Matlab Based Simulation of Thermoelectric-Photovoltaic Hybrid System

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ABSTRACT

The higher electrical energy demand is increasing in cars by installation of the safety control system, Air Conditioner, and other vehicle-borne electronic devices. In this project Thermoelectric and photovoltaic hybrid system using SEPIC converter for automotive applications circuit was designed and simulated using MATLAB/simulink software. Thermoelectric Photovoltaic hybrid system mainly used to recover waste heat from exhaust of cars and convert them into electricity and also utilizing renewable energy. Air-Conditioner, Car lights, initial starting of engine and other electronic devices in car get supply directly from Thermoelectric-Photovoltaic hybrid circuit system or indirectly from car battery which also get charged by Thermoelectric-Photovoltaic hybrid circuit .

***Keyword* - :** Thermoelectric, Hybrid energy system, Photovoltaic, Hybrid Vehicle.

I.INTRODUCTION

With ever-increasing oil consumption and concern of environmental protection, there is fast growing interest in vehicles globally [1]. Compared to internal combustion engine, hybrid vehicle supplies more electrical energy from the vehicle system can satisfy the higher electricity demand because of the installation of the safety control system, air conditioner, and other miscellaneous vehicle borne electronic devices [2]. So there is a pressing need to develop energy-efficient power sources for Automotive, including the on-board sole energy and hybrid energy sources as well as renewable energy sources, such as solar energy conversion and the waste heat recovery technology [3].As shown in Fig. 1, in a typical energy flow path of the ICEV, only about 25% of the fuel combustion energy is utilized to propel the vehicles, whereas about 40% is wasted in the form of waste heat of exhaust gas [4].

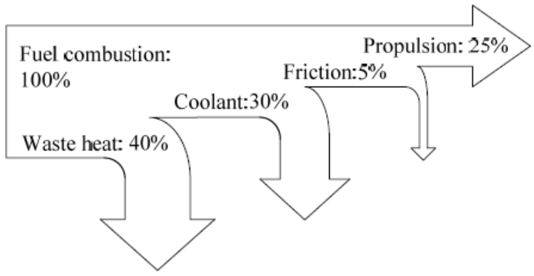

Fig.1 Typical energy flow path in an ICEV

It means that the fuel economy of ICEV can be increased by up to 20% simply by capturing the waste heat of exhaust gas and converting about 10% of it to electricity with thermoelectric (TE) modules. The research on waste heat energy recovery of the exhaust gas in HVs has been actively conducted in recent years [5]. TE modules can directly convert the heat energy to electrical energy. However, the output power characteristics of the TEG are highly nonlinear and heavily depend on the cooling system, external load, and heat source a proper power conditioning circuit and maximum power point tracking (MPPT) control are required. On the other hand, the use of solar energy has been proposed for HVs so as to improve their fuel economy and to promote the concept of on-board renewable energy. However, similar to that of TEG, the output power characteristics of the photovoltaic (PV) panel are highly nonlinear and heavily depend on the ambient temperature, irradiance, and external load, the proper MPPT control and power conditioning circuit are also required. Unfortunately, the TEG and PV array panel need to be separately operated even though they are installed in the same HV. It says that two set of DC-DC converters, controlling units, DC-AC inverters and even charging battery packs are needed resulting in heavy weight, high cost, and large volume. Compared with the single PV or TE energy producing source, the TE-PV hybrid energy source can offer some advantages, namely the better energy security due to the use of multiple energy sources, the higher fuel economy due to the increase of on-board renewable energy, and the higher control flexibility due to the coordination for charging the same pack of batteries. So the

Thermoelectric-Photovoltaic hybrid energy source is promising for the application to HVs.

II. CIRCUIT DESIGN

The formulas which are used to design the circuit are as follows

1. TEG Design

To Model the proposed TEG system there are two commercially available thermoelectric generators are experimentally studied for the proposed system, the Hi-Z and Tellurex TEG modules [6]. In Fig .2 a TEG consists of two dissimilar materials, n-type and p -type semiconductors, connected thermally in parallel and electrically in series.

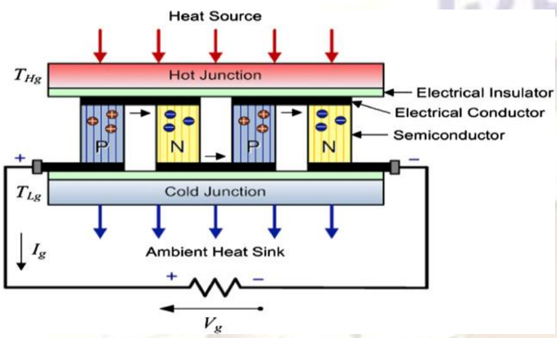

Fig.2 Schematic diagram of the thermoelectric generator

Heat is supplied at one end, i.e. the hot junction, at a temperature T_{Hg}, while the other end, that is the cold junction, is maintained at a lower temperature T_{Lg} by a heat sink. As a result of the temperature difference, an output voltage V_g is generated so that a current I_g flows through an external load resistance. The power output depends upon the temperature difference, the properties of the semiconductor materials and the external load resistance [10]. For the heat conduction effect, the Joulean heat and the energy supply or removal to overcome the Peltier–Seebeck effects are combined for the whole generator arrangement.

The rate of heat supply

$$Q_{Hg}=(\alpha_g*I_g*T_{Hg})-1/(2*I^2_g*R_g)+k(T_{Hg}-T_{Lg}) \quad (1)$$

The rate of heat removal

$$Q_{Lg}=(\alpha_g*I_g*T_{Lg})-1/(2*I^2_g*R_g)+k(T_{Hg}-T_{Lg}) \quad (2)$$

The output voltage

$$V_g=\alpha(T_{Hg}-T_{Lg})-(I_g*R_g) \quad (3)$$

The net output power,

$$P_g=\alpha I(T_{Hg}-T_{Lg})-(I^2_g R_g) \quad (4)$$

and the thermal efficiency,

$$\eta=P_{Hg}/Q_{Hg} \quad (5)$$

$$\alpha=\Delta V_{THg}/\Delta T_g \quad (6)$$

ΔV_{Thg} electromotive force (emf) is generated according to the Seebeck coefficient α_g

ΔT_g Temperature difference between both junctions

A dimensionless figure-of-merit Z is usually employed as a measure of efficiency of materials in thermoelectric generation, defined as [3]:

$$Z=\alpha^2_g\sigma_g/(\lambda_e+\lambda_p) \quad (7)$$

where σ_g is the electrical conductivity, and λ_e and λ_p are the electronic and lattice components of the thermal conductivity, respectively. The numerator of this expression is the so-called power factor.

2. PV Module Design

The PV array consists of several photovoltaic cells in series and parallel connections. From Fig.3 a solar cell can be modelled by a current source and an inverted diode connected in parallel to it [7]. It has its own parallel and series resistance. In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and it can be neglected. The output current from the photovoltaic array is

$$I=I_{sc}-I_d \quad (8)$$

$$I_d=I_o(eqV_d/kT-1) \quad (9)$$

where I_o is the reverse saturation current of the diode, V_d is the voltage across the diode, q is the electron charge, T is the junction temperature in Kelvin (K) and k is boltzmann constant (1.38*(10-19) J/K)

From eq. 8 and 9

$$I=I_{sc}-I_o(eqVd/kT-1) \quad (10)$$

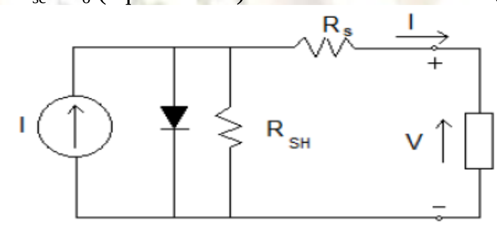

Fig 3 Single diode model of a PV cell

Using suitable approximations,

$$I=Isc-Io(eq((V+IRs)/nkT)-1) \quad (11)$$

where, I is the photovoltaic cell current, T is the temperature (in Kelvin),V is the PV cell voltage, and n is the diode ideality factor.

3. SEPIC Converter Design

SEPIC converter is non-inverting and can generate voltages either below or above the input. The input current is non-pulsating but the output current is pulsating [8]. The SEPIC circuit has three dynamic energy storage elements, C1, L1 and L2.

$$M=V_0/V_1 \quad (12)$$

$$D=t_{ON}/T \quad (13)$$

D as a function of M is :

$$D=M/M+1 \quad (14)$$

Output voltage can be expressed as :

$$V_0=(D/1-D)V_1 \quad (15)$$

Where M is the conversion ratio, D is the duty cycle, V_1 is the input voltage, V_0 is the output voltage, T is the switching period, t_{ON} is the on time when the switch is close.The behaviour of any switch mode circuit is strongly dependent on the continuity of the currents in the inductors and the voltage on the capacitor. In this paper, the converter is operated in Continuous Current Mode

Calculating the value of L2:

$V = L\, di/dt$ (16)

Where V is the voltage applied to the inductor, L is the inductance, di is the inductor peak to peak ripple current and dt is the duration the voltage applied.

$L = V.dt/di$ (17)

$dt = 1/F_s \times D$ (18)

It is common way to select the same value for both input and output inductors in SEPIC designs

For input inductor L1:

$I_{rms} = (V_{out} \times I_{out})/(V_{in\ (min)} * \eta)$ (19)

$I_{peak} = I_{rms} + (0.5 \times I_{ripple})$ (20)

$I_{ripple} = (V.dt)/L$ (21)

For the output inductor L2:

$I_{rms} = I_{out}$ (22)

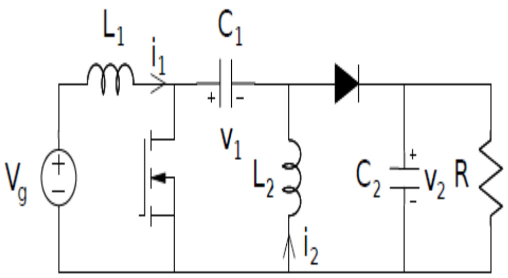

Fig.4 An Ideal SEPIC converter

III. SIMULATION OF TE-PV HYBRID SYSTEM

The output characteristics of the TEG and PV panel are measured at specific working conditions by changing the rheostat value as the external load. Thermoelectric panel and MPPT algorthim was designed in matlab using coding. Photovoltaic panel and SEPIC converter was designed with necessary circuit components. The Fig.5 and Fig.6 shows the designed matlab circuit for TE-PV hybrid system with fixed duty cycle and with MPPT technique

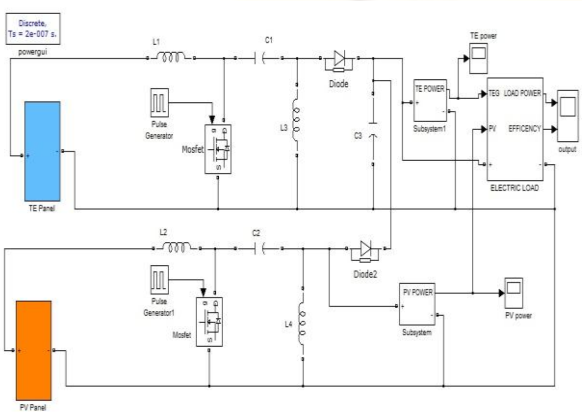

Fig.5 TE-PV hybrid system with fixed duty cycle

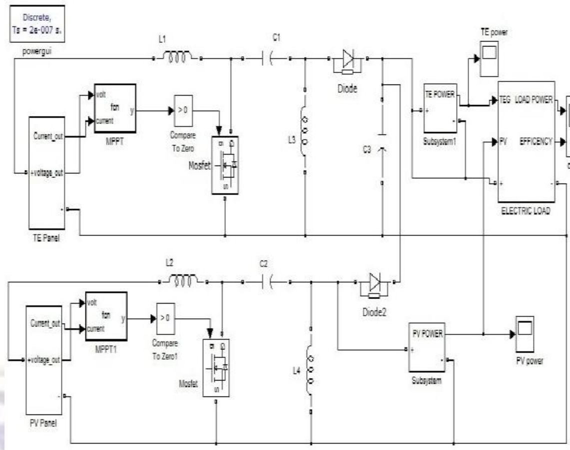

Fig.6 TE-PV hybrid system with MPPT

When the temperature of a cold- side of the TEG is at around 50ºC, the output characteristics of TEG are recorded at hot-side temperatures, 150 ºC is shown in Fig.7 [18]

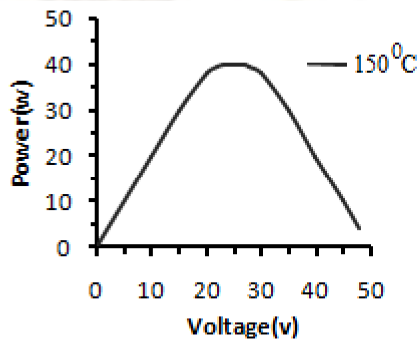

Fig.7 Output characteristic of TEG

With the surface temperature of 50 ºC and irradiance is 950W/m^2 the output characteristics of the photovoltaic panel are shown in Fig.8 [18]. The output power of PV and TEG panel are heavily dependent on the irradiance and temperature difference respectively.

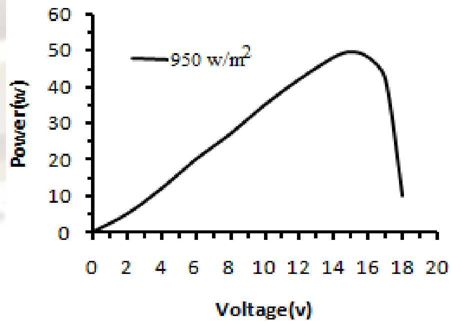

Fig.8 Output characteristic of PV

With varying external load, the output power changes significantly. The above output characteristic figures show the need of the power conditioning circuit [18]. At the same time, the internal resistances of TEG and Photovoltaic panel can be obtained which equal the resistance of the rheostat at MPPs. With a measured output characteristics of the TEG and PV panel , the power conditioning circuit can be designed. By tuning the duty cycle of the pulse width modulation switching signal, the maximum power point can be tracked at each branch. It confirms that the MPPT controllers are able to maintain the maximum power point operation even under the sudden change in load. In –order to verify the MPPT control method, a comparison is done. One is based on a fixed PWM signal with 50 kHz frequency and 65% duty cycle to the system, the other one is driven by MPPT controller with a PWM signal at constant 50 kHz and initial duty cycle 65%. The result in Fig.9 shows that the TE-PV hybrid energy system can achieve MPP under various external factors.

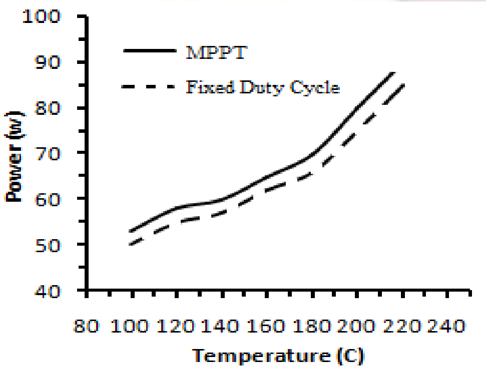

Fig.9 Comparison of Output Power

IV. SIMULATION RESULTS

The simulated results of TE-PV hybrid system with fixed duty cycle in Fig.10 shows that the efficiency is not constant and it is varying according to temperature, irradiance and also the surrounding climatic conditions.

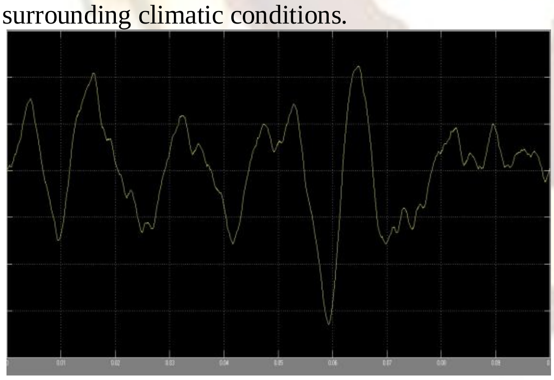

Fig.10 Comparison of Efficiency vs. Time of TE-PV hybrid system with fixed duty cycle

The simulated TE-PV hybrid energy system circuit with MPPT shows that their output parameters were almost constant. In Fig.11 shows that the maximum power can be utilized by using MPPT technique

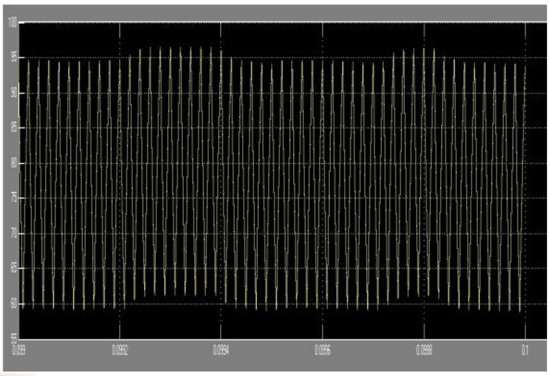

Fig.11 Comparison of Efficiency vs. Time of TE-PV hybrid system with MPPT

V. CONCLUSION

In this paper, TE-PV hybrid energy system circuit with SEPIC converter as power conditioning circuit and P&O (perturb and observation) algorithm as maximum power point tracking (MPPT) method are designed with and without MPPT. The designed circuit has been simulated in matlab/simulink software.

The result confirms that the

- The simulated TE-PV hybrid energy system circuit without MPPT shows that its output parameters were not constant.
- The simulated TE-PV hybrid energy system circuit with MPPT shows that their output parameters were almost constant.
- Thermoelectric block was operated between the temperature 50^0 C in the cold side and 150^0 C in the hot side
- Photovoltaic block operated at the temperature 40^0C and irradiance is $950W/m^{2.}$
- The efficiency of the TE-PV hybrid system with MPPT is almost around 80%.

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