INTEGRATION OF RENEWABLE ENERGY STORAGE USING HYBRID WIND AND SOLAR TECHNOLOGY

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Abstract

The use of energy storage devices and its technology has been the main focus to capture energy from sun and wind. This energy can be used during peak hours or when sun and wind resources are not available. Intermittent sources of energy play a significant part for this solution. Different storage technologies have been discussed in detail in this work. Hybrid Optimization Model for Electric Renewable (HOMER) PC demonstrating programming is being utilized to display the power framework, its physical conduct and its life cycle cost. Eight units of 850 kW wind turbines and 1 MW sunlight based PV modules were recognized as most practical to supply for 3MW load where the payback time of the framework is 3.4 years. Solar Simulink model has been made for graphical representation for its current and voltage relationship.

Keywords: Solar Energy, Wind Energy, Hybrid System, Renewable Energy.

I. Introduction

The need of different energy storage methods is the need of the hour, to be integrated with abundant intermittent energy resources easily available. The regions need to be identified where both solar and wind energy can be captured through
hybrid methods and stored for later use. Over the years the energy share of solar, wind and biomass has increased without competing with conventional energy sources. One of the parameter for this development was increase in prices of conventional energy, the shortage of sources in future; the increase in use of conventional energy has led to global warming. This has leaded the countries around the world, to make impact on the development of renewable energy. Among all the countries the Germans program is considered the best until now which has lead the strong growth in this sector. However the approach was taken in doubt due grid stability problems which gave rise to the need of mega watt scale energy storage solutions [I].

The production data of the renewable energy from all 25 Organizations for Economic Co-operation and Development (OECD) countries are used. For the policy to take complete effect, the production of renewable energy should be implemented according to the increasing trend of the production of renewable energy. Present universal pattern in power era is to use renewable vitality assets [II]. Sun oriented, wind, biomass, miniaturized scale hydro frameworks can be viewed as appropriate other options to routine power. With the desire of advancing power era in view of non-ordinary renewable vitality, the Pakistani Government acquainted a Vitality Policy with accomplish a 10% focus of force era from beginning to end, non-customary renewable vitality [III].

In this paper, trends for the integration of renewable energy sources and energy storage systems are presented by model of hybrid solar and wind farms and making an economic analysis for a period of 25 years. The paper is organized into the following sections. In section I, a review of the different types of energy resources available particularly wind and solar energy. In section I, we describe the different energy storage systems (EES)which is the main concern with the focus on bulk storage. In section II, the detailed analysis of the use of wind and solar energy in the hybrid renewable model. Wind power curve, its speed and distribution along with the use of Gamesa G58 850KW wind turbine. The solar energy using 300 Watts Solar modules for 1 Mega Watt system where Feeder 5 in Nandipur grid substation is used as the primary load demand that the proposed power system should cover. The economic analysis of the model is discussed with its initial cost, running cost and total cost of ownership (LCOE). In section III, we present the matlab solar model, in which photo voltaic panel takes the input as solar irradiance, temperature, series resistance, etc. This physical signal is then converted into electrical signal for measurement of current and voltage. Now renewable energy resources are discussed in detail.

A. Wind Energy

Wind energy is produced by passing the wind from the turbine, which then moves the blades and which spins the shaft of the generator. The generator is used to generate
the electricity. Wind helps in generating the mechanical energy from kinetic energy. Later generator helps in conversion of mechanical energy into electrical energy. Wind energy is a type of solar energy. The cause of wind is the sudden changes in heat in the atmosphere by the sun. This is because the equator part of the earth is heated more as compared to other parts of the world [IV]. Wind power density is defined as the measurement of the quantity of energy available at the location. Pakistan is facing energy crisis due to the effect of more energy demand and less energy generation. To solve this energy crisis one of the available and affordable source is renewable source of energy. Wind power is a variable power. Wind power generation is pollution free as compared to conventional power generation using fossil fuel. For a reliable supply in the city, wind power is used in addition with different electric power generation plants [V]. In the power generation using wind turbine, weather forecasting can help in determining the power generation statistics. Turbines running in wind are not sufficient enough to change over 60% of the dynamic energy into the mechanical energy by turning a rotor. The hypothetical most extreme power effectiveness is 0.59. This is called "most extreme power coefficient": \( C_p \text{ max} = 0.59 \) [VI]

Saddling the air (Wind) has been the major and most established techniques for creating vitality. Wind energy is a type of solar energy. A being the cross sectional area of the rotor is presented to change the speed \( V \) with m/s unit and shown in Fig. 1. Wind is air in motion. An air mass flowing through an area \( A \) (m\(^2\)) with a Velocity \( V \) (m/s) represents mass flow rate is equal to kinetic energy per second or the power possessed by moving air is, therefore,[VII]

\[
K_e = m \cdot c \cdot V
\]  
(1)

Substituting for mass flow rate in the equation for power in the wind,

\[
k = n \cdot c \cdot V
\]  
(2)

\[
\text{Power} = K \cdot C_p \cdot \frac{1}{2} \cdot p \cdot A \cdot V^3
\]  
(3)

Where:
- \( p \) = power output expressed in kilowatts
- \( C_p \) = maximum power coefficient. It ranges from 0.25 to 0.45.
- Its theoretical value is 0.59
- \( \rho \) = air density
- \( A \) = rotor swept area,
- \( V \) = wind speed expressed in miles per hour (mph)
- \( k = 0.000133 \), is a constant. It yields power in kilowatts.
As shown in equation above, the wind power is equal to three times the wind speed. So, here as the wind speed is getting two times, power of the wind will become eightfold.

\[
\text{The wind power density } E_D = \int_0^{\infty} P(v)f(v)dv = \frac{1}{2}pc^3r \left( \frac{K + 3}{k} \right)
\]

The HAT (Horizontal Axis Turbine) for the swept area of rotor is,

\[ L = \frac{p}{v} \]

Where, D is the rotor distance across in meters.

**B. Solar Energy**

Sun is the largest source of solar energy. It is available free of cost. It is a source of renewable form of energy. It is classified as active or passive solar. Classification is dependent on how the solar power is generated from solar rays. The sun has an energy potential in between 1500 to 50000 exa joules i.e. EJ. This energy is far more than the overall consumption of earth. The earth's total energy consumption in the year 2012 was 560 EJ [IX]. It is a clean and affordable source of energy available for free. The massive portion of solar radiations is accepted by Earth and 30% reflects back. The most part of the energy is absorbed by clouds, land, and sea. Three spectrums cover most of the part of solar light; they are visible, nearer to infrared and nearer to ultraviolet. The solar radiations absorbed by earth's surface and oceans cover around 70% of the earth's total area. When the warm air containing evaporated water rises above the earth's surface from the oceans, causes circulation of atmosphere. Then the water cycle is completed as the air is reached at a high altitude, the clouds are formed from the water vapor. These clouds rain on the earth's surface which completes the water cycle [X].
II. Energy Storage Systems

The systems which are used to store the energy and use at a later stage are usually called as energy storage systems. Energy is available in different forms such as chemical, potential, electricity, kinetic, heat, light, radiations from sun, temperature, etc. This energy is converted to a more convenient or economical form to store and use at a later stage. The bulk energy storage is implemented with hydroelectric dams. Energy storage is classified into several storage systems viz. Fossil fuel storage (Nuclear Fuels and conventional storage), mechanical (like electrical energy converted to a higher elevation), pumped (Hydroelectricity reservoir) and hydroelectric storage, flywheel, compressed air, thermal storage, electrochemical like rechargeable battery, super capacitor, ultra-battery, etc. Energy storage is the main concern nowadays with the focus on bulk storage. The world’s dependency of power is much on conventional fossil fuel power plants. The research is being done for bulk storage methods so that energy can be stored and used at a later stage. The focus is now shifted to renewable energy sources generation and storage in bulk [XI].

A. Hydroelectricity Storage (Pumped)

This type of storage is specially used for load balancing in peak demands. With more than 120 GW, pumped hydro capacity control plants speak to almost 99 % of overall introduced electrical capacity limit, which is around 3 % of worldwide era limit. Potential energy is used by this method for storage of energy. This energy is stored at reservoir at a lower elevation. Then the energy is pumped to a higher elevation. That’s why the name pumped storage. The stored water then flows through the turbine to generate electricity. The electricity generated and then used for pumping water back to reservoir manages revenue when the demand is on peak. Its revenue increases when the energy is supplied at higher rates during peak period. The peak periods are not more than 6 to 8 hours. The total installed capacity of hydroelectric power plant worldwide is 1,064 GW. When the electrical supply demand is not high the power is used to elevate the water into the upper reservoir. At peak time water is allowed to flow through the turbine which generates the electricity and supplied where needed [XII].

B. Compacted air vitality stockpiling (CAES)

CAES is a method for storing energy. The energy is stored using compacted air and can be utilized later with the help of compacted air. Here, the energy can be used during peak load demands. Heat is created when the air is compacted. After compression the air becomes warmer. When expanded the air becomes colder. The
heat generated during compression may be stored and used when the air is expanded. This improves the storage efficiency. The compacted air and expansion of air is used to store the energy and used when needed. The air can be stored in different forms such as adiabatic, diabetic or isothermal. In adiabatic process the heat production is continuous when air is compressed and power is generated when it returns. In diabetic process the heat is compressed with intercoolers as waste [XIII]. The compression process is done by renewable energy. In isothermal process the temperature of operation is continuously exchanging heat with the environment. This maintains compression and expansion. This process can approach hundred percent efficient for energy storage theoretically transferring heat to the environment.

C. Flywheel vitality stockpiling (FES)

The primary parts or components of a flywheel are vacuum enclosure, magnetic bearings, cylindrical rotor, hub and motor/generator. The rotor is covered by bearings. The rotor is placed into the vacuum chamber. This placement is used to reduce the friction. They are connected to the electric motor and generator in combination. Mechanical bearings increases frictions, to reduce friction magnetic bearings are used. The flywheels with mechanical bearings take two hours to reduce their energy from 50% to 80%. The friction is increased when the force is exerted against mechanical bearings by the force of the flywheel’s angular momentum. The friction can be reduced or avoided when the axis of flywheel is aligned and is parallel to the earth’s axis rotation. The flywheel which contains magnetic bearings and along with that high vacuum are capable of maintaining mechanical efficiency of more than 97% and round trip efficiency of more than 85% [XIV]. Flywheels are specially used to balance load for UPS i.e. Uninterrupted Power Supply for the special application like data centres. With this they saved a sufficient area as that of battery systems. Flywheels discharge rates are faster. Flywheels are also used to launch aircraft systems since conventional power systems cannot support rapid release of the aircraft system.
D. NiCad and Nickel-Metal hydride Battery

These batteries are rechargeable, denoted by NiCad and NiMH respectively. The efficiency of charging and discharging of these types of batteries is 66% and 92% respectively. The chemical reaction at the positive electrode of NiMH is the same as that of NiCad. Both electrodes use nickel oxide hydroxide cells. Hydrogen alloy is used in place of cadmium for all the negative electrodes. The capacity of NiMH battery can be 2 to 3 times the capacity of an equivalent NiCd battery. Ni-MHs energy density is capable and can be equal to that of a lithium ion battery. The durability of the battery is around 180 to 2000 cycles. The power of the battery is around 250 to 1000 W/kg. The cell voltage is around 1.2 volts which is called as nominal voltage. The Ni-MH cells were started selling commercially in the year 1989. Ni-MH batteries have been used in hybrid vehicles around the world [XV].

E. Lithium Particle Cells (Li-particle)

Li-ion batteries are an important innovative warehouse of energy. It ranges from small to large size applications such as hybrid cars, laptops, mobiles, power bank, etc.). Li-ion cells with 3.7 V single cells are extensively available and widely used. This can be used to achieve the required voltage for specific applications. When compared with Ni-Cd and Ni-MH cells one Li cell can be three times of the Li-ion cell volts.

When the cells are manufactured on a mass basis its cost reduces. This makes the use of Li particle cells in masses. The market share of the cells is more than 45%, still the challenges accounts for some large scale manufacturing of Li cells. The cell contains circuits of insurance inside it which adds to the total cost per kWh. The Li cells are highly reactive to air which can cause fire.

F. Flow Battery

It is also called as redox flow battery. It is a type of electrochemical cell. Here, two chemical components are inserted in liquids. The system which consists of liquid is separated by a membrane. The voltage of cells ranges in the typical range of 1.0 to 2.2 V. This battery can be used as extra fuel tanks which can be helpful in an emergency. Flow battery has more advantages as compared to general rechargeable batteries. It has separate liquid tanks. It is long life. The electrolyte volume decides the capacity of energy. The power depends on the surface area of the electrodes contained in a battery. It also has an advantage of variable layout, long cycle life, its response time is also quick, and no harmful emissions. Low cost of maintenance. It is tolerable to overcharge or over discharge. These types of batteries operate at a very higher current and much power densities. This technical advantage makes flow
batteries very much useful for high-capacity vitality storage. There is major application for these kinds of batteries. They are used for load balancing, Uninterrupted Power Supply, in electric cars, for backup power system.

G. Superconducting attractive vitality stockpiling (SMES)

SMES is Superconducting Magnetic Energy Storage. It stores energy in a loop for superconductor or in a magnetic field coil. The direct current stream through the coil helps in making of magnetic field. Cryogenic temperature is used to cool the coil which as a result keeps up the framework. This shows the superconducting properties. The current flows with zero loss. Therefore, the energy remains towards an attractive field. This energy is discharged. It gets back to the control framework by transforming the magnetic energy to power by releasing the coil. SMES are different from other types of storage. It gets transform from alternating current to direct current in the PCS arrange. The frameworks are enabled with fast reaction and full competency.

III. Solar and Hybrid Design

The crossbred control framework includes the power project which is constructed in combination with a thermal cycle power plant. Through the re-enactment procedure, establishment of 8 quantities of 850 kW wind turbines and 1 MW sunlight based PV modules were recognized as most practical to supply normal of 3MW load associated with lattice where the straight forward payback time of the framework was 3.4 years.

A. Wind Turbine

Wind turbines are intended to labour for 120,000 hours all through their assessed life-traverse of 25 years. So lifetime of the wind turbine considered in this review is expected as 25 years. The assessed support costs for present day machines are in the scope of 1.5% to 2% of the first venture per annum [V]. Initial capital cost for a wind turbine plant at rupees 230 million/MW and operational and maintenance cost for wind turbine power plant of 2% of initial capital cost [VII]. According to that, a 0.850MW power plant capital cost will be 196 million rupees (1.6 million USD) and the expected O&M cost for the same power plant would be 5.9 million rupees (32,000 USD) per year.
Table 1. GAMESA G58 850 kW Wind turbine specification

| Specification          | Value       |
|------------------------|-------------|
| Rated Power            | 850 kW      |
| Startup WS (Wind Speed)| 3.0 m/s     |
| Rated WS               | 12m/s       |
| Cut out WS             | 21m/s       |
| Tower height           | 55m         |
| Rotor diameter         | 58m         |
| Swept area             | 2642 m²     |
| Power Regulation       | Pitch regulated with variable speed |

B. Photovoltaic Arrays

The sharp NDF4Q300 300W solar module is selected for design which has life time of 25 years and 15.3% efficiency. Electrical characteristics of Sharp NDF4Q300 are given in table 2. Assumed installation cost of 1MW PV array system will be 4 million USD with operation and maintenance cost at 1% of total investment cost.

Table 2. Electrical characteristics of Sharp NDF4Q300 solar module

| Maximum Power          | 300 W       |
|------------------------|-------------|
| Cell Type              | Aggregates of Silicon Crystals |
| Cell Information       | 72 cells in Series |
| Voc (Open-Circuit Voltage) | 45.11 Volts |
| Vpm (Maximum Power Voltage) | 35.20 Volts |
| Isc (Short-Circuit Current) | 8.940 Ampere |
| Ipm (Maximum Power Current) | 8.521 Ampere |
| Solar Module's Efficiency | 15.310%    |
| Maximum- System Voltage (Direct Current) | 1000 Volts |
| Dimensions             | 9941971 x 46 mm |
C. Converter

Two processes are involved in the conversion one is from alternating current (AC) to direct current (DC) and the other from direct current (DC) back to alternating current (AC). The process of AC to DC is called conversion and the circuit used is converter. Conversion process is also called as amendment. The process of DC to AC is called inversion and the circuit used is called as inverter. Inversion is also called as reversal. The inverter and rectifier efficiencies were thought to be 90% and 85% for this review. Inverter limit size was chosen as 250 kW at a cost of 0.25 million USD and inverter lifetime of 15 years. Working and upkeep cost is expected 1% of the inverter cost.

Table 3. Input to the HOMER software

| Type     | Size  | Capital Investment per Unit($) | O&M cost per year | Lifetime |
|----------|-------|--------------------------------|-------------------|----------|
| Wind     | 850kW | 1.6 Million USD                | 32,000 USD        | 25 Years |
| PV       | 1000kW| 3 Million USD                  | 30,000 USD        | 25 Years |
| Converter| 250kW | 1 Million USD                  | 20,000 USD        | 15 Years |

The components are chosen by considering present availability in the global market. The costs are decided on the basis of national and international prices of the required elements and the cost of the project.

D. Local Grid

The interconnection of a network for distribution of electric power from the generator to the user is called an electrical grid. The power produced locally is sold to the grid at the price of 0.2 US dollar (Rs. 25.09) per kWh which is the flat tariff rate given by Pakistan Sustainable Energy Authority (NCRE) for non-conventional renewable energy sources for a period of 20 years [XII]. The governing average generation cost of diesel power plants in Pakistan is 0.4 USD/kWh. The delivered power generated by the proposed wind-solar hybrid power plant is assumed to replace the generation of high cost diesel power that would otherwise cover the local load. Therefore, local electricity purchase price is considered as 0.4 USD for the system analysis.

E. Economic inputs

The monetary info parameter for this plan including the yearly genuine financing cost and venture lifetime are required for the HOMER re-enactment. Expected power plant lifetime is 25 years and yearly genuine financing cost is 10%.
Table 4. Average Ampere reading of Feeder 5 (District Areas) – Nandipur Grid

| Time  | Load(A) | Time  | Load(A) |
|-------|---------|-------|---------|
| 00:00 | 66      | 12:00 | 86      |
| 01:00 | 65      | 13:00 | 80      |
| 02:00 | 62      | 14:00 | 82      |
| 03:00 | 59      | 15:00 | 84      |
| 04:00 | 62      | 16:00 | 92      |
| 05:00 | 68      | 17:00 | 94      |
| 06:00 | 95      | 18:00 | 98      |
| 07:00 | 75      | 19:00 | 142     |
| 08:00 | 72      | 20:00 | 140     |
| 09:00 | 77      | 21:00 | 116     |
| 10:00 | 80      | 22:00 | 85      |
| 11:00 | 83      | 23:00 | 55      |

In this paper, the load of Feeder 5 in Nandipur grid substation is used as the primary load demand that the proposed power system should cover. Hourly data of above average load profile was uploaded into the HOMER model. Average daily demand of Feeder 5 is 3MW while peak demand is 4.7MW.

Fig. 2. Average Load Curve of Feeder 5 (District areas) – Nandipur Grid
F. Optimization

Subsequent to recreating the majority of the conceivable framework setups, HOMER shows a rundown of arrangements which are categorized by the clear price i.e. life-cycle price, i.e. utilized to analyze the distinctive framework plan alternatives. The NPC of a segment is the present estimation of the considerable member of expenses of be introducing and working that segment over the venture lifetime, less the present they considerable number of incomes that it gains over the venture lifetime. HOMER computes the NPC of every part in the framework and of the framework all in a 1 estimation of Figure 2 demonstrates the classified HOMER improvement comes about. In modes plan sort it demonstrates just the most reduced NPC arrangement.

![HOMER optimization Results](image)

Fig. 3. Overall HOMER optimization Results

In figure 3 it is shown that 8 wind turbines and 1000 kW PV module with 1000 kW converter gives the cheapest configuration. This configuration has COE of 0.129 USD/kWh and NPC value of 35,039,764 USD.

Since a 1 MW solar installation costs more than double the 1MW wind turbine, the HOMER model always gives priority to wind power. So it chooses a maximum
number of wind turbines. But in such case the delivered power is much more than the load requirement (excess generation is fed into the grid as grid sales), so a configuration with minimum excess power is selected for the actual design. It has 6 wind turbines with 3000 MW PV modules and 3000 MW converter.

Fig. 4. Monthly average power production of the selected hybrid system.

Total annual power generation from the hybrid system is 20.27GWh, where solar contributes with 5 GWh (25%) and 15.27GWh (75%) are derived from wind. Annual generation details obtained from HOMER are given in table 5 and figure 4. PV Output and wind turbine variations on the yearly basis are shown in figure 5 and 6, respectively.

Fig. 5. Annual PV output variation
Fig. 6. Annual wind turbine output variation

G. Funds Assessment

The financial do ability in the project was examined using simple payback method. This method is the duration to repay the total amount invested. The principal funds in this context are related to the purchasing and installation of wind - solar power mixed system.

Total generation capacity of plant = 20.27 GWh/year
Initial investment = 21.6 million USD
Simple payback period = 3.4 years
Internal Rate of Return (IRR) = 29.6%.

MATLAB model of the PV (Photo Voltaic) panel and its simulations are implemented with 60 watt, 36 cells solar model has been simulated in the MATLAB Simulink. After simulations it shows the graph of voltage vs. current and power vs. voltage. The PV panel takes the input as solar irradiance, temperature, series resistance, etc. This physical signal is then converted into electrical signal for measurement of current and voltage. The scope shows the current and voltage readings which are then shown graphically in figure 7, 8 and 9 respectively.
Graph above shows the current and voltage readings of a solar cell. The measurement of current and voltage is taken at different temperatures as 0, 25, 50 and 75 degreescentigrade. Once the solar modules are deployed, its power may decrease by around 3%. The power of the solar power plant varies according to the weather, course of time, production, etc. Similar graph has been demonstrated using Simulink as per below.
IV. Conclusion

The hybrid solar and wind energy technologies along with the integration of renewable energy storages will play an important role in the stability of the grid. It should be possible to develop an efficient solution to maximize the gain from renewable energy while maintaining a focus on the large scale energy storage.

In this paper, such region has been identified to take advantages of both solar and wind to its maximum level and its economic analysis. The energy crisis can be overcome using the hybrid techniques and future lies in the storage methods of these energies.

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