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Paper Authors

M.SANTOSHI KUMARI, M NAVEEN BABU, Dr.A.PURNA CHANDRA RAO
St. Ann's College of Engineering and Technology, Nayani Palli Village, ChallaReddy Palem Post, Vetapalem Mandal, Chirala, A.P

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PHOTOVOLTAIC/WIND HYBRID POWER SYSTEM INTERCONNECTED WITH ELECTRICAL UTILITY ALONG WITH FEASIBILITY ANALYSIS

[1]M.SANTOSHI KUMARI,[2]M NAVEEN BABU$_{\text{M.Tech,(Ph.D)}}$,[3]Dr.A.PURNA CHANDRA RAO$_{\text{Ph.D}}$
[1]M-tech student Scholar, Dept of E.E.E, St. Ann's College of Engineering and Technology, Nayani Palli Village, ChallaReddy Palem Post, Vetapalem Mandal, Chirala, Andhra Pradesh
Assistant Professor, Dept of E.E.E, St. Ann's College of Engineering and Technology, Nayani Palli Village, ChallaReddy Palem Post, Vetapalem Mandal, Chirala, Andhra Pradesh
Professor & Head of the Department, Dept of E.E.E, St. Ann's College of Engineering and Technology, Nayani Palli Village, ChallaReddy Palem Post, Vetapalem Mandal, Chirala, Andhra Pradesh

ABSTRACT

This project focuses on Modelling and Simulation of Photovoltaic/Wind Hybrid Power System Interconnected with Electrical Utility along with Feasibility Analysis. By taking Photovoltaic's all Radiation, Temperature, Maximum Power Point Tracking with Perturb & Observe Algorithm, Wind Speeds and Variation of Load Demand, a computer simulation model has been developed in MATLAB Simulink environment. Our intention is by the interconnection of the Photovoltaic/Wind Systems to the Grid, the total load demand has to supply by the entire system. If the Photovoltaic and Wind units produce power more than the Load demand, then the excess power will be transmitted to the Electrical Utility (Grid). If they are unable to meet the required load demand, then the deficit power will be supplied by the Grid. And also Feasibility Analysis was done for both Photovoltaic, Wind Systems. Performed the necessary calculations of Net Present Value, Internal Rate of Return, Annuity, Cost Annuity, KWh Cost and Dynamic Payback Period of each system

1 Introduction

All electricity problems should be solved to overcome the obstacles, which e the countries' development strategic plans is facing. Power shortage is the most common problem regarding the execution of the countries' development plans. The HPGS is considered the most effective solution to overcome this problem and to meet the power demand. Wind turbine (WT), photovoltaic (PV), storage batteries (SB), gas turbine (GT), and utility are connected together to form the HPGS.

Natural gas distribution network is included for the first time to supply the required fuel (natural gas) for the gas turbine, where all its operational conditions are considered. The most important operational conditions should be taken into consideration during the design of this system. They are pressure drop and speed flow. New meta-heuristic optimization techniques have been used to design the mentioned hybrid power system, where CSA, FA, and FPA are used to obtain the HPGS components sizing.The increasing energy demand, increasing costs and exhaustible nature of fossil fuels, and global environment pollution have generated huge interest in renewable energy resources. Other than hydroelectric power, wind and solar are the most useful energy sources to satisfy our power requirements. Wind energy is capable of producing huge amounts of power, but its availability can't be predicted. Solar power is available during the whole day but the solar irradiance levels change because of the changes in the sun's intensity and shadows caused by many reasons. Generally solar and wind powers are complementary in nature. Therefore the hybrid photovoltaic and wind energy system has higher dependability to give steady power than each of them operating individually. Other benefit of the hybrid system is that the amount of the battery storage can be decreased as hybrid system is more reliable compared to their independent operation.There are many definitions of Hybrid Power Systems (HPS). Hybrid Power Systems is defined as small set of co-operating units, generating electricity or electricity and heat, with diversified primary energy carriers (renewable and non-renewable), while the co-ordination of their operation takes place by utilisation of advanced power electronics systems. HPS by definition have been constructed for the generation of electricity or electricity and heat. Mostly, they are connected to the power grid, but they can also work independently feeding separated receivers, from one or several homes/farms, small industrial plants to large local communities. Grid-connected HPS provide electric power reserves and allow surplus power to be fed back to the grid when HPS generate more power than receivers and local energy storage systems require. Obviously, the major aim of HPS is to supply remote, off-grid communities where the costs of connection to the long-distance transmission or distribution grid are too high. HPS use few technologies connected with power generation such as different power generation devices, different energy storage technologies and advanced microprocessor control/ supervision systems. In our opinion hybrid power systems (plants) are a good way to increase availability and flexibility of power supply systems and to have available and flexible sources of electricity which optimize utilisation of primary energy carriers. It may be achieved by combining different primary energy carriers (renewable and non renewable) utilising, electrical energy storage facilities, and advanced power electronics and microprocessor systems for control/supervision.In reference to [1], L. Wang and C. Singh introduce, the design of a hybrid power system, includes both the wind power and solar power. This design is based on the cost, reliability, and emission criteria. The authors take into consideration failure of the equipment, the stochastic generation, and load variation using the probabilistic methods. The modified particle swarm optimization is applied to obtain the system design for different scenarios. L. Liqun and L. Chunxia [2], discuss the opportunity of applying a standalone hybrid wind-photovoltaic battery system for the remote areas of Shanghai. A simulation model is applied for the proposed model and the authors execute financial and risk analysis for it. The authors, also analyze all the environmental and economic considerations. Moreover, the conventional optimization techniques such as genetic algorithm and particle swarm techniques have been applied in order to obtain the cost and emission design for the proposed system.In reference to [3] S. Trazouei, F. Tarazouei, and M. Ghiamy the design of a standalone hybrid system is introduced, which is combined of wind turbine, photovoltaic system, and diesel generator. The imperialist competitive algorithm (ICA), particle swarm optimization (PSO) and ant colony optimization (ACO) have been applied. The authors consider the annual cost as the objective function should be minimized considering the system reliability constraints. Finally, the hybrid system results are obtained consisting of number of the wind turbines, the number of PV panels, number of diesel generators, the annual cash flow, and the system reliability.

2 PHOTOVOLTAIC TECHNOLOGY

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.Photovoltaic's is the field of technology and research related to the devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation. The photovoltaic effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers. On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side.However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction. Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load. When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is extracted once the circuit is closed on an external load.

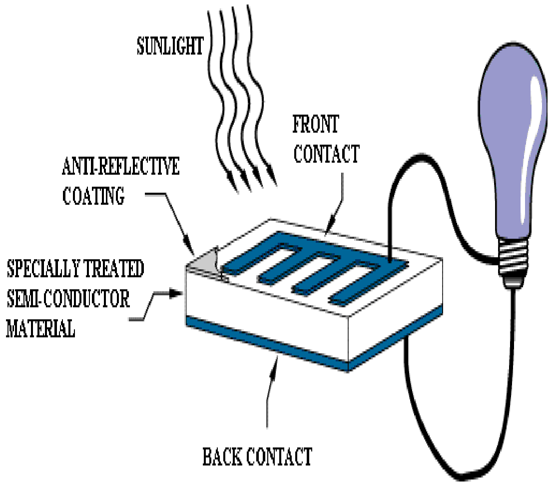


Fig: 1 photovoltaic system

2.1 Functioning of the photovoltaic cells The word “photovoltaic” consists of two words: photo, a Greek word for light, and voltaic, which defines the measurement value by which the activity of the electric field is expressed, i.e. the difference of potentials. Photovoltaic systems use cells to convert sunlight into electricity. Converting solar energy into electricity in a photovoltaic installation is the most known way of using solar energy.The light has a dual character according to quantum physics. Light is a particle and it is a wave. The particles of light are called photons. Photons are massless particles, moving at light speed. The energy of the photon depends on its wavelength and the frequency, and we can calculate it by the Einstein's law, which is:

$$E = h\nu$$

WhereE- photon energy, h - Planck's constant = $6.626\times10 - 34$Js

In metals and in the matter generally, electrons can exist as valence or as free. Valence electrons are associated with the atom, while the free electrons can move freely. In order for the valence electron to become free, he must get the energy that is greater than or equal to the energy of binding. Binding energy is the energy by which an electron is bound to an atom in one of the atomic bonds. In the case of photoelectric effect, the electron acquires the required energy by the collision with a photon. Part of the photon energy is consumed for the electron getting free from the influence of the atom which it is attached to, and the remaining energy is converted into kinetic energy of a now free electron. Free electrons obtained by the photoelectric effect are also called photoelectrons.

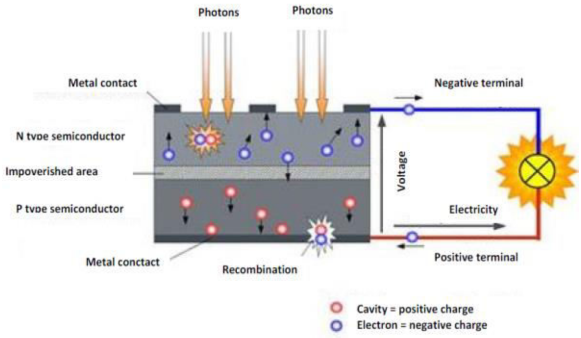


Fig.2: functioning of photovoltaic cells

2.2 PV CELL MODEL

The equivalent circuit of a PV cell is shown in Fig..3. It includes a current source, a diode, a series resistance and a shunt resistance.

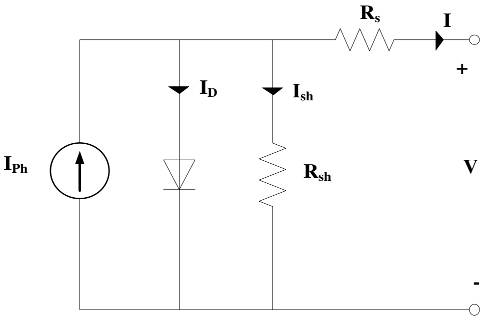


Fig 3 PV cell equivalent circuit.

In view of that, the current to the load can be given as:

$$I = I_{ph} - I_s(\exp\frac{q(V+R_s I)}{NKT}) -1) - \frac{(V+R_s I)}{R_{sh}} \quad (1)$$

In this equation, $I_{ph}$is the photocurrent, $I_s$is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, N is the ideality factor of the diode, and $R_s$and $R_{sh}$are the series and shunt resistors of the cell, respectively. As a result, the complete physical behavior of the PV cell is in relation with I_{ph}, I_s, $R_s$and $R_{sh}$from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand.

3.WIND ENERGY

3.1 Importance of wind Energy and wind Power:

The modern lifestyle depends tremendously on the use and existence of fossil fuels. With levels of these fuels constantly decreasing, we should act now to become less dependent on fossil fuels and more dependent on renewable energy sources.

The decreasing levels of fossil fuels isn't the only reason why we should begin to use renewable energy. Pollution is becoming a huge problem in many countries around the world, especially the developing world. With carbon emissions at an all time high, air quality can be very low in some areas, this can lead to respiratory diseases and cancer.

The main reason to switch to cleaner energy production methods is the global warming aspect. The more carbon dioxide we pump into the atmosphere, the greater the effect becomes. We can't just stop using fossil fuels thinking that global warming will go away, but we can slow down and dilute the effects of global warming through the wide spread use of renewable energy resources.Renewable energy flows involve natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat, as the Agency explains: Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.Renewable energy resources and significant opportunities for energy efficiencyexist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources, would result in significant energy security and economic benefits.

Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services

- **Power generation**. Renewable energy provides 19% of electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas.
- **Heating**. Solar hot water makes an important contribution to renewable heat in many countries, most notably in China, which now has 70% of the global total (180 GWth). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50–60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly.

- **Transport fuels**. Renewable biofuels have contributed to a significant decline in oil consumption in the United States since 2006. The 93 billion liters of biofuels produced worldwide in 2009 displaced the equivalent of an estimated 68 billion liters of gasoline, equal to about 5% of world gasoline production.

In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power, requiring utilities to use more renewable energy (even if this increases the cost), and providing tax incentives to encourage the development and use of such technologies. There is substantial optimism that renewable energy investments will pay off economically in the long term.There are many natural energy sources out there, but you have to decide which method is best for you, as all of these sources depend on your current environment.The installation of a solar panel or a wind turbine to boost every homes power supply would be an amazing step forward. Some governments are in the process of supplying solar panels to hundreds of households to test this method of energy saving.A technology set to be very important in the future is geothermal energy. With geothermal energy, you are able to extract heat from within the earth and transform it either into a hot water system, or if there is plenty of this energy, a geothermal power plant. Huge amounts of money have been flowed into research of this method, especially in recent years, in order to make the current technology more effective.

3.2 Wind Energy and Wind Power

Fig 4 Wind Farm

Airflows can be used to run wind turbines. Modern utility-scale wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have become the most common for commercial use; the power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically up to the maximum output for the particular turbine. Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms. Typical capacity factors are 20-40%, with values at the upper end of the range in particularly favorable sites.

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand. This could require wind turbines to be installed over large areas, particularly in areas of higher wind resources. Offshore resources experience average wind speeds of ~90% greater than that of land, so offshore resources could contribute substantially more energy.Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity.

3.3 How Wind Power Is Generated

The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

3.4 Wind Turbines

Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

3.5 Design of a Wind Turbine

A typical modern wind turbine can be broken down into its major parts, which are the:

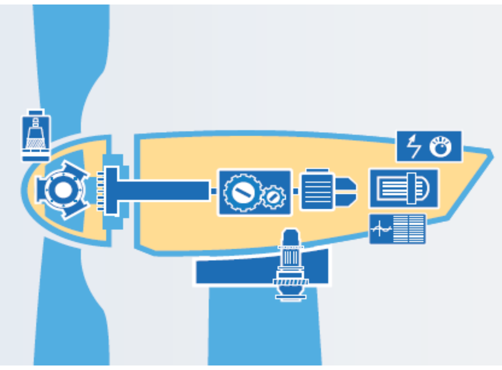


Fig 5 Internal Design of a Wind Turbine

3.5.1 Blades

Modern turbines typically use three blades, although other configurations are possible. Turbine blades are typically manufactured from fibre glass reinforced polyester or epoxy resin. However, new materials, such as carbon fibre, are being introduced to provide the high strength-to-weight ratio needed for the ever larger wind turbine blades being developed. It is also possible to manufacture the blades from laminated wood, although this will restrict the size.

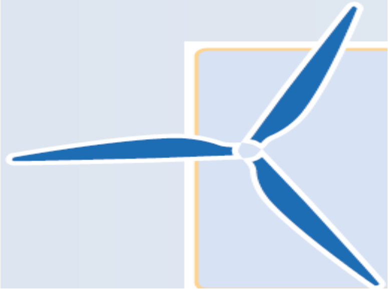


Fig 6 Rotor Blades

3.5.2 Nacelle

This is the main structure of the turbine and the main turbine components are housed in this fibreglass structure.

Fig 7 Nacelle Housing

3.5.3 Rotor Hub

The turbine rotor and hub assembly spins at a rate of 10 to 25 revolutions per minute (rpm) depending on turbine size and design (constant or variable speed). The hub is usually attached to a low speed shaft connected to the turbine gearbox. Modern turbines feature a pitch system to best adjust the angle of the blades, achieved by the rotation of a bearing at the base of each blade. This allows rotor rpm to be controlled and spend more time in the optimal design range. It also allows the blades to be feathered in high wind conditions to avoid damage.

Fig 8 Rotor Hub

3.5.4 Gearbox

This is housed in the nacelle although “direct drive” designs which do not require one are available. The gearbox converts the low-speed, high-torque rotation of the rotor to high-speed rotation (approximately 1500 rpm) with low-torque for input to the generator.Gears increase the low rotational speed of the rotor shaft in several stages to the high speed needed to drive the generator.

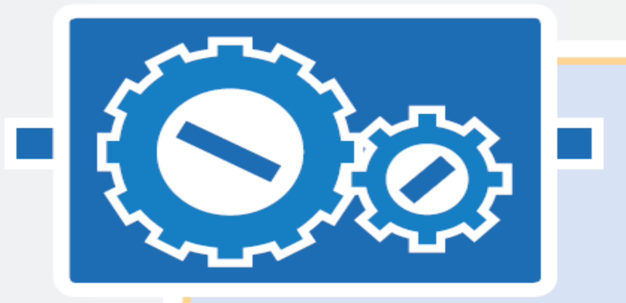


Fig 9 Gear Box

3.5.5 Generator

The generator is housed in the nacelle and converts the mechanical energy from the rotor to electrical energy. Typically, generators operate at 690 volt (V) and provide three-phase alternating current (AC). Doubly-fed induction generators are standard, although permanent magnet and asynchronous generators are also used for direct-drive designs. It converts mechanical energy into electrical energy. Both synchronous and asynchronous generators are used.

Fig 10 Generator

3.5.6 Controller

The turbine’s electronic controller monitors and controls the turbine and collects operational data. A yaw mechanism ensures that the turbine constantly faces the wind, Effective implementation of control systems can have a significant impact on energy output and loading on a turbine and they are, therefore, becoming increasingly advanced. The controllers monitor, control or record a vast number of parameters from rotational speeds and temperatures of hydraulics, through blade pitch and nacelle yaw angles to wind speed. The wind farm operator is therefore able to have full information and control of the turbines from a remote location.

3.5.7 Tower

These are most commonly tapered, tubular steel towers. However, concrete towers, concrete bases with steel upper sections and lattice towers are also used. Tower heights tend to be very site-specific and depend on rotor diameter and the wind speed conditions of the site. Ladders, and frequently elevators in today's larger turbines, inside the towers allow access for service personnel to the nacelle. As tower height increases, diameter at the base also increases.

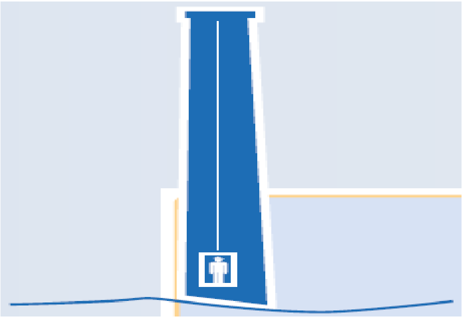


Fig 11: Tower

3.5.8 Transformer

The transformer is often housed inside the tower of the turbine. The medium voltage output from the generator is stepped up by the transformer to between 10 kV to 35 kV; depending on the requirements of the local grid.Step-up transformers design is one whose secondary voltage is greater than its primary voltage. This kind of transformer steps up the voltage applied to it.A step up transformer converts alternating current from one voltage to another voltage. It has no moving parts and works on a magnetic induction principle. It can be designed to step up or step down voltage. So a step up transformer increases the voltage and a step down transformer decreases the voltage.The step-down transformer is evidenced by high turn count of the primary winding and low turn count of secondary winding. As a step-down unit, this transformer converts high voltage, low current power into low voltage, high current power. The larger gauge wire used in the secondary winding, which doesn't have to conduct as much current, may be made of smaller gauge wire.

(4) Economical evaluation

4.1 Sizing of PV System

The appropriate PV generator for a particular load is determined by the daily energy demand KWh, the sizing of the PV system is based upon other factors like inverter efficiency, Peak Sunshine Hours (PSH)

The peak power of PV generators is given by, P_{pv}

$$P_{pv} = \frac{E_L}{\eta_v \eta_R PSH} S_f \qquad 2$$

WhereE_Ls the daily energy consumption in KWh/day

PSH is peak sun shine hours also called as the solar irradiance taken on an average =5.4 $^{KWh}/_{m^2}$

η_v Is the inverter efficiency =0.92

η_R Is the efficiency of the charge regulator =0.9

S_f Is the Safety Factor for compensation of resistive losses and PV-cell temperature =1.15

No of modules required is selected from peak power of the PV generator and peak power of each module

$$No.of\ modules = {}^{P_{PV}}/_{P_{mpp}} \qquad 3$$

4.2 Sizing the Battery Block

The storage capacity of battery block for such systems is considerably large. Therefore, Special lead acid battery cells (block type) of long life time (0 to 10 years), high cycling Stability-rate (1000 times) and capability of standing very deep discharge should be selected. Such battery types are available capacity (C_{Wh}) of the battery block, necessary to cover the load demands for a period of 1.5 days without sun.

$$C_{Ah} = 1.5 \times \frac{E_L}{V_B} \times DOD \times \eta_B \times \eta_V \qquad 4$$

Where, V_B and η_B are voltage and efficiency of battery block while DOD is the permissible Depth Of Discharge rate of a cell assuming realistic values of η_B =0.85, DOD=0.75 and η_B =220V we obtain C_{Ah}.

Watt-hour capacity of the battery block is given by

$$C_{Wh} = C_{Ah} \times V_B \qquad 5$$

4.3 Charge Regulator

The Charge Regulator (CR) is necessary to protect the battery block against deep discharge and over charge. Input/output ratings of CR are fixed by the output of the PV array and V_B. In this case the appropriate rated power of CR is 25 kW. In this power range it is recommended that the CR should have a maximum power control unit.

4.4 Economical Evaluation of Energy Supply Systems

The outcome of a project is established through a set of economic indicators. These indicators for PV, diesel and grid extension will then be compared with each other. In order to establish the absolute or relative acceptability of an investment, we can use two different procedures, the static method and the dynamic method. They differ from each other in the sense that the dynamic method takes into account the different times at which payments on an investment are receivable. This means in our cases that payments are discounted if they come after a project is commissioned. Therefore, by using dynamic procedures, receipts and payments are given higher value the earlier they fall and lower value later. Because of this time component in evaluating investment linked payments, the Dynamic method produce undoubtedly better results than the static method. Factors that need to consider for Economic feasibility are

1) Net Present Value
2) Internal Rate of Return
3) Annuity
4) Cost Annuity
5) Dynamic Payback Period

4.4.1 Net Present Value (NPV)

The NPV of an investment project at time t=0 is the sum of the present values of all cash inflows and outflows linked to the investment.

$$NPV = -I_0 + \sum_{t=0}^{T}(R_t - I_t)q^{-t} + L_T q^{-T} \qquad 6$$

$$q^{-t} = (1 + i/100)^{-t} \qquad 7$$

Where

I_0= Investment cost at the beginning of the project

T= Life time of the project

R_t= Return in time period t,

I_t = Investment in time period t,

q^{-t}= Discount factor,

i = Discount rate,

L_T = Salvage value after life time T years,

A project is said to be profitable when NPV>0 and greater the NPV the more profitable, Negative NPV indicates that we are unable to met the minimum interest.

4.4.2 Internal Rate of Return (IRR)

Internal rate of return computes for what value of interest NPV will be zero, so it expresses the achievable interest tied-up in the investment. $0 = -I_0 + \sum_{t=o}^{T} R_t \left(1 + IRR/100\right)^{-t} + L_T\left(1 + IRR/100\right)^{-t}$ 8

4.4.3 Annuity (A)

The annuity converts all net cash flows connected with an investment project in to a series of annual payments of equal amounts

$$A = NPV \times RF(i,T)$$

9

$$RF = \frac{q^t(q-1)}{q^t - 1}$$

10 $q = 1 + \frac{i}{100}$

11

Where RF is the capital recover factor A=0: interest on the capital invested is obtained at least at level of cut-off interest rate .The energy alternative with highest A is the most favorable one.

4.4.4 Cost annuity (A_k)

Cost annuity is used to evaluate the relative favorability of investment projects on the basis of costs per annum or per unit production.

$$A_k = \left[\left(\sum_{t=0}^{T} k_0 q^{-t}\right) RF(i,T)\right] + (I_t - L_t)RF(i,T) + L_T i) \qquad 12$$

KWh-cost = $A_k / total\ yearly\ KWH\ produced$

Where k_0 the operating cost per time period, project with is lowest A_k is selected

4.4.5 Dynamic Payback Period (DPB)

The purpose of calculating DPB is to determine the time point at which the capital invested in a project will be recovered by annual returns, within its service time.

$$DPB = \frac{I_0}{\left[\left(\sum_{t=0}^{T}(R_t - I_t)\right)/T\right]}$$

13

5.Proposed Concept

5.1 Introduction

As energy demands around the world increase, the need for a renewable energy sources that will not harm the environment has been increased. Some projections indicate that the global energy demand will almost triple by 2050as in [1], [2]. Renewable energy sources currently supply somewhere between 15% and 20% of total world energy demand. PV and Wind Energy Systems are the most promising as a future energy technology. A 30% contribution to world energy supply from renewable energy sources by year 2020 as in [2] would reduce the energy related CO2 emission by 25%. D. Hansen et. al. [3] presented a number of models for modelling and simulation of stand-alone PV system with battery bank verified against a system installed at RisΦ national laboratory. The implementation has been done using Matalb/simulink. Hang-Seok Choi, et. al. [4] presented a new zero current switching inverter for grid-connected PV system.The proposed circuit provides zero current switching condition for all the switches, which reduces switching losses significantly. It is controlled to extract maximum power from the solar array and to provide sinusoidal current into the electrical utility. Gregor P. Henze, et. al [5] investigated an adaptive optimal control of a grid-independent PV system consisting of a collector, storage, and a load. The control algorithm is based on Q-Learning. Pedro Rosas [6] presented the basic influences of wind power on the power system stability and power quality. It has introduced also an aggregate wind farm model that support power quality and stability analysis from large wind farm. Koch F., Erlich I. and Shewarega F. [7] presented simulation results using a representative network containing wind power generations of up to 30%. Furthermore, modelling and simulation of different types of wind generators integrated into a multi-machine power system discussed. Koch F., et. al. [8] described the effect of large wind parks on the frequency of the interconnected system on which they are operating. Additionally, the effect of the landscape and atmospheric condition at the location of the wind unit on the output power incorporated into the simulation. With increased penetration of WES various researches for modelling of WTG connected to the EU proposed as in [9]-[13]. Debra J. Lew et. al [14] presented a designed hybrid wind/photovoltaic systems, using batteries for households in Inner Mongolia using the optimization program HOMER and model Hybrid. R. Chedid and Saifur Rahman [15] introduced a decision support technique for design of PV/WES HPS. The proposed PV/Wind HPS composed of four design variables (WTG's), PV arrays, batteries and grid-linked substations. The design of a PV/WES HPS based on political and social conditions and uses trade-off /risk method. But most of the researches haven't modelling and simulation of PV/Wind HPS at the point of connection of operation in details.So, the objective of this project is to present modelling, simulation, design and analysis of PV/Wind HPS (Hybrid Electric Power System). In addition to that Feasibility analysis was also done for PV and WIND Systems.

5.2 The Proposed System Model

The system model shown in Fig 5.1 represents PV/Wind HPS connected to a 50 Hz, 22 kV EU. PV system connected to EU through a DC/DC boost converter, DC/AC inverter, LC filter and step-up transformer [18]. WTG connected to EU through back to back converter, LC filter and step-up transformer [15]. The load connected to 22kV Bus through a step-down transformer. The power obtained from PV system is applied to an IGBT's inverter. The task of the boost DC/DC converter drains the power from the PV system and feed the DC link capacitor with a maximum power point tracker. The variable which will be sensed for the controller of PV system are PV solar cell array current I_{pv}, DC link voltage, V_{dcpv}, inverterfilter output currents I_{fpva}, I_{fpvb}, I_{fpvC}, load phase currents I_{La}, I_{Lb}, I_{Lc} and load phase voltages V_a , V_b , V_c . The variables which will be sensed for the controller of WTG are DC link voltage, V_{dcw}, inverter filter output currents I_{invaw}, I_{invbw}, I_{invcw},load currents I_{La}, I_{Lb}, $I_{Lc}$and load phase voltages V_a, V_b, V_c. To provide the active filtering function, the filter output currents are controlled to ensure that the utility line currents and load current are sinusoidal and in phase with the phase voltage. The filter output currents are also controlled to pass power from the PV/Wind HPS to the load and/or EU. The DC link voltage,V_{dcpv} and V_{dcpw} must be controlled to behigher than the peak line voltage of the EU. The proposed system control scheme for the system under study usually uses the Instantaneous Reactive Power Theory, IRPT. The load currents and load voltages are sampled and transformed into the two-axis αβ-coordinate system and then into the rotating dq-coordinate system. IRPT uses the park transformation, as in equation 17 to generate two orthogonal rotating vectors α and β from the three-phase vectors a, b and c. This transformation is applied to the voltages and currents and so the symbol x issued to represent volt or current. IRPT assumes balanced three-phase loads and does not use the X_0 term [18], [19], [20].

$$\begin{bmatrix} X_0 \\ X_\alpha \\ X_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix}\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix}$$

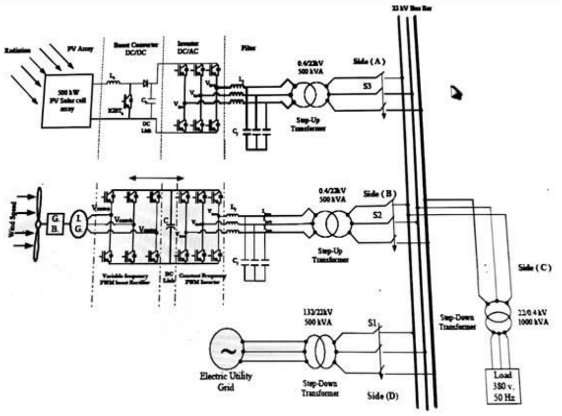


Fig 12 Power and control circuit of PV/WTG HEPS Interconnected with EU to feed the load

5.3 Mode of Operation

There are two modes of operation:

Mode 1: When the generated power from PV/Wind HPS is lower than the load demand then the deficit power will be supplied from the EU. Presumably, the power factor will be within the allowed limits.

Mode 2: When the generated power from PV/Wind greater than the load demand then the surplus power will be transmitted to the EU. In this condition, the power factor of the ac source will deteriorate.

5.4 Simulink Model

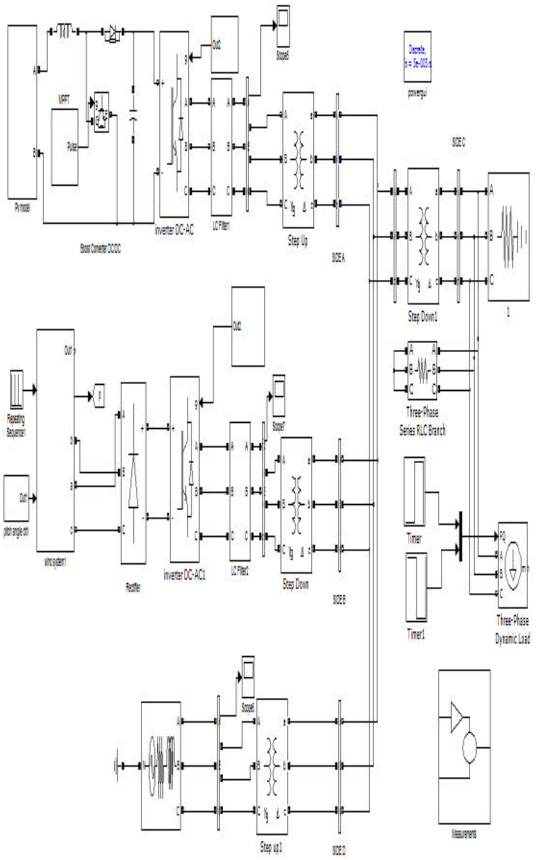


Fig 13 Simulink circuit of PV/Wind Hybrid Power System Interconnected with Electrical Utility

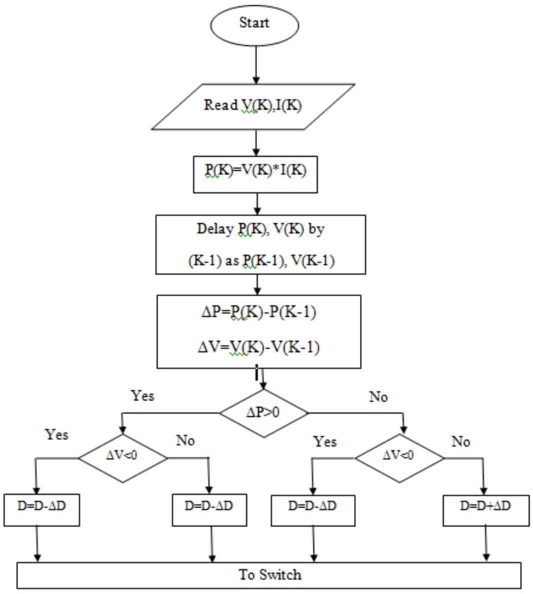


Fig 14 Flowchart for P & O Algorithm Maximum Power Point Tracking (MPPT) using P&O

The MPPT for the PV system was shown here

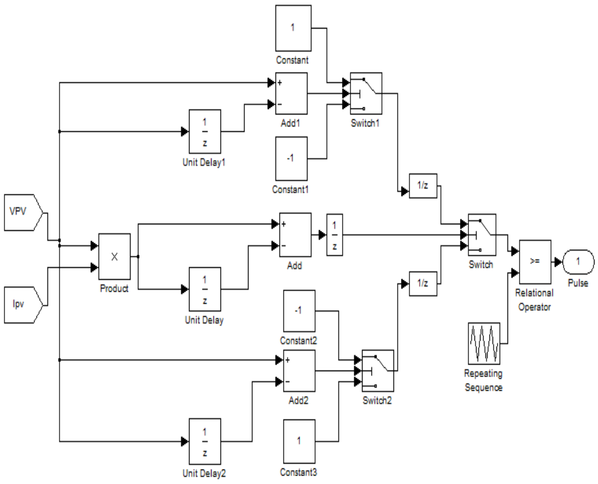


Fig 15 MPPT Simulink Using Perturb and Observe Algorithm

The P&O algorithm is also called "hill-climbing", while both names refer to the same algorithm depending on how it is implemented. Hill-climbing consist of a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturb the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both name refer to the same technique.In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented [21]. The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP. This problem is common also to the INC method, as was mention earlier. A scheme of the algorithm is shown in Fig 14

6. Simulation Results

The Simulation circuit of the PV/Wind HPS Interconnected with EU has been simulated using Matlab/simulink as shown in Fig 13. Here, the total power load level is 500 kW with 759.67 A per phase load current for a duration 0.2 sec. After 0.2 sec the load have been changed from 500 kW to 900 kW with 1367.408 A per phase load current for a duration from 0.2 sec to 0.4 sec. Finally the load is suddenly changed to 500 kW with 759.67 A per phase load current for a duration from 0.4 to 0.5. The variation of the generated power from hybrid PV/WTG according to radiation and wind speed variation is also shown in Fig 16.From Fig 16, it can be seen that there is a surplus power in the period from 0.1 sec to 0.3 sec., so the surplus power will be injected to the EU for this period. On the other hand, there is a deficit power in the period of 0.1 sec and in the period from 0.3 to 0.5 sec. So, the EU will supply the load demand in cooperated with hybrid PV/WTG for these periods.

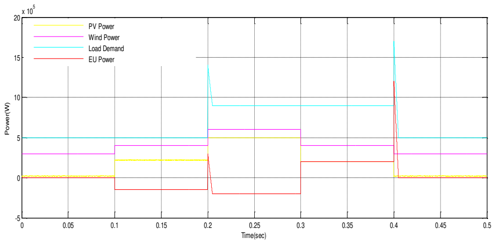


Fig 16: Generated Power from PV/WTG, Grid Power along with Load Demand.

Fig 17 shows the inverter line current injected by the WTG in the side (B) and Fig 16 shows the inverter line current injected by the PV system in the side (A).

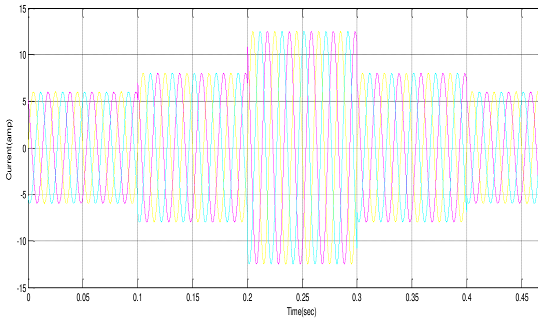


Fig 17: Inverter Line current from WTG to the Load/Grid in the side (B).

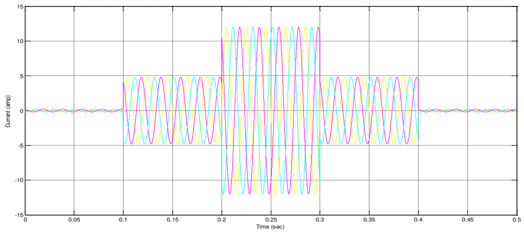


Fig 18: Inverter Line current from PV to the Load/Grid in the side (A).

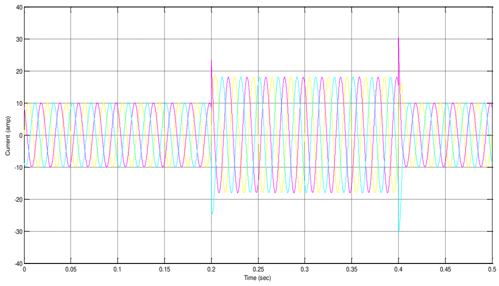


Fig 19: Load Line Current in the side (C).

On the other hand the load line current of the load demand in the side (C) is shown in Fig 19 and Fig 20 is the Grid line current in the side (D).

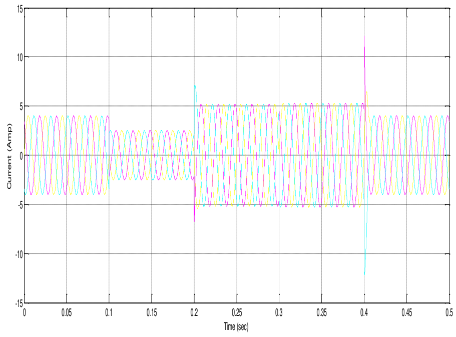


Fig 20 Grid line current in the side (C)

Fig 21 displays the simulated power factor of the grid. It can be seen that the power factor is leading in the period of surplus power and lagging in the period of the deficit power.

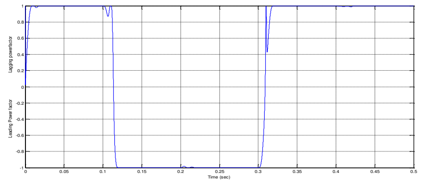


Fig 21 Power Factor of the Grid for the Hybrid PV/WTG system.

Here Fig 22 and Fig 23 shows the power factor of the PV and Wind system.

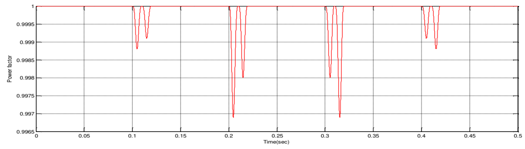


Fig 22: Power Factor of the WTG Inverter.

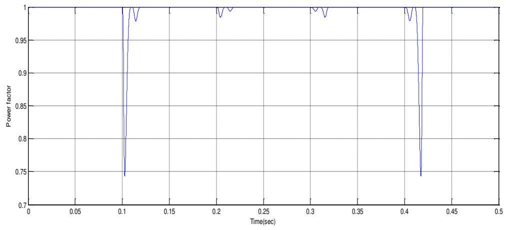


Fig 23: Power Factor of the PV Inverter.

The power factor of the WTG inverter is very close to one as shown in Fig 20 while Fig 21 shows the power factor of PV inverter. From these Figs it can be seen that the proposed model is very excellent.

6.2 Economic Calculations

The necessary calculations that will required for the installation of PV and Wind units are calculated here as follows

6.2.1 Sizing of PV System

$$P_{pv} = \frac{E_L}{\eta_v \eta_R PSH} S_f \qquad 15$$

Where E_Ls the daily energy consumption =500KWh/day

PSH is peak sun shine hours also called as the solar irradiance taken on an average =5.4$^{KWh}/_{m^2}$

η_v is the inverter efficiency =0.92

η_R is the efficiency of the charge regulator =0.9

S_fIs the safety factor for compensation of resistive losses and PV-cell temperature =1.15

Substituting the above values the peak power of the PV generator is obtained as

$$P_{pv} = 128.6Kw$$

To install this power a mono-crystalline PV-module type is selected it is rated at 12V DC and have a peak power of 53W is selected

No of modules required is selected from peak power of the PV generator and peak power of each module

$$No.of\ modules = {}^{P_{pv}}\!/_{P_{mpp}} = 2426\ modules \qquad 16$$

6.2.2 Sizing of Battery Block

$$C_{Ah} = 1.5 \times \frac{E_L}{V_B} \times DOD \times \eta_B \times \eta_V \qquad 17$$

Where V_B and η_B are voltage and efficiency of battery block while DOD is the permissible depth of discharge rate of a cell Assuming realistic values of η_B=0.85, DOD=0.75 and η_B=220V we obtain.

$$C_{Ah}\text{=1999.4Ah}$$

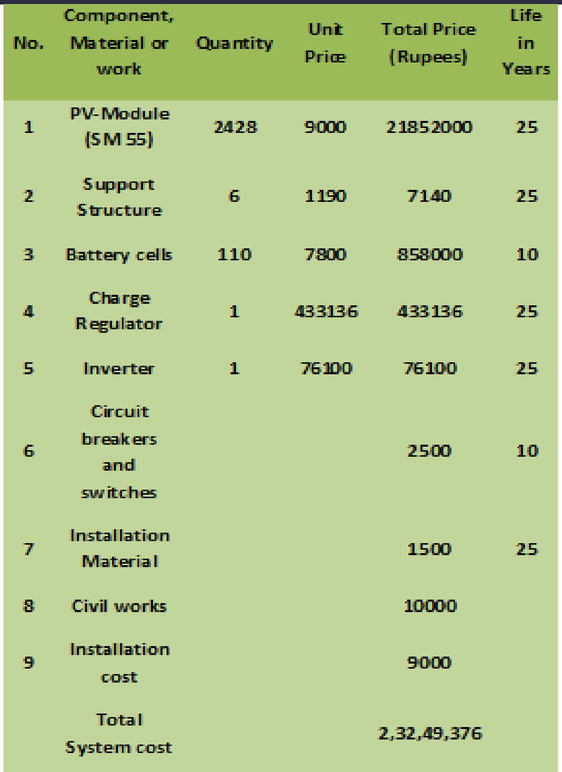
Watt-hour capacity of the battery block is given by

$$C_{Wh} = C_{Ah} \times V_B \qquad 18$$

$$C_{Wh} = 439.8\text{KWh}$$

6.3 Cost calculations associated with PV system

The costs associated with the individual units which are in need for the installation of PV are tabulated here.



No.	Component, Material or work	Quantity	Unit Price	Total Price (Rupees)	Life in Years
1	PV-Module (SM 55)	2428	9000	21852000	25
2	Support Structure	6	1190	7140	25
3	Battery cells	110	7800	858000	10
4	Charge Regulator	1	433136	433136	25
5	Inverter	1	76100	76100	25
6	Circuit breakers and switches			2500	10
7	Installation Material			1500	25
8	Civil works			10000	
9	Installation cost			9000	
	Total System cost			2,32,49,376	

Table 1: Costs Associated with PV installation

6.3.1 Net present value (NPV)

The NPV of an investment project at time t=0 is the sum of the present values of all cash inflows and outflows linked to the investment.

$$NPV = -I_0 + \sum_{t=0}^{T}(R_t - I_t)q^{-t} + L_T q^{-T} \qquad 19$$

$$q^{-t} = (1 + i/100)^{-t} \qquad 20$$

Where, I_0= Investment cost at the beginning of the project=23249376 Rupees,

T= Life time of the project, 25 years

R_t= Return in time period t, 7,30,000 Rupees

I_t = Investment in time period t, 17,21,000 Rupees

q^{-t}= Discount factor, 11.2

i = Discount rate, 8%

L_T = Salvage value after life time T years, 2324973.6 Rupees

By substituting the above values we will get NPV as,

$$NPV = +98,95,765.12$$

A project is said to be profitable when NPV>0 and greater the NPV the more profitable, Negative NPV indicates that we are unable to met the minimum interest.

6.3.2 Internal Rate of Return (IRR)

Internal rate of return computes for what value of interest NPV will be zero, so it expresses the achievable interest tied-up in the investment.

$$0 = -I_0 + \sum_{t=o}^{T} R_t\,(1 + IRR/100)^{-t} + L_T(1 + IRR/100)^{-t} \qquad 21$$

By substituting the values used we get i as 18%.

6.3.3 Annuity (A)

The annuity converts all net cash flows connected with an investment project in to a series of annual payments of equal amounts

$$A = NPV \times RF(i,T) \qquad 22$$

$$RF = \frac{q^t(q-1)}{q^t - 1} \qquad 23$$

$$q = 1 + \frac{i}{100} \qquad 24$$

$$q = 1.08$$

Then,

$$A = 8,69,275$$

Where RF is the capital recover factor A=0: interest on the capital invested is obtained at least at level of cut-off interest rate .The energy alternative with highest A is the most favorable one.

6.3.4 Cost annuity (A_k)

Cost annuity is used to evaluate the relative favorability of investment projects on the basis of costs per annum or per unit production.

$$A_k = [(\textstyle\sum_{t=0}^{T} k_0 q^{-t})RF(i,T)] + (I_t - L_t)RF(i,T) + L_T i) \qquad 25$$

KWh-cost $= A_k/total\ yearly\ KWH\ produced$

$$A_k = 5,16,309.96$$

KWh-cost $= A_k/total\ yearly\ KWH\ produced$

KWh-cost = 3.536 Rupees.

6.3.5 Dynamic Payback Period

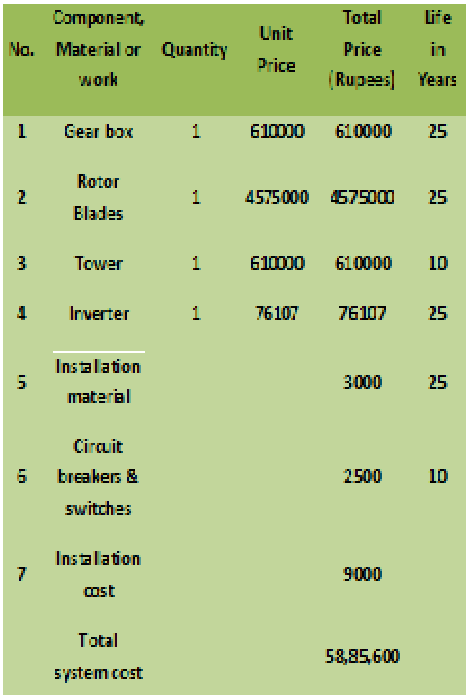
The Dynamic Payback Period of the Project is,

$$DPB = \frac{I_0}{[(\sum_{t=0}^{T}(R_t - I_t))/T]} \qquad 26$$

$$DPB = 4.6 years$$

6.4 Cost calculations associated with Wind System

The costs associated with the individual units which are in need for the installation of PV and Wind units are tabulated here.



No.	Component, Material or work	Quantity	Unit Price	Total Price (Rupees)	Life in Years
1	Gear box	1	610000	610000	25
2	Rotor Blades	1	4575000	4575000	25
3	Tower	1	610000	610000	10
4	Inverter	1	76107	76107	25
5	Installation material			3000	25
6	Circuit breakers & switches			2500	10
7	Installation cost			9000	
	Total system cost			58,85,600	

Table 2: Costs Associated with Wind system installation

6.4.1 Net present value (NPV)

The NPV of an investment project at time t=0 is the sum of the present values of all cash inflows and outflows linked to the investment.

$$NPV = -I_0 + \sum_{t=0}^{T}(R_t - I_t)q^{-t} + L_T q^{-T} \quad 27$$

$$q^{-t} = (1 + i/100)^{-t} \quad 28$$

Where, I_0= Investment cost at the beginning of the project=5885600 Rupees,

T= Life time of the project, 25 years

R_t= Return in time period t, 7,30,000 Rupees

I_t = Investment in time period t, 12,25,000 Rupees

q^{-t}= Discount factor, 11.2

i = Discount rate, 8%

L_T = Salvage value after life time T years, 5,88,560 Rupees

By substituting the above values we will get NPV as,

$$NPV = +43{,}91{,}432$$

A project is said to be profitable when NPV>0 and greater the NPV the more profitable, Negative NPV indicates that we are unable to met the minimum interest.

6.4.2 Internal Rate of Return (IRR)

Internal rate of return computes for what value of interest NPV will be zero, so it expresses the achievable interest tied-up in the investment.

$$0 = -I_0 + \sum_{t=o}^{T} R_t\,(1 + IRR/100)^{-t} + L_T(1 + IRR/100)^{-t} \quad 29$$

By substituting the values used for the investment we get i as 18%.

6.4.3 Annuity (A)

The annuity converts all net cash flows connected with an investment project in to a series of annual payments of equal amounts

$$A = NPV \times RF(i,T) \quad 30$$

$$RF = \frac{q^t(q-1)}{q^t - 1} \quad 31$$

$$q = 1 + \frac{i}{100} \quad 32$$

$$q = 1.08$$

$$A = 385567.7$$

Where RF is the capital recover factor A=0: interest on the capital invested is obtained at least at level of cut-off interest rate .The energy alternative with highest A is the most favorable one.

6.4.4 Cost Annuity (A_k)

Cost annuity is used to evaluate the relative favorability of investment projects on the basis of costs per annum or per unit production.

$$A_k = [(\textstyle\sum_{t=0}^{T} k_0 q^{-t})RF(i,T)] + (I_t - L_t)RF(i,T) + L_T i \quad 33$$

KWh-cost = $A_k/total\ yearly\ KWH\ produced$

$$A_k = 4{,}34{,}271.2$$

KWh-cost = $A_k/total\ yearly\ KWH\ produced$

KWh-cost = 2.97 Rupees.

6.4.5 Dynamic Payback Period

The Dynamic Payback Period of the Project is,

$$DPB = \frac{I_0}{[(\sum_{t=0}^{T}(R_t - I_t))/T]} \quad 34$$

$$DPB = 4.3 years$$

Cost analysis of each system

	PV System	Wind System
NPV	+98,95,765.12	+43,91,432
Annuity	8,69,275	385567.7
Cost Annuity	5,16,309.96	4,34,271.2

Dynamic Payback Period	4.6 Years	4.3 Years
KWh Cost	3.536 Rupees	2.97 Rupees

Table 3: Cost Analysis

6.5 Cash Flow diagrams

6.5.1 PV System:

Capital cost=2,32,49,376Rs.

Operation And Maintenance cost =8,60,500Rs.

Benefits=7,30,000Rs.

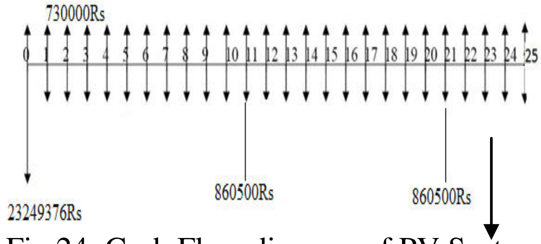


Fig 24: Cash Flow diagram of PV System

6.5.2 Wind system

Capital cost=58,85,600Rs.

Operation And Maintenance cost =12,25,000Rs.

Benefits=7,30,000Rs.

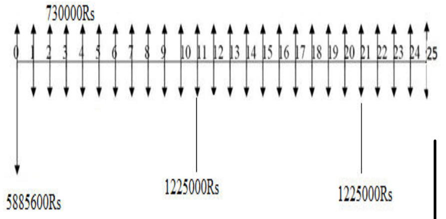


Fig 25: Cash Flow diagram of Wind System

7.Conclusion

From the results obtained above, the following are the salient conclusions that can be drawn from this project work are, This paper provides sectionalized work of PV/Wind Hybrid Power System interconnected with Electrical Utility has been simulated in Matlab/Simulink environment. From the simulation results we can conclude that the power generated from the two individual units PV/Wind are enough to supply the load demand, in case if they are unable to meet the load demand the deficit power will supplied by the EU. Also the cost analysis of the PV/Wind system is feasible.

References

[1] H. H. El-Tamaly et. al. ,"Design and Control Strategy of Utility Interfaced PV/WTG Hybrid System", The Ninth International Middle East Power System Conference, MEPCON'2003, Minoufiya University, Faculty of Eng., Shebin El-Kom, Vol. 2, Dec. 16-18, 2003, pp. 699-674.

[2] International Energy agency report, "Key Issues in Developing Renewables", 1997.

[3] D. Hansen et. al. ," Models for a Stand-alone PV System", Risϕ□National Laboratory, Roskilde, Norway, Dec. 2000.

[4] Hang-Seok Choi, et. al. "Grid-Connected Photovoltaic Inverter with Zero-Current Switching", International Conference on Power Electronics ICPE 2001, Oct. 2001, pp.251-255.

[5] Gregor P. Henze & Robert H. Dodier, "Adaptive Optimal Control of a Grid-Independent Photovoltaic System", Proc. on Journal of Solar Energy Engineering, Vol. 125, No. 1, February 2003, pp. 34-42.

[6] Pedro Rosas, "Dynamic Influences of Wind Power on the Power System", Ph.D. Thesis, ØRsted-DTU, Section of Electrical power Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark, 2003.

[7] Koch F., Erlich I. and Shewarega F., "Dynamic Simulation of Large Wind Farms Integrated in a Multi Machine Network", IEEE PES General Meeting, Toronto, Ontario, Canada, July 13-17, 2003.

[8] Koch F, et. al. "Simulation of the Dynamic Interaction of Large Offshore Wind Farms With the Electric Power

System", Owemes, Naples, Italy, April 10-12, 2003.

[9] A. S. Neris, N. A. Vovos and G. B. Giannakopoulos, "A variable Speed Wind Energy Conversion Scheme for Connection to Weak AC Systems", IEEE Transactions on Energy Conversion, Vol. 14, No. 1, March 1999, pp. 122-127.

[10] Kim Johnsen, and Bo Eliasson, "Simulink Implementation of Wind Farm Model for use in Power System Studies", Nordic Wind Power Conference, 1-2 March, 2004, Chalmers University of Technology.

[11] Mariusz Malinowski and Steffen Bernet ," Simple Control Scheme of PWM Converter Connecting Wind Turbine with Grid-Simulation Study", Nordic Wind Power Conference, Chalmers University of Technology, March 2004, pp. 115-121.

[12] Jan Pierik, Johan Morren and Sjoerd de Haan, "Dynamic Models of Wind Farms for Grid-integration Studies Case study Results", Nordic Wind Power Conference, 1-2 March 2004, Chalmers University of Technology.

[13] Florin Iov et al. ,"Advanced Tools For Modelling, Design and Optimization of Wind Turbine Systems ", Nordic Wind Power Conference, 1-2 March, 2004, Chalmers University of Technology.

[14] Debra J. Lew et. al., "Hybrid Wind/Photovoltaic Systems for Households in Inner Mongolia", International Conference on Village Electrification Through Renewable Energy, New Delhi, 3-5 March 1997.

[15] R. Chedid and Saifur Rahman, "A Decision Support Technique For the Design of Hybrid Solar-Wind Power Systems", IEEE Trans. on Energy conversion, Vol. 13, No. 1, March 1998, pp. 76-83.

[16] O. Omari1, et. al. , "A Simulation Model For Expandable Hybrid Power Systems", 2nd European PV-Hybrid and Mini-Grid Conference, Thursday, 25th Sept. and Friday, 26th Sept. 2003, Kassel, Germany.

[17] Yarú Najem and Méndez Hernández, "Assessment of the Energy Production by Means of the Clearness Index in Hybrid Systems", 2nd European PV-Hybrid and Mini-Grid Conference, Thursday, 25th Sept. and Friday, 26th Sept. 2003, Kassel, Germany.

[18] H. H. El-Tamaly and Adel A. El-baset, "Computer Modelling and Simulation of Wind Energy System Connected to Utility Grid" Proceedings on 2004 International Conference on Electrical, Electronic and Computer Engineering ICEEC'04 , 5-7 September 2004, Cairo, Egypt.

[19] H. H. El-Tamaly and Adel A. El-baset Mohammed, "Computer Simulation of Photovoltaic Power System Interconnected With Utility Grid", Al-azhar Engineering Eighth International Conference, Vol. 8, No. 7, December 24 - 27, 2004, pp. 57-64

[20] Barbosa P. G. et al., “Novel Control Strategy for Grid-Connected DC/AC Converters with Load Power Factor and MPPT Control”, Congresso Brasileiro de Eletrônica de Potência, COBEP '95-III, Paulo 1995.

[21] V. Di Dio , D. La Cascia, R. Miceli .”A Mathematical Model to Determine the Electrical Energy Production in Photovoltaic Fields Under Mismatch Effect,” 2009 IEEE, pp 46-51.