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Hybrid Generation of Electric PowerComposed of Distributed Generating Units

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***Abstract*-In this paper we study the possibility of using two systems consisting of PV in order to preserve the limited fossil fuels and MTG system to meet the increasing load demand. This hybrid combination is environmental friendly and has low emissions of greenhouse gases from MTG. This system can work as standalone or grid connected system. In this each individual PV & MTG system components are analyzed using mathematical equations and modeled for software simulation. Then individual systems are combined to form overall system.**

Hybrid system is operated in such a way to reduce the total cost of generation and fuel flexibility. At last the overall system is tested for different disturbances like variation in fuel, irradiation profile and variation in load demand which normally occurs in PV/MTG Hybrid power system.

***Keywords*:PV, MTG,Simulation**

I. INTRODUCTION

Energy crisis created a pertinent need to find and develop alternative energy sources such as solar, wind, ocean etc. Sun, being the cleanest renewable power resources in the world, provides enormous opportunities to harness energy. And with the development of better technologies the improvements will get better. The power fluctuations in PV can cause power quality problems; the hybrid system with at least one controllable system such as micro-turbine is helpful. This MTG system is interesting because it has high efficiency and low emission and fuel flexibility.

This paper presents the simulation studies of both the generation systems. The basic principle of this distributed power generation system is to describe the corresponding control strategy of each unit which makes PV power generation unit output power as much as possible. This distribution power generation system consisting of PV Array and micro turbine generation the prediction model is examined by MATLAB/Simulink software.

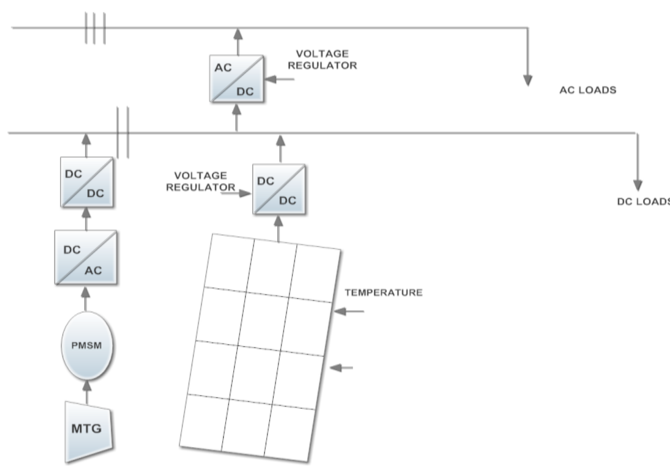

Fig .1 Block diagram of hybrid generation system

Photovoltaic System:

PV cell is a semi-conductor diode. The basic working principle of photovoltaic cell is based on the photoelectric effect. PV Cell simply converts the sun energy into electricity. The PV cell characteristics have basically three points open circuit voltage (V_{oc}) , short circuit current (I_{sc}), Maximum power point(MPP). The maximum power that will be extracted from PV Cell will be at maximum power points.

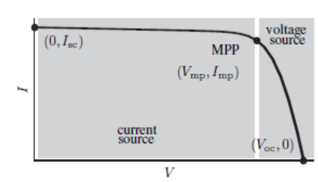

Fig. 2 Characteristic I-V curve of a practical photovoltaic device

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The performance of PV cell and module should be measured under a set of standard test condition. Essentially, these specify that the temperature of cell should be 25^{o}C and that the solar irradiation incident on the cell should have total power density of 1000watts per square meter(Wm^{-2}) with a spectral power distribution know as air mass of 1.5(A.M 1.5) .

II. MODELING OF PHOTOVOLTAIC ARRAY

Fig2.1 shows the ideal photovoltaic cell. The basic equations from the theory of semiconductors that mathematically describes the I-V characteristics of the ideal photovoltaic cell is

$$I = I_{pv} - I_d \quad (1)$$

$$I_d = I_{o,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (2)$$

Where $I_{pv,cell}$ is the current generated by the incident light, I_d is the Shockley diode equation, $I_{o,cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge(1.60217646.10^{-19}C), K is the Boltzmann constant(1.3806503.10^{-23}J/K), T is the temperature of the p-n junction and *a*is the diode idealityconstant.

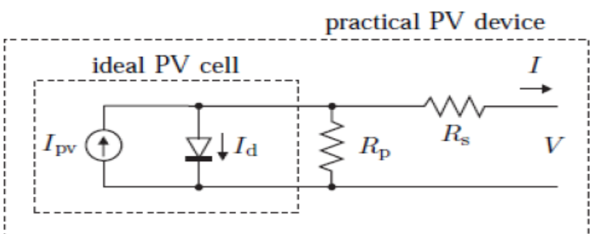

Fig. 3 Singlediode model of theoretical photovoltaic cell and equivalent circuit of the photovoltaic device including the series and parallel resistances.

The basic equation of the elementaryphotovoltaic cell does not represent the I-V characteristics of practical photovoltaic array[1]. Practical arrays are composed of several connected photovoltaic cells and observation of characteristics at the terminals of the photovoltaic array requires the inclusion of the additional parameters to the equation:

$$(3)\quad I = I_{pv} - I_o\left[\exp\left(\frac{V + IR_s}{V_t a}\right) - 1\right] - \frac{V - IR_s}{R_p}$$

Where I_{pv} and I_o are photovoltaic and saturation currents of the array and $Vt = \frac{NskT}{q}$ is the thermal voltage of the array with $N_s$cells connected in series. The I-V characteristics of the photovoltaic device shown in fig 2.depends on the internal characteristics of the device and on external influences such as irradiation level and temperature. The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation

$$(4)\quad I_{pv} = \left(I_{pv,n} + k_1\Delta_T\right)\frac{G}{G_n}$$

Where $I_{pv,n}$ is the light generated current at the nominal condition, Δ_T=T-T$_n$ (being T and T$_n$ the actual and nominal temperature), G[W/m^2] is the irradiation on the device surface and G_n is the nominal irradiation.

The diode saturation current I_o and its dependence on the temperature can be expressed as

$$(5)\quad I_o = I_{o,n}\left(\frac{T_n}{T}\right)\exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right]$$

$$(6)\quad I_{o,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right) - 1}$$

Where E_g is the band gap energy of the semiconductor, and $I_{o,n}$ is the nominal saturation current:

$V_{t,n}$ being the thermal voltage of N_s series connected cells at the nominal temperature T_n.

The photovoltaic model described in above section can be improved if the I_o in the above eq is replaced by

$$(7)\quad I_o = \frac{I_{sc,n} + k_1\Delta_T}{\exp\left(\frac{V_{oc,n} + K_v\Delta_T}{aV_t}\right) - 1}$$

This modification aims to match the open-circuit voltages of the model with the experimental data for a very large range of temperatures. The above equation is obtained from the eq6 by including in the equation the current and the voltage coefficients K_v and K_1.

IIIMICRO-TURBINE MODELING

MTG systems are considered a viable form of energy resource in the context of distribution generation. Although

MTG systems have long been used in various systems, eg:- aerospace applications. The objective of the project is to provide a general performance evaluation of a MTG system[6]. This project also considers two power electronics converter schemes, i.e. AC -DC-AC converter.

Micro-turbine are small gas turbines which burn gaseous or liquid fuels to create a high energy gas stream that turns electrical generator. There is growing interest in the application MTGs as they can start quickly and are especially useful for on-peak power supply for grid support. Generally MTG systems range from 30 to 400kilowatts while conventional gas turbines range from 500kW to more than 300MW.

There are mainly two types of micro turbine systems available, single shaft model and two shaft models. In single shaft design, a single expansion turbine turns both the compressor and the generator, two shaft models, on the other hand, use a turbine to drive the compressor on the shaft and a power turbine on a separate shaft connected to a conventional generator via a gear box which generates AC power at 60 Hz or 50 Hz.[7]

In this paper a description of the MTG system is given and mathematical models for all the system components are presented. The basic components of a micro turbine generation system are the compressor, turbine, recuperator, high speed generator and power electronics interfacing. The basic diagram of a single shaft micro-turbine based generation system is shown in fig 3.1

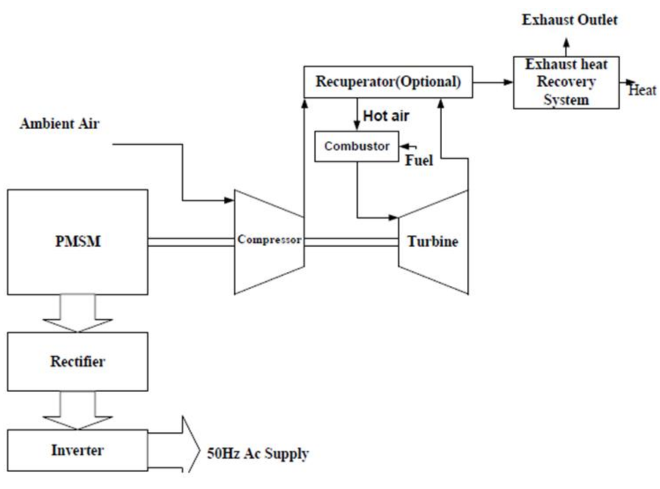

Fig. 4 Micro-turbine based CHP system (single shaft design)

Micro turbines, like large gas turbines, operate based on the thermodynamic cycle known as the Brayton cycle. In this cycle, the inlet air is compressed in a radial (or centrifugal) compressor. The compressed air is mixed with fuel in the combustor and burned. The hot combustion gas is then expanded in the turbine section, producing rotating mechanical power to drive the compressor and the electric generator, mounted on the same shaft (single-shaft design). In a typical micro turbine, an air to gas heat exchanger (called a recuperator) is added to increase the overall efficiency. The recuperator uses the heat energy available in the turbine's hot exhaust gas to preheat the compressed air before the compressed air goes into the combustion chamber thereby reducing the fuel needed during the combustion process.

3.1Mathematical model for micro turbine

The micro turbine system presented in this section is based on the gas turbine model presented by Rowen. The components of the single-shaft gas turbine modeled include speed control, temperature control and the fuel system. The three control functions of the micro turbine are: speed control acting under part load conditions, temperature control acting as an upper output power limit, and acceleration control to prevent over speeding. The output of these control function blocks are all inputs to a least value gate (LVG), whose outputs the lowest of the three inputs and results in the least amount of fuel to the compressor-turbine as shown in Fig 3.1.1. This figure shows the per unit representation of a micro turbine, along with its control systems. Each subsystem of the micro turbine is discussed in the following subsections.

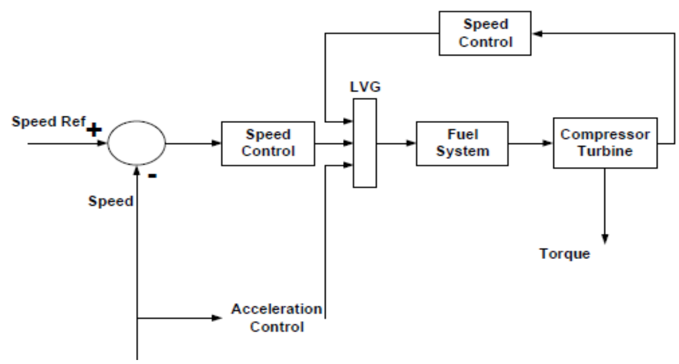

Fig .5 Block Diagram of micro-turbine

2.4Speed and Acceleration Control

The speed control operates on the speed error formed between a reference (one per-unit) speed and the MTG system rotor speed. It is the primary means of control for the micro turbine under part load conditions. Speed control is usually modeled by using a lead-lag transfer function, or by a PID controller. In this paper a lead lag transfer function has been used to represent the speed controller, as shown in 3.2.1.In this figure K is the controller gain, T1 (T2) is the governor lead (lag) time constant, and Z is a constant representing the governor mode (droop or isochronous). A droop governor is a straight proportional speed controller in which the output is proportional to the speed error. An isochronous speed controller is a proportional-plus-reset speed controller in which the rate of change of the output is proportional to the speed error. Acceleration control is used primarily during turbine startup to limit the rate of the rotor acceleration prior to reaching operating speed. If the operating speed of the system is closer to its rated speed the acceleration control could be eliminated in the modeling, which is the case in this study.[6]

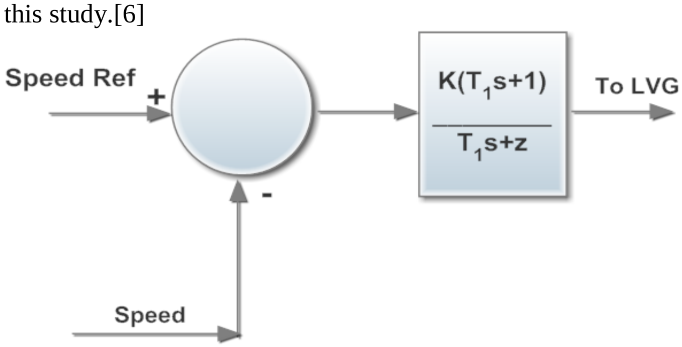

Fig.6 Speed controller of micro turbine

3.2 Fuel System

The fuel system consists of the fuel valve and actuator. The fuel flow from the fuel system results from the inertia of the fuel system actuator and of the valve positioner, whose equations are given below. The valve positioner transfer function is:

$$E_1 = \frac{K_v}{T_{vs} + c} F_d \qquad (8)$$

and the fuel system actuator transfer function is:

$$W_f = \frac{K_f}{T_{fs} + c} E_1 \qquad (9)$$

In (1) and (2), $K_v(K_f)$ is the valve positioner (fuel system actuator) gain, T_v, T_f are the valve positioner and fuel system actuator time constants, c is a constant, Fd and El are the input and output, respectively, of the valve positioner and W_f is the fuel demand signal in p.u.

The output of the LVG, V_{ce}, represents the least amount of fuel needed for that particular operating point and is an input to the fuel system. Another input to the fuel system is the per unit turbine speed N (limited by the acceleration control). The per-unit value for V_{ce} corresponds directly to the per-unit value of the mechanical power from the turbine in steady state. The fuel flow control as a function of V_{ce} is shown in Fig 3.3.1

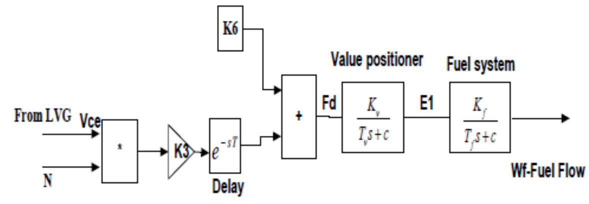

Fig .7 Block diagram of Fuel system

The value of V_{ce} is scaled by the gain K3 (K3= (I-K6)), then delayed and offset by the minimum amount of fuel flow K6 to ensure continuous combustion process in the combustion chamber. K6 is essentially the minimum amount of fuel flow at no load, rated speed.

3.3 Compressor-Turbine

The compressor-turbine is the heart of the micro turbine and is essentially a linear, non-dynamic device (with the exception of the rotor time constant). There is a small transport delay TCR, associated with the combustion reaction time, a time lag TCD, associated with the compressor discharge volume and a transport delay TTD , for transport of gas from the combustion system through the turbine. The block diagram of the compressor-turbine package is shown in Fig3.4.1. In this figure both the torque and the exhaust temperature characteristics of the single-shaft gas turbine are essentially linear with respect to fuel flow and turbine speed and are given by the following equations:

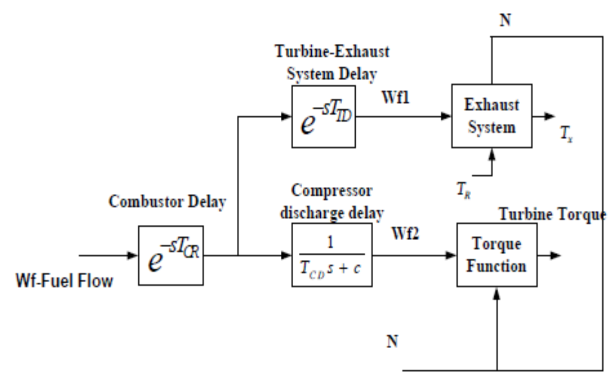

Fig . 8 Compressor-turbine package of a micro turbine

$$Torque = K_{HHV}(W_{f2} - 0.23) + 0.5(1 - N)(F) \qquad (10)$$

$$Exhaust\ Temp., Tx = K_{HHV}(W_{f2} - 0.23) + 0.5(1 - N)(F) \qquad (11)$$

Where KHHV is a coefficient which depends on the enthalpy or higher heating value of the gas stream in the combustion chamber and TR is the reference temperature. The KHHV and the constant 0.23 in the torque expression cater for the typical power/fuel rate characteristic, which rises linearly from zero power at 23% fuel rate to the rated output at 100% fuel rate.

The input to this subsystem is the p.u. fuel demand signal Wf and outputs are the p.u. turbine torque and exhaust temperature (F).

3.4 Temperature Control

Temperature control is the normal means of limiting gas turbine output power at a predetermined firing temperature, independent of variation in ambient temperaturecharacteristics. The fuel burned in the combustor results in turbine torque and in exhaust gas temperature. The exhaust temperature is measured using a series of thermocouples incorporating radiation shields as shown in the block diagram of the temperature controller (Fig. 3.5.1). In Fig. 3.5.1, T_t, is the temperature controller integration rate and T_3, T_4 are time constants associated with the radiation shield and thermocouple, respectively. K_4 and K_5 are constants associated with the radiation shield and T_5 is a constant associated with the temperature controller. The output from the thermocouple is compared with a reference temperature, which is normally higher than the thermocouple output. This forces the output of the temperature control to stay on the maximum limit permitting the dominance of speed control through the LVG (Fig 3.2.1). When the thermocouple output exceeds the reference temperature, the difference becomes negative, and the temperature control output starts decreasing. When the temperature control output signal becomes lower than the speed controller output, the former value will pass through the LVG to limit the turbine's output, and the turbine operates on temperature control. The input to the temperature controller is the exhaust temperature (T_x) and the output is the temperature control signal to the LVG.

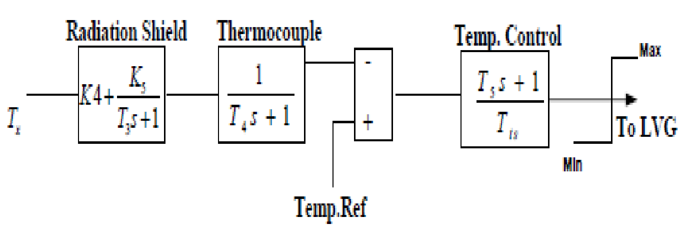

Fig. 9Temperature controller of a micro turbine

IV. HYBRID PHOTOVOLTAIC / MICRO-TURBINE SYSTEM

A hybrid generation system consisting of a 12kW PV and a 32kW MTG system along with the power electronics interfacing is presented in this section. Although a hybrid plant may use other combinations of energy sources, the combination of PV generation and MTG systems are particularly complimentary. PV power generation is high on capital cost and low on operational cost; once installed there no ongoing fuel costs and the maintenance costs are also very low. On the other hand, gas turbine generation is low on capital cost and high on operational cost compared to PV turbine due to its need for fuel and maintenance. This combination is also environmentally friendly in that the emission of greenhouse gases from the micro-turbine is very low compared to the conventional fossil fuel steam turbines.

4.1Power Electronics Interface

In order to realize a hybrid system, the output voltage of dc-dc converter component should be maintained at a predetermined level so that the interconnection between the different components of the hybrid system can be achieved. This is made Possible by employing power electronics interface which has the ability to control the System output variables such as voltage, to keep or bring them to match their reference values after a disturbance. In the hybrid configuration considered, the PV and the MTG system each have their own power electronics interface and the control logic is the same in both cases. The power electronics interface comprises of a rectifier and voltage source inverter.

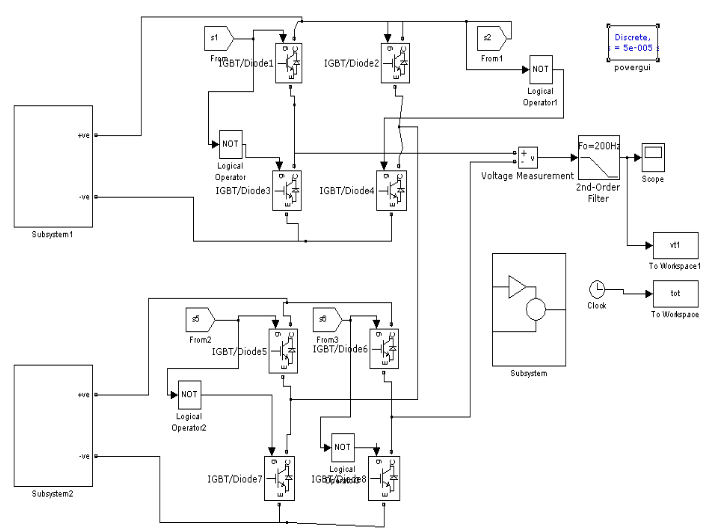

Fig. 10 Simulink/Block diagram

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V.RESULTS

The photovoltaic array is simulated with an equivalent circuit model based on the photovoltaic model of Fig. 3. Fig.11 Is the Boost converter output voltage of the PV system. Fig.12 Is the Boost converter output voltage of the MTG system. Fig.13 is the output DC voltage of the hybrid PV/MTG system. Fig.14 is hybrid PV/MTG system inverter output voltage.

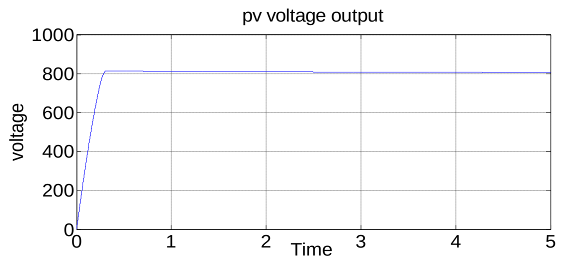

Fig.11Boost converter Output voltage of PV Model

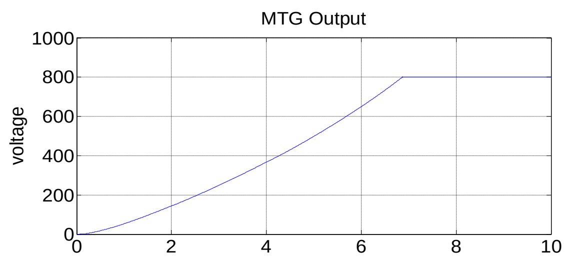

Fig. 12 Boost converter output voltage of MTG system

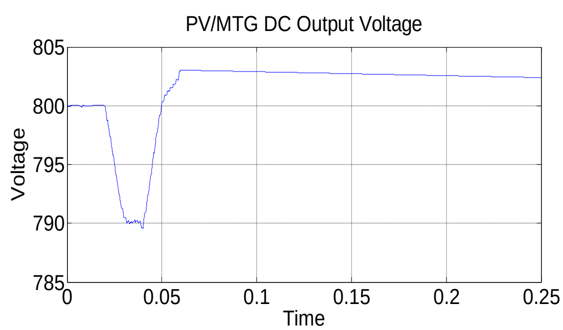

Fig. 13 Output DC voltage of PV/MTG system

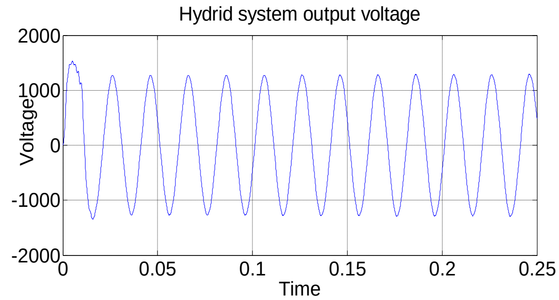

Fig. 14 Inverter output voltage of PV/MTG system

VI.CONCLUSION

The available power from the renewable energy sources is highly dependent onenvironmental condition such as radiation, and ambient temperature. To overcome thisdeficiency of the solar cell we integrated them with the micro-turbine generation system. The main conclusion is that it is possible to build hybrid solar and micro-turbinegeneration system which allows optimal utilization of renewable uncontrolled primaryenergy source. It is possible with using of dynamic controlled back up source, i.e., micro-turbine generation system. In addition, cost of produced energy has decreaseddespite equipment costs increase. It was possible because total number of working hoursin year can be increased using hybrid system.

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