Simulation of combined photovoltaic, Thermal & Biogas Hybrid System

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***Abstract*-- The main problem today is the shortage of energy and environmental pollution. These problems can be avoided by employing renewable energy schemes. The most common renewable energy resources include Wind Energy, Tide Energy, Solar Energy, Hydrogen Energy, Bio Energy, Terrestrial Heat Energy and Thermal Energy and so on. Pakistan is affluent in almost all these resources especially in Thermal Energy and Solar Energy. The areas in Pakistan like Sindh, Baluchistan and South Punjab possess the weather conditions to be very friendly for these utilities of Renewable Energy resources. Thermal Panels along with Solar Panels can be used to utilize Solar Energy in these areas. The electrical energy can be extracted from solar energy directly by means of Photovoltaic cells but thermal energy is first converted to heat energy and this heat energy in turn is used to drive Turbine to get the electrical energy. If both these technologies are combined to work together, the solar energy can be absorbed by solar panel more efficiently. The research work demonstrates how these schemes can be combined together to achieve the desired goal. Furthermore, working of photovoltaic/thermal panels depend solely on weather conditions, so a biogas generator is used along with photovoltaic/thermal panels in order to maintain constant power.**

***Index Term*-- Renewable Energy, Distributed Power system, Biogas Generator, Modeling and Simulation**

I. INTRODUCTION

The electrical energy demand is increasing all over the world day by day. There is a growing awareness for renewable energy resources in Turkey as a result of rapidly increasing population and industrial development [1]. Due to this reason, most of the countries are diverting their attention to utilize renewable energy resources because by increasing population with every day, the industrial growth and the utilization of electrical energy is also increasing. There are also some limitations like pollution and limited energy resources which must be taken into account. So we have to adopt a system which is pollution free and economically more efficient. Now the renewable energy resources like solar energy, wind energy and biogas power plants has made it possible to produce economic power which was available previously only with big power plants. Many small scale power plants utilizing both renewable and non renewable energy resources can be combined together to produce steady electricity. This scheme is known as Distributed Power System.

DPS can be designed by combining

- Thermal and Solar Energy;
- Biogas and Solar Energy;
- Biogas and Thermal Energy;
- Biogas, Thermal and Solar Energy etc.

The all above mentioned sources can be classified into two types, Controlled Sources and Uncontrolled Sources [2]

Controlled Sources:

Output power can be controlled according to the load requirement by limiting the input power like biogas power plant.

Uncontrolled Sources:

Output power cannot be controlled by limiting the input power as in solar system where output power is solely dependent on weather.

But controlled and uncontrolled sources can be combined together by means of DPS to get constant output power [3]. In the first section of this research work, solar and thermal panels are combined together which are both uncontrolled. Then, in the second section, Biogas power system is joined with the above mentioned system to smooth the output power.

II. DEMONSTRATION OF THE SYSTEM

Solar energy can be made useful by photovoltaic cells which generate electric power directly. Solar thermal panels can be utilized to produce heat energy [4]. A system is suggested to convert a large portion of this energy into electric energy. The hybridization of the two schemes provides distinct advantages as far as cost, the small demand of the land area and installation are concerned [5]. The main drawback of the system is that the overall efficiency of the combined system will be smaller than that of standalone system. A simple diagram describing a basic structure is shown in fig. 1 [6]. The thermal part consists of transparent plastic layers having cellular inner walls and working medium is made circular. Under the plastic layers, silicon photovoltaic cells are jointed and insulated thermally.

The sun light enters through the plastic layers and the working medium produces electricity in the solar cells. The heat energy is absorbed by both working medium and plastic layers. Thermal insulation is present under the silicon layer. The overall construction is housed by a case and is covered with a glass layer composed of a specific filter coating to overcome the power loss due to reflection.

The system suggested to convert a part of energy which is obtained from solar radiation, into electrical energy is shown in fig. 2 [6]. The combined photovoltaic/thermal panels are connected to a heat/electrical energy conversion unit consisting of a heat exchanger and a turbine generator and converter unit is connected to the grid either in parallel mode of operation or stand alone mode of operation. In parallel mode, by introducing a static switch, ups operation can be achieved as well by employing energy storage devices like storage tank on the thermal side or battery in the dc link.

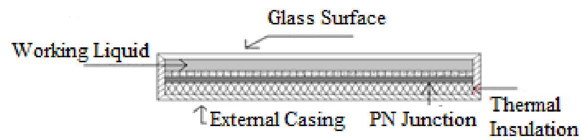

Fig 1. Combined PV/T Panel

As the temperature of the working liquid increases, steam will be produced directly hence the principle of binary cycle steam turbine is used. The actual working liquid is made to circulate by means of a pump through the thermal panel, heat exchanger and the storage tank in the secondary system, including a turbine and a condenser. An organic liquid of low boiling point is utilized. A steam generator having some heat input can be employed to achieve the safety of the energy supplied.

The direct electrical energy conversion can be achieved by incorporating a charge controller that receives the current supplied by the photovoltaic panel and ensures the conditioning of the battery.

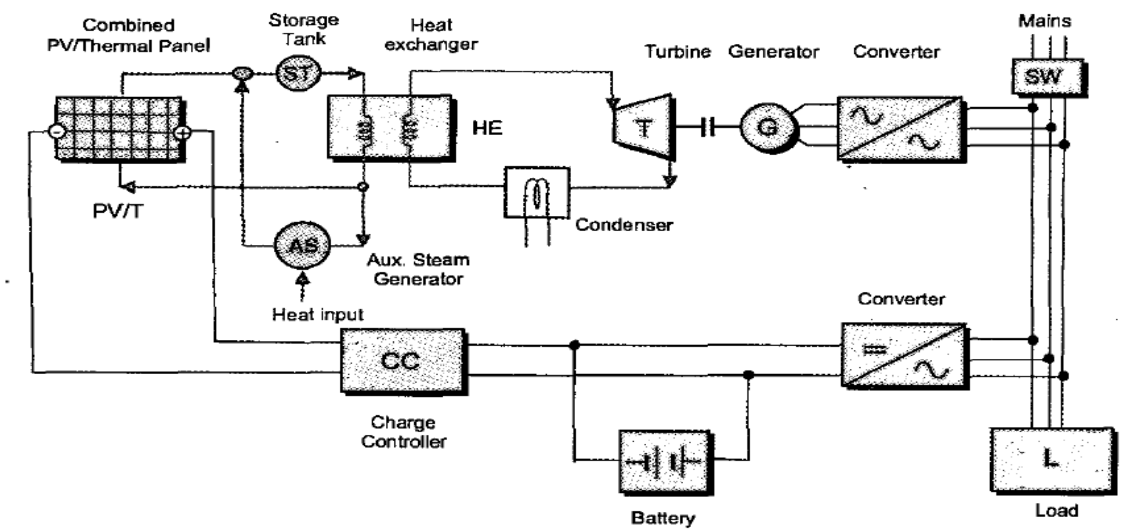

Fig. 2. Complete block diagram of Photovoltaic/Thermal DSP

It protects battery from over charging and deep discharging. The electrical energy produced by photovoltaic cells is used to supply to the grid by means of DC/AC converter and to charge the battery as well. The function of the charge controller is to sustain the battery voltage to a maximum value in case of excess charge and disconnect it from the load to prevent deep discharge in case of deficiency of charge.

III. BIOGAS IN DISTRIBUTED POWER SYSTEM

In the modern world of social development, energy crisis and environmental pollution are getting high attention. Therefore it is high time to develop new energy and renewable energy resources such as bio-energy, solar energy, wind energy, tide energy, small waterpower, terrestrial heat energy, and hydrogen energy etc. The comparatively dominant one for research is, distributed power system is the solar and wind power. The main drawback of the solar system is that it is the slave of weather and micro-net don't provides the electricity steadily. Anaerobic biodegradation with the help of microorganism of organic material is the key producer of biogas. The plants, animal wastes, rubbish are main sources to generate biogas. The biogas production can supply electricity steadily and the power output is controllable [7]. So the authors offer the wind-biogas renewable energy distributed power system and the biogas generator is used to balance the output power of the system. This system can provide the constant power.

IV. BIOGAS GENERATION WORK PROCESS

The biogas is generated from anaerobic biodegradation of organic materials during the absence of oxygen and the presence of microorganisms. The process includes a series of metabolic reactions among which various groups of microorganisms, executing in three different steps, hydrolysis, liquefaction acid genesis and methanogenesis. The process produces mainly CH4, CO2 and a solid mixture. The biogas generation is developing with the biogas usage. The biogas produced by the industry wastage, agriculture and town is employed to drive the turbine engine to generate electricity. The biogas generation is composed by the biogas pool, desulphurizing tower, special pressure pot, gas engine and generator, which is shown in Fig. 4 [7].

The block diagram of the combined PV/T and biogas system is shown below in fig. 3

V. SIMULATION STUDIES

The working process of the overall system is quite complex. It is a great challenge to analyze this kind of system due to the presence of several energy storage devices and

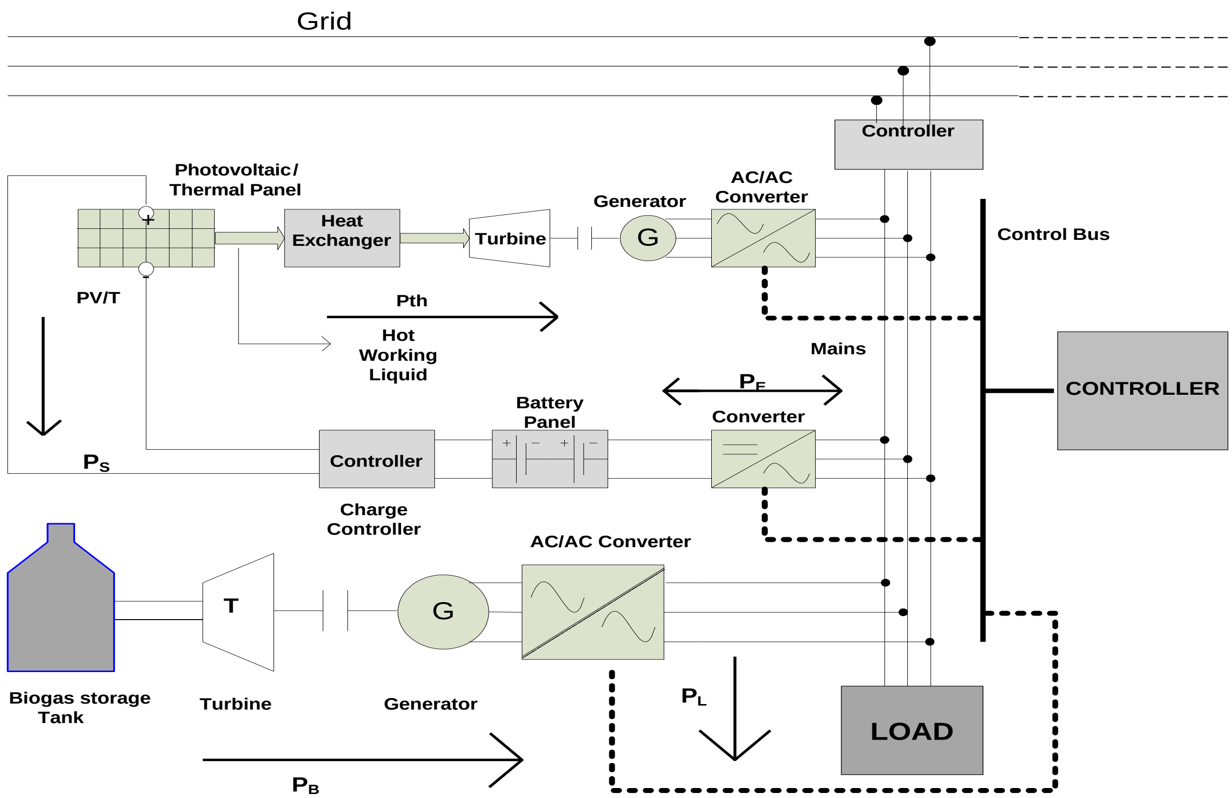

Fig. 3. PV/T and Biogas DPS

many non linear look up table blocks. This kind of system can be developed by doing the extensive modeling and adapting various simulation schemes. This research work consists of simulation which employs the energy balance in the energy conversion section, taking into account Photovoltaic Panels, charge controllers and battery module will be presented. Furthermore, the output of the battery system is fed to the PID controller which is used to control the opening and closing of the Biogas Engine Valve.

A simplified block diagram of Simulink model with a system of 120W, 24V battery having capacity of 2Ah, is presented. It contains three sections: Battery, Photovoltaic Cell and Charge Controller. The PID Controller realizes the voltage regulation and outputs current to the dc-dc convertor accordingly. The Photovoltaic Cell current is determined by the radiation intensity of sunlight which is represented by the look up table. The load profile with respect to time is also

The source of biogas is waste of industries, agriculture and Towns etc. This biogas is fired to drive some generator or turbine [2].The biogas power generation is controlled power generation mechanism and it can be used to balance the power output from PV/T panels.

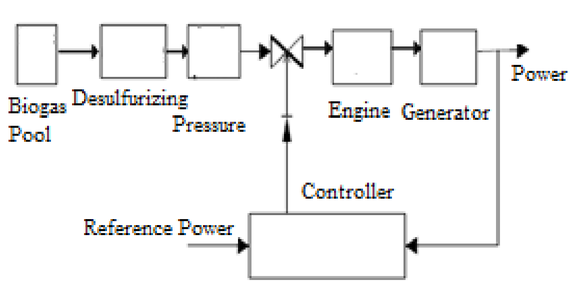

Fig. 4. Unit of Biogas Generation

determined using a look up table. When pu value is multiplied by the rated value of the load current, we get the instantaneous value. The resulting current of the three sections described above is the battery current. When the battery current is integrated, we get the charge stored in the battery. This charge is then converted to battery voltage by means of battery q-v curve.

VI. SIMULATION RESULTS

The simulation consists of a PV/T system in conjunction with a Biogas engine. The output of the battery is compared with a constant value and the error signal is given as input to a valve controller of a Biogas engine. The valve controller is basically a PID controller which controls the opening and closing of the valve hence limiting the fuel according to the fluctuations in the battery voltage and load requirement. The results of the simulation including the battery voltage and the biogas engine speed are shown below in fig. 5 and in fig. 6.

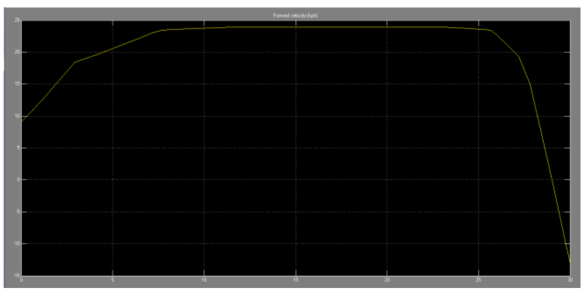

Fig. 5. Battery voltage vs Time Curve

The biogas engine speed is displayed as under in fig. 5

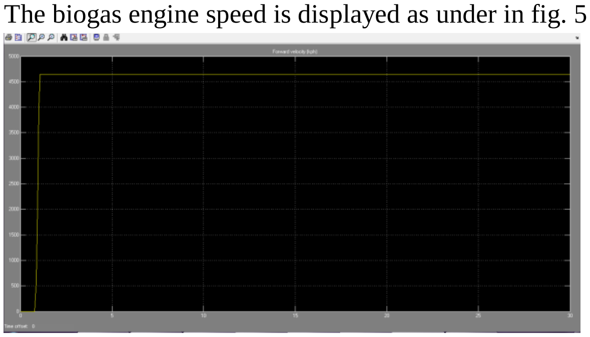

Fig. 6. Biogas engine speed vs Time Curve

This engine is used to drive the generator at constant speed hence producing constant voltage

The biogas simulator diagram is shown in fig. 7

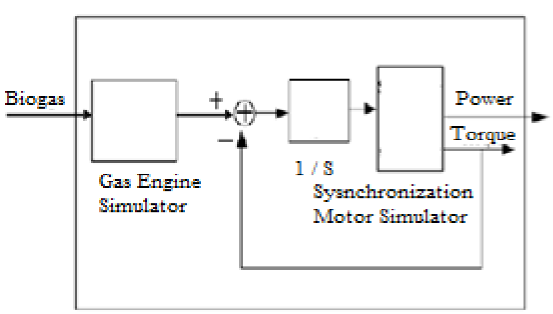

Fig. 7. Biogas Simulator

The biogas simulator consists of a gas engine module, a controller and a synchronization motor simulator [7]. The synchronization motor simulation can be carried out according to the following steps

$$v_{qs}{}^{s} = \frac{2}{3} v_{as} - \frac{1}{3} v_{bs} - \frac{1}{3} v_{cs} = v_{as} \quad \text{……1}$$

$$v_{ds}{}^{s} = -\frac{1}{\sqrt{3}} v_{bs} + \frac{1}{\sqrt{3}} v_{cs} \quad \text{……………………2}$$

$$v_{qs} = v_{qs}{}^{s} \cos\theta_e - v_{ds}{}^{s} \sin\theta_e \quad \text{………..…3}$$

$$v_{ds} = v_{qs}{}^{s} \sin\theta_e + v_{ds}{}^{s} \cos\theta_e \quad \text{…………....4}$$

These voltages in synchronously rotating reference frame are then used to evaluate the currents in the same reference frame according to the motor model given below [8]

$$\begin{bmatrix} Vqs \\ Vds \\ 0 \\ 0 \\ Vfr \end{bmatrix} = \begin{bmatrix} Rs+sLqs & WeLds & sLqm & WeLdm & WeLdm \\ -WeLqs & Rs+sLds & -WeLqm & sLdm & sLdm \\ sLqm & 0 & Rqr+sLqr & 0 & 0 \\ 0 & sLdm & Rdr+sLdr & 0 & sLdm \\ 0 & sLdm & 0 & sLdm & Rfr+s(Llfr+Ldm) \end{bmatrix} \begin{bmatrix} Iqs \\ Ids \\ Iqr \\ Idr \\ Ifr \end{bmatrix}$$

……5

The torque and speed are then evaluated according to the expression

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad \text{……………....6}$$

$$T_e = T_L + \frac{2}{P} J \frac{d\omega_e}{dt} \quad \text{.....................................7}$$

Phase currents are then found using the above expressions for currents

The simulation results are as under

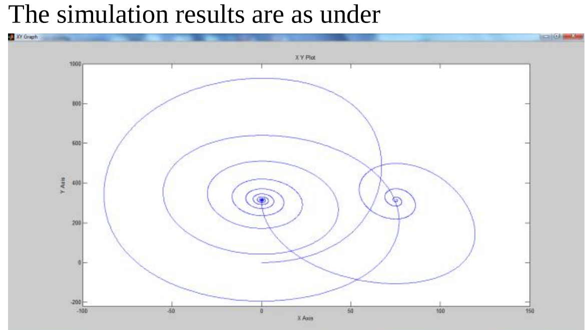

Fig. 8. Torque vs Speed Curve

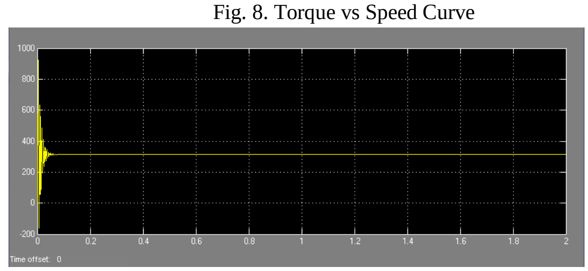

Fig. 9. Motor Speed vs Time Curve

VII. POWER FLOW OF THE SYSTEM

The power generated by Photovoltaic panel is DC which is converted to AC through a DC/AC convertor and then supplied to AC bus bar. The current from the Thermal part and Biogas part is AC and supplied to AC bus bar through an AC/AC convertor as shown below. Now there exist three relationships between power generated and power supplied to the load

Case I:

If

$P_{TH} + P_S > P_E + P_L$

Then $P_G > 0$ i.e. the system will supply power to grid

Case II:

If

$P_{TH} + P_S > P_E + P_L$

Now the controller will compensate the deficiency by the Biogas Generator such that

$P_{TH} + P_S + P_B > P_E + P_L$

So again $P_G > 0$

Case III:

If

$P_{TH} + P_S + P_B < P_E + P_L$

Then $P_G < 0$; Hence the grid system will remove the deficiency of power

VIII. CONCLUSIONS

From the above results, it is clear that a DPS has very great importance. Especially in countries like Pakistan where energy crisis are very severe, we have to adopt these kinds of schemes to combine many renewable resources in such a way that the cost of the overall system is acceptable and the system provides consistent output power.

The output of the battery is compared with the constant value and the error signal is applied to the PID controller. As long as the error signal is zero, the input of the valve controller is zero and the biogas energy system remains idle hence no resource will be utilized and cost will be less. When the battery voltage undergoes change, the error signal is applied to the valve controller and the biogas valve open itself accordingly. The engine drives the generator in accordance with the load demand and fulfills the deficiency of the output power.

IX. FUTURE RECOMMENDATIONS

There are many types of Distributed Power System possessing their own advantages and disadvantages. So those can also be designed by incorporating careful design of the controllers. But as far as the undergoing type is concerned, the following aspects can be discussed:

1) The controller which is used to control the power generated by the Bio gas generator can be replaced by a Model Predictive Controller because of its advantages over PI controller. Model predictive control is an advanced method of process control being used in process industries such as chemical plants and oil refineries etc.MPC controller uses the model of the entire system to predict the behavior of the dependent variables of the modeled dynamic system with respect to changes in process independent variables. The predicted outputs are then compared with the actual outputs in order to generate the error signal. This error signal is used again to generate the control signals. Making use of these features, it should be possible to increase the control performance even more. Hence, explicit MPC might be a promising alternative to PI control for electrical drives.MPC controller uses the model of the entire system to predict the behavior of the dependent variables (outputs) of the modeled dynamic system with respect to changes in process independent variables. The predicted outputs are then compared with the actual outputs in order to generate the error signal. This error signal is used again to generate the control signals [9]

2) Since the power control strategy is always a closed loop system, either it is a distributed power system or a standalone structure, the stability is very important otherwise the output of any block may become infinity and the components may undergo damages. There are many schemes like “Routh Hurwitz Criterion” to analyze the stability

3) The analysis of the cost of this system can be done by comparing it with the cost of wapda. There are two types of costs

i) Investment cost

ii) Running cost

Investment cost of the system can be calculated by taking into account the cost of each component like controller, battery, P/V panels, engine, generator etc including the cost of labor. The running cost of solar system is very low since it is utilizing the sunlight. Only batteries have to be replaced almost after three years. But the cost of biogas system is higher because biogas should be arranged for every time and also engine and generator maintenance at specified routine is also required

4) The design of the hardware of the above system can be done using smart grids

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