Designing, Development and Demonstration of a 2kW Wind-Biogas Hybrid Electric Generation Plant

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I. STATUS OF WORK BEING DONE IN OTHER NATIONAL/INTERNATIONAL INSTITUTIONS/INDUSTRIES

Much of the work has been done at National & International level in the field of Hybrid Renewable Systems. Most common hybrid models are Wind-Biogas, Wind-Solar PV, Wind Solar Thermal, Wind-Biomass, Solar Thermal-Biogas, Solar PV-Biogas etc. Most of the academic work is limited to the modelling of various hybrid systems and analysis of results based on the variation in different parameters. Range of parameters includes pure technical designing terms to social and economic factors. Some of the most notable references are mentioned below.

A hybrid system comprising of wind and biomass sources has been modeled by Abdur Raheem et al. [2]. The anaerobic digestion of animal dung was used in mesophilic temperature conditions with efficient biogas generator. The wind-biomass hybrid system with the 100 % renewable energy penetration (65 % biomass and 35 % wind) has been found to be the most economical system with COE of 0.268 $/kWh. The COE for Diesel-biomass system has been found to be 0.425 $/kWh at the diesel price of 1.2 $. A comparison between the biomass-wind-diesel-PV systems have been established in terms of net present value and COE. A sensitivity analysis showed that the net present value increased as the renewable energy fraction decreased linearly. It has been found that biomass contributes more than any other source if in the system [2].

Suitability of hybrid energy systems for rural areas has been studied. It was found that although renewable technologies have come a long way in terms of research and development, there are still certain obstacles in terms of their efficiency and optimal use. Major challenges found in the study have been highlighted. The renewable energy sources, such as solar PV and FCs, need innovative technology to harness more amount of useful power from them. The poor efficiency of solar is major obstruction in encouraging its use. The manufacturing cost of renewable energy sources needs a significant reduction because the high capital cost leads to an increased payback time. It should be ensured that there should be minimal amount of power loss in the power electronic devices. The storage technologies need to increase their life-cycle through inventive technologies. Standalone systems are less adaptable to load fluctuations. Large variation in load might even lead to entire system collapse. Though hybrid energy systems could be potential solutions for the electricity problems in the rural region yet vast research is needed in this aspect to make it technically feasible to be employed at these areas. The prime focus of study should be the cost of the system and its output [5].

Analysis of solar biomass hybrid system has been done and it has been found that for small to medium scale applications hybrid solar biomass plants are currently a feasible option for tri-generation (electricity, cooling and heating) in India, providing solar capital subsidies remain in place. Industrial process heat also presents a viable option for applications with effective utilization of heat. At these scales there are better options for generating electricity only. However hybrid solar biomass power plants will become an increasingly attractive option as steam energy storage methods improve, solar thermal cost decreases and biomass feedstock and fossil fuel prices rise. Focus should be made to make technological improvements to the heat cycle of small scale hybrid plants due to low energy and exergetic efficiencies. While biomass only systems are economically more viable however for a small independent rural area where supply of biomass as feed stock is plenty; Hybrid plant should be scaled in India [4].

Economic feasibility study of stand-alone wind biogas hybrid for electrification of remote area of Pakistan has been conducted. In this paper, the economic feasibility of hybrid renewable system in one of the remote areas of Balochistan, was studied for electricity supply. It is found that the wind speed in the province Balochistan is good enough to start wind turbines projects. The three hybrid systems were analyzed to the location. The wind /biogas system has been found to be the most economical choice with COE equal to 0.118 US$/kWh. This system also helps to reduce the CO2 emission. The effect of diesel prices and lifetime of the components of the system on COE were also analyzed through a set of different values. The prices of diesel vary from 1 US$/liter to 2 US$/liter with the gap of 0.2. It has been observed that ranking of the systems does not affect with the variation in diesel prices. Therefore, it might be economically suitable to build the system comprising of the components as a system for the remote area of Balochistan [3].

Feasibility study of renewable energy-based micro grid system in Somaliland’s urban centers has been conducted. The area considered in this study is Hargeisa, Somaliland's major urban center. Using HOMER simulation software, the prospects of adding a considerable share of RE penetration are analyzed. Optimization modeling plus sensitivity analyses were conducted to compare technically as well as economically the benefit of either a diesel-only scenario or a hybrid case. NPC and COE were used as the major economic parameters in the analysis. Results show that the diesel-based power system is about1.5 times more expensive, based on NPC results, than a hybrid micro grid system at the present diesel
price, making it an expensive option. It has also been revealed the possibility of almost 58% RE penetration that can serve the local electricity demand with a COE of just USD0.288/kWh. This COE is almost a 30% reduction of the base case. This study also finds that wind is more economical than PV systems in Hargeisa. Finally, this study is expected to contribute to the knowledge of RE potentiality in Somaliland. In that regard, and in terms of policy-related contributions, the study acts as a source that provides and uncovers, in scholarly terms, the suitable usability and potentiality of RE resources to the government and other local or international investors. It also exhibits a local-oriented analysis of hybrid power system viability in Somaliland for the industry operators and other interested parties in Somaliland by emphasizing what key drivers need to be focused. Lastly it demonstrates the cost-effectiveness of the proposed system and the possibility of reducing diesel dependence in Somaliland's electric market [1].

A study of hybrid solar biomass power plant without energy storage has been conducted. Hybridization of solar and biomass energies is proposed for power generation to address the issues associated with individual technologies. The plant fuel efficiency increases with an increase in solar support, boiler pressure and Temperature but the hybrid plant thermal efficiency decreases with an increase in steam temperature. The optimum boiler Pressure decreases (50–40 bar) with an increase in solar sharing (10–50%). The changes in fluid flow, energy interactions and performance have been plotted with local time under variable solar radiation conditions. Since the solar collector is designed at 350 °C of steam compared to 450 °C of steam at biomass combustion, a more quantity i.e. 60% water is supplied to solar Collectors and the rest of 40% is supplied to biomass furnace for equal sharing of energies in peak time. The specific output from the plant is 0.8MW/kg of steam with the total heat supply of 3MW. The cycle thermal efficiency under the specified conditions is 27%. The fuel efficiency increased from 15% to 32% with the participation of solar energy. During day operation, there is a drop in hybrid plant thermal efficiency from 15% to 11% with addition of solar collectors because of low collector efficiency compared to combustion [6].

II. BASIC CONCEPT

Generation of Electricity from Wind Turbines can be divided in to modes- Grid Connected & off Grid. Grid Connected Wind Turbines are of Large Scale with Capacity Ranges from 500 kW to 5MW. For AC Power Generation, Frequency must be at 50 Hertz (In India). To achieve this Wind Turbine use highly sophisticated Control System such as Blade Pitch Control, Stall Control, Yaw Control, Torque Control, Doubly Fed Induction Generator Control etc.

Adoption of all such Control Systems is not feasible at Small to Medium Scale Wind Turbines (<100KW) due to Cost, Operational & Availability issues. Therefore instead of fine controlling the Generated Frequency, they produce DC Power and store it in Batteries. Batteries utilize in above operations are Lead Acid types due to Lower Cost and High Availability. Stored Power will then converted into AC through an Inverter.

Average life time efficiency of a Lead Acid Battery is ~ 70% and that of an Inverter is ~ 80-85%. Therefore there combine Electrical Efficiency is < 60%, which means there is at least 40% wasting of available Electric Power. To solve this problem and to generate direct AC Power, there should be some auxiliary source of power to constantly compensate the variation in wind power.

Cattles plays an important role in Indian staple diet and therefore available throughout the country and correspondingly Cattle Dung is available in abundance for the generation of Biogas. In cases where resources and economics permit the installation of both Biogas Plant and Wind Turbine, a Wind-Biogas Hybrid System can be used for production of High Efficiency, Continuous and Dependable Source of Electrical Energy.

Also it is important to mention that in above mentioned model, Biogas can be easily replaced by any regular liquid or gaseous fuel (Petrol, Diesel, Natural Gas and Fuel Oil etc.) to generalize the model and increase its scope of application.

Technical details

Project will consist of Three Main Components:

- Wind Turbine (Horizontal Axis [HAWT] or Vertical Axis [VAWT])
- Biogas Engine (Internal Combustion or Steam Engine)
- Close Loop Controlled Coupling Method (Mechanical, Hydraulic or Electromagnetic)

A. Wind Turbine

A Wind Turbine of 1KW Power Range will be Designed, Fabricated & Tested for the Project. Due to Low Power Range (1 KW) a VAWT might be the preferred choice. Controls of Turbine will involve Wind Direction Tracking & Excessive Speed Braking. Any type RPM Control within Permissible Range will not be applied. It is important to mention that aim of the Project is designing of an Efficient Coupling Mechanism rather than the designing of a High Efficiency Wind Turbine.

B. Biogass Engine

A Biogas Engine (2-3 kW) for the conversion of Heat to Shaft Power is required in project. An Engine having Power Rating 2-3 times of Wind Turbine will be required, since operating an Engine under very low loads is highly inefficient thermodynamically, which will be the case when Wind Turbine will rotate at Rated Capacity (Full Power).
A readymade Biogas IC Engine will be the preferred choice. If not available a Steam Turbine of same capacity range will be purchased. In later case Boiler might not contain Steam Super Heating & Condensing System due to cost limitations.

In case of either Engine, Designing of Control System for the Power & RPM is major part of the project. That will be a Fully Electronic Close Loop Control by adjusting the Fuel (Biogas) Supply of Engine for the Fine Adjustment of Output Power & RPM in accordance with the Power & RPM supplied by Wind Turbine.

C. Coupling System

Designing of a Coupling Mechanism to combine the power of Biogas Engine & Wind Turbine is the most challenging part of the project. In the mechanism, Alternator rotating at 1500 RPM will be directly connected to the Biogas Engine and Coupling should supply the available Wind Turbine Power to Alternator Shaft at different Power & RPM levels. An important precautionary feature of coupling is, there should not be any Reverse Transmission of Power (from Biogas Engine to Wind Turbine) in either case. Types of proposed coupling mechanism are:

1) Mechanical Linkage Coupling: A Mechanical Linkage will offer the Highest Efficiency but at the same time probability of Power Reversal is Highest in it. Power Transmission Efficiency can be as high as 95%. Also the Initial Cost of a Mechanical Linkage will be the Lowest among three proposed mechanisms. Linkage components will include Gear Boxes, Fly Wheels, Linking Shafts and Eccentric Wheel Friction Drive. Process involves the Transmission of Wind Power through an Eccentric Friction Drive to a Fly Wheel directly coupled to Alternator Shaft and a feedback control system for adjusting the fuel supply of Biogas Engine accordingly, in order to maintain desired RPM & Torque at Alternator Shaft.

2) Hydraulic Coupling: Hydraulic Coupling have negligible chances of Power Reversal and it might have the Highest Initial Cost, Power Transmission Efficiency will be in range of 80%. Linkage components are Gear Box, Progressive Cavity Water Pump, Pelton Wheel Water Turbine, Piping, Valves, Pressure and Flow Controllers. Process involves utilizing Wind Turbine as a Water Pump and directing this water in a controlled way to a Pelton Wheel Turbine, directly coupled to the Alternator Shaft. Again a close loop control system will adjust the fuel supply of Biogas Engine according to the Torque Transmitted by Water Turbine.

3) Electromagnetic Coupling: Electromagnetic Coupling also have negligible chances of Power Reversal with Moderate Initial Cost lies between above mentioned methods. It seems the most promising method of power transmission with possibility of highly precise control and compact system. Tentative Transmission Efficiency will in range of 80%. Coupling components involves Gear Boxes, DC Generator, Temporary Small Lithium Ion Battery Buffer, Coulombic Charge Meter, DC Drive and DC Brushless Motor. Process will involve Generation of DC Power at Variable RPM and Direct application of this Power to a Brushless DC Motor Directly Coupled to Alternator Shaft through a DC Drive. DC Drive will ensure the rotation of DC Motor at desired RPM. Also small Lithium Ion Battery Buffer (of few minutes) will compensate for any variation in received and supplied power and provide time for DC Drive for stable control. Further Feedback Control System of Biogas Engine will adjust the Fuel Supply for desired Torque Transmission.
Along with above a Small Biogas Collection and Storage System will be required for the Collection & Transportation of Biogas from nearby areas. Possible storage will either be a Biogas Balloon or Small Pressure Vessel.

During Project, detailed theoretical analysis of above and other possible coupling mechanism will be done. After finalization of one mechanism, a small prototype will be build and after the success of same final setup will be fabricated and tested. In case of any modification, above procedure will be repeated.

Successful Project Outcome will provide a Working Model of Wind-Biogas (or any Liquid/Gaseous Fuel) Hybrid System, that can be applicable at all Small to Medium Scale Wind Energy Systems.

III. POTENTIAL USERS & ACTION PLANT FOR UTILIZING PROJECT OUTPUT

Potential users are the Private & Government Parties (Individual, Institutions, Organizations, and NGO etc.), who are interested in setting up Small to Medium Scale High Efficiency Wind Turbine based Electricity Generation Plant. Interested Parties can get the prototype of implemented Plant and also the basic design of larger scale plants. Working Model to be constructed under project will also help in creating awareness and confidence in setting up the Wind-Biogas Hybrid based Electric Power Plants.

REFERENCES


