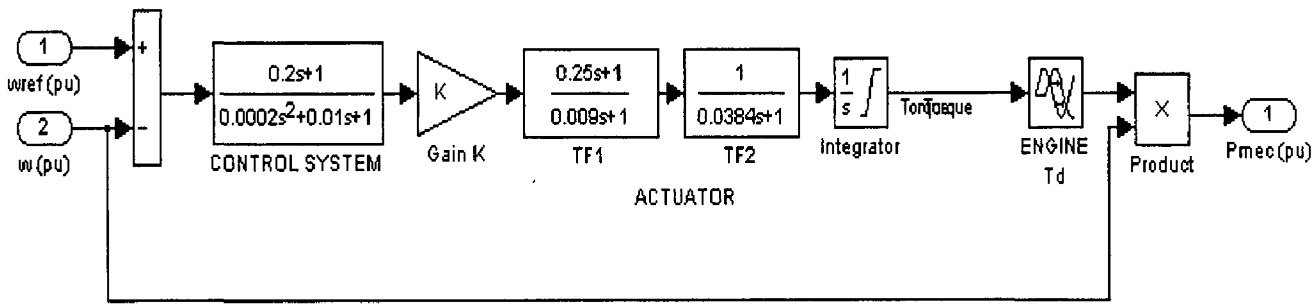

Fig 9.14 Diesel Engine and governor Block diagram

9.3.1 Wind-Diesel hybrid system short circuit transient regimes under fault conditions

Short circuit regimes can occur in isolated systems or grid connected system the system has to sustain this transient and to regain its performance under transients. In this thesis the performance of the wind-diesel hybrid system was studied under different types of faults such that to study the stability of the hybrid system, in fig 9.15 shows the voltage profile of the hybrid system when single phase to ground fault is applied to the hybrid system at 2 seconds and cleared at 2.5 seconds. 0.5 seconds fault is huge time in power systems. Fig 9.16 shows the voltage profile of the hybrid system under the 2 phase to ground fault conditions applied at 2 seconds. After clearing the fault it was observe that the system sustains its normal operating conditions such that the system can be operate normally under high stress regimes.

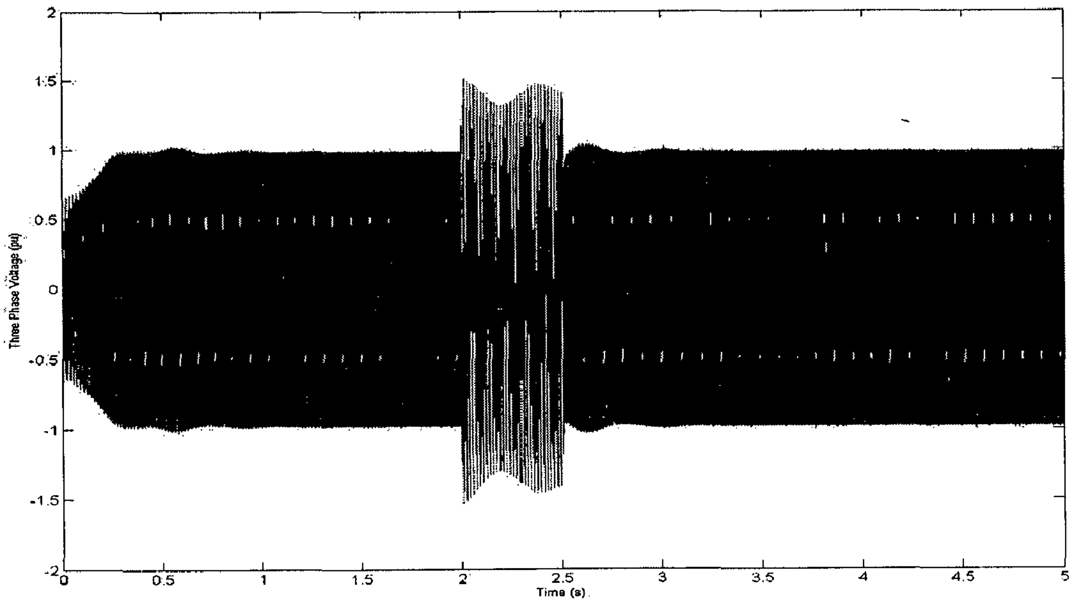

Fig 9.15 Voltage of Hybrid System in pu under the single phase fault condition

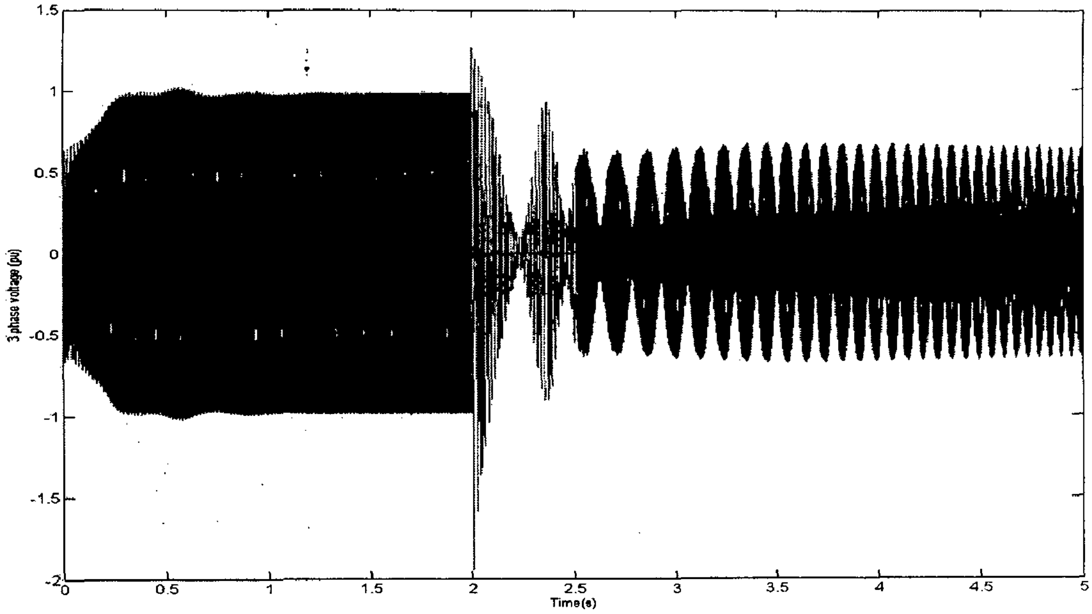

Fig 9.16 Voltage of Hybrid system under 2 phase to ground fault condition

Fig 9.17, and fig 9.18 shows the reactive power (Kvar) profile of the synchronous condenser used in the hybrid system. The synchronous condenser is used to maintain system voltage profile with in limits by controlling the excitation of the synchronous machine, the excitation control is performed by standard excitation block provided in Simulink/Matlab, when there was sudden changes in the system the synchronous condenser controls the excitation block by sensing the voltage error signal from the phase locked loops such that system voltage is maintained within the specified limits. The synchronous condenser also provides the Reactive power (Kvar) to the Induction generator. The system is tested with single phase and double phase to ground fault conditions.

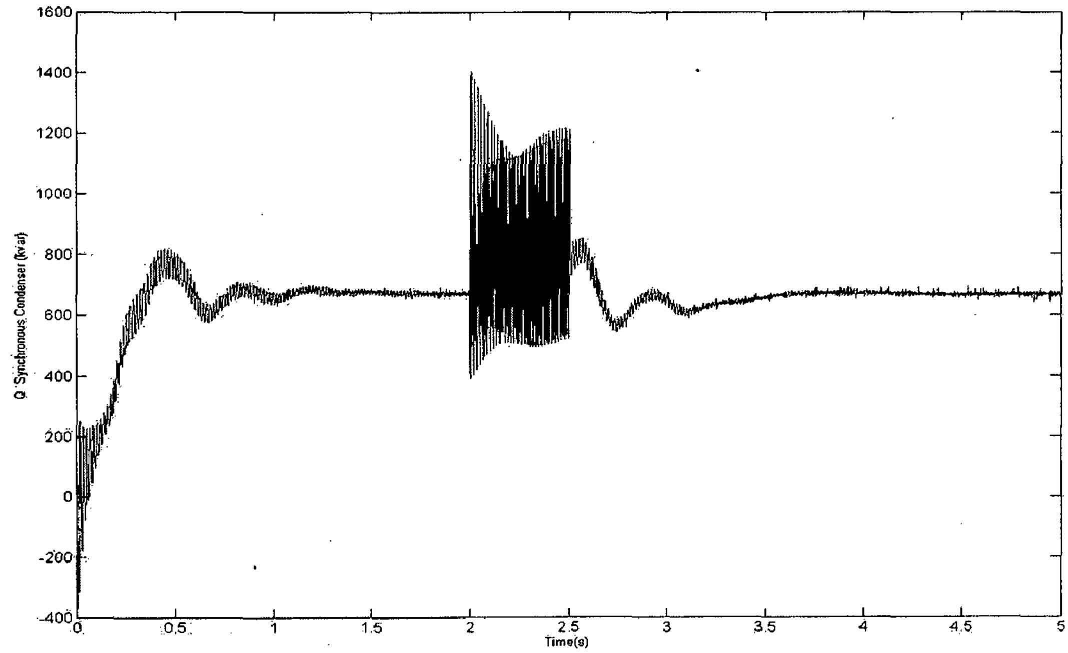

Fig 9.17 Reactive Power of Synchronous Condenser (kvar) under single phase fault

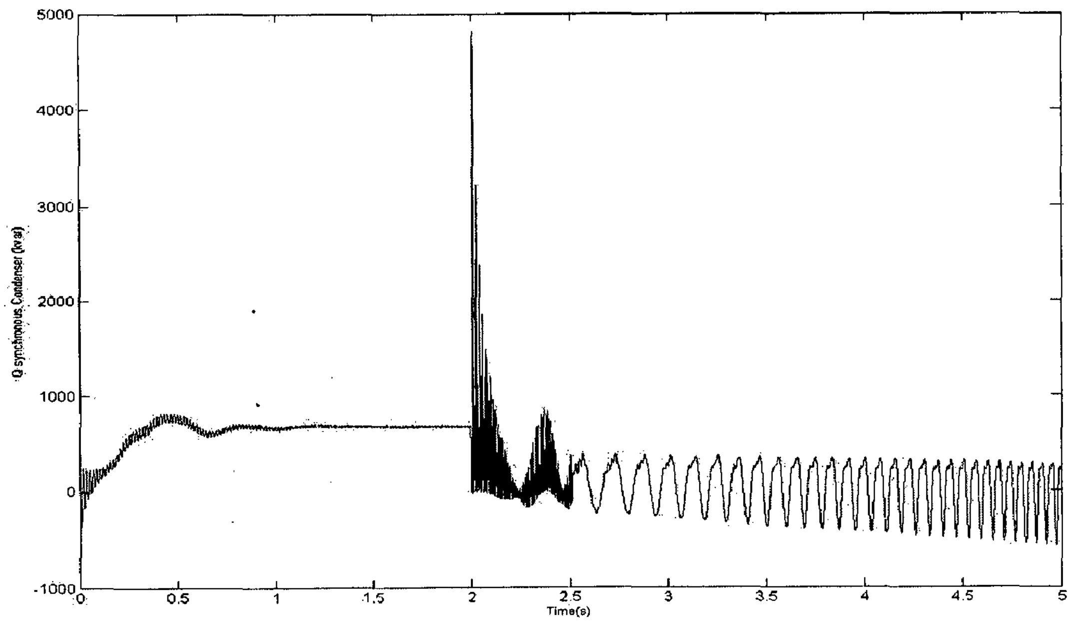

Fig 9.18 Reactive Power of Synchronous Condenser (kvar) under 2-phse to ground fault

Fig 9.19 shows the Diesel generator Mechanical Power (P_{mec}). At 2 seconds a single phase and 2 phase to ground faults was applied on the system it was observed that the mechanical power of the diesel engine goes up in order to supply the load, by using the control system in the diesel engine model as shown in fig 9.14 it was possible to maintain the P_{mech} within the specified limits, again at 3 seconds a 25kw of R-L load was applied near the Diesel generator the total simulation was run for 5 seconds. It was observed the system was able to maintain the stability at 4.3 seconds. Fig 9.20 shows the Diesel generator Mechanical Power under 2 phase to ground fault conditions such that the generator was subjected to sudden transients. The transients were slowly decayed at the steady state.

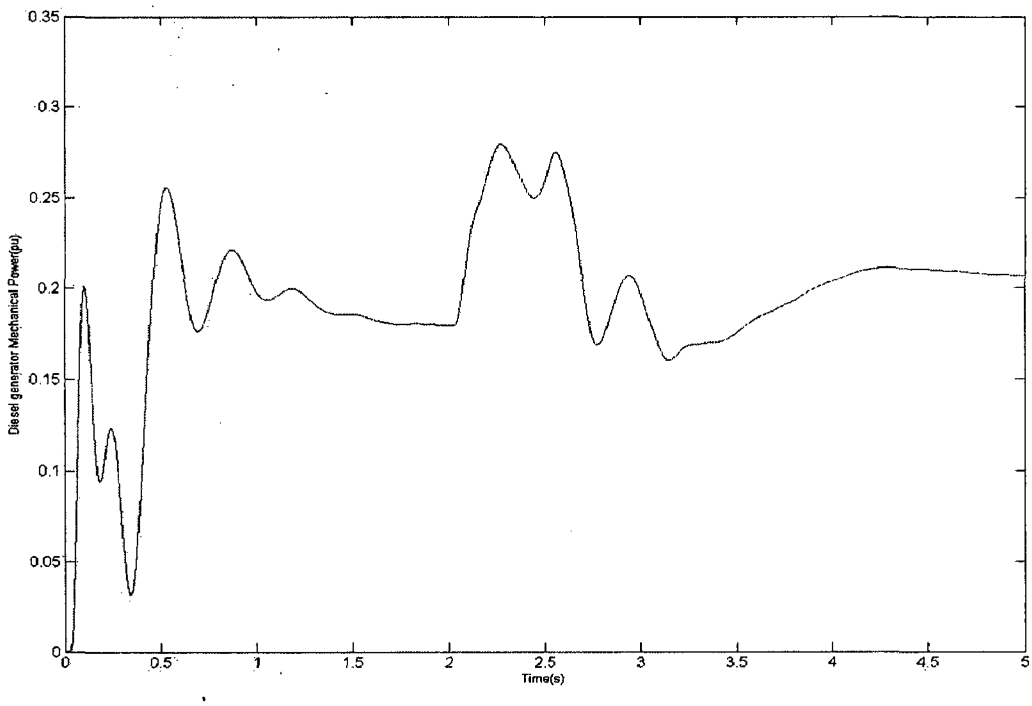

Fig 9.19 Diesel Generator mechanical Power (pu) under single phase fault condition

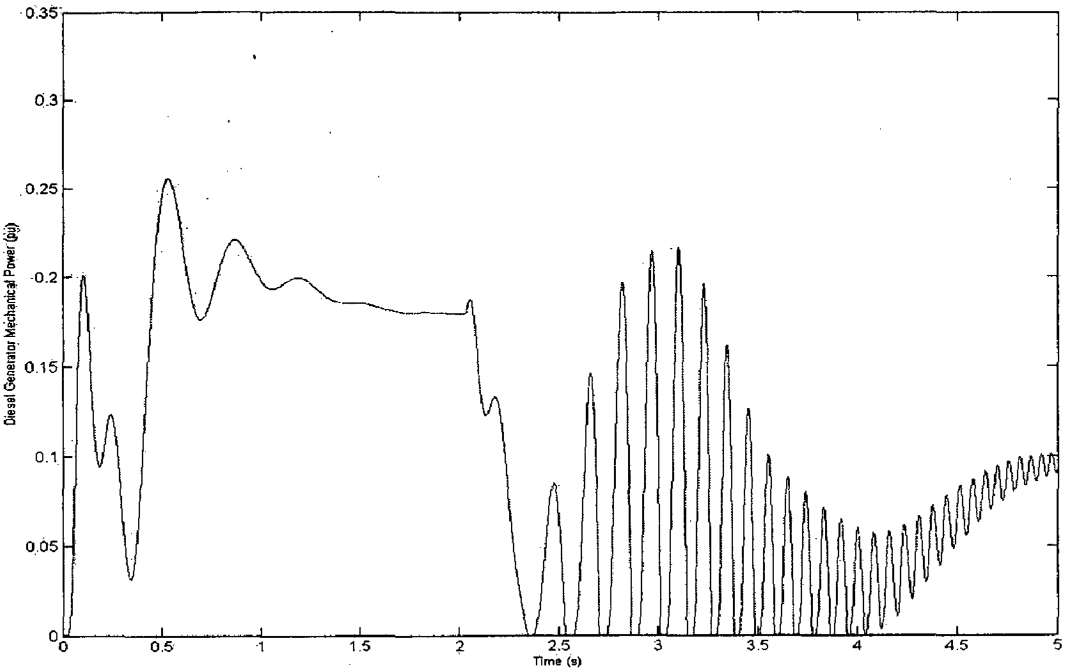

Fig 9.20 Diesel Generator Mechanical Power under 2 phase to ground fault conditions

Fig 9.21 shows the Diesel Generator speed in (pu) it was observed that at 2 seconds a single phase fault was occurred makes the system speed goes down when the fault was cleared at 2.5 seconds due to hunting of the machine the system speed overshoots and there after the speed of the Generator was successfully obtain to stable state as shown in the Fig.9.21 the Actuator was used in the Diesel engine block which takes the reference speed from the generator and gives the error signal after comparing with the reference signal. Actuator can be represented in form of a single order transfer function block the appropriate K values can be obtained from the k-predictive adaptive control method. Similarly Fig 9.22 shows the Diesel generator speed in (pu) under 2 phase to ground fault conditions.

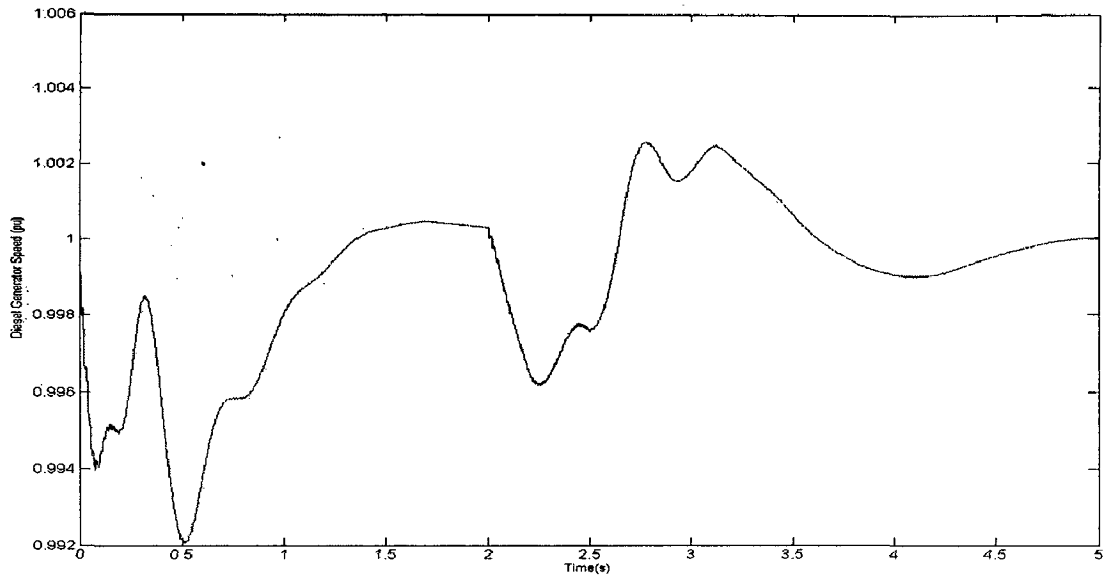

Fig 9.21 Diesel Generator speed profile under single phase to ground fault conditions

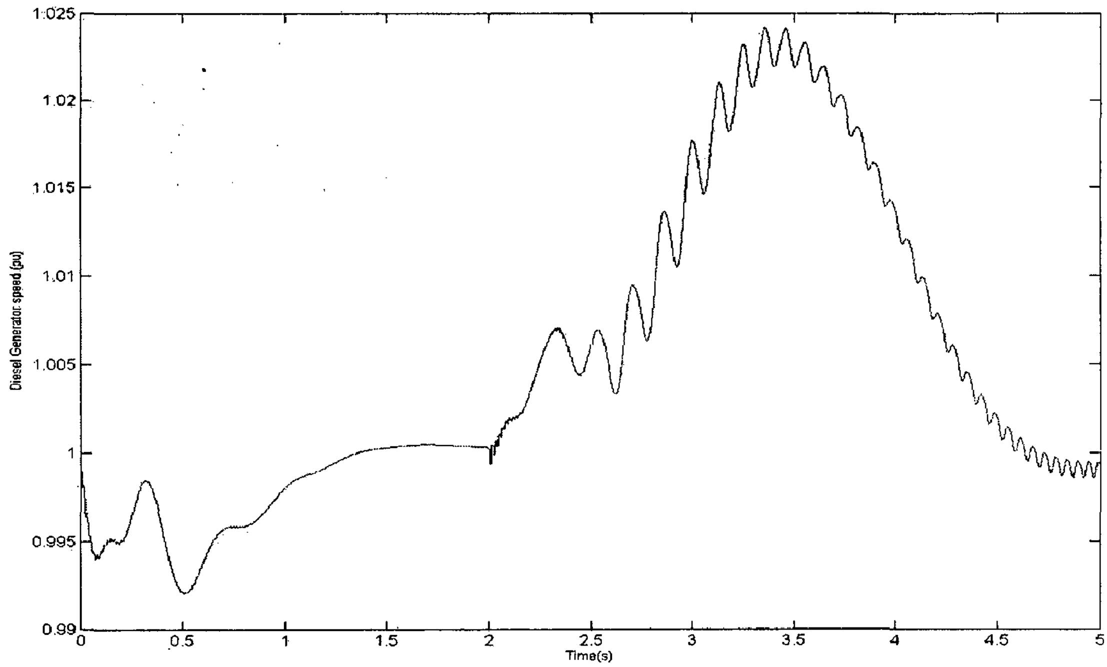

Fig 9.22 Diesel Generator speed profile under 2 phase to ground fault conditions

Fig 9.23 shows the three phase current profile of the hybrid system it was observed that the Load current of the faulted phase was overshoot at the 2 seconds due to single phase fault it was gradually decreased before it came to normal value the fault was cleared at 2.5 seconds and there after the system was able to maintain the normal values. Fig 9.24 shows the current profile under 2 phase to ground fault conditions.

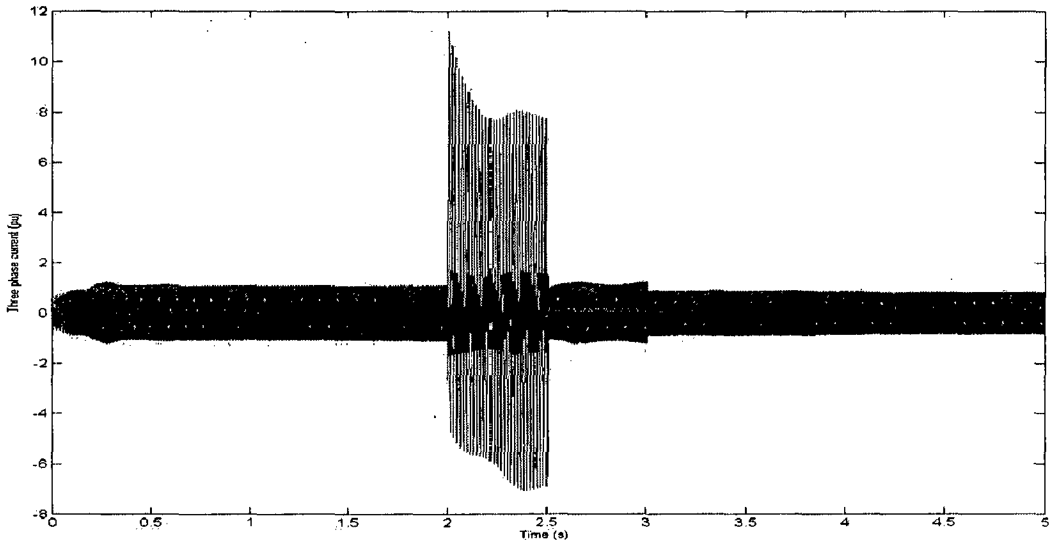

Fig 9.23 Three phase Load current of hybrid system under single phase fault conditions

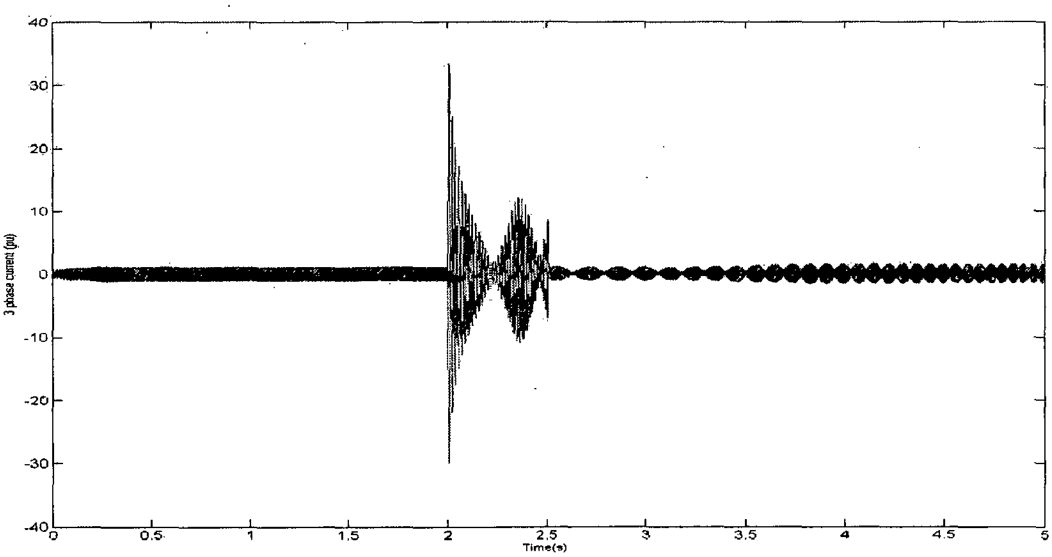

Fig 9.24 Three phase Load current of hybrid system under 2 phase to ground fault Conditions

Fig 9.25 shows the wind power output of Induction generator. The controller was used to control the wind turbine torque output which is given to the induction generator. The mechanical power output of the wind turbine is function of the blade pitch angle (deg) and tip speed ratio and wind speed in (m/sec). This mechanical power is divided with the generator speed output to obtain the torque (Tm) applied to the induction rotor. It was observed in the fig 9.25 the wind power is able to maintain within the specified limits of wind speeds. In this simulation the wind speed was fixed to 11 (m/sec) then at 3 seconds it was reduced to 8 (m/sec) the power output was gradually reduced. Fig 9.26 shows the wind power output profile under 2 phase to ground fault conditions the system was not able to maintain stability with in the simulation run period therefore it can be concluded that the wind generator was to maintain stability with in the period.

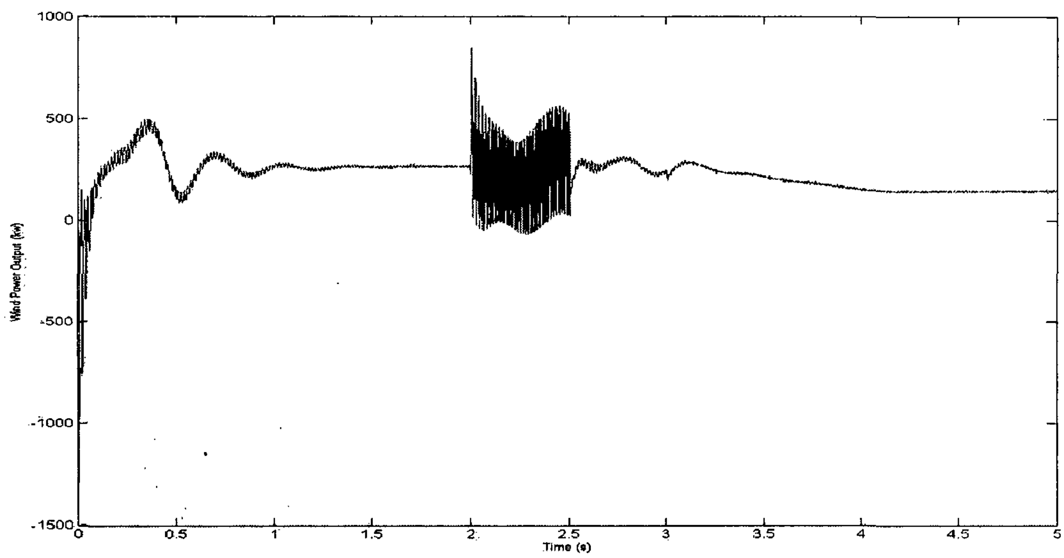

Fig 9.25 Wind Power Output (kw) under single phase to ground fault conditions

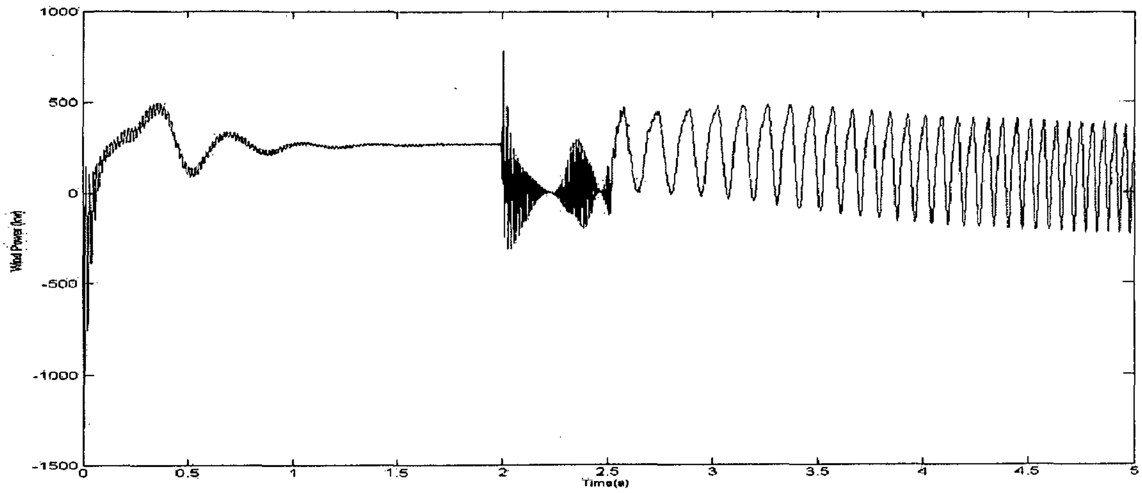

Fig 9.26 Wind Power output (kw) under 2 phase to ground fault conditions

Fig 9.27 shows the load power profile of the Wind-Diesel hybrid system. Initially the hybrid system was applied with load of 300 kw. At 3 seconds the 100 kw load was suddenly removed from the system. The short circuit is applied at 2 seconds and was cleared at 2.5 seconds. The system is sustainable to maintain the stability with the simulation period as shown in the fig.9.27.

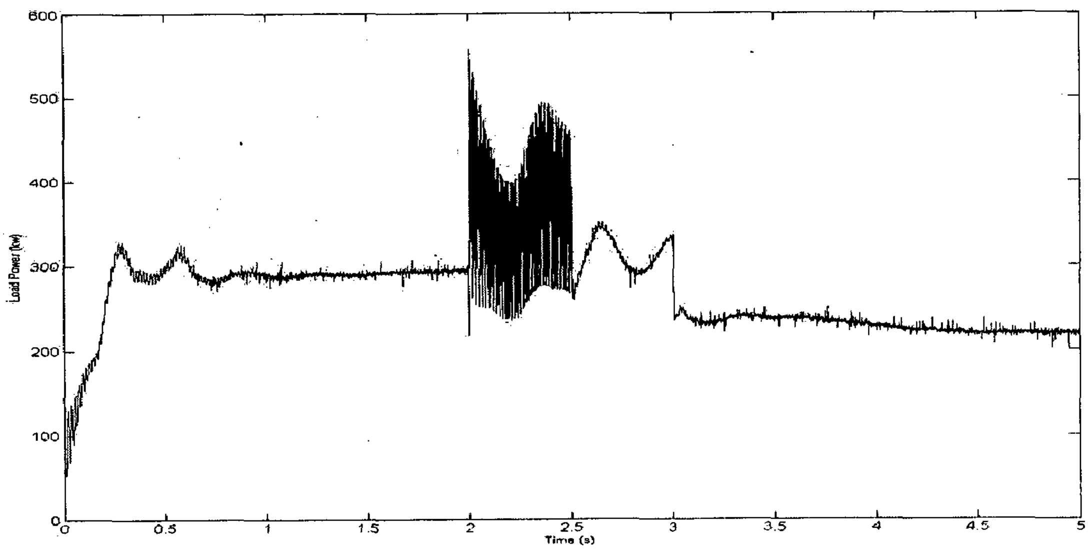

Fig 9.27 Load power output of the Wind-Diesel Hybrid system under single phase fault

Fig 9.28 and 9.29 represents the frequency plots of the wind-diesel hybrid system. The frequency regulator input is represented by the voltage's frequency. There is used a three Phase Phased Locked Loop (PLL) system to measure the frequency of the 3-phase voltage of the network. Therefore the measured frequency is compared to the reference frequency (60 Hz) in order to obtain the frequency error. Afterwards, this error is integrated in order to obtain the phase. A PD type controller derives the error phase. The analog signal is afterwards converted to 8-bit signal that commands the switching elements from the dump load. The dump load is used to dissipate the excess power produced by the windmill and simultaneously to maintain constant the frequency.

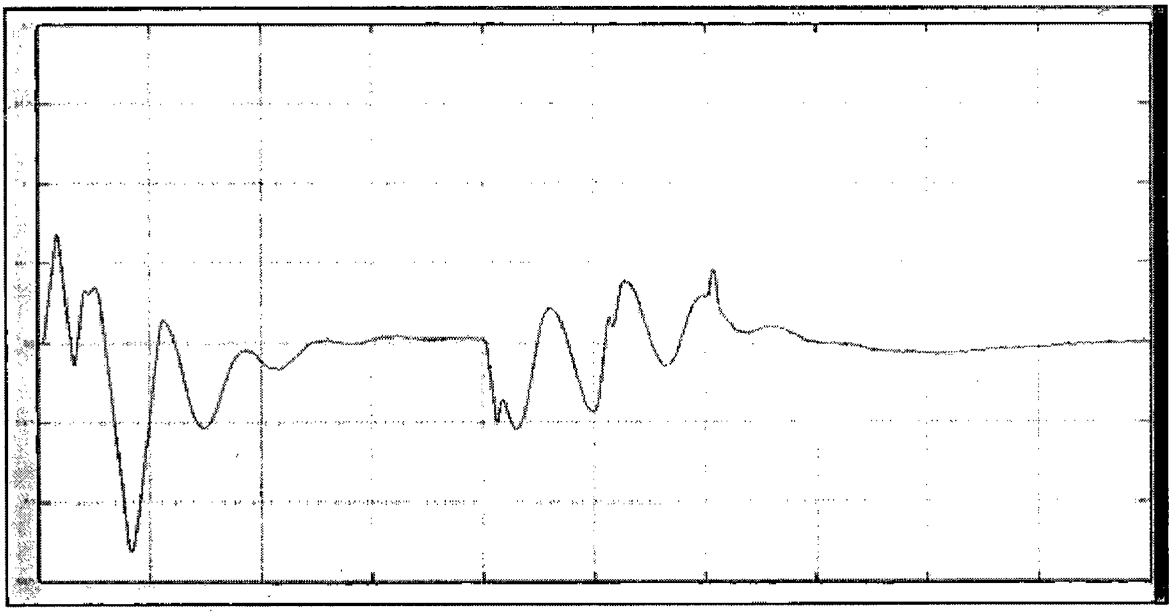

Fig 9.28 Frequency of the hybrid system under single phase fault condition

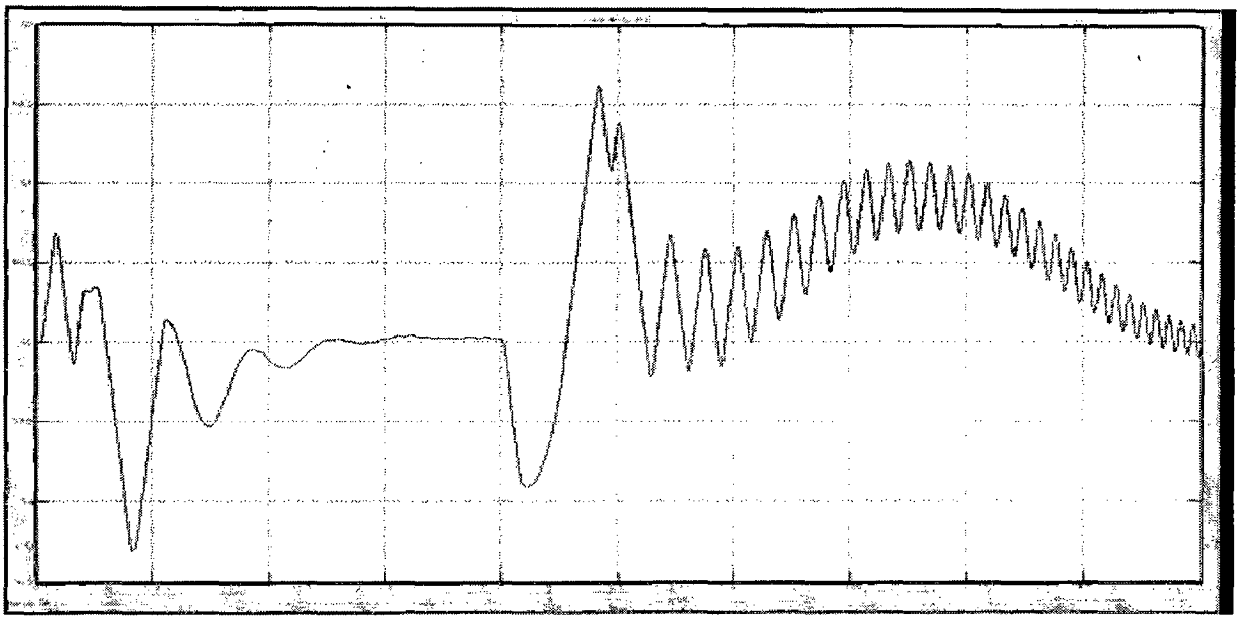

Fig 9.29 Frequency of the hybrid system under two phase to ground fault condition

9.3.2 Wind-Diesel hybrid system transient regimes under constant wind speed conditions

The wind speed of the stand alone hybrid system was maintained at 10 m/s. and the simulation is run for 5 seconds. A load of 100 kw was suddenly removed from the system at 3 seconds. Fig 9.30 the load power output in kw. Fig 9.31 shows the frequency of the system.

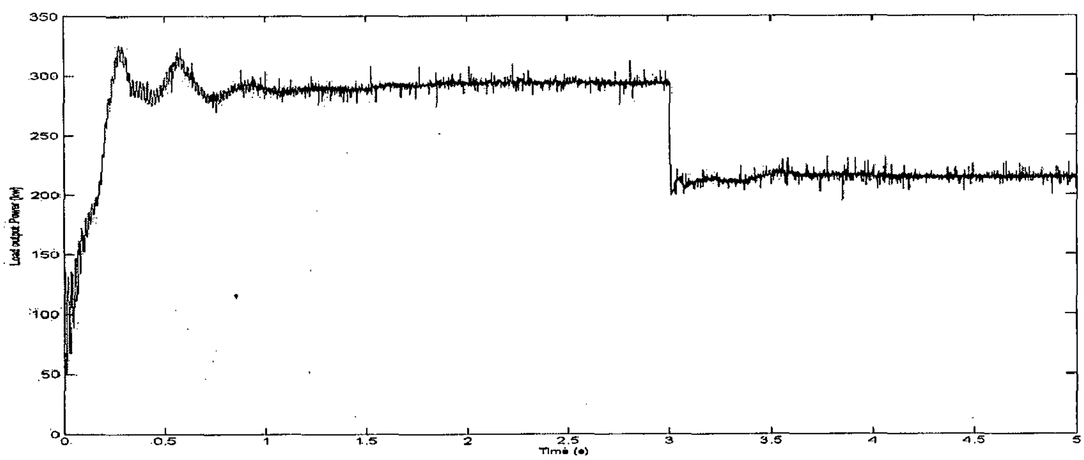

Fig 9.30 Load output power in (kw) at constant wind speed of 10 m/s

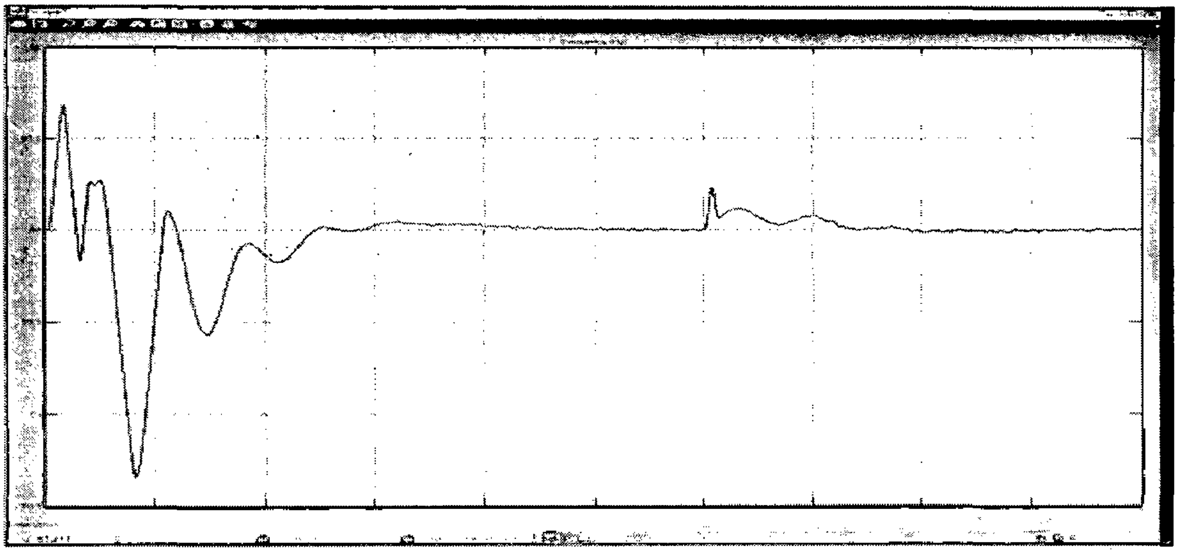

Fig 9.31 Frequency of wind-diesel hybrid system at constant wind speed of 10 m/s

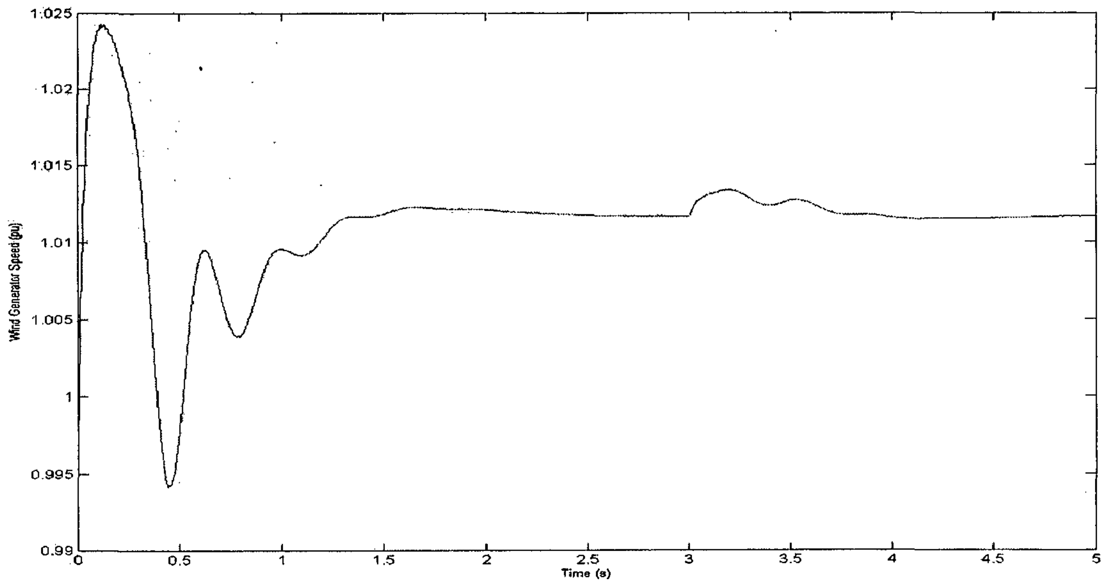

Fig 9.32 The Wind Generator speed in (pu) at constant wind speed of 10 m/s

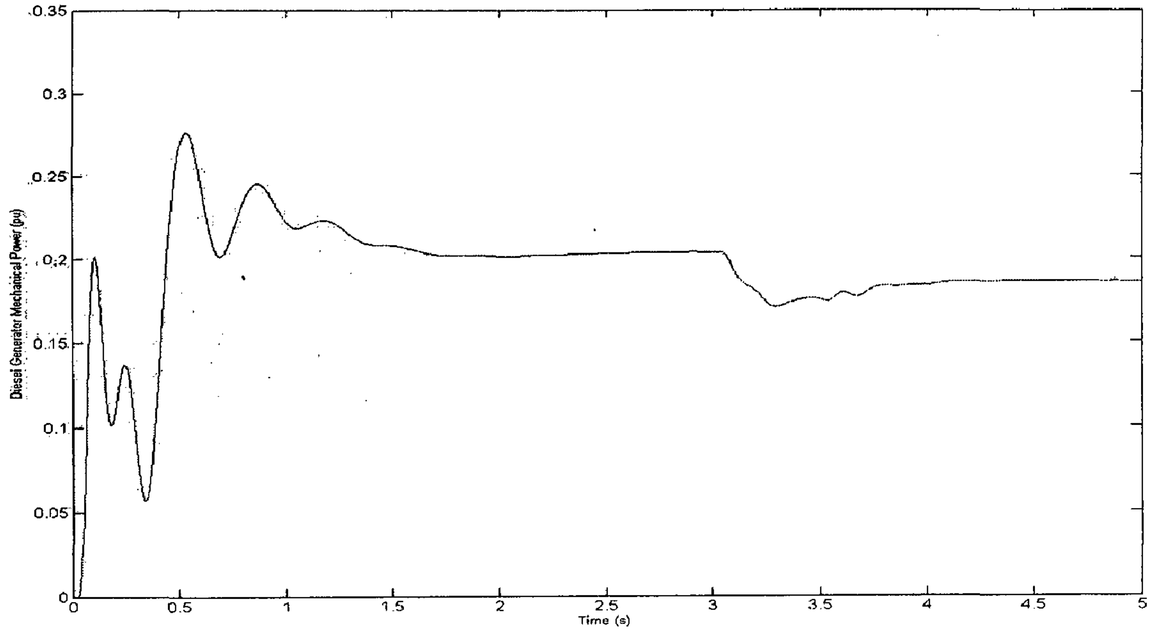

Fig 9.33 Diesel generator Mechanical power in (pu) at constant wind speed of 10 m/s

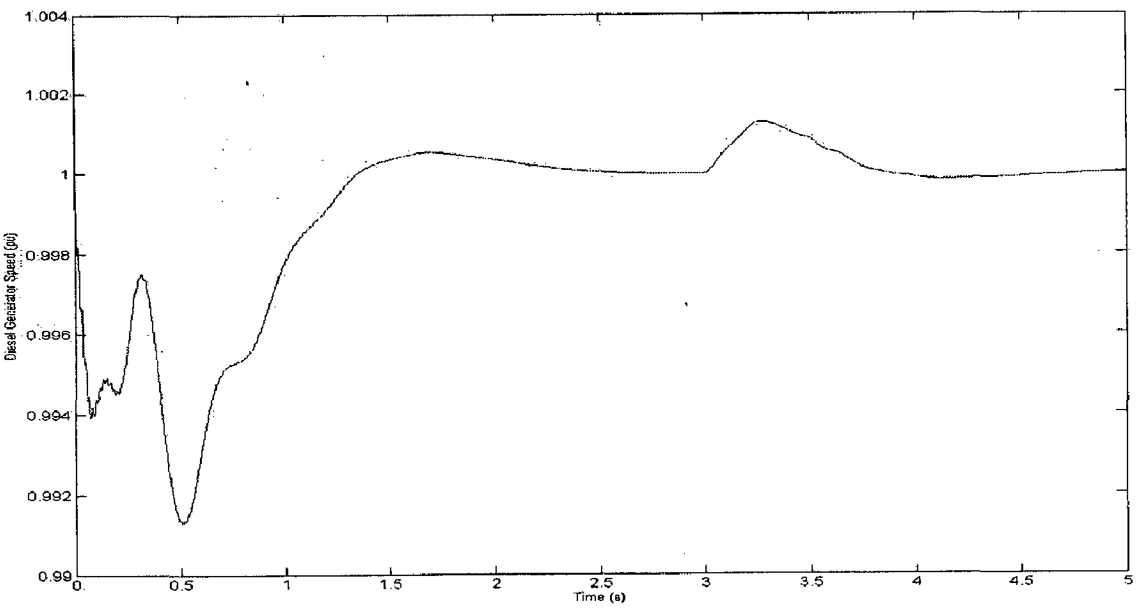

Fig 9.34 Diesel generator speed in (pu) at constant wind speed of 10 m/s

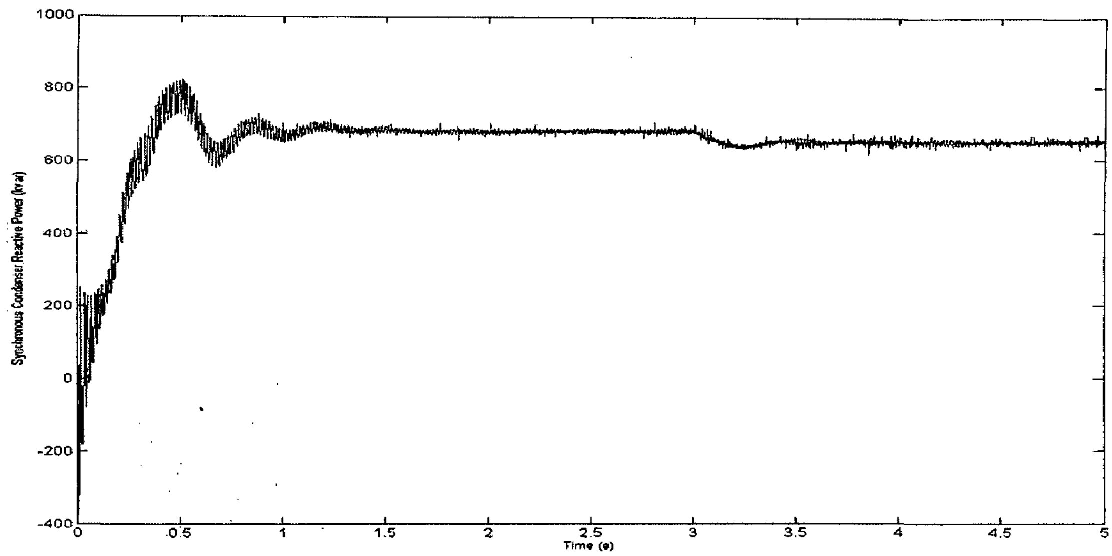

Fig 9.35 Synchronous Condenser reactive power in (kvar) at constant wind speed of 10 m/s

The wind speed was maintained constant at 10 m/s. the load of the wind-diesel hybrid system is maintained constant the load of 100 kw was removed from the system at 3 seconds. The wind generator output was constant through out the simulation irrespective of the load. The remaining power required for to supply the load was taken from the diesel generator. Fig 9.36 shows the wind power output profile

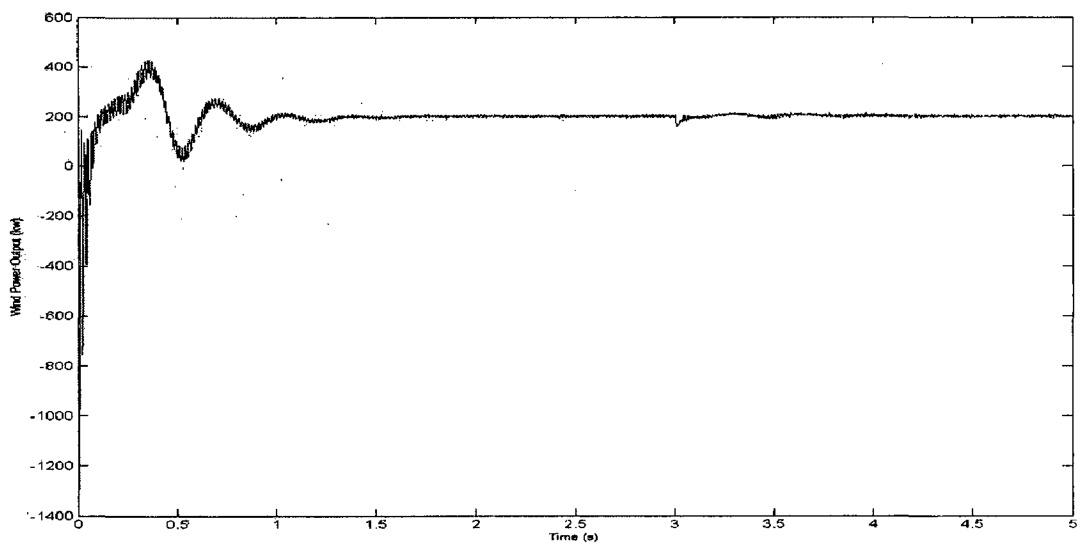

Fig 9.36 wind output power in kw at constant speed of 10 m/s

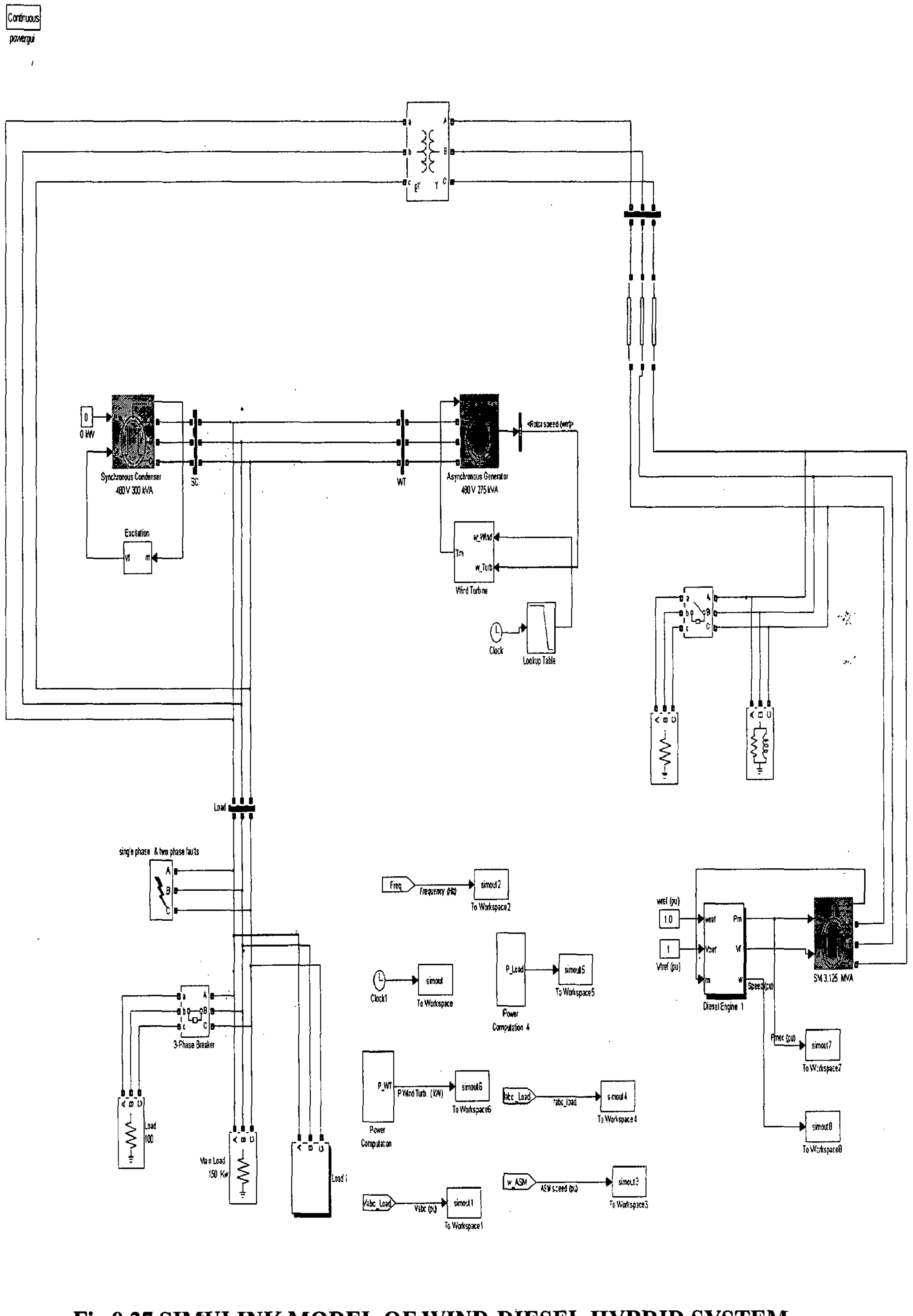

Fig 9.37 SIMULINK MODEL OF WIND-DIESEL HYBRID SYSTEM

9.4 RELIABILITY EVALUATION OF WIND-DIESEL HYBRID SYSTEM

The Reliability evaluation of the stand alone wind-diesel hybrid plays vital role in evaluation of system performance under steady state. Reliability of the system does not much concern about the dynamic transients of the system. This reliability study gives the amount of energy supplied to the load with out block out continuously. And also gives the expected number of days the energy cannot supply to the load. Evaluation of Reliability indices determines the system reliability. By knowing the values of this indices appropriate system can be selected to maintain reliable supply through out the certain period. The intermittent characteristics of wind energy seriously affect the reliability of wind diesel hybrid systems. Hence a matter of research interest in arriving at the adequacy levels for such schemes. In this thesis an attempt has been made to evaluate Energy Index of Reliability (EIR) which is express as a function of Expected Energy Not Supplied (EENS) using Wind-Diesel hybrid System consisting of one or more wind oblique diesel units. This will help in arriving at the most suitable schemes having expectable Level of adequacy. These results will help the system planners and utility administrators to evaluate and upgrade the size and optimize the hybrid systems.

The Matlab program based on the method presented in this thesis was given in appendix 2 was developed to calculate the Expected Energy Not supplied(EENS) and Energy Index of Reliability (EIR), Loss Of Load Expectation (LOLE). The proposed model can be adopted to analyze different hybrid system schemes to obtain an optimal system configuration. A series of case studies were conducted to calculate the reliability indices of various schemes based on current load data. The results are shown in the following figures fig 9.38 and fig 9.39 and fig 9.40

The increase of diesel generator number leads to dramatic improvement in system reliability. When diesel generator number reaches 3, the Energy Index of Reliability (EIR) still increases dramatically. By comparing these figures, it can be seen that although the increase in system capacity can make the system more reliable, the improvement is very marginal after some level, and the investment also increases greatly. Therefore an appropriate system scheme not only keeps system stable, but also makes system cost effective.

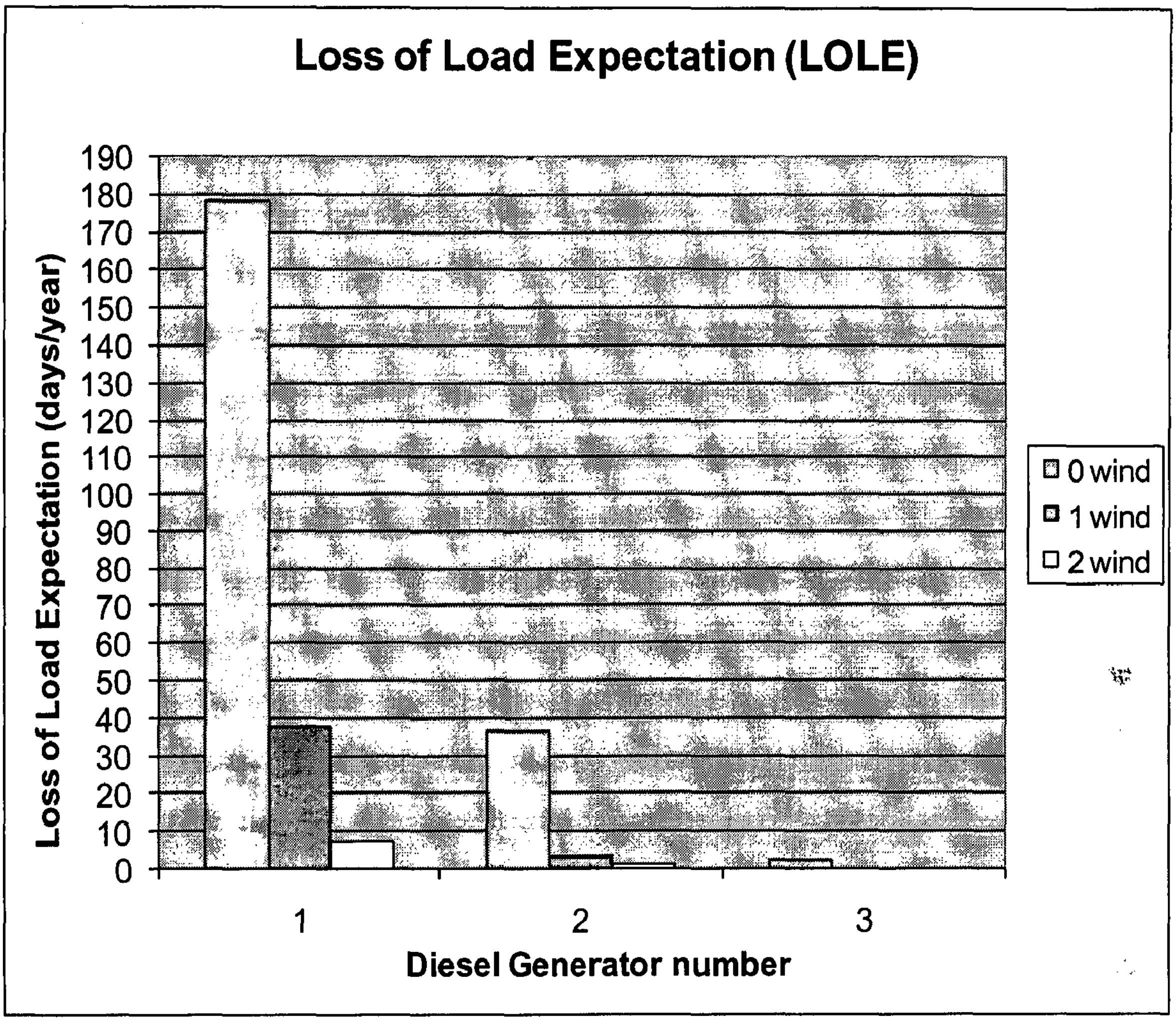

Fig 9.38 LOLE vs. System Configuration

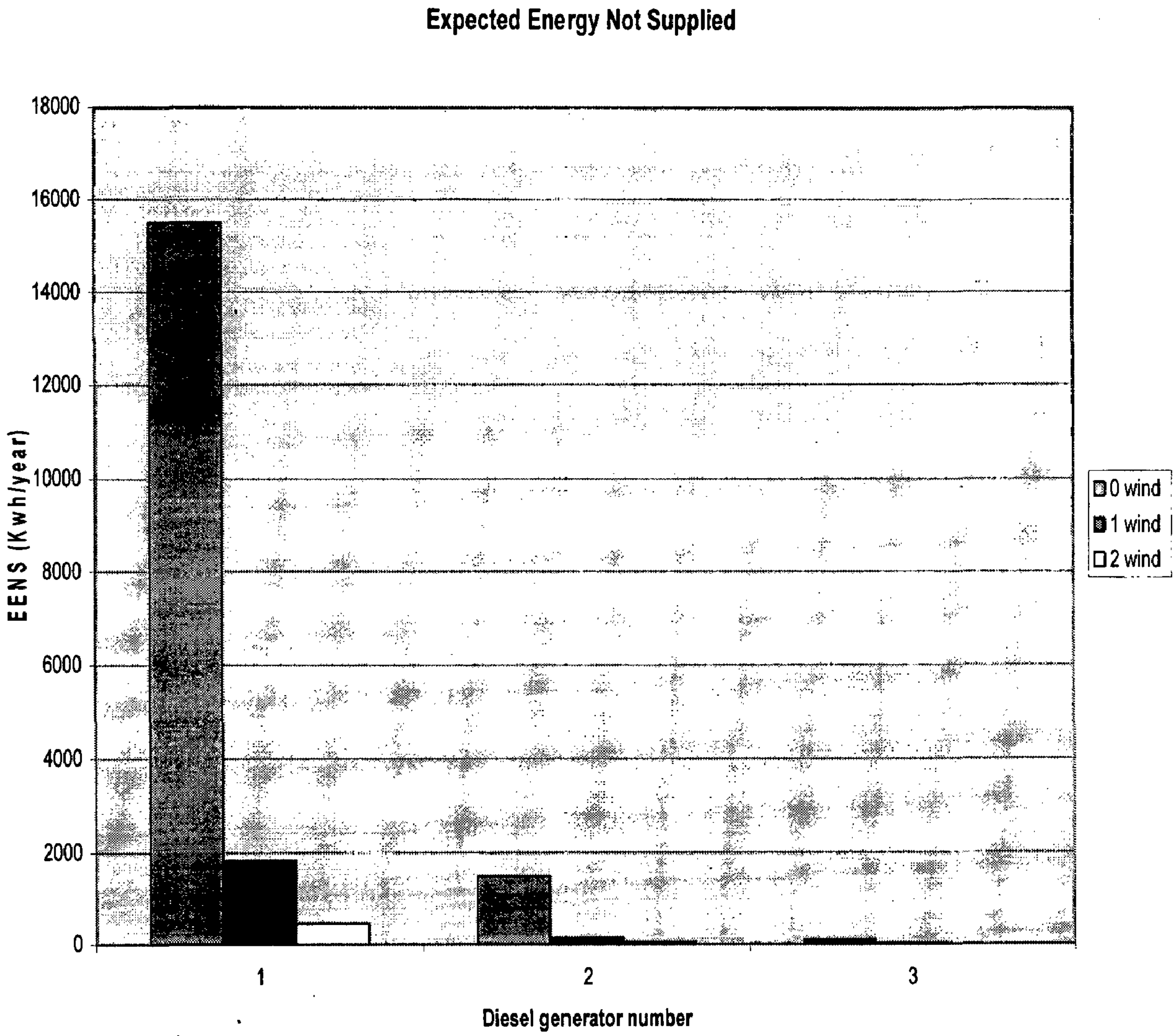

Fig 9.39 EENS vs. System Configuration

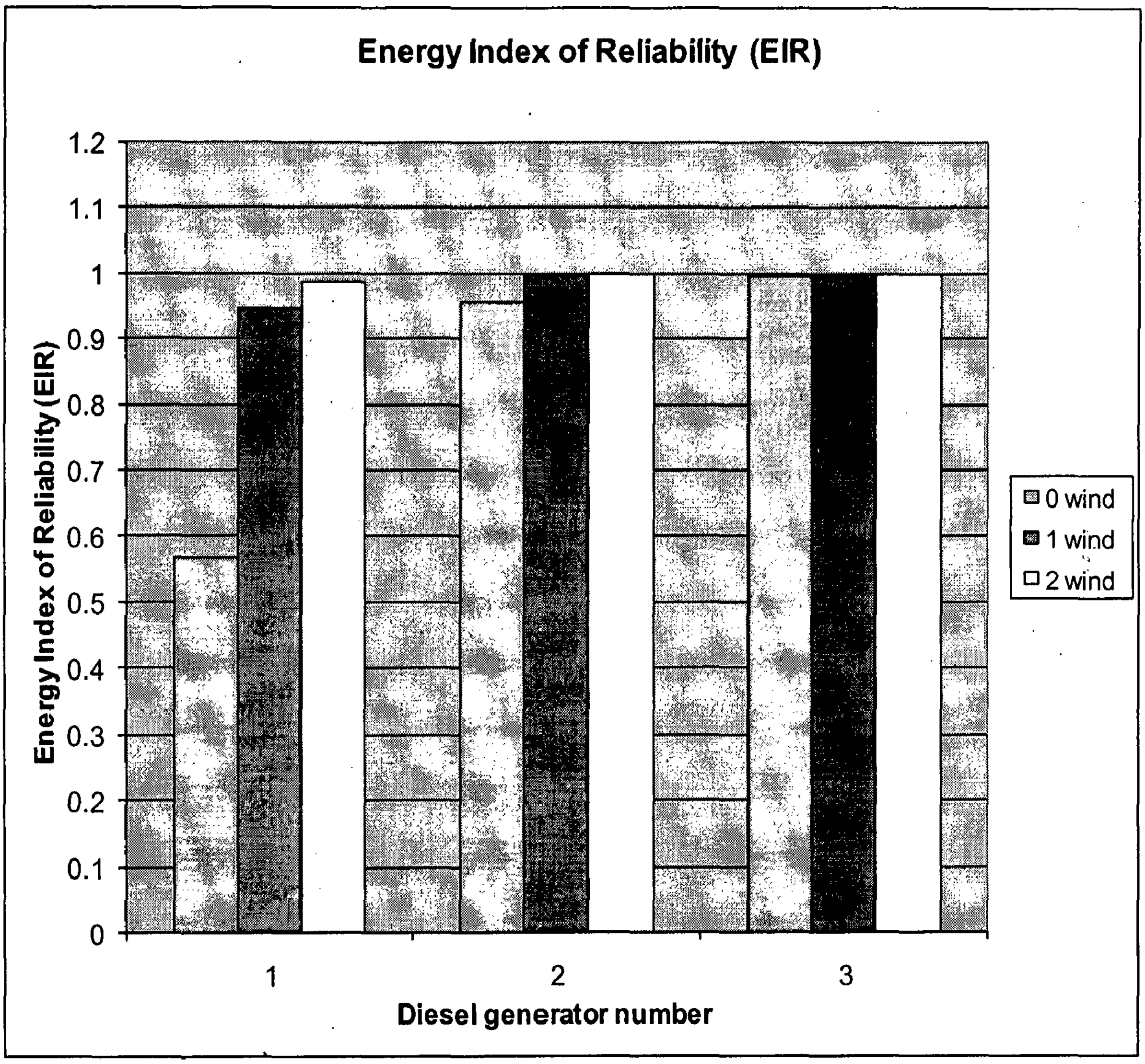

Fig 9.40 Energy Index of Reliability vs. System Configuration

CONCLUSIONS

Wind-Diesel Hybrid systems were most suitable for the remote areas and hilly regions were it is difficult for laying transmission lines. In a remote areas there used to be two general solutions for its electrification: making a connection to the closest grid or using diesel generation to get self-sufficiency. Diesel generators can provide reliable power supply when properly maintained even though diesel generators can provide reliable power this involves cost, therefore the system cost increases. Wind energy has received considerable public attention since the last decade, and has since been the fastest growing energy source. Wind energy is also free from the Pollution, naturally available from the atmosphere. By using Wind generation along with the Diesel generation it can be possible to supply reliable power at less cost. Unfortunately wind generation depends on nature the system cannot depend on the wind totally. When wind speed is high the diesel can be kept standby and total power from the wind turbines were supplied to the loads and the remaining load power can be supplied from the diesel engines such that the cost of the system can be reduced.

The performance of the wind-diesel system can be judged by two things

1. When it supplies reliable power supply through out the period without any block outs.
2. When the system voltage and frequency was maintained within the specified limits.

In this Thesis reliability indices were used to evaluate the reliability of the Wind-Diesel hybrid system. The reliability indices include EENS (Expected Energy Not Supplied), and LOLE (Loss Of Load Expectation). EENS, LOLE were the most widely used probabilistic techniques for evaluating the adequacy of a given generation configuration. This reliability studies help in selecting optimal hybrid system suitable for the particular remote area. This will helpful for the system planner and utility administrators to evaluate, upgrade, size and optimize the hybrid power systems, The voltage and frequency levels of the system plays vital role in deciding the reliability of the power system. Generally the voltage and frequency levels will be less that there specified limits when were there is more reactive loads than the resistive loads in that particular area, faults, sudden change in loads and also variable wind speeds in this case.

In this Thesis Wind-Diesel hybrid system was implemented in Simulink in such a way that the voltage and frequency variations were absorbed when there were sudden change loads, and for electrical faults, change in wind speeds, and successful in maintaining stability of the system from the Transient conditions. This Simulink model deals only with WO (wind only), WD (Wind-Diesel) modes. In this thesis it was not focused about the control system required for switching from WO modes to WD modes when ever there were changes in the wind speeds.

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APPENDIX A

Asynchronous machine model

The mathematical model of the asynchronous machine presents two subcomponents: the electrical system and the mechanical system. The equations (34)-(42) represents in fact the park dq-asynchronous machine model.

Electrical system equations

$$U_{qs} = R_s i_{qs} + \frac{d}{dt}\left(L_s i_{qs} + L_m i_{qr}\right) + \omega(L_s i_{ds} + L_m i_{dr}) \quad (34)$$

$$U_{ds} = R_s i_{ds} + \frac{d}{dt}(L_s i_{ds} + L_m i_{dr}) - \omega\left(L_s i_{qs} + L_m i_{qr}\right) \quad (35)$$

$$U_{qr} = R_r i_{qs} + \frac{d}{dt}\left(L_r i_{qr} + L_m i_{qs}\right) + (\omega - \omega_r)(L_r i_{dr} + L_m i_{ds}) \quad (36)$$

$$U_{dr} = R_r i_{ds} + \frac{d}{dt}(L_r i_{dr} + L_m i_{ds}) + (\omega - \omega_r)\left(L_r i_{qr} + L_m i_{qs}\right) \quad (37)$$

$$T_e = \frac{3}{2}\rho\left((L_s i_{ds} + L_m i_{dr}) i_{qs} - \left(L_s i_{qs} + L_m i_{qr}\right) i_{ds}\right) \quad (38)$$

Where

$$L_s = L_{is} + L_m \quad (39)$$

$$L_s = L_{is} + L_m \quad (40)$$

Mechanical system equations

$$\frac{d}{dt} w_m = \frac{1}{2j}(T_e - T_m) \quad (41)$$

$$\frac{d}{dt} \theta_m = w_m \quad (42)$$

Where

R_s, L_{is} – Stator resistance and leakage inductance

R_r,L_{ir} - rotor resistance and leakage inductance

L_m - magnetizing inductance

L_s , L_r - Total stator and rotor inductances

U_{qs}, i_{qs} - q axis stator voltage and current

U_{qr} ,i_{qr} - q axis rotor voltage and current

U_{ds}, i_{ds} - d axis stator voltage and current

U_{dr}, i_{dr} - d axis rotor voltage and current

W_m - angular velocity of the rotor

θ_m - angular velocity of the rotor

P - number of pole pairs

Wr - electrical angular velocity ($W_m \times P$)

θ_r - electrical rotor angular position ($W_m \times P$)

T_m - shaft mechanical torque

J - combined rotor and load inertia constant

Diesel-Synchronous unit

$$\dot{q}_{ffr} = \frac{1}{\tau_c}\left(-q_{ffr} + q_d(t - \tau_d)\right) \quad (43)$$

Where

q_{ffr}= effective fuel flow rate

q_d = fuel flow rate input

τ_d= Time delay of combustion

τ_c = Time constant representing the actuator and combustion process dynamics

$$\dot{\theta}_{cl} = w_d - w_s \tag{44}$$

$$\dot{w}_s = \frac{1}{J_d + J_{fc}}\left(\epsilon k_c k_v q_{ffr} - \left(D_d + D_{fc} + D_{cl}\right)w_d + D_{cl}w_s - k_v\rho_o - c_{cl}\theta_{cl}\right) \tag{45}$$

$$\dot{w}_s = \frac{1}{J_{fw} + J_s}\left(C_{cl}\theta_{cl} + D_{cl}w_d - \left(D_{cl} + D_s + D_{fw}\right)w_s - T_s\right) \quad (46$$

Where

$\dot{\theta}_{cl}$= torsion angle between the engine and the generator shaft

w_d= rotational speed of the diesel engine

w_s =rotational speed of the electrical generator

$J_d + J_{fc}$ = total inertia of the diesel engine with flywheel and clutch

$J_{fw} + J_s$ = total inertia of the flywheel and electrical generator

$\in$= Fuel efficiency

K_c = a constant relating pressure and fuel consumption

K_v = Stroke volume of the engine

C_{cl}, D_{cl}= torsional stiffness and damping of the coupling respectively

θ_{cl} = torsional angle between the engine and the generator shaft

$D_d + D_{fc}$ = total frictional damping of the engine with flywheel and clutch

$D_{fw} + D_d$ = total frictional damping of the flywheel and electrical generator

ρ_o = Zero torque pressure

System parameters of Typical Diesel Engine

SYSTEM PARAMETERS	VALUE RANGE	NOMINAL VALUE
Actuator gain constant K_2 (per unit)	1.0	1.0
Actuator time constant τ_2 (s)	0.05~0.2	0.125
Engine torque constant K_1 (per unit)	0.8~1.5	1.15
Current driver constant K_3 (per unit)	1.0	1.0
Engine dead time τ_1(s)	0~1.0	0.5
Plant and flywheel acceleration J(s^{-1})	0.1~0.5	0.3
Friction coefficient ρ(per unit)	0.1	0.1

Technical specifications of Wind Turbines

GENERAL SPECIFICATIONS	250 KW TURBINE
Supplier/producer	WES BV
Life expectancy	Min 20 years
Nominal Power	250 kw
Cut in wind speed (m/s)	< 3 m/s
Cut out speed (m/s)	25 m/s
Nominal Wind speed (m/s)	12 m/s
Survival wind speed (m/s)	60 m/s
Hub Height	31-51 m
Number of Blades	3
Rotor Diameter	30 m
Rotor Swept area	564 m^2
Passive Power Regulation	Blade angle adjustment
Voltage	480v/60 Hz
Degree of Protection	IP 54
Generator Type	asynchronous

No. of poles	4
Frequency variable	25-75 Hz
Blade weight	327 kg
Blade Length	13.4m
Rotor weight	2500 kg