Novel Renewable Energy Source in Standalone Microgrid Application with Island Load Management

M. Teke, M.Ö. Yatak, and E. S. Y. Yaseen

***Abstract*—Renewable energy sources, which use natural sources to generate energy, are currently replacing conventional energy sources to fulfil the world's expanding energy demands. However, photovoltaic and wind energy, which are among these types of energy sources, are not steady and not available for 24 hours in a day. As an alternative, it is possible to extract and use hot water from the earth all the time. Therefore, this study proposes a thermoelectric generator that uses hot water from the hot spring area to generate free electricity as a new renewable energy source in a microgrid application. In this system, the microgrid is standalone without a battery storage system because the thermoelectric generator is in operation for 24 hours in a day (day and night). In this way, the cost of the battery is eliminated by removing it from the system. In this paper, a novel generation method is proposed in microgrid applications as a renewable energy source. In addition, load management system was implemented to control three types of residence loads. The main advantage of this study is to generate electricity from renewable sources like photovoltaic and thermoelectric to demand without much wasting energy by controlled loads according to the proposed load management algorithm. In this study, the microgrid and energy management control is modeled with MATLAB/Simulink. The results showed that the essential load is always active through thermos electric generator besides the absence of battery storage system.**

***Index Terms*—Renewable energy, thermoelectric generator, island microgrid, energy management system.**

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I. Introduction

As the world's population grows, human must find ways to reduce or eliminate air pollution, which requires finding new energy sources. In addition, energy demand is increasing not only in urban areas, but also in rural areas without utility infrastructure. In 2018, more than 860 million people lacked access to electricity. Therefore, it is essential to supply rural areas and off-grid systems with reliable, environmentally friendly energy delivery solutions. As a result, interest in renewable energy sources has increased significantly in recent years. 2019 has been recognized as the year with the fastest development of renewable energy with projected investments of USD 301 billion, of which 47% is earmarked for solar energy and 47% for wind energy. Renewable power capacity was supplied in at least 32 countries to generate over 10 GW of electricity by the end of 2019. Several countries have also made proposals, such as Germany, which aims to use 31% and 49% renewable energy by 2020 - 2030, respectively, and California, which aims to use 33% renewable energy by 2020. Iceland, followed by Norway, has the largest renewable energy capacity per capita in the world in 2021 [1]. In recent years, the share of nuclear power in the EU electricity production has been reduced, while the capacity for generating energy from renewable sources has increased so electricity generation in the EU has changed dramatically through innovations in wind and solar energy [2]. In addition, if the high uncertainty and lack of inertia in renewable energy systems are not carefully managed, the increase in renewable energy sources usage can lead to instability in power grids. To avoid this situation, strong control techniques and a robust design should be used. In this regard, the Microgrid (MG) concept has fascinated the energy business for the past two decades. The United States Department of Energy defines microgrids as: "A group of interconnected loads and distributed energy resources (DERs) inside well-defined electrical boundaries that act as a single controllable entity relative to the grid and can operate in grid-connected and island-mode." [3]. Even if a microgrid is capable of working in both modes, the islanded design is more complex, but it is also a viable alternative for electrifying rural areas. Microgrids have the potential to facilitate the injection of large amounts of reliable renewable energy sources (RES) into power grids, reduce greenhouse gas emissions, and lower energy prices [4]-[5]. The main components of an integrated management grid are conventional DERs such as diesel generators and micro turbines, non-conventional DERs such as renewables, energy storage systems such as batteries, and loads that can be classified as critical, non-critical [4]-[8].

RES such as wind and solar offer challenges for load management and operations. These are power supply state, frequency deviations due to lower system inertia [9]-[10], organized operation of microgrids [11], effective coordination between the energy and demand management systems [9], effective system operation, management of multiple DERs with poten-

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tially conflicting demands [9]-[12], and an effective protection system that accounts for power flow in both directions in the system [9].

Belkaid and the others [13] proposed a configuration combining PV and TEG for the production of electricity from solar radiation and lost heat. They used double inputs boost converters. The load management was not studied but the power could be produced continuously with these two sources.

In this paper, an island load management system with a thermoelectric generator and photovoltaic is presented in a microgrid application without a battery storage system. Also, when the proposed renewable energy sources are used with a load management controller that can continuously read the power supply from TEG and PV sources and make the right decision to bring our microgrid into a stable mode, the proposed system can run for 24 hours without dropping critical loads. also focuses on the efficient use of available energy and distributes the loads. In addition, this approach considers cost minimization and consumer convenience through priority allocations.

The organization of this paper is as follows: Section 2 offers the research methodology and describes the major steps of microgrid structure. The explanation of renewable energy sources (PV and TEG). Additionally, MPPT dc-dc converter with the P&O algorithm and loads has been explained. In Section 3, the parameters of the thermoelectric generator and photovoltaic system are illustrated in detail. In addition, load management for microgrids operating in island mode is explained. The illustration concludes with results and conclusions.

II. Methodology

In this paper, design of island microgrid that consists of thermoelectric generator (TEG) and Photovoltaic (PV) generator is presented. These sources are connected to the DC-DC boost converter controlled with Maximum Power Point Tracking (MPPT) algorithm. The output of the converter is connected to the off grid inverter used to convert DC to AC voltage and this inverter operates loads. The smart meters measure the consumption of the energy and record the voltage and current level. Fig. 1 shown the layout of the proposed system.

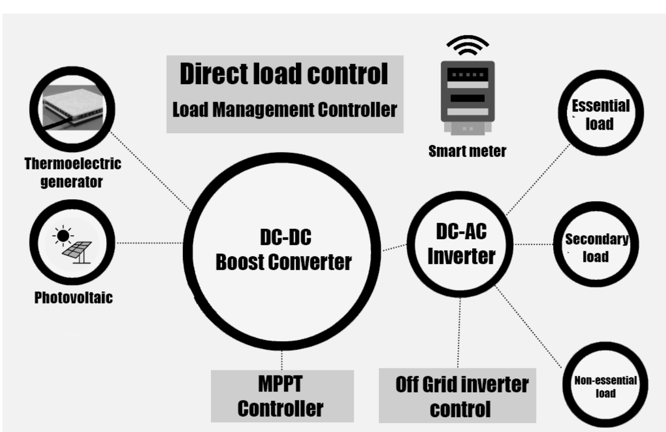

Fig. 1. Proposed system layout.

A. Thermoelectric Generator

Thermoelectric generators (TEGs), also known as Seebeck generators, are solid-state devices that convert heat flow (temperature difference) directly into electricity by exploiting the Seebeck effect [14]. TEGs work like heat engines, but they are smaller and don't have any moving parts. A thermoelectric module is a circuit that contains thermoelectric materials that generate energy from heat.

A thermoelectric module consists of n-p type of semiconductors. When there is a temperature difference between the ends of the materials, an electric current flows through the circuit. As a rule, the magnitude of the current is directly proportional to the temperature difference. Fig. 2 shows the structure of TEG module.

TEG manufacturers supply data sheets with the TEGs. If impedance matching is provided, the data sheets specify the maximum power, current, and voltage. They also ensure the maximum hot and cold surface temperatures of TEGs. In addition, they specify one of the most important requirements, the Seebeck coefficient. When a TEG is modelled using a temperature difference and the Seebeck coefficient, it is easy to determine the power extracted from the TEG. To achieve the required power, they must be connected both in series and in parallel [15]-[16]. They are connected in parallel to increase current and in series to increase voltage. TEG users in the industrial sector can perform the most accurate modelling by connecting TEGs in series and parallel. Heat transfer induces electron transfer from n-type to p-type semiconductors. Consequently, a voltage is generated according to (1) [17]:

$$V_{OC} = \alpha.\Delta T \quad (1)$$

where V_{OC} is the open circuit voltage, α is the Seebeck effect and ΔT represents the different of temperature (hot and cold). The Seebeck value differs from one material to another. So the good Seebeck value is between 100 and 300 $\mu V/K$. Also, the short current value can be determined by (2) [17]:

$$I_{TEG} = V_{OC} / \left(R_{\text{int}} + R_L \right) \quad (2)$$

where R_{int} is the internal resistance and R_L represents load resistance. So, the TEG power can be calculated at MPP when R_{int}=R_L by using (3) [17]:

$$P = \left(V_{OC} \right)^2 \cdot R_L / \left(R_{\text{int}} + R_L \right) \quad (3)$$

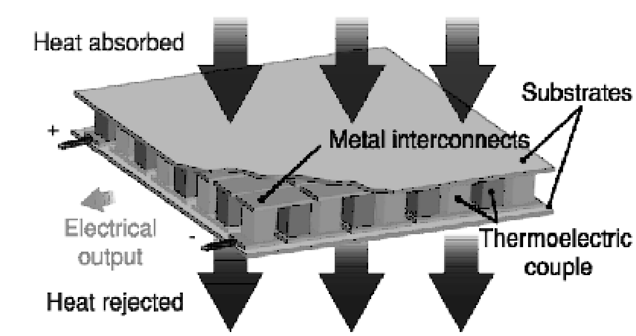

Fig. 2. TEG module structure

B. Photovoltaic Generator

Photovoltaic cell is an electrical device that converts light energy directly into electricity via the photovoltaic effect. They can also be connected in parallel or in series to produce larger voltages, currents and power. Photovoltaic modules are the basic building blocks of PV systems and consist of PV cells sealed in an environmentally friendly laminate. When creating a large PV array, individual PV modules are connected in series and parallel to each other. Photovoltaic arrays or modules connected in a specific order to form a string. A photovoltaic panel consists of one or more pre-wired and field-ready PV modules. Thin film cells, crystalline cells, Gratzel cells or dye sensitized solar cells and multilayer cells are the four types of photovoltaic cells. These different forms are illustrated in [18]. To understand the performance of PV, they can be thought as a diode. When the cell is hit by light energy, electron-hole pairs are formed. An electric field separates the electrons and holes at the diode junction, and the junction potential is used to drive them through an external circuit. Due to this energy loss, some current flows back through the series and shunt resistance of the semiconductor [19]. Fig. 3 shows the equivalent circuit.

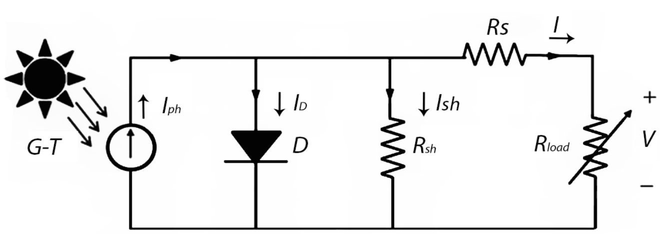

Fig. 3. Photovoltaic equivalent circuit

PV cells can be modelled with a parallel diode, a shunt resistor, and a constant current source. The series resistor links all three of these parts together. Assuming that the sunlight-generated current I_{ph} is the same as the output current, the current through diode I_D and the shunt leakage current I_{sh} are subtracted from this value as shown in (4),

$$I = I_{ph} - I_D - I_{sh} \tag{4}$$

Both the resistance in the series and the properties of the semiconductors have an influence on the internal resistance of the current flow. How much current flows into the ground depends on how high the resistance of the shunt is. In an ideal PV cell, there are no series losses. The power of the PV cell can be greatly reduced if the temperature in the equivalent circuit is not higher than the current through the diode and the current through the ground shunt. This is written in (5),

$$I_D = I_d \cdot \left(\frac{q.V_{OC}}{Acf.K_b.T} \right) - 1 \tag{5}$$

I_D Diode current, q electron charge value $1.6*10^{-19}$ (C), A_{cf} constant curve fit, K_b $1.38*10^{-23}$ constant of Boltzmann $1.38*10^{-23}$ (Joule/°KT).

Also, the output current is represented by (6) [20]:

$$I = I_{ph} - I_{OS} \left\{ \exp\left(\frac{q.V_{OC}}{Acf.K_b.T} \right) - 1 \right\} - \frac{V_{OC}}{R_{sh}} \tag{6}$$

where:

$$I_{ph} = \frac{G}{100} \left[I_{scr} + K_1 \left(T - 25 \right) \right] \tag{7}$$

$$I_{OS} = I_{or} \left(\frac{T}{T_r} \right)^2 .\exp\left[q.E_{GO}.B.K_B \left(\frac{1}{T_r} - \frac{1}{T} \right) \right] \tag{8}$$

Also, *V,I is* output voltage and current of cell, I_{OS} is reverse saturation current of cell, *B is* factor of p-n semiconductor junction, K_1 short circuit actual temperature coefficient at I_{scr} (K_1*=0.0017 A/°C*), *G* is average irradiation of solar *W/m*^{2}, I_{scr} is short circuit current at 25 *°C* and 1000 *W/m*^{2}, I_{ph} is generated light current, E_{G0} is Silicon band gap, T_r is reference temperature (301.18 *°K*), I is Saturation-current at T_r in cell, R_{sh} is shunt resistance, R_s is series resistance, I_{mpp} is current at maximum power point, and V_{mpp} is the voltage at maximum power point.

C. *Boost Converter*

Converters are electronic devices that efficiently shift the voltage level between two values. The converter used in this study belongs to the category of non-isolated converters that boost the DC voltage from a low value to a high one. The boost converter circuit is shown in Fig. 4. Duty cycle of the switch S1 regulates the output voltage according to the MPP. The frequency of the switch S1 is chosen from a few kHz to a few MHz depending on the chosen switch type.

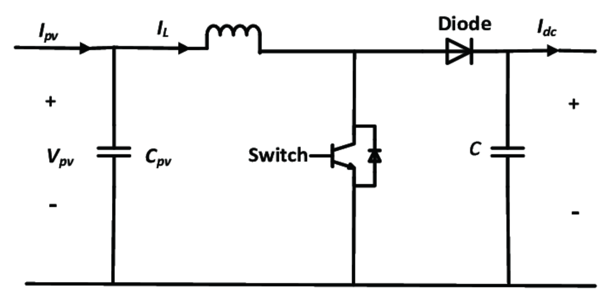

Fig. 4. Boost converter equivalent circuit

When S1 switch is on, L1 coil stores energy in its magnetic field because of the current through it and the switch. No current flows through the D1 diode, C1 capacitor supplies the load current. When the S1 switch is off, the charged L1 coil current is immediately supplied with its back-electromotive force and the L1 coil voltage is added to the source voltage. As a result, the output voltage is greater than the input voltage [17]. MPPT aims to extract the most power from a PV generator and TEG under changing atmospheric conditions, especially solar radiation and temperature. The MPPT algorithm changes the duty cycle of the DC-DC converter to match the resistance of the load as seen from the source Rin to the optimal internal resistance of the PV generator and TEG

D. Perturb & Observation (P&O) Algorithm

In Perturb & Observation (P&O) method, the voltage of the source is changed before the output power is determined. If the voltage gain increases the power, then the voltage is further increased. If the power decreases as the voltage increases, the voltage of the PV and TEG sources is decreased to achieve a larger value for the output power. The fluctuations in the operating voltage are determined by a constant value. As the system constantly searches for the MPP, the P&O algorithm ensures that the output power of the PV and TEG fluctuates around the MPP. This method is simple, requiring only three calculations to track the MPP. The oscillation of output power is natural and this is the disadvantage of the method. There are updated versions of P&O in the literature that improve MPP tracking performance, but there is no evidence of improved performance under variable irradiance conditions [21]-[22]. Fig. 5 is the flowchart summarizing the P&O algorithm.

E. Off Grid DC-AC Inverter

Off-grid inverters convert DC to AC for AC power appliances. They are intended to operate independently and do not synchronize with the grid. In this study, off-grid inverter was designed and controlled to use in island microgrid. It draws electricity from the boost converter and transforms it to AC.

F. Loads and Load Management System

In this study, the loads are in three type of loads which are essential main load, secondary load and non-essential load. These loads are connected with smart meters to calculate and forecast generated power from renewable energy sources (PV and TEG). Direct load control algorithm is proposed to schedule loads operation according to power generation state.

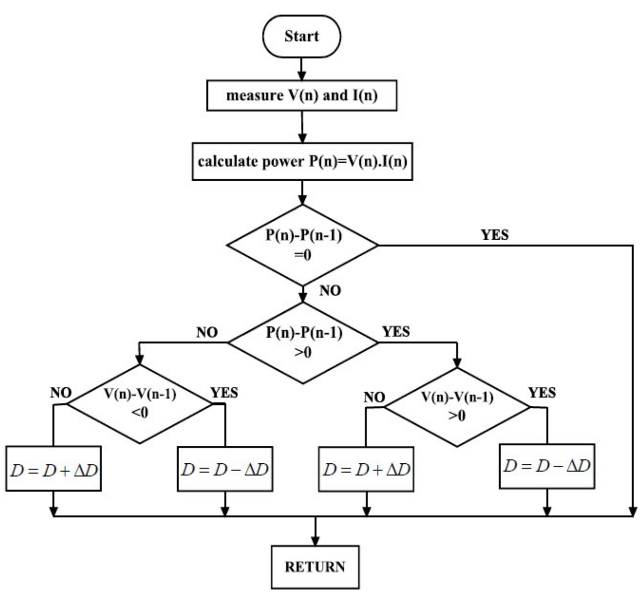

Fig. 5. P&O algorithm

III. DISCUSSION AND RESULTS

In large scale grids, load management is usually a contingency plan of last resort. In a community microgrid, load management is especially important because there are fewer power resources. Since the community microgrid aims to improve the efficiency and reliability of the power supply, the controlled loads must be carefully selected to ensure the adaptability of the system. This study is concerned with load management. Microgrids can have essential, secondary, and non-essential loads.

A. Thermoelectric Generator and Photovoltaic System Parameters Details

This paper presents a microgrid design contain of thermoelectric generator and photovoltaic as a renewable energy supply source. Total capacity of suggested microgrid is 90 *kW*. Thermoelectric generators provide 52 *kW* and PV system generates 38 *kW* at MPP. Fig. 6 shows the proposed design of TEG in MATLAB/Simulink.

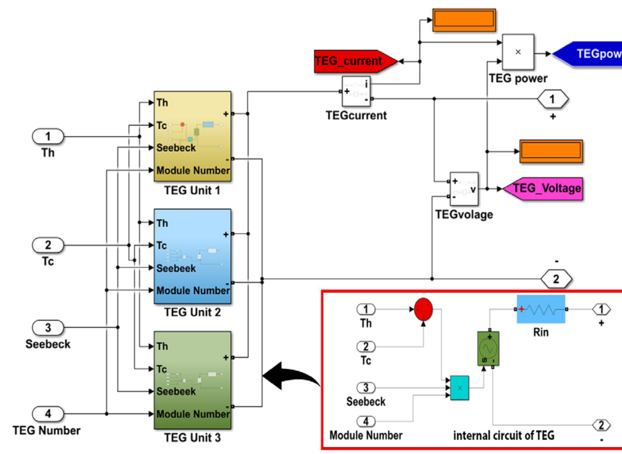

Fig. 6. Thermoelectric generator model in MATLAB/Simulink

Table I illustrates the parameter of thermoelectric generators. TEG contains of 290 modules connected in series and in 3 parallel units. So, the total TEGs are 870 in this study.

TABLE I
TEG PARAMETERS

Parameter	Value
TEG Max power	60 [watts]
Hot temperature applied	100 [C°]
Cold temperature	0 [C°]
Seebeck	0.185 [μ V/K]
No. of series TEG number	870/3

For the PV array, there are 20 parallel and 15 series connected modules per string. In this study, the results were assumed while the temperature of cell is constant. The selected module was 10Agreen Technology A10J-M60-230 with maximum power 230 W per panel with open circuit voltage 37 V and short circuit current 8 A. Table II shows the parameters in detail.

TABLE II
PV Parameters

Parameter	Value
Maximum power	230 [watts]
Cell per module	60
Open circuit voltage	36.42 [V]
Short circuit current	8.1 [A]
Voltage at maximum power point	30.36 [V]
Current at maximum power point	7.58 [A]

B. Microgrid Load Management on the Island Mode Operation

Distributed generation and grid equal to a micro grid's total load. In isolated mode, load management must continuously balance load and generation to preserve system stability until further generation is added. Load management must monitor supply source capacity and load to manage load.

The sun is not always present, and on many days, there may be no wind. Therefore, PV and wind energy are not stable and not available for 24 hours in a day. However, it is possible to extract and use hot water from the earth. Therefore, this study proposed a thermoelectric generator that would use hot water from hot spring area to generate free electricity as a new renewable energy source in microgrid application.

1. Essential loads

These are the most important loads within the microgrid, as they cannot fail for any reason.

2. Secondary loads

Loads that can be temporarily removed or replaced with other sources to alleviate peak loads. These are loads can be removed when there is not enough power energy supported.

3. Non-essential loads

These loads use surplus electricity. When renewable energy sources do not provide excess power, these loads are ramped down to ensure microgrid stability and prevent blackouts. Examples include household loads and backup power. Backup generators can be remotely connected in advance to reduce the load on the microgrid system.

The results are obtained on two scenarios. First one is constant irradiation with variable temperature for TEG and the other one is constant temperature with variable irradiation for PV generation. These experiments were done on load operation state in standalone proposed microgrid.

1) *Constant irradiation PV with variable temperature TEG*

Since hot water is available for 24 hours a day, the essential load is always on operation. This is shown in Fig. 7, on the load currents graphic with red plot. The water temperature rises to 70 °C at 0.2nd second and so the total power reaches to 60 *kW*. At this point, the secondary load is on operation. At the 4th second, water temperature rises to 100 °C and the total power reaches to 90 *kW*. After that, the non-essential load is on operation too. According to the scenario, the temperature decreases to 80 °C at 0.6th second and the total power decreases to 80 *kW*. The non-essential load is no longer active. As long as, the temperature does not fall below 60°C, the secondary load continues actively.

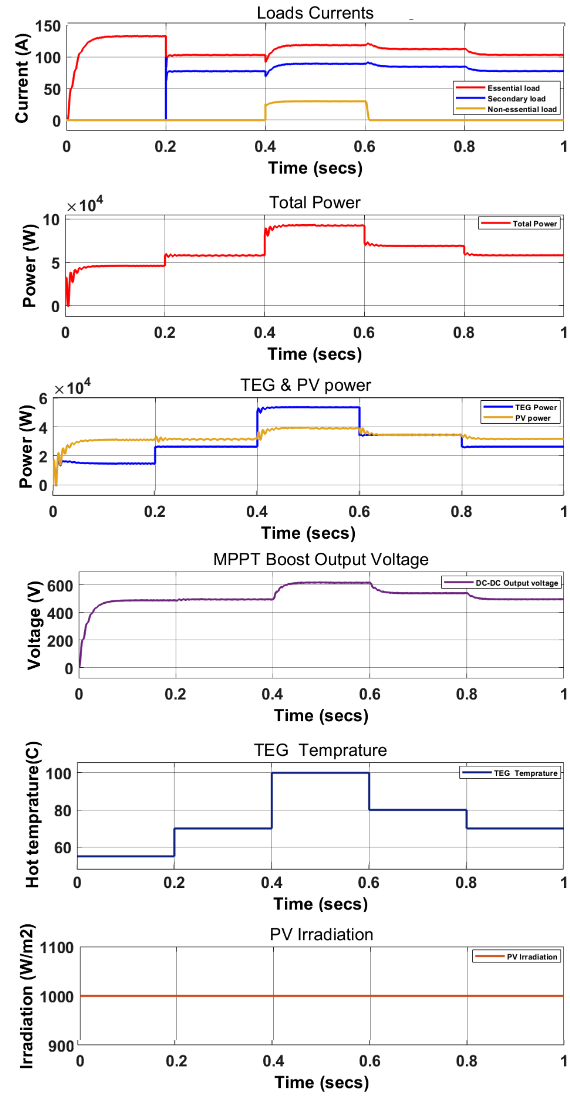

Fig. 7. Constant irradiation PV with variable temperature TEG results.

2) *Constant temperature TEG with variable irradiation PV*

According to the second scenario, the water temperature in the thermal spring was kept constant at 100 °C. The produced power from TEG always keeps the essential load active. When the irradiation rises to 500 W/m^2, the total power is 65 *kW* and the secondary load is active from that time. Irradiation rises to 800 W/m^2, the total power reaches to 82 *kW* and the non-essential load is activated. At the 0.8th second, the irradiation decreases to 500 W/m^2 and the total power decreases to 70 *kW*. From this point, non-essential load is passive. This scenario and the plots can be seen from Fig. 8. These two figures show that the essential load is always active through TEG in spite of the absence of the battery storage system.

Furthermore, a diesel generator may be used for emergency times when there is maintenance or a need to generate a heavy load from outside the island grid.

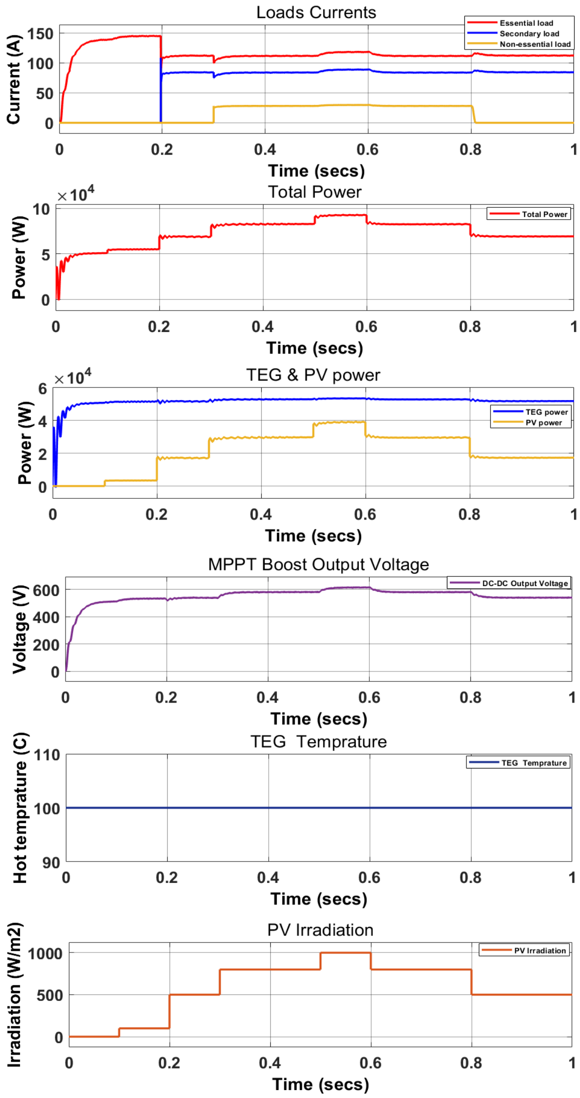

Fig. 8. Constant temperature TEG with variable irradiation PV results.

IV. Conclusion

This paper presented island load management system illustrated in thermoelectric generator and photovoltaic in microgrid application without using battery. Also, this system can be work 24 hours without shedding in electricity according to proposed source with load management control which read the power supply from TEG and PV sources continuously and make a right decision to get our microgrid in stable mode. From all obtained result that the system has stable operation. The essential load is always active through TEG.

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