International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-2 Issue-2, January 2013

Hybrid Photovoltaic-Thermo Electrical Power Generation for Water Pumps

Neel Kamal, D.K.P. Singh

Abstract— ***Water is a basic need of human beings along with food and air. There is a large escalation of demand for fresh water because of the rapid industrial growth and explosion of population all over the world. Thus, it has become pertinent to do further research in this field to improve the sea water desalination process. The separation of salts from seawater requires significant amounts of energy. When the energy is produced from fossil fuels, this approach can harm the environment, and as desalination requires significant energy, this in turn is costly. Therefore, there is a need to employ environmentally-friendly and affordable energy sources, specifically renewable energy, in order to desalinate seawater. Renewable energy comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are naturally replenished. Renewable energy can be used for seawater desalination.***

Photovoltaic water pumping applications are one of the most common uses of PV power throughout the world, with thousands of solar-powered water pumps installed both in industrialized and developing nations. Hybridization of PV with Thermoelectric modules can increase the overall efficiency of the solar energy conversion system by keeping the temperature constant within limits. For enhanced control of water pumps vector control of motor/pump is used which can work satisfactorily with non-constant power output of Photovoltaic-TE Hybrids with super capacitors or energy storage support. This paper is an attempt to explore the efficient mean of water pumping through augmentation of thermoelectric conversion to increase overall efficiency of PV array for pump operation of sea water desalination. The study of thermoelectric is done to illustrate its usefulness in hybrid model of PV and thermoelectric modules. Model of hybrid combination of Thermoelectric – PV array have been developed and simulation results are also presented in this paper.

Index Terms— ***Hybridization, PV array, TE Generator, Sea water desalination.***

I. INTRODUCTION

PV systems can be used for pumping water for irrigation of land, as well as for pumping drinking water[1]. Usually different types of electricity generators are combined into a so-called hybrid system. The efficiency of Photovoltaic systems deteriorates with the increase in temperature.

However, concentrating the light on PV array surface increases its efficiency but, poses further problem of deterioration due to additional concentration of heat. If conventional passive heat sink is used it will become bulky and slow in dynamics as the level of concentration is increased. For such type of applications active heat sinks such as *Thermoelectric Coolers* can be used. In this paper, a hybrid of PV–TE is proposed which can offer the best choice for concentrating type of systems. The subsequent section of the paper deals with hybrid PV-TE system for its overall performance improvement. If PV panel is used in configuration; thermoelectric modules are placed on the back of the PV panels which can collect the heat from the PV panel very fast through drawl of current absorbing extra heat with respect to ambience. This way the extra heat will be removed from PV panel and its efficiency would increase, together with this, the TE system would also produce additional electric power. This would in turn increase the efficiency of the PV system, and the hybrid system would produce additional energy through drawl of current from principles of the see-beck effect. The temperature of PV panel may be maintained through continuous removal of heat by the TEG. A maximum power point tracker is a DC to DC converter to achieve optimum matching [5]. A commonly used simple technique is the Perturb & Observe (P&O) algorithm.

It is the urgent need calling for an alternative power supply that makes solar energy more appealing, this paper will contemplate the prospects of producing fresh water and power simultaneously using solar thermal apparatus. The aspiration to run desalination facilities by the power produced using the renewable energy sources have been pursued for many years. However, due to the availability of the energy and the expensive cost, the application of which in large scale is still limited, especially in developing countries [1].

Dr Frank Dimroth, head of the group from Fraunhofer Institute of Solar energy System ISE, Germany with his researchers' team have achieved a record efficiency of 41.1% for the conversion of sunlight into electricity. Sunlight is concentrated by a factor of 454 and focused onto a small $5mm^2$ multi-junction solar cell made out of GaInP/GaInAs/Ge (gallium indium phosphide, gallium indium arsenide on a germanium substrate)[4]. Wenham et al [6] had reported that the efficiency of the concentrated plate module was to be 15%, greater than that of flat plate module. In GaP/InGaAs/Ge 3 junction solar cells with an efficiency of 37.4% at 200suns AM1.5 have been successfully fabricated by Yamaguch et al. [7].

Manuscript received January 2013
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Based on the principle of thermoelectric generator the performance analysis and mathematical model can be established. Through the comparison between the simulation results and physical experimental results, the accuracy of the mathematical model can be confirmed. The performance optimization of the thermoelectric generator could be carried out. The internal optimization is for couple leg size of the each element and the external optimization is for distribution of the heat transfer surface areas or heat conductance for the two heat exchanger and to optimize the external load and internal resistance matching[8] The thermoelectric implemented model in SPICE compatible environment accounts for all temperature dependant characteristics of thermoelectric materials to include the nonlinear voltage current and electro thermal coupled effects[9]. Lihau Chen and Dong Cao introduced the basic structure and principle of the thermoelectric model. The electric model of the TE modules can be embedded in the simulation software for the circuit design and analysis. The power electronics technologies provide solution for thermoelectric generation with features like load interfacing and maximum power point tracking.

Combined photovoltaic /thermal system with concentrator is an efficient way to convert more solar radiation into thermal and electrical energy and reduced the cost of the system if the cost of the concentrator is less than the cost of the displaced photovoltaic material which contributes about 50% of the total cost of the photovoltaic system. Over the last decade, numbers of studies are existed in literature on solar concentrating photovoltaic /thermal air and water heating system .Such as Garg et al. [10] have reported a performance analysis about a hybrid photovoltaic/thermal (PV/T) collector with integrated CPC troughs. O'Leary et al.[11] analyzed the thermal electric performance for actively cooled concentrating photovoltaic system. Othman et al. [12] present a double pass photovoltaic /thermal system air collector which twenty-three tungsten lamps were used to simulate solar radiation.

This paper will present a modeling of solar energy conversion system employing photovoltaic and thermoelectric cells as basic unit for the conversion system to operate a sea water desalination plant. The effectiveness of integrated renewable energy can be enhanced keeping the battery energy storage system with this PV-TE hybrid energy generation. Although a lot of work has been done and many technological advances have emerged for desalination, but a little has been done to the integrated system for improving the water quality and increase the desalination rate. Hence the present work has been proposed.

II. MODEL OF THE PV CELL

The simple equivalent circuit of a solar cell is a current source in parallel with a diode [2]. The output of the current source is directly proportional to the light falling on the cell. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in Figure 1.

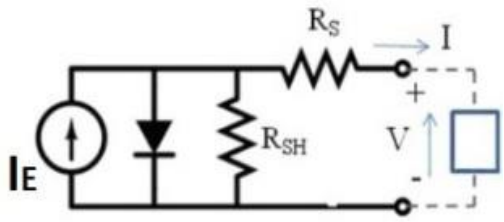

Fig.1. Circuit diagram of the PV model

In an ideal cell, the total current I is equal to the current I_E generated by the photoelectric effect minus the diode current I_D and shunt resistance current I_{SH}, according to the equation:

$$I = I_E - I_D - I_{SH} \quad \text{-------------------------------- (1)}$$

$$I_E - I_O(\text{EXP } QV/KT - 1) \quad \text{----------------------------- (2)}$$

Where I_O is the saturation current of the diode, Q is the elementary charge 1.6×10^{-19} Coulombs, K is a constant of value 1.38×10^{-23} J/K, T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). The diode ideality factor is taken n which is between 1-2 (1.3 is the typical for silicon solar cell).A more accurate model will include two diode terms; however, we will concentrate on a single diode model in this document. Expanding the equation gives the simplified circuit model shown below and the following associated equation, where n is the diode ideality factor.

$$I = I_L - I_O\{\text{EXP}[V + I.R_S)/nKT] - 1\} \quad \text{--------------------- (3)}$$

III. TEG SIMULATION

$$P = n[a(T1 - T2) * (R + RL)^2 \quad \text{-------------------------(4)}$$

Power output of the thermoelectric module depending on the Temperatures T_1 & T_2 of the surfaces of the generator

n = no of thermoelectric elements

$a = 2.3 \times 10^4$

$T_1 = 150°$ C

$T_2 = 50°$ C

$R = 2.3622 \times 10^4$ ohm

R = 0.3 ohm

IV. HYBRID PV-TE SYSTEM

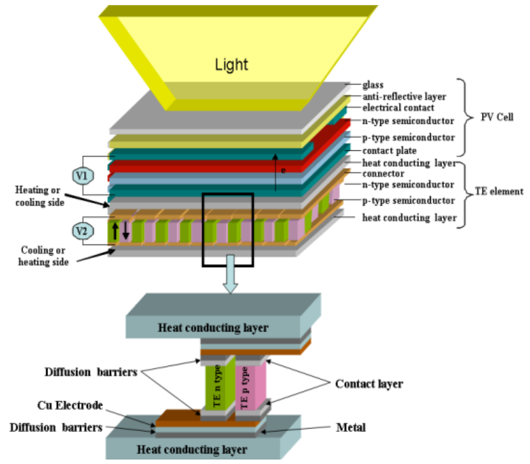

Fig.2 PV/TE hybrid system and the thermoelectric device

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Fig. 2 shows the hybrid PV-TE system model a block of PV Panel and another of thermoelectric module. These are coupled in such a way that the solar insolation increases the temperature of the hotter side of the thermoelectric module. This rise in the temperature is in effect is the result of rising temperature on the surface of PV array. The control scheme eventually curbs the rise, lower the temperature gradient and finally stabilize it to a lower referenced level. To study the effect of the concept individual loads are connected to each module. The result depicts the current output contribution of each module.

The Hybrid system shown in Fig.3 is operated with resistive load at the output terminals. Solar insolation is increased, in this setup, from zero to about 1500 w/m ^{2} which depicts the condition from day break till afternoon. As the insolation increases the temperature of the PV array will go on increasing till a saturation point is reached. The considered saturation point is 150ºC which corresponds to a solar insolation of 1000w/m^2. The current in Photovoltaic system increases with increase in insolation till a max current is reached at an insolation of about 500 w/m^{2}after this point the current increase is very slow manner. The current in thermoelectric module also increases with increase in temperature of the Photovoltaic panel. The current in thermoelectric module increases parabolically with the increase in temperature. At insolation of 1000 W/m^{2}temperature saturates and the output of the thermoelectric module becomes constant.

Performance Evaluation of Integrated System

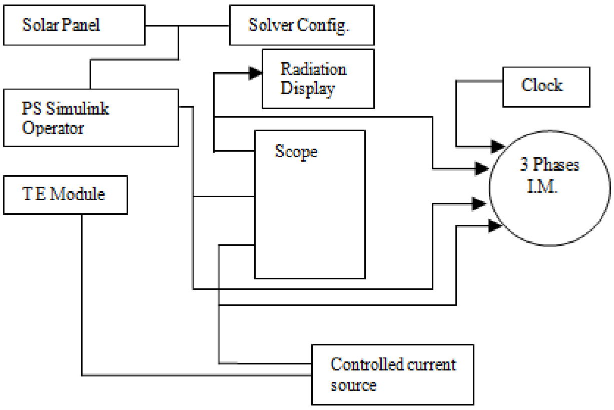

Fig.3. Hybrid Photovoltaic and Thermoelectric Generator system feeding 3 phase induction motor (water pump)

Fig 2 shows various components of the whole setup, the power requirement is purely met up from the PV panel and TE modules. This PV panel module is basically a collection of eight PV arrays with cumulative voltage output of 361 V. This PV panel module supplies power to the 3 phase bridge inverter which is controlled by the vector controller. The main function of speed controller is to provide the reference torque for the vector controller. The output of speed controller is limited to a proper value in accordance to the motor rating to generate the reference torque for the vector controller. The speed controllers realized using the simulink tool box is PI speed controller. The reference flux component of the stator current in synchronously rotating reference frame using referencing rotor flux is obtained from the no load testing of the motor. The reference torque component of the stator current in the synchronous rotating reference frame using the reference torque is obtained from the speed controller. This developed subsystem using simulink toolbox carries out conversion of the quantities from the three phase synchronously rotating frame to two phase stationary reference quadrature axis frame I_q and the director axis frame I_d. Three phase reference sine waves proportional to the desired currents based on certain criteria are generated and compared with the measured instantaneous values of the output currents.

Starting Dynamics

When three phase squirrel cage induction motors are fed from a controlled voltage and frequency source, the motor is started at low frequency decided by the controller and finally runs at the steady state condition at the set reference value of speed. The reference speed here is set at 1430 rpm with a torque limit set as per the pump characteristics. In each case the starting current is also inherently limited within the twice of the rated current. When the motor builds up the required starting torque to reach the set reference speed, the speed error reduces to almost zero rpm the winding current also reduces to the rated value and the developed torque becomes the load torque as observed in the starting response shown in Fig. 4. The rise time of speed from 0 to 90 % is 0.08 s with no overshooting of speed.

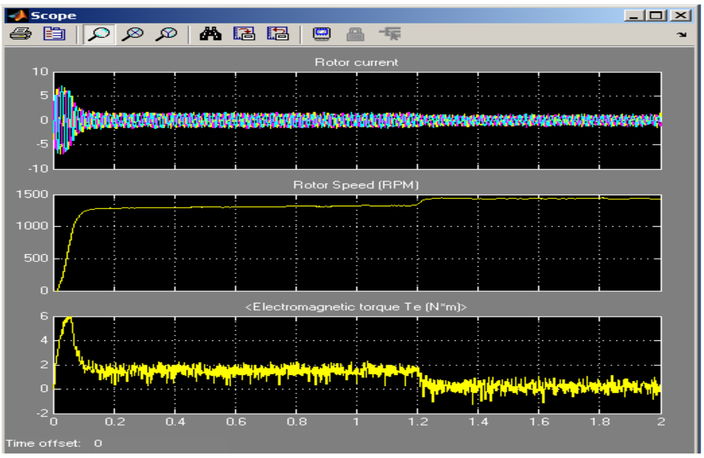

Fig.4.Output graph of PV/TE powered vector control of water pump

V. CONCLUSION

The performance of the water pumps connected to the photovoltaic systems both during steady state operation and transient operation has been investigated and demonstrated through MATLAB simulations. Photovoltaic systems must be operated near the maximum power point to extract maximum energy from the system. The efficient way of using this heat is by using thermoelectric conversion modules. The presented simulation results reveal the effectiveness of the proposed hybrid technique.

The number of TE modules must be increased to cover the total surface area on the back of PV Panel for proper operation of the controller. Using vector control induction motor drive for pump operation the motor is started at low frequency decided by the controller and finally runs at the steady state condition at the set reference value of speed thus reducing the initial inrush current load on the Solar panel. When the motor builds up the required starting torque to reach the set reference speed, the speed error reduces to almost zero rpm the winding current also reduces to the rated value and the developed torque becomes the load torque as observed in the starting response. The work has carried out for modeling of solar Energy conversion system employing photovoltaic and thermoelectric cells as basic unit for the conversion system. The simulation of pumping system with vector control of pump/motor powered by photovoltaic generation has to be successfully demonstrated.

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