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EFFICIENT DESIGN OF ISLAND LOAD MANAGEMENT IN MICROGRID SYSTEMS BASED ON FUZZY LOGIC

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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THE DEGREE OF MASTER OF SCIENCE
IN
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BY

ETHAR SULAIMAN YASEEN YASEEN

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By Ethar Sulaiman Yaseen YASEEN

August 2022

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science

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Ethar Sulaiman Yaseen YASEEN

ABSTRACT

EFFICIENT DESIGN OF ISLAND LOAD MANAGEMENT IN MICROGRID SYSTEMS BASED ON FUZZY LOGIC

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Master of Science in Electrical - Electronics Engineering
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August 2022

Sun and wind are not always present during the day. For this reason, photovoltaic and wind energy varies and cannot be used at all hours of the day. However, it is possible to extract and use hot water from the ground. In this study, a simulation of microgrid application was performed using a photovoltaic power system and thermoelectric generator sources. Since the hot water from the spa areas is available at any time of the day, the microgrid system is designed in a way that no battery is needed and the cost is reduced when the battery is removed from the system. The priorities of the classified loads were controlled by a fuzzy logic controller based on the generated power of the utilized energy sources. Loads are divided into primary, secondary, and third-priority loads, and the system is designed in such a way that there is no interruption of the primary load in all power generation conditions. When the generation power increased, the control system switched on the second and third loads according to the applied rules. No instability was observed in the system during the transition of the loads to the active-passive state. The energy balance between supply and demand in the microgrid system was successfully implemented in the Matlab/Simulink environment.

2022, 61 pages

Keywords: Renewable energy RE, Thermoelectric generator TEG, Photovoltaic PV, Island microgrid, Energy management system EMS.

ÖZET

BULANIK MANTIĞA DAYALI MİKROGRİD SİSTEMLERDE ADA YÜK YÖNETİMİNİN VERİMLİ TASARIMI

Ethar Suliaman Yaseen YASEEN

Elektrik - Elektronik Mühendisliği, Yüksek Lisans

Tez Danışmanı: Dr. Öğr. Üyesi Mustafa TEKE

Ağustos 2022

Güneş ve rüzgâr gün içerisinde her zaman mevcut değildir. Bu nedenle Fotovoltaik ve rüzgâr enerjisi değişkenlik gösterir günün her saati kullanılamaz. Ancak topraktan sıcak su çıkarmak ve kullanmak mümkündür. Bu çalışmada, Fotovoltaik ve termoelektrik kaynaklar kullanılarak mikro şebeke uygulaması simülasyonu gerçekleştirilmiştir. Kaplıca bölgelerinden çıkan sıcak su günün her saatinde erişilebilir olması nedeniyle, mikro şebeke sistemi akü grubuna ihtiyaç duymadan tasarlanmıştır ve batarya grubu sistem dışında bırakıldığından maliyet düşürülmüştür. Kullanılan enerji kaynaklarının üretim kapasitelerine göre, çalışma öncelikleri sınıflandırılmış yüklerin kontrolleri, bulanık mantık denetleyicisi aracılığıyla yapılmıştır. Yükler birinci, ikinci ve üçüncü önceliğe sahip olacak şekilde sınıflara ayrılmış ve enerji üretiminin olduğu her durumda birincil yükte kesinti yaşanmayacak şekilde sistem tasarlanmıştır. Enerji üretimi arttıkça denetleyici sistem uygulanan kural tabanına göre ikinci ve üçüncü yükleri çalışır hale getirmiştir. Yüklerin aktif pasif duruma geçişi esnasında sistemde hiçbir kararsızlık görülmemiştir. Mikro şebeke sisteminde arz talep arasındaki enerji dengesi başarıyla Matlab/Simulink ortamında uygulanmıştır.

2022, 61 sayfa

Anahtar Kelimeler: Yenilenebilir enerji YE, Termoelektrik jeneratör TJ, Fotovoltaik PV, Ada mikro şebekesi, Enerji yönetim sistemi EYS

PREFACE AND ACKNOWLEDGEMENTS

I would like to thank my father, my mother, my wife and all of my family members for supporting and encouraging me to get my master's degree in electrical and electronic engineering. Also, I would like to say thanks to my advisor, Asst. Prof. Dr. Mustafa TEKE, for his advice and suggestions to complete this work.

Ethar Suliaman Yaseen YASEEN
Çankırı-2022

CONTENTS

LIST OF ABBREVIATIONS

DLC	Direct load control
DR	Demand response
DSM	Demand side management
EMS	Energy management system
FLC	Fuzzy logic control
HEM	Home energy management
MPPT	Maximum power point tracking
PV	Photovoltaic
P&O	Perturb and Observe
RES	Renewable energy sources
TEG	Thermoelectric generator

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1. MICOGRID OVERVIEWS AND SCOPES

1.1 INTRODUCTION

A microgrid is a self-sufficient power energy system that serves different geographical swaths of land. For decades, microgrids have been used to generate power in rural areas, as well as military and industrial operations in remote areas. However, it is increasingly being used in urban areas. It relies heavily on renewables, including photovoltaic and wind turbines. New developments can become self-sufficient by using on-site power generation and storage. Many European countries have passed legislation governing microgrids and localized energy production. Wind turbines are now being used to generate power and feed microgrids in many large and small developments. Small-scale energy systems can store excess energy for later use or feed it back into larger power grids. As a model for power, microgrids continue to face several obstacles. Microgrid adoption is hampered by a lack of understanding about microgrids and the downsides of government policy. In general, microgrid technology may be used to provide energy in distant places, such as urban apartment complexes, offices, and schools. When microgrid technology is used, a new generation and distribution network must be constructed.

The goal of implementing a microgrid is to provide several benefits to both customers and electric utility providers. When a microgrid is linked to a user's application, it may increase quality and lower cost. Additionally, it cuts emissions. By installing a distributed energy production system with microgrid capacity, the electric utility provider may decrease energy flow on transmission and distribution lines, hence reducing losses and extra energy expenditures. Additionally, microgrids may help lower grid load by resolving electricity-related grid failures and assisting the grid in repairing itself. Microgrid adoption also helps to reduce emissions and mitigate the effects of climate change.

Additionally, the microgrid may easily disconnect and isolate itself from the utility grid in the event of a utility grid outage, causing no load disruption in the microgrid. By reducing grid demand, a microgrid may help prevent the electricity system from failing during peak loads. Microgrids provide environmental benefits due to their use of low- or no-emission engines. The use of power and heat in a microgrid may move the generation closer to the consumer, improving energy efficiency. Additionally, Microgrid may help its customers save money on power by producing part or even all of their own power. All of this may be characterized as a perfect microgrid advantage. On the other hand, microgrids have a disadvantage in that they must be evaluated and regulated to ensure appropriate voltage, frequency, and power quality criteria while maintaining power and energy balance. Electrical energy must be stored in battery banks, which requires more space and upkeep.

Renewable energy is a critical issue for researchers and scientists to address in order to extract energy from all of these sources and convert it to electrical energy. With growing global concern over the energy crisis and global warming, electricity generation and renewable energy have become extremely appealing topics in recent years. Electricity equates to increased energy efficiency and thus to significant energy savings, whereas renewable energy generation equates to independence from fossil fuels and thus to emissions of zero. As a result, the combination of electricity and renewable energy generation points to a viable path toward human efficiency and energy development. However, significant challenges in a number of areas, including how to collect and use renewable power efficiently and economically, and also how to process and convert electric power to meet the demands of practical applications.

Renewable energy is gaining popularity worldwide, and all these new energy sources may be critical in the fight against climate change. Solar power, wind turbines, hydropower systems, geothermal energy, and biomass are the most popular renewable energy sources because they self-renew and never run out. In spite of the fact that coal and oil account for approximately 80% of energy consumption.

As more creative and cost-effective techniques of receiving and generating energy become available, renewable energy will become a more significant source of power generation. Residential solar panels that can sell extra energy back to the grid are all gaining in popularity.

There have been supply chain disruptions lockdowns, and emerging financial problems. In addition, renewable energy production has increased in recent years because it is more sustainable. Infrastructure costs, such as those associated with the construction and installation of wind and solar plants, present a significant obstacle. Power plants are more expensive to build but cheaper to operate and maintain. Providing power on demand is hampered by the inability to start generating it quickly enough. It’s impossible to generate solar energy at night, and wind energy can only be generated when it's blowing. Storage solutions can help overcome barriers to renewable energy adoption.

Not all states and regions have the resources to set up grids for storing electricity powered by renewable or wind turbines. The electricity transmitters built for coal and other fossil fuels must be upgraded significantly before they can be used with renewable energy sources. Billionaires with clout in politics fund the fossil fuel industry. This has an impact on renewable energy's growth prospects, as huge renewable energy sources fail due to a lack of proper policy support. Renewable energy benefits must be made known to the general public. Renewable energy will play an increasingly crucial part in energy generation in the future due to growing public awareness, government incentives, and technological breakthroughs.

Residential lights and air-conditioning units are turned on late at night as the day progresses, increasing the demand for electricity. This will continue throughout the day as people plug in various appliances. When it comes to electricity demand, there are peaks and valleys all throughout the day, as well as on weekends and during holidays like festivals. This can only be achieved by a utility adopting demand-side management (DSM), which cuts or adjusts electricity use throughout peak times. Comprehensive load research can identify DSM opportunities by understanding the utility's load curve, primarily its patterns of seasonal and daily variations, and the behavior of various consumer categories. DSM opportunities there is an urgent need for demand-side management, which benefits everyone because it keeps utilities from having to buy expensive capacity to supply demand. As a result, less power is needed from polluting fossil fuels, and the environment is made cleaner and safer. If the supply-demand side balance for electricity is properly not balanced, the grid problems such as power dissipation or increases may be one of the main problems.

On the demand side, reducing peak demand times efficiently increases the power ratio between supply and demand. With an ever-increasing global demand for energy, more energy should be generated to keep up living standards and better serve the customer. However, as more people use electricity and the load becomes more unpredictable, issues with the power grid and the consumer may arise. An energy management system is considered necessary for a smarter grid because automated systems provide accurate results and predictions, assist electrically led utilities in optimizing the functionality of their generation units, and assist a system in operating more efficiently.

Modern power systems are being forced to undergo radical changes as the global demand for electricity grows. Information and communication technologies are driving this revolution (Lee et al. 2016), further increasing government pressure as well as public understanding of the value of reducing emissions and increasing the renewable energy. These concerns sparked the development of the Microgrid concept, which has progressed significantly over the last decade and has recently benefited from smart grid technologies. Microgrids have the potential to increase local reliability, lower costs, improve power quality, and reduce distribution network losses (Elsied et al. 2016, Rahman et al. 2016). Microgrids must rely on renewable energy while balancing the use of other sources of energy. Balancing is more difficult with renewable sources because they are unpredictable and intermittent. By balancing supply and demand in a Microgrid with advanced DSM and a reliable communication system, energy inefficiency can be reduced.

DSM is composed of two components: demand response DR and smart management systems. This can be accomplished by reducing load during periods of high demand or by shifting load to periods of limited supply off-peak recently, DR has been investigated in Microgrid applications. The two types of price-based DR programs are response time direct load control DLC and economy demand response programs. Consumers are encouraged to make short-term, quick changes to how much energy they use in response to signals from the operator about the direct load control method or energy policy. Consumer effects on all aspects of the system have been investigated, including carbon production. The Home energy management system is a hardware / software platform which enables consumers to monitor overall peak loads and change or decrease demand to actually reduce consumption. The HEMS can modify or lower the load to optimize energy usage during peak hours or when the network's condition is badly impacted via DR signals DLC (Direct Load Control) or pricing.

Smart home system, with integrated HEMS, adds to the distribution system's performance, reliability, economics, and energy conservation. According to (Aghajani et al. 2015), a home energy management system can save 23.1 percent on electricity and 29.6 percent on residential peak-load demand. A Home energy management system also reduces energy waste according to (Safamehr and Rahimi-Kian 2015). Building a model that can organize multiple unique appliances simultaneously may be difficult (Bruni et al. 2016).

1.2 Thesis Objectives and Scope

The major goal of this thesis is to find a design for an island load management in microgrid systems to utilize all devices without wasting energy when there is a surplus of energy. Furthermore, the goal of this microgrid design is to remove batteries from the proposed system because they are energy-consuming and expensive. The aim of this idea is to optimize the system by scheduling the loads according to the state of generation sources. Furthermore, the island load management system also works to achieve flexibility between the loads and source, achieving greater efficiency and reliability in the microgrid system after reading and comparing the amount of generation and loads and making a decision according to the proposed algorithm. Additionally, in this study, a novel method of generation in microgrid systems, which has no mechanical parts and generates electricity in silent mode, which is a thermo-electrical generator, is proposed with a photovoltaic system. The challenge of the presented microgrid is the operation without a battery storage system. This means the study will reduce microgrid costs and battery monthly or yearly maintenance.

1.3 Motivation

It is easy to know the microgrid component, but it is difficult to know how the whole system works. So, with many sources for a microgrid, the system behavior is uncertain. So, in order to design an effective energy management system, microgrid research on modeling and simulation is currently being studied by several research groups worldwide. Modeling is important in power energy management systems. An accurate model can help the power utility reduce costs and improve emissions. It is also essential for reliability and load demand.

Also, because the balance between supply and demand is important, this thesis aims to achieve flexibility and efficiency between supply and demand to get an ideal balance and provide the consumer with electricity during the day without any interruption. This thesis examines new management based on energy management systems by forecasting power and load demands, thus increasing the efficiency of microgrid systems. The modeling and management approaches proposed in this thesis are designed for island microgrids. As a result, the microgrid system described in this thesis can be implemented in the tropics, remote areas, and small cities and villages, particularly in hot spring areas, to provide free electricity to consumers while reducing losses and emissions.

1.4 Methodology

In this thesis, a robust microgrid system using PV and thermoelectric generators as renewable energy sources is presented. These sources will be connected to an MPPT converter with a Perturb & Observation algorithm. By using power electronics, this DC voltage will be controlled by an AC off-grid inverter and then supply the load. Our proposed microgrid will supply load by using fuzzy logic load control according to smart meters, which will be connected to secondary and non-essential loads. So for this thesis, we will test the performance of the thermoelectric generator in different cases with PV. Also, microgrid operation after applying an island load management algorithm will be tested by Matlab-Simulink.

2. LITERATURE REVIEW

Many domains of islanded Microgrids have been the topic of recent research projects. Also during faults or disturbance events have researchers concentrate on operation of autonomous Microgrids (Liu *et al.* 2018). Aside from disruption events, a comprehensive investigation of Microgrid stability has been conducted. To assure the stability of Microgrids by overcoming frequency and voltage transients, article (Mahmood *et al.* 2014) explained droop control strategy system. Recent Microgrid research has also concentrate on the economics of Microgrids; the goal is to cost-effectively arrange supply and demand side (Gazijahani *et al.* 2017, Moradi *et al.* 2017). Moreover, the cost of generating, market rates, and optimal load operating schedules have all been given special consideration (Khodaei *et al.* 2015).

Research on this subject concentrate on integrating distributed generation and storage systems. In terms of planning the distributed sources of energy with storage integration, tools for load and generation forecasting were used. Furthermore, according to an article in (Nwulu and Xia 2017, Ahmad *et al.* 2016) inaccuracies exist in predicting techniques. A small change in the demand-supply imbalance can have a significant impact in rural areas where there is a lack of storage space. In addition, system-wide failures could result from unregulated load usage and ineffectual storage dispatch (Ahmad *et al.* 2016). Diesel generators have also been used to support Microgrid operations based on current literature on the successful integration of advanced generation with storage. Optimization and predicting technologies, as well as the internet, are used to schedule the loads as well as generation units. Despite this, rural inhabitants in developing countries lack access to contemporary amenities such as reliable internet and robust infrastructure (Llanos *et al.* 2017). Residential, commercial, and industrial loads can be detected within the Microgrid, and power network connections are established utilizing a cutting-edge, incredibly advanced Zig-bee structure (Salemink *et al.* 2017). Fuzzy logic controls utilized in making decision because it based on human reason also make sensible conclusions in an imprecise and unpredictable climate. Furthermore, customers who have joined in the Demand response programs, which are an expensive option, have been allotted their own storage. Researchers in (Gokuleshvar *et al.* 2017) discussed

Microgrid architecture with an emphasis on load forecasting and efficient dispatch. The performance of the Microgrid under poor conditions, on the other hand, has not been examined by these researchers.

Oliveira *et al.* (2017) the fuzzy system controller chooses the right mode of operation from three options: survival decision, critical decision, and emergency decision. The fuzzy neural toolbox is used to make predictions about load power. They have chosen to design around the conventional power grid, with diesel generators being only used in emergency situations. The fuzzy controller is used in optimized the transfer of energy between both the main grid and the Microgrid. The controller considers on how the weather affects PV systems, what time of day or night it is, how much electricity is being used, and how much electricity is being used. Also, consumers and loads that change based on criticality have been ignored (Roiné *et al.* 2014). Designed a multi-input, multi-output control system with four inputs: load, wind, storage, and solar photovoltaic energy, and nine outputs. These outputs serve as switches that enable the choice of the available source and the loads. The primary power grid was set up in this way to increase system dependability. In an island Microgrid, proactive load shedding has been utilized to lower blackouts (Derrouazin *et al.* 2017). Using load and generation estimates, the approach predicts blackouts. When battery charge drops below 30%, a blackout occurs. This method predicted generation capacity and load. Internet weather forecasting is problematic on rural Microgrids (Michaelson *et al.* 2017). The use of monthly average values of solar radiation or wind speed is shortcoming of several of the proposed methodologies, including those underpinning some software platforms. For optimization, however, it is preferable to use hourly actual or simulated values of electrical load, solar radiation, or wind speed (Luna-Rubio *et al.* 2012, Sedighi and Moradzadeh 2020) .Another software disadvantage is the model's insufficient control, which is manifested by the inability to make changes to the program, limiting the development of new equipment control strategies. At the same time, most research on hybrid energy system size optimization does not take into account the likelihood of a demand response. Only a few studies have been undertaken to the authors' knowledge in order to evaluate the influence of load shifting on size optimization (García-Vera *et al.* 2020, Amrollahi and Bathaee 2017).

Gil *et al.* (2021) investigates how the deployment of demand response impacts the optimal size of HES and the economic factors that make up the net current cost. The load expectation loss is zero in the analysis, all energy sources are renewable, and environmental performance was not taken into mind. The study (Kumar *et al.* 2020) presents the results of the optimization of autonomous HES with and without the use of electrical load control. It is shown optimizing of battery storage system reduced in size and the technical, economic, and environmental performance of the HES is improved. However, this article does not present a methodology for adjusting the electrical load schedules and considers a conditional example of a modified load schedule. A recent paper (Chauhan and Saini 2017) described a novel method for optimizing HES in terms of electrical load control. It has been demonstrated that using demand response can cut the cost of energy by more than 20% and the cost of the BESS by roughly 10%. The impact of a demand response on the appropriate size of the HES, on the other hand, has not been adequately examined. Only the investment costs of the HES components and the cost of energy are shown for a system with and without load management, while other economic and environmental variables are ignored. A paper (Yolda *et al.* 2017) discusses the scheduling of specific household loads in addition to HES sizing optimization. The ideal switching intervals of many appliances were discovered in this study, and the size of the HES was optimized as a result. A model for small HES sizing optimization based on local resource evaluation and demand side management is given in a study. The water pump load was shifted to the night hours as part of the load shifting process. As a result, the HES were reduced in size, and the key economic, technical, and environmental parameters improved. However, because the load shifting capability in the situation is limited, one combination of HES components without a demand response was discovered that has nearly the same objective function cost of energy value. In a paper (Shafiullah 2016), a large amount of savings in system sizes and costs were gained using a demand response technique.

3. PHOTOVOLTAIC SYSTEM

Climate change is the most talked-about topic on the planet right now. The use of fossil fuels is one of the main causes of climate change. Installing renewable energy sources like photovoltaic panels is one of the most common and effective ways to stop climate change (PV). It is free, clean, and always available. If a photovoltaic system is not connected to the power grid, it is called a stand-alone system. If it is, it is called a "grid-connected system." In places that are not connected to the power grid, photovoltaic systems are used. In these systems, the power of the PV system is determined by how it is used. The maximum power point (MPP) for photovoltaic (PV) sources is based on the amount of light, the load factor, and the temperature. A grid-connected PV system is used in places where it is easy to connect to the power grid. Since 1900, the average temperature of the whole world has gone up by 1.2 to 1.4 degrees Fahrenheit per decade. Over the last 2.4 million years, the Earth's climate has changed between ice ages and warmer times. Countries are trying to cut down on their emissions of carbon dioxide, chlorofluorocarbons, and other greenhouse gases.

The Commission's policy is to reduce air pollution by 85-95 percent of what it was in 1990 by 2050. The goal of the European Commission was to cut CO2 emissions by 40%. 60 percent in the years 2030 and 2040." Domestic emissions will be reduced by 30% by 2030 and 40% by 2050 under the current strategy. On the other hand, the EU is not making rules to cut CO2 emissions by 20% from what they were in 1990 (Kijewska and Bluszcz 2016).

It is well known that photovoltaic (PV) power generation plays a crucial role in reducing greenhouse gas emissions. Solar energy systems have a lifespan of 25 years, which is a disadvantage of solar energy. Since the cost of building a photovoltaic (PV) system is now quite low, the use of renewable energy, especially solar energy, has increased massively worldwide in recent years, particularly in the last decade. In 2016, global installed PV capacity was about 310 GW, but in 2017 it increased by about 85 GW, bringing global solar capacity to 395 GW in 2017. By the end of this year, global capacity could reach 700 GW and 4,500 GW by 2050 (Lynn 2010). As the number of

PV system installations grows, Europe is considering regulating the end-of-life disposal of PV modules as outlined in the Waste Electrical and Electronic Equipment Directive (Kijewska and Bluszcz 2016). Photovoltaic systems can be installed in regions where there is no other option, such as in deserts and on rooftops. We can also use solar systems as the only source of energy in remote areas where there is no electricity grid, a situation called "off-grid," which is difficult and costly to implement. However, the vast majority of solar energy is generated by grid-connected systems.

Researchers have focused on lowering the cost and increasing the efficiency of solar systems in recent decades. The current research could lead to the creation of a modular photovoltaic technology technique. In comparison to a decade ago, the company can now produce less expensive and more efficient power generation panels. We can assume that as technology advances, the cost of producing one watt will fall on a daily basis. The generated electricity is crucial for enhancing the efficiency of photovoltaic power plants since it increases income while dropping the cost of energy produced from other sources by almost the same amount. The operator has the most influence on the efficiency of a photovoltaic system, which can be increased or decreased throughout manufacturing; the efficiency of PV panels in commercial applications ranges from 8 to 15%, depending on manufacturing techniques and materials; the efficiency of the inverter ranges from 95.5 to 98 percent; and the methodology used to find maximum power point tracking (MPPT), which is greater than 98 percent, increases efficiency. Both the inverter and the solar panel are difficult and costly to replace. Moreover, we are unable to change the existing system. Maximizing power point (MPP) is the most efficient and simple approach to increasing efficiency. If this method is used on existing plants, changing the control algorithm may yield the same outcomes. The impact of the MPP on the photovoltaic system is instantaneous, increasing electricity production while decreasing costs (Nowak-Ocło and Yildirim 2020). Maximum power point tracking techniques are necessary to collect the maximum amount of power that a solar panel or array can provide because MPPT solar energy power voltage has a non-linear characteristic at a given point on the power-voltage curve where the power is greatest (Enrique *et al.* 2007). This point (MPP) moves as the panel's irradiance or temperature changes. Presumably, radiation and temperature conditions do not remain constant over time. This is the primary justification for using the MPPT. Seasonal variations in irradiance and temperature cause fluctuations in power output (Ozcan and Ersoz 2019). In addition, when atmospheric conditions change, such as when there are clouds, the irradiance varies very rapidly, requiring a recalculation of the panel's power output. MPPT technology is the most efficient and practical solution. MPPT algorithms have been discovered and published in recent years and might vary in different ways, such as being easy or challenging to implement. It is also beneficial in both effective and ineffective practice.

3.1 Elements of Solar Cell Operation

Silicon is the most common material used in industrial solar panels, but other materials are occasionally employed. However, silicon is superior because it is abundant and inexpensive in nature. Silicon comprises 26% of the crust of the globe. The semiconductor has the capacity to convert electromagnetic radiation to electric current. Solar cells use this semiconductor feature to provide an electric current.

Radiation generates charged particles, which are quickly separated to form an electric current suitable for the creation of the solar cell. Describe in detail how semiconductors operate in (Schmidt and Dullweber 2016) solar cells contain a P-N junction as an intrinsic component. P and N are connected through a silicon semiconductor that has been enriched with impurity atoms. Most of the charge carriers in N-type semiconductors are free electrons. Most of the charge carriers in P-type semiconductors are holes. Since the p-layer has a lot of holes, most of the charge in a p-type semiconductor is carried by the holes. Since there are a lot of electrons in the n-layer of n-type semiconductors, they carry most of the charge. When p-type and n-type semiconductors are put together, they make a junction. A depletion zone p-n junction is made when a p-type semiconductor is connected to an n-type semiconductor. The p-n junction shows how p-type semiconductors are different from n-type semiconductors. P-type and N-type semiconductors are put together to make it. Still, some electrons from the N side and some holes from the P side make it to the N side. Since this is true, the electrons and holes at the junction cancel each other out. Only negative ions stay on the p side, and only positive ions stay on the n side. In the depletion zone, there are no more cell phone charge carriers on either side of the intersection (D). On the n-type side, there are no free electrons, and on the p-type side, there are only donor and acceptor ions that can't move. On each side of the PN junction, there are only fixed donor and acceptor ions. Because there are no moving charge carriers in this area, it is called the depletion region. The potential barrier is the difference in potential VD from one side of the junction to the other. It prevents electrons and holes from moving forward (Schmidt and Dullweber 2016).

The structure of solar cells has already been discussed. Now we'll talk about how a solar cell works at its core. When photons from the sun hit a solar cell's p-n junction, not all of them have enough energy to break the p-n junction and make solar energy. Based on how many photons it has, it can be put into three groups: Some photons are reflected, but they don't affect the panel's top surface. The rest of the bugs run behind the cover. Those that don't have enough energy to make the p-n junction also pass through the cell without getting hurt. Because of this, the photon couldn't hurt the p-n junction. A high-energy photon can shatter the silicon gap, resulting in an electron-hole pair on both sides of the p-n junction. The electric field in the cell moves the charges in opposite directions to generate current (electrons towards the n-side and holes towards the p-side). On both sides, metal connections are used to join it. The effect of irradiation is proportional to the quantity of current produced, as shown in Figure 3.1. When irradiance is high, more photons with sufficient energy are produced, allowing the solar cell to create more current.

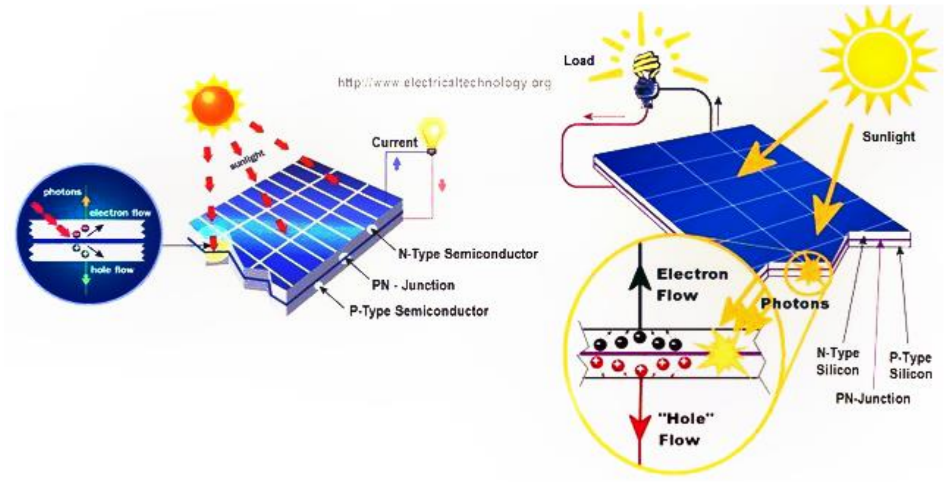

Figure 3.1 PV cell structure and operation (Sreega *et al.* 2017).

3.2 Equivalent Circuit of Solar Cell

As illustrated in Figure 3.2, the performance of the PV panel can be defined by a single basic diode model. A PV module is a group of identical, series-or parallel-stacked branching cells.

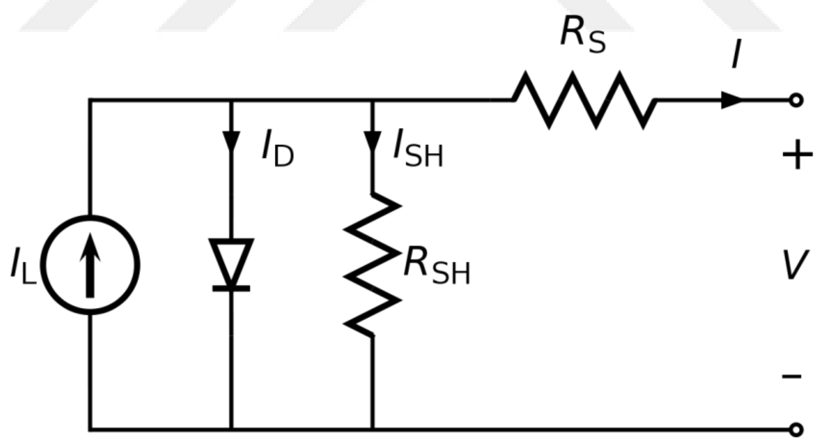

Figure 3.2 Equivalent circuit of photovoltaic cell (Koffi *et al.* 2015).

The Equation 3.1 determines the current output of a solar cell:

$$I = I_L - I_0\left(e^{\frac{q(V - IR_s)}{AKT}}\right) - \frac{V - IR_s}{R_{sh}} \tag{3.1}$$

Where I refer to the output current, I_L refer to generated light current, I_0 saturation current , q represented to electronic charge constant $1.6*10^{-9}$, K is the constant of Boltzmann $1.38 *10^{-23}$ Joule / °KT , Rsh refer to the shunt resistance , A the diode's factor of ideality, Rs series resistance for solar cell and T is the temperature of solar cell.

3.3 PV - IV Characteristic and Maximum Power Point Generation

Current caused by a short circuit could be Equation 3.2:

$$I_{SC} \approx I_L \tag{3.2}$$

For the solar cell to generate the maximum amount of power, the P-V characteristic current and voltage must be at their highest levels. Current is greatest in a short circuit, while voltage is greatest in an open circuit. This position on the P-V diagram is called the maximum power point (MPP). Figure 3.3 demonstrates MPP. Evidently, MPP possesses the maximum voltage and current.

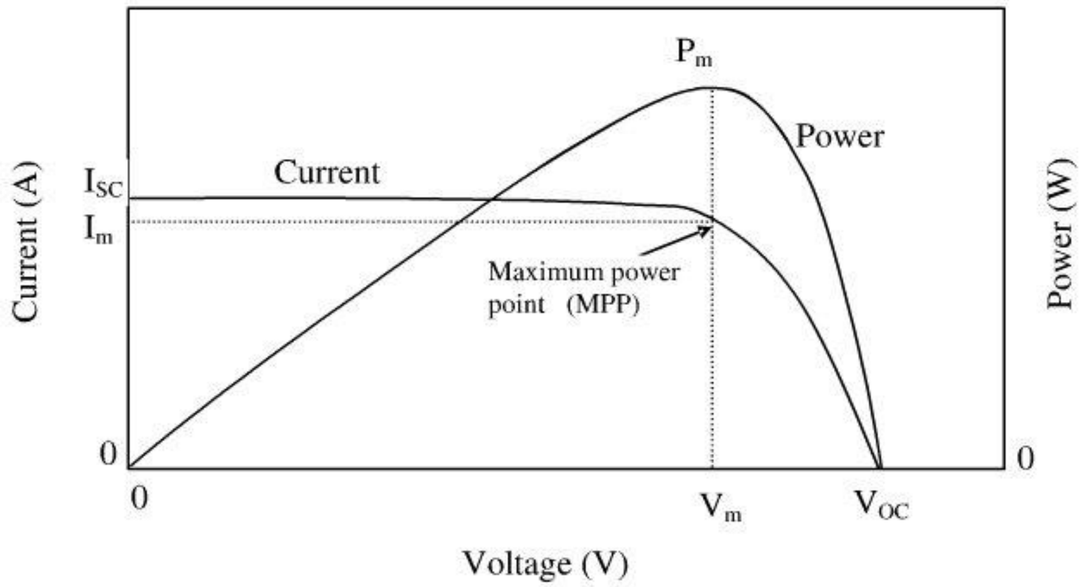

Figure 3.3 PI-V at maximum power point.

3.4 Fill Factor

A fill factor is a percentage that indicates the ratio between the actual maximum power rating and the theoretical maximum power rating. The blue section of the diagram shown in Figure 3.4 represents the PV cell's maximum allowable voltage (Voc) and current (Isc) under the most extreme conditions.

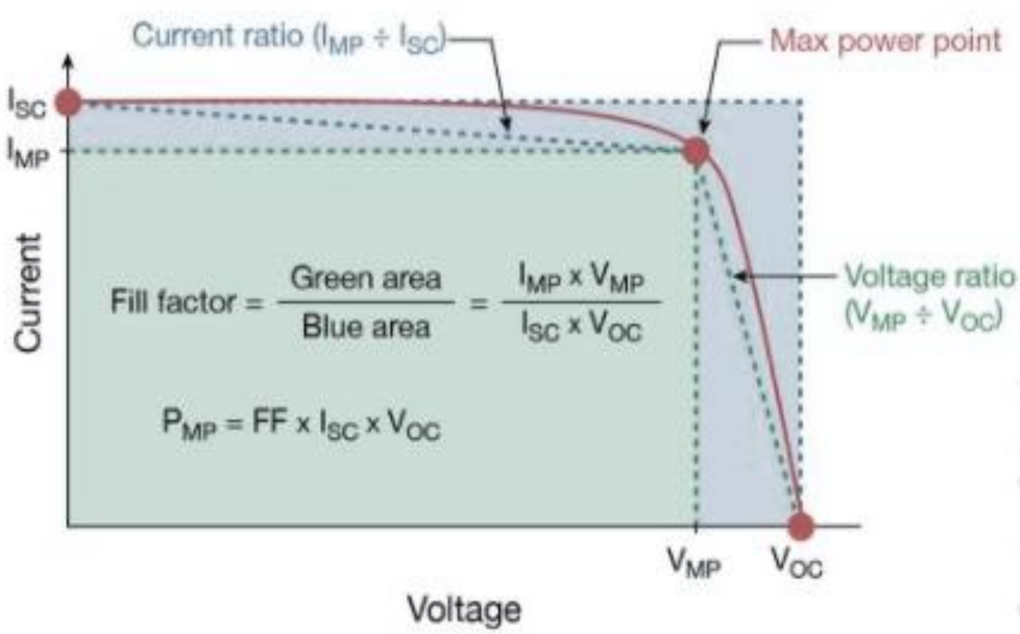

Figure 3.4 Fill factor (Taha *et al.* 2019).

This is theoretically impossible for the PV cell. The green area represents the actual maximum power$Impp$ and $Vmpp$. As indicated by the equation, the fill factor is the ratio of the green area to the blue area Equation 3.3.

$$FF = \frac{I_{MPP} V_{MPP}}{I_{SC} I_{OC}} \tag{3.3}$$

3.5 Effects of Irradiation and Temperature in Solar Cell

Irradiance and temperature have direct effects on the operation of a solar module's panel. Irradiance and temperature are the two key parameters that have a direct impact on solar panel performance. Because temperature and irradiance variations affect the output power of the panel, the MPPT attempts to determine the maximum usable power of the panel in the event of a temperature or radiation variation. Irradiance is proportional to the current produced by the solar cell. As a result, increasing irradiance generates more current. The results show that a change in irradiance affects the current more than a change in temperature. As illustrated in Equations 3.1, the irradiance of a PV cell affects the generated power during typical operation.

As previously stated, altering the PV panel's irradiance has little effect on the open voltage. The effect of increasing irradiance on the short circuit characteristic curve, however, is logarithmic, as seen by the equation (3.3). The distinctively sculpted below indicates that any change in irradiance has an immediate effect on the panel's current output. Any increase in current generation leads to a proportional increase in the amount of power produced by the panel. Figure 3.5 shown the PV and IV characteristic at constant temperature (25°C).

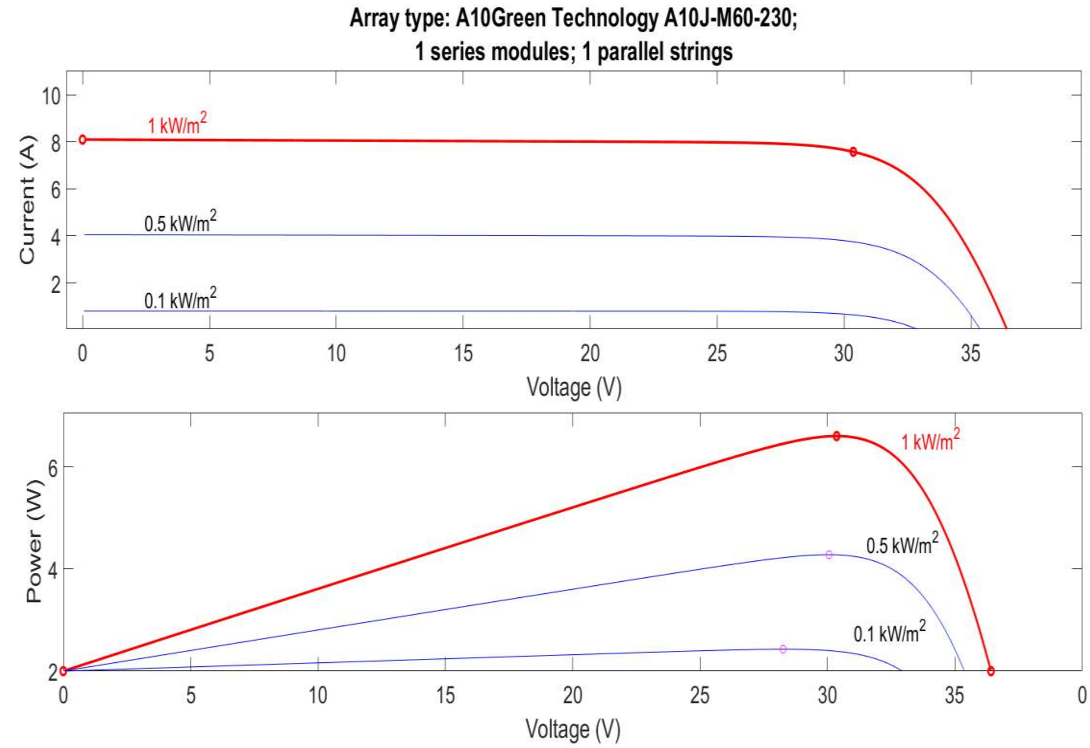

Figure 3.5 Example for solar cell IV and PV characteristic at constant temperature.

Irradiance has a significantly higher influence on current than it does on voltage. As a result, the voltage fluctuation caused by irradiance is ignored. The voltage and current created in response to an increase in irradiance are both positive, resulting in an increase in power output. Nonetheless, the voltage shift is dependent on temperature. As the temperature rises, the voltage produced drops. The following equation illustrates the effect of temperature on Voc Equation 3.4:

$$Voc(T) \approx V_{OC}^{STC} + \frac{K_{V\%}}{100}(T - 273.15) \tag{3.4}$$

As stated previously, the effect of temperature on voltage and current is distinct. Figures 1.9 and 1.10 illustrate the impact of temperature on the creation of current and power. As the temperature goes up, the voltage goes down a lot more than the current goes up, so the amount of power made goes down. Figure 3.6 explain the PV and IV characteristic at constant irradiation (1000 W/m2).

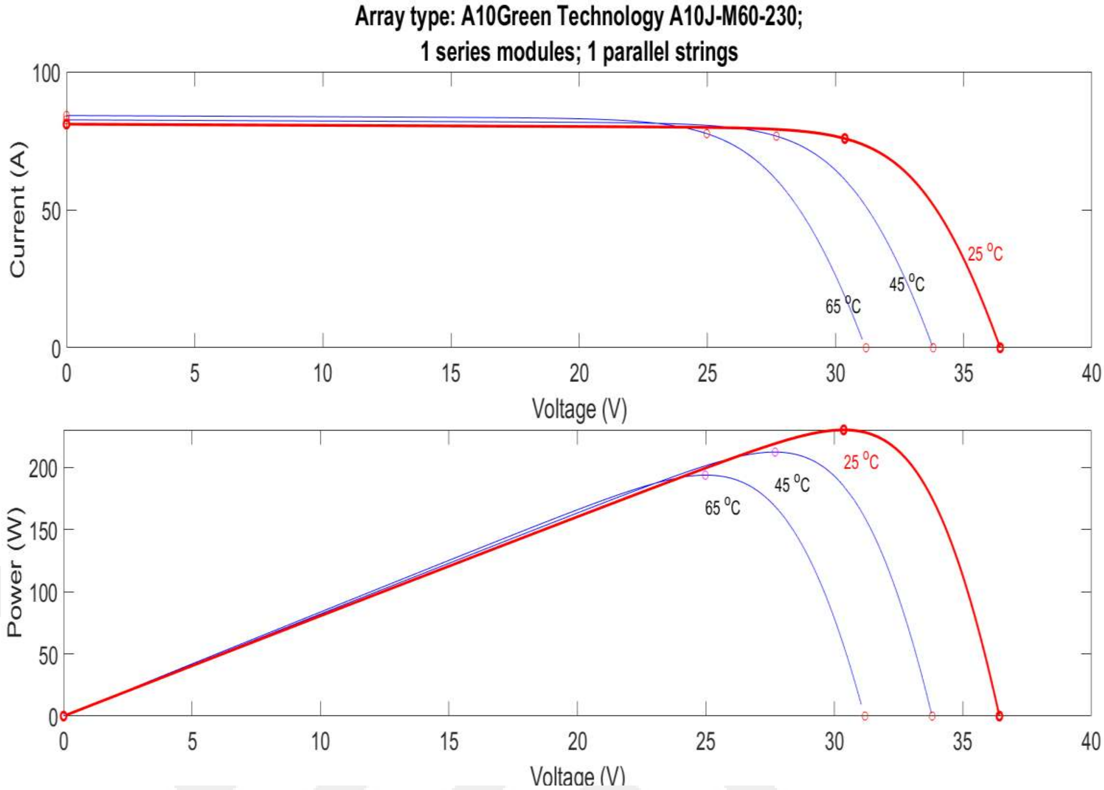

Figure 3.6 IV and PV characteristic at constant irradiation (1000 W/m2).

Clearly, when the weather changes, the irradiance and temperature decrease or increase, and weather changes can occur at any time of a day and can be sudden or gradual. Utilize MPP to track the new peak power generated as a result of this modification; if the MPPT is slow in detecting the peak power, large power losses will occur, and vice versa.

4. THERMOELECTRIC GENERATOR

TE generator technology has numerous benefits. Due to the exceptionally high power densities, miniature thermoelectric generators are possible. A 100-watt TEG unit, for instance, needs around one-fifth of the area required by an equivalent solar system. In addition, as long as there is a heat source and a cold dissipation side, the power is constant. Therefore, the real output of a 100-watt solar system can be six to seven times greater. Waste heat, which is by definition free, is required for the technology to be cost-effective. By utilizing thermoelectric generators, geothermal energy can be transformed to electricity (TEGs). The TEGs instantaneously convert the heat energy to electrical energy. Thermoelectric (TEG) technology is utilized for both air conditioning and energy production. Because it contains no moving parts and generates no greenhouse gases, TE technology is durable, environmentally friendly, and silent. Commercial thermoelectric modules (TEMs) have a conversion efficiency of less than 10%. Two types of ceramic plates are sandwiched between two thermoelectric material elements of the n and p types, which are connected in series to form a thermoelectric module. The elements, which are solid-state, vibration-and noise-free heat pumps that transfer heat from one surface to another, are powered by direct current electricity. A heat sink can be utilized to disperse heat from the hot side of an assembly, transforming it into a cooling unit. In addition to heat transfer, thermoelectric modules are frequently employed to generate electricity by converting heat energy into electrical current, thus enabling the recovery of waste heat from the industrial process. As a result of the development of numerous prospective thermoelectric generating materials, the efficiency of power generation has increased significantly in recent years. With a temperature difference between modules, thermoelectric modules can generate direct current. With a greater temperature difference, more energy will be generated and the conversion of heat to electricity will be more efficient. Thermoelectric modules, which have no moving components and are small and lightweight, are applied in numerous industries, including military, medical, industrial, consumer, and research and laboratory contexts. In Figure 4.1, we explain the structure of thermoelectric generators.

Thermoelectric effects are reversible processes in which heat energy is converted directly into electrical energy (Brownell and Hodes 2014). The physical transport characteristics of thermoelectric materials, such as thermal conductivity, Seebeck coefficient, and electric conductivity, as well as their energy conversion efficiency, influence direct energy conversion. These materials are suitable for thermal-to-electrical and electrical-to-thermal energy conversion.

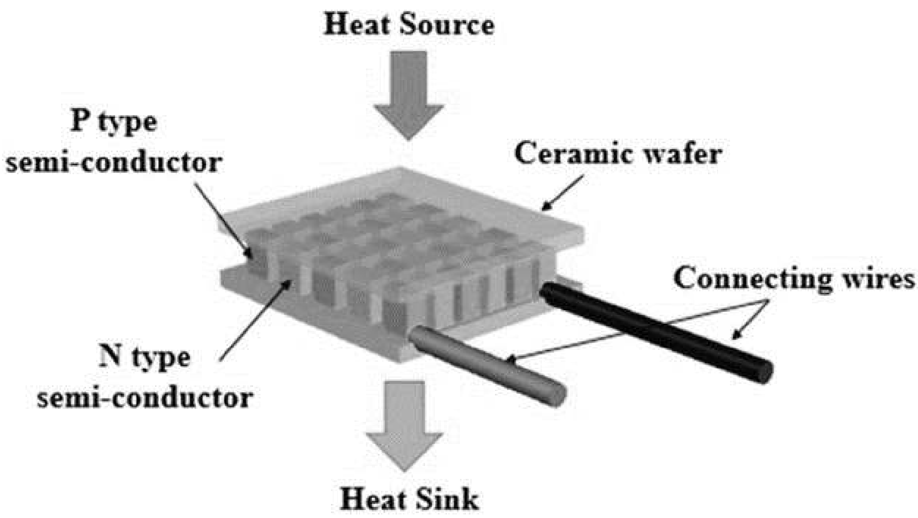

Figure 4.1 General structure of thermoelectric generator (Ahmad *et al.* 2020).

4.1 Difference Between Peltier and Seebeck Effect

The Peltier effect is the conversion of electrical energy into thermal energy, which has cooling and heating applications. In these instances, a thermoelectric cooler (TEC) is employed (Simons *et al.* 2005). The Seebeck effect refers to the conversion of thermal energy into electrical energy, which has applications in power generation. In these circumstances, a thermoelectric generator (TEG) is used (Champier *et al.* 2011, Champier *et al.* 2010). Figure 4.2 explain the difference between Seebeck effect and peltier effect.

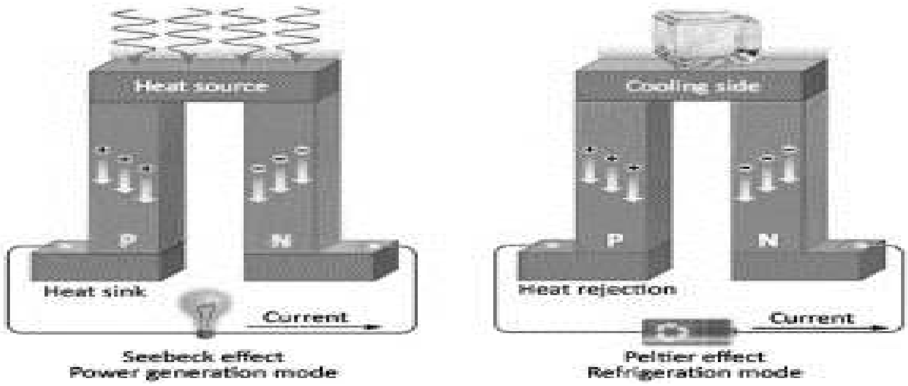

Figure 4.2 Seebeck effect and peltier effect operation diagram (Chaturvedi 2014).

4.2 Seebeck Effects

When a temperature differential across a conductor creates a voltage at the conductor's ends, this is known as the Seebeck effect. The junctions of a circuit are formed by joining two separate conductors, A and B Figure 4.3. These conductors are electrically connected in series and thermally connected in parallel. Th is hotter than Tc. The Seebeck effect happens when charge carriers (electrons or holes) move across (or against) temperature changes in conductors because of thermal diffusion.

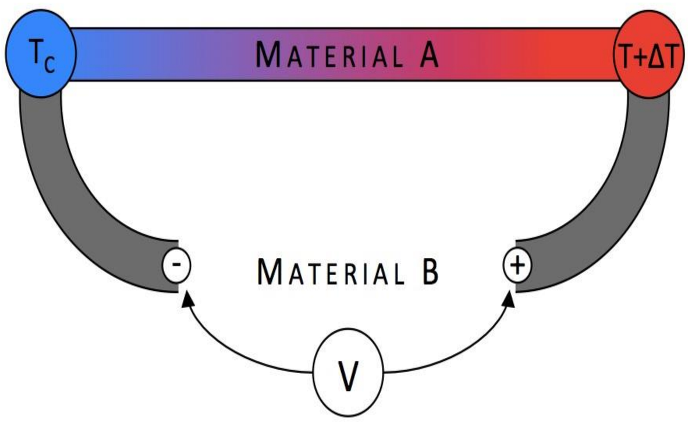

Figure 4.3 Seebeck effect idea.

The Equation 4.1 for the Seebeck or TEG voltage at the electrical circuits is:

$$V = \underbrace{(\alpha_A - \alpha_B)}_{\alpha_{AB}} \cdot \underbrace{(T_h - T_c)}_{\Delta T} \qquad (4.1)$$

Where α_A and α_B represent the Seebeck coefficients for conductors A and B in $V.K^{-1}$, respectively.

The Seebeck coefficient of a thermoelectric material α_{AB} is the connecting parameter between the temperature difference at the input and the voltage difference at the output. In addition to temperature, two other physical transport parameters affect the Seebeck coefficient of a thermoelectric material (thermal conductivity and electric conductivity). It shows how well the thermoelectric material works.

Its magnitude ranges from $\mu V.K^{-1}$ to $mV.K^{-1}$ and its sign is influenced by the semiconductor material and junction temperature. Additionally, the sign of the Seebeck coefficient is determined by whether the electric current is carried by electrons (e) or holes (h+). If e is driving the electric current, the sign of the Seebeck coefficient is negative. If h+ is moving the electric current, the Seebeck coefficient has a plus sign (Neeli *et al.* 2016).

The Seebeck coefficient of a good material is 100 – $300V.K^{-1}$. The temperature is calculated using data from the manufacturer's catalog. Temperature of industrial TEGs is 350 °C.

4.3 Equivalent Circuit of Thermoelectric Generator TEG

The electrical equivalent circuit of a TEG an internal resistor, functions as a temperature-dependent voltage source. By connection to the TEG, power is generated. Maximum power can be generated by the TEG when the load value and the internal resistance of the TEG are equal (Mamur and Coban 2020). As the load increases, so does the generation power. An open-circuit voltage can be calculated using the TEG terminals. Figure 4.4, illustrated the equivalent circuit of TEG.

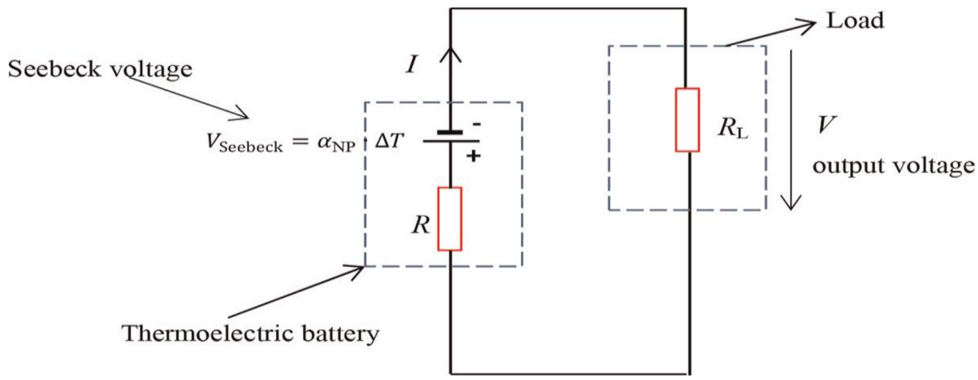

Figure 4.4 Equivalent circuit of TEG (Saima 2016).

The short circuit of TEG terminals has the same impact on the load. As a result, the TEG experiences a short-circuit current. When the power from a TEG is at the MPP point, the open-circuit voltage and short-circuit current are both at their half-values as shown in Equations 4.2 and Equation 4.3:

$$V_{mpp} = \frac{Voc}{2} \tag{4.2}$$

$$I_{mpp} = \frac{Isc}{2} \tag{4.3}$$

V_{mpp}, I_{mpp} are the voltage and current at the maximum power point, while I_{sc} is the short circuit current. Also the TEG current shown in the Equation 4.4:

$$I_{TEG} = \frac{V_{OC}}{(R_{in} + R_L)} \tag{4.4}$$

Where I_{TEG} current of thermoelectric generator TEG, R_{in} internal resistance of TEG and R_L represented to load resistance.

The level of power generated by the TEG is determined as shown in Equation 4.5 by the resistance of the load as well as the resistance of the TEG itself.

$$P = \frac{V_{OC}^{2} \cdot R_L}{\left(R_{int} + R_L\right)^2} \tag{4.5}$$

Where P is the output power of the thermoelectric generator TEG. Variations in load and temperature have a direct impact on the amount of power generated. The MPP changes as the temperature differential increases because the power value increases. The MPP value for a given temperature differential can be calculated by applying an equivalent and constant load to the internal resistance of the TEG. MPP, on the other hand, fluctuates as temporal disparities alter. The load must be dynamic in order to track the MPP value over time. In this study, the TEG is linked to the load through dc to dc MPPT boost converter.

4.4 Components of Thermoelectric Power System

Thermoelectric generation system contain of:

1. Thermoelectric generator (TEG), If is kept between the hot and cold sides of the device, the voltage at the TEG output terminals can power an external circuit and send power to an external electrical load. One TEG can put out anywhere from 1 to 125 watts of power. When you add more TEGs to a modular connection, the power can go up by up to 52 kW and the temperature can go up by almost 100°C.

2. Heat sources, such as hot springs it may be a natural, free source of hot water for the thermal generator. There are several hot springs in the world that have not been used to generate power, particularly in Turkey. There are about a thousand hot springs in Turkey. Using geothermal technology, it is also feasible to increase the temperature of the hot water by one degree through the earth's heat.

3. Cold source, Heat exchangers (heat sinks, coils, cooling blocks, and radiators) are used in the heat transfer system to improve heat dissipation across the TEG; this procedure is important for obtaining a higher temperature difference across the TEG

(Wang *et al.* 2012). A heat sink is a device that transfers heat from a hot surface to a fluid (gases, ambient air, or liquids); the metal heat sink is analyzed and developed for TEG systems. To increase the rate of heat dissipation, the fins' size, heat transfer coefficient, and thermal conductivity are all increased. When a high heat flow rate is given to the hot side of the TEG and the cold side is kept at a low temperature, the TEG requires a heat sink, resulting in a high conversion efficiency. The design of the TEG has a considerable impact on its efficiency in this scenario.

4. DC-DC converter, voltage conversion power electrical circuit designed to adjust the voltage level of a DC source (Kütt *et al.* 2018). Because the TEG's output voltage is low or variable, a DC-DC converter is required; its job is to increase the TEG's output voltage (which is dependent on the number of TEGs linked in series and the TEG's attributes) to meet the needs of the external load. These DC-DC converters must be precisely controlled. The Maximum Power Point Tracking (MPPT) technique must be used in the DC-DC converter controller in this case. To increase the system's feasibility in the real world, as much electrical output power as possible must be collected from TEGs; the efficiency of TEG operation can be measured by evaluating the operation of the DC-DC converter and the MPPT management.

Figure 4.5 illustrated the general TE energy components.

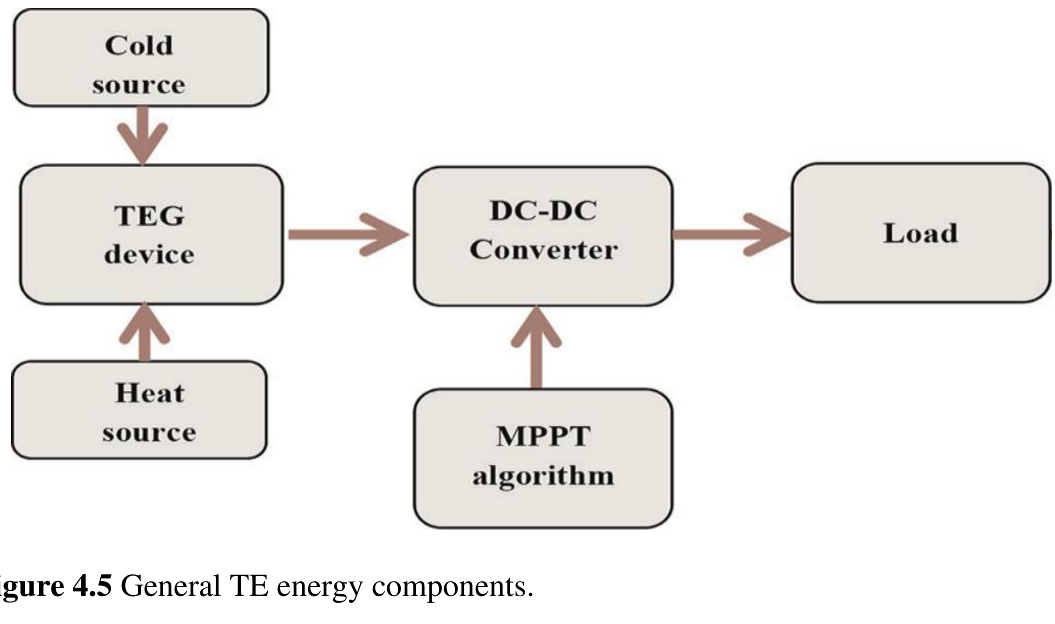

Figure 4.5 General TE energy components.

5. MICROGRID

5.1 Type of Microgrids

Microgrids can operate in two modes: connected to the grid and in island mode. The microgrid is normally connected to the grid via the substation transformer. It is also intended to have enough generation capacity to meet at least a fraction of demand once removed from the distribution system. Existing power utility policies typically restrict unintentional islanding and automatic resynchronization of a microgrid, owing to concerns about human and equipment safety. Because renewable energy sources are intermittent, additional energy sources (such as diesel) and storage components are required for microgrids to run independently or to balance electricity while grid-connected. To get the most out of microgrid resources, it may be necessary to have infrastructure for both islanded and grid-connected modes of operation, as well as a smooth way to switch between the two. Control techniques for microgrids can be centralized, decentralized, or distributed. These are various methods of decision-making. When all system decisions are made in one location, decision-making is centralized (node). Communication across the system is centralized at the central node, which collects all information from each subsystem node. Centralized control systems reduce the number of subsystem controllers while raising the communication and computation complexity of the supervisor. The assignment of a controller to each decentralized subsystem Inter-subsystem communication is unnecessary because all control decisions are based purely on local data. However, ensuring variables such as system-wide stability and optimality is unachievable. A central supervisor is not required for enhanced decentralized control (hybrid decentralized or distributed), but it is not totally decentralized. Alternatively, each subsystem could have its own controller that can communicate with other controllers. This sharing may enable better judgments to be made without relying solely on local facts.

Renewable or non-conventional distributed energy resources (DER) are used in microgrids. DERs are energy sources that are positioned near local loads and are designed for energy generation and storage. Distributed energy resources range from simple systems designed for a single or multiple homes to very big systems designed for remote island grids or large populations, and they may be found almost anywhere renewable energy resources are available. DER can bring numerous benefits, including improved system reliability, reduced transmission and distribution losses, and increased efficiency. Some DERs can provide power in the event of a blackout or disturbance. As a result, DERs are viewed as a way to reduce the use of fossil fuels and traditional energy sources. DER units are made up of distributed generation and distributed power or storage units that have varying capacities and characteristics. Wind turbines, solar, micro-hydro, biomass, geothermal, ocean waves and tides, fuel cells, diesel generators, and our suggested thermoelectric generator are all examples of distributed generating systems. When main sources undergo dynamic variations, distributed power or storage stabilizes and allows DG units to run at a steady and stable output regardless of load changes, giving ride-through capability. When generation and load cannot be precisely matched, distributed power is used. Batteries, super capacitors, and flywheels are examples of distributed storage or power technology. Distributed generating and distributed storage devices are often connected to a microgrid at low to medium voltage. Wind and hydro turbines are examples of AC power sources, whereas solar, fuel cells, and energy storage devices are examples of DC power sources. Hybrids are microgrids that use many types of DG. Because of the advantages of combining AC and DC electricity, these hybrid AC/DC microgrids are seen as the distribution and transmission systems of the future. To integrate AC/DC sources and loads into a hybrid system, a well-defined and standardized framework or strategy is required. There are three types of techniques: DC-coupled, AC-coupled, and hybrid-coupled. DC electrical systems are gaining popularity due to their high efficiency, durability, and ease of installation. In a DC-coupled system, many DGs and DSs are connected to the same DC bus. Interface converters connect the DC bus to the AC bus. When DC power sources are the major power producers for the microgrid, this setup is appropriate. AC loads can be connected to either the AC or DC bus using an inverter. Depending on the power exchange requirements between DC and AC buses, converters may be required for bidirectional power flow between AC and DC buses. A DC-coupled microgrid may accommodate a variety of DGs without requiring synchronization. However, coordination of the operations of the interface converters may be required (synchronizing with each other or with the grid in grid-connected mode). DC microgrids have been proposed as a means of increasing energy availability at the point of use and connecting distributed renewable energy sources with energy storage. Furthermore, it has been noted that the efficiency of batteries, thermoelectric generators, fuel cells, and variable-speed DC generators has grown. Individual interfacing converters connect various DG to the shared AC bus in AC-coupled hybrid microgrids. Multiple-port converters are used in some AC-coupled microgrids to replace many power conversion stages. They do this by combining many power sources into a single converter.

Today, microgrids are replacing conventional electrical systems around the globe. Microgrids are a novel form of electrical grid. They consist of small, low-voltage power supply networks that can, for instance, power a small village. Microgrids are a technique to make the conventional electrical grid network cleaner, more dependable, more secure, more cooperative, and more efficient. Therefore, the objectives of microgrids are to: use more renewable energy; add storage; increase the efficiency of energy supply; make the system more resilient; and make it easier to make changes. Microgrids are anticipated to be more reliable and less expensive than typical centralized grids. To construct a functional microgrid, however, you require sophisticated control. When creating individual controllers, converters, and battery chargers, intelligence is required.

However, even if a microgrid is well-designed, it will not produce much energy if it is not well operated. As a result, intelligent design is insufficient on its own. You will also need smart management. As a result, good microgrid management is critical. Intelligent energy management of microgrids can be used to do a lot of things, like cut costs, lighten the load, and match the patterns of power production and use.

A smart microgrid management system might, for instance, improve the management of renewable energy by adding extra loads or storage elements during periods of peak supply and shutting off dispatchable loads during periods of low supply. It could also compensate for periods of low renewable energy supply by sending power from the main grid. Due to the high start-up and maintenance costs of renewable energy sources, such as photovoltaic and thermoelectric generators, as stated in our thesis, it is crucial that the microgrid be operated efficiently. This type of microgrid requires an intelligent management system. A microgrid can be managed in two ways: supply management and demand management. Supply management controls how much energy is made so that it fits within the system's limits. Demand management, on the other hand, is any method that reduces how much energy is used.

5.2 Strategies in Microgrid management

1. Supply management involves scheduling the generation of energy sources to satisfy the system's constraints. There are two sorts of supply management strategies: isolated microgrids and grid-connected microgrids.

2. Demand management is any strategy that reduces energy consumption or alters how energy is used on the customer side of the power grid in lieu of increasing supply capacity.

5.2.1 Demand management strategies

Demand can be managed in a variety of ways, including preservation programs, task changes, and undertaking more vital tasks. Demand-side management includes load management. Loads might be secondary or non-essential when it comes to controlling the flow of electricity. A supervisory control system can provide set points for controlling the output power of a dispatchable unit from the outside. The majority of the time, the output power of a non-dispatchable DG unit is determined by how well its primary energy source is operating. In practice, a portion of the noncritical load can be dispatchable and placed in a demand control strategy to lower peak load or smooth the load profile, or to schedule the load serving for specified time intervals when more power is available, such as when intermittent DG units are running. Load shedding pertains to the portion of the load that is unmanageable Figure 5.1. When the load demand curve and supply availability curve intersect, optimal utilization is achieved.

The management plan must also ensure that priority is given to the Microgrid critical loads. From a more specific perspective, there are four management stages:

1. Energy management is concerned with operational costs such as fuel use, energy consumption, facility heating, cooling, and ventilation, manipulation of mechanical subsystems, and optimization of energy flow.

2. Power management is the monitoring, analysis, and manipulation of steady states, operation, and system characteristics of electrical components in order to influence an electrical system's immediate operational conditions toward the required values (power, voltage, and frequency), as well as equipment status. Energy management includes power management.

3. Supply management is the analysis and control of the acquisition and utilization of resources such as energy and other operational supplies and materials. Energy management also includes supply management.

4. Distribution management is the process of keeping an eye on, analyzing, and making changes to the parts of an electrical distribution system that allow power to flow, manage loads, control voltage, and so on.

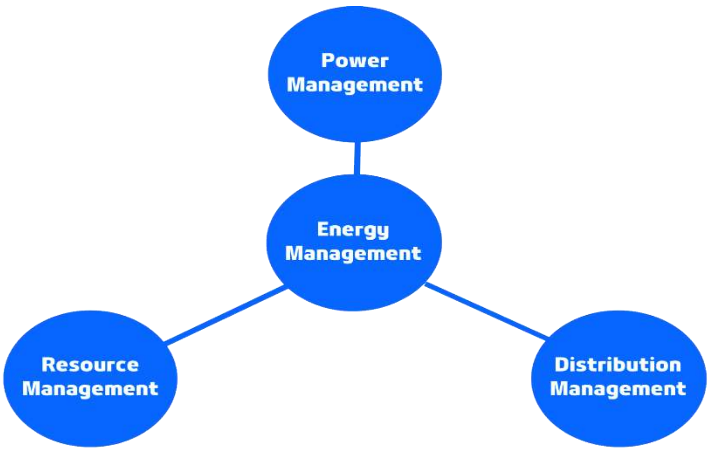

Figure 5.1 Stages of Microgrid management.

5.3 Microgrids and Energy Efficiency

In the past, large power plants at central locations supplied our electric grid. Transmission and distribution lines carry electricity from these power plants to end users. But as solar, wind, and battery storage technologies improve along with associated control systems and energy efficiency strategies, they may become more important than large centralized power plants.

In the past, electricity was generated at a central station. Also, transmission lines lose about 6% of power, which means additional costs for transportation. With distributed generation and microgrids, transmission losses could be reduced by at least 6%, making the system run better. And the odds continue to improve. Some microgrids are built to utilize direct current (DC) directly from the power supply. It could save an additional 7–30% of energy. Laptops and other solid-state devices run on DC power. Before the device can use the power, it is usually converted from direct current (DC) to alternating current (AC) so it can be sent through the high voltage lines. When we change from DC to AC and back to DC, we "use" an additional 7 to 30% of power.

These grids have two types of benefits: 1) potential economies of scale through big-scale grid construction, and 2) the value of load diversity, because it is unlikely that we will all turn on our appliances at exactly the same time. Our combined peak load exceeds the sum of our individual peak loads.

With microgrids and modern technologies, individuals can better manage their electricity by identifying its source and usage. This could assist them in saving money. For example, if I am responsible for my own peak load, I would probably buy energy-efficient appliances and smart controls so that the total amount of energy I use and the energy in the peak load are much lower than if the cost of energy-efficient technology was split evenly among all consumers.

Energy efficiency can also take advantage of microgrid resilience. For example, reducing energy waste ensures that a microgrid functions well and efficiently, reducing the need for on-site power generation. For example, a hospital that has upgraded its HVAC, insulation, lighting, and windows will use less of its microgrid when operating autonomously. This means that microgrids with limited fuel supplies can run longer or that less expensive generation equipment needs to be purchased at the beginning of the project.

Microgrids are one of several technologies that are changing the face of energy efficiency. More importantly, they work well with other ways to save energy. For example, microgrids can be made more efficient by using digital tools such as artificial intelligence, Internet of Things products, and smart meters to monitor energy use; by using combined heat and power plants to reuse waste heat; and by building power capacity for electric vehicles that can be charged when the power goes out.

By combining and linking new and old ways of saving energy, microgrids can make an important contribution to the energy transition and the transition to a world of active efficiency. Although there are still issues that need to be addressed before microgrids can be deployed at scale, such as the high cost of entry and the lack of a clear regulatory framework, the potential of microgrids can be magnified with a vision that looks to the future.

6. SIMULINK AND RESULTS

This study presents a design of an island microgrid structure with a novel renewable energy source that can generate electrical power for free and for 24 hours in simple and suitable ways. This source works in a hybrid system with a PV power system in a standalone microgrid. As we explained in previous sections, the thermoelectric generator had no mechanical component and produced electricity for free. The system design consists of thermoelectric generators and photovoltaic arrays as renewable energy sources connected to an MPPT dc-dc boost converter with a controlled off-grid DC-AC inverter with RLC filter to the load shown in Figure 6.1. Control of the microgrid is accomplished by utilizing the principles of power supply management and a distributed architecture. Maintaining a proper balance between power generation and consumption for maximum efficiency is a crucial aspect of power supply management. Because of the supply side management system, the proposed system reliably makes sure that loads are supplied without power loss.

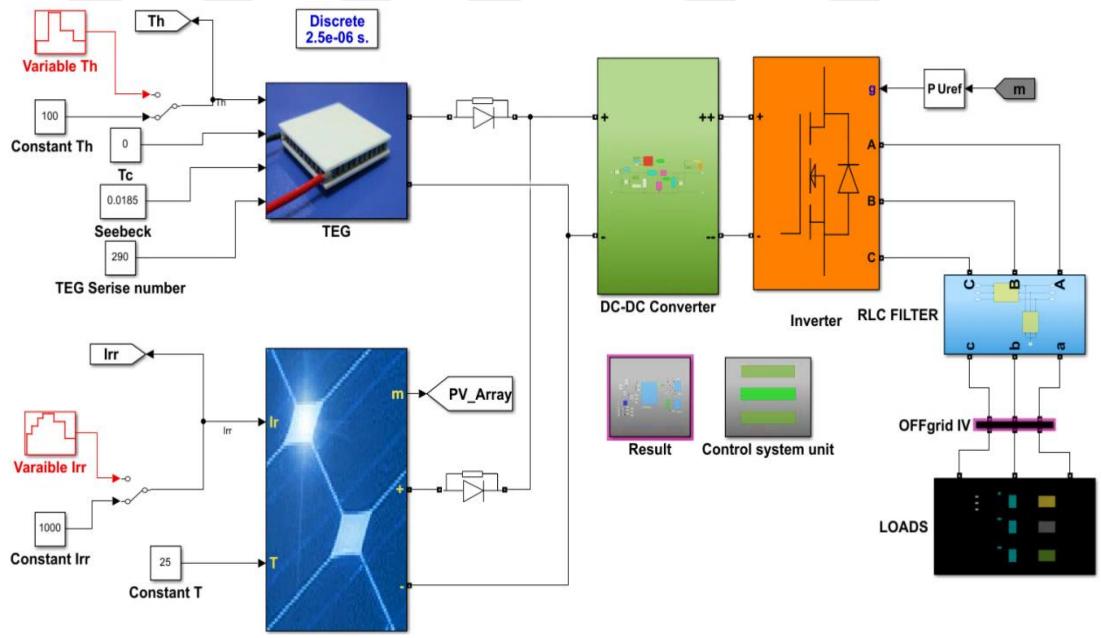

Figure 6.1 Whole proposed microgrid design in matlab environment.

6.1 Thermoelectric Generator Design

Full TEG module built by using Matlab environment. Figure 6.2 illustrate TEG system contain of three parallel group of thermoelectric generator each group have 290 module of TEG. ΔT Difference temperature in proposed TEG were 100°C with Seebeck coefficient 185 $\mu V.K^{-1}$. Also, in the internal circuit of TEG, the value of internal resistance R_{in} were 4 ohm. In the Simulink the power obtained in temperature and Seebeck coefficient. So, thermoelectric generator designed to get at maximum power point 53 kW. Table 6.1 is the datasheet of proposed TEG.

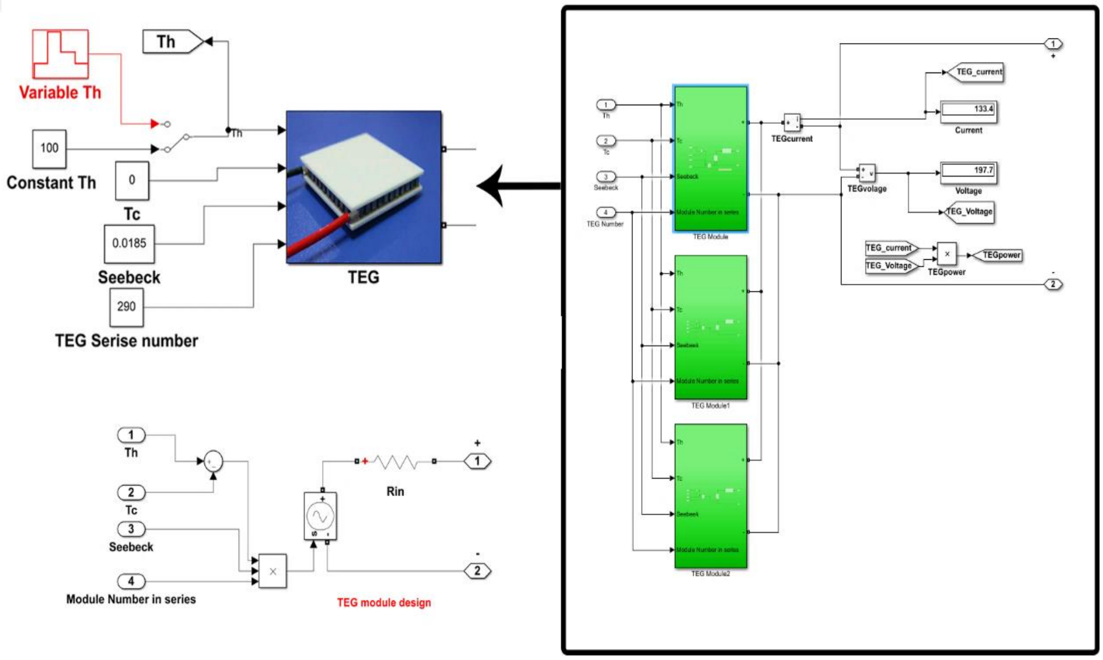

Figure 6.2 Thermoelectric generator design and the internal circuit diagram.

Table 6.1 TEG Parameter and datasheet for one module

Parameter	Value
Maximum difference temperature	100 °C
Open circuit voltage	1.85 V
Short circuit current	0.46 A
Internal resistance	4 Ω
Seebeck coefficient	185 $\mu V.K^{-1}$

Number of TEG	870/3

The output results of TEG in proposed Microgrid shown in Figure 6.3 under different hot temperatures.

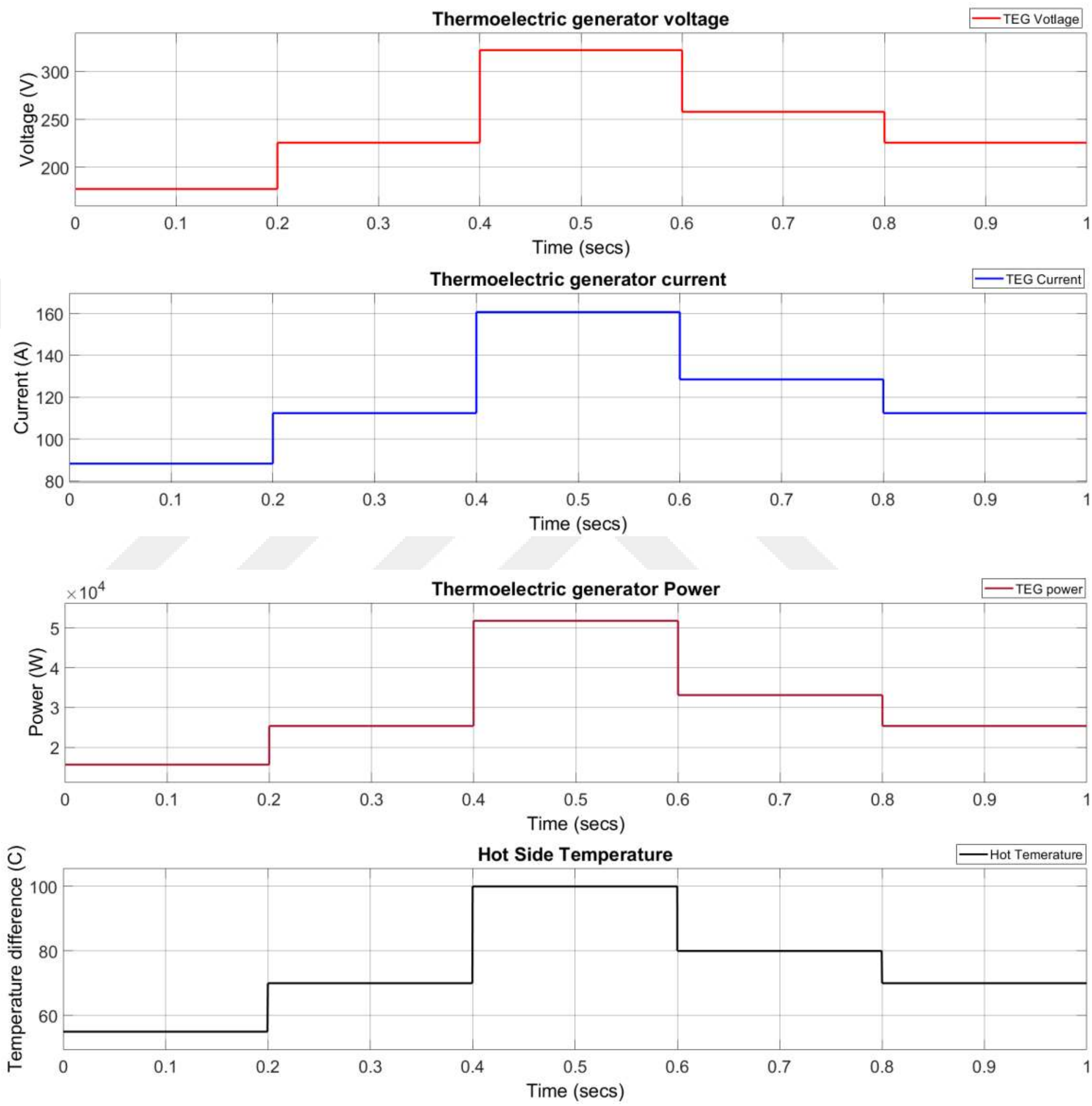

Figure 6.3 Thermoelectric generator Voltage, Current and Power under different temperature.

6.2 Photovoltaic PV Design

In this system, there are 20 parallel and 15 series connected modules per string. In this study, all PV results assumed the temperature of cell is constant. The maximum power is 230w per panel with open circuit voltage 36.5V and short circuit current 8.1A. Figure 6.4 shown the Photovoltaic in Matlab environment.

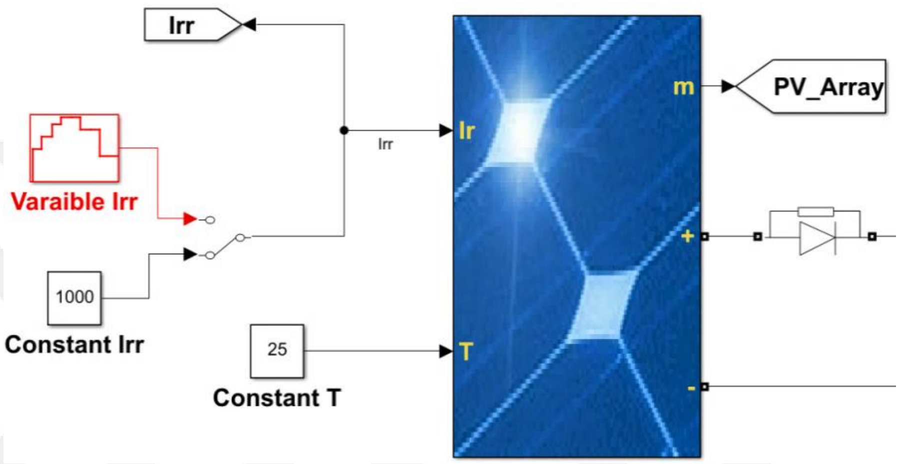

Figure 6.4 Photovoltaic design in Simulink.

Array type A10 Green Technology A10-M60-230 proposed in this study. As shown in Figure 6.5 IV-PV characteristics of chosen photovoltaic array depending on different irradiation in constant temperature 25°C.

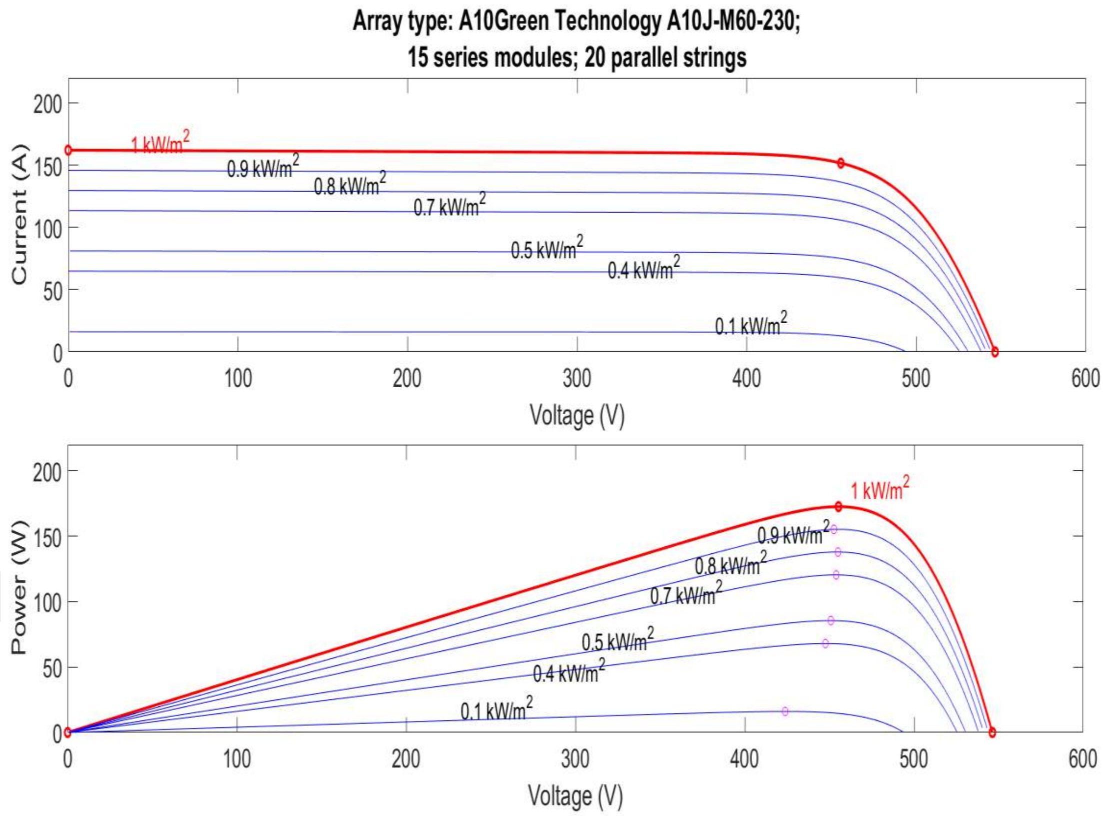

Figure 6.5 Photovoltaic PV- IV characteristics.

Datasheet of proposed PV array A10 Green Technology A10-M60-230 shown in Table 6.2.

Table 6.2 Parameter and datasheet for one PV module

Parameters	Values
Maximum power	230W
Cell per module	60
Open circuit voltage	36.4 V
Short circuit current	8.1 A
Voltage at maximum power point	30.36 V
Current at maximum power point	7.58 A

Photovoltaic voltage, current and power in proposed microgrid shown in Figure 6.6.

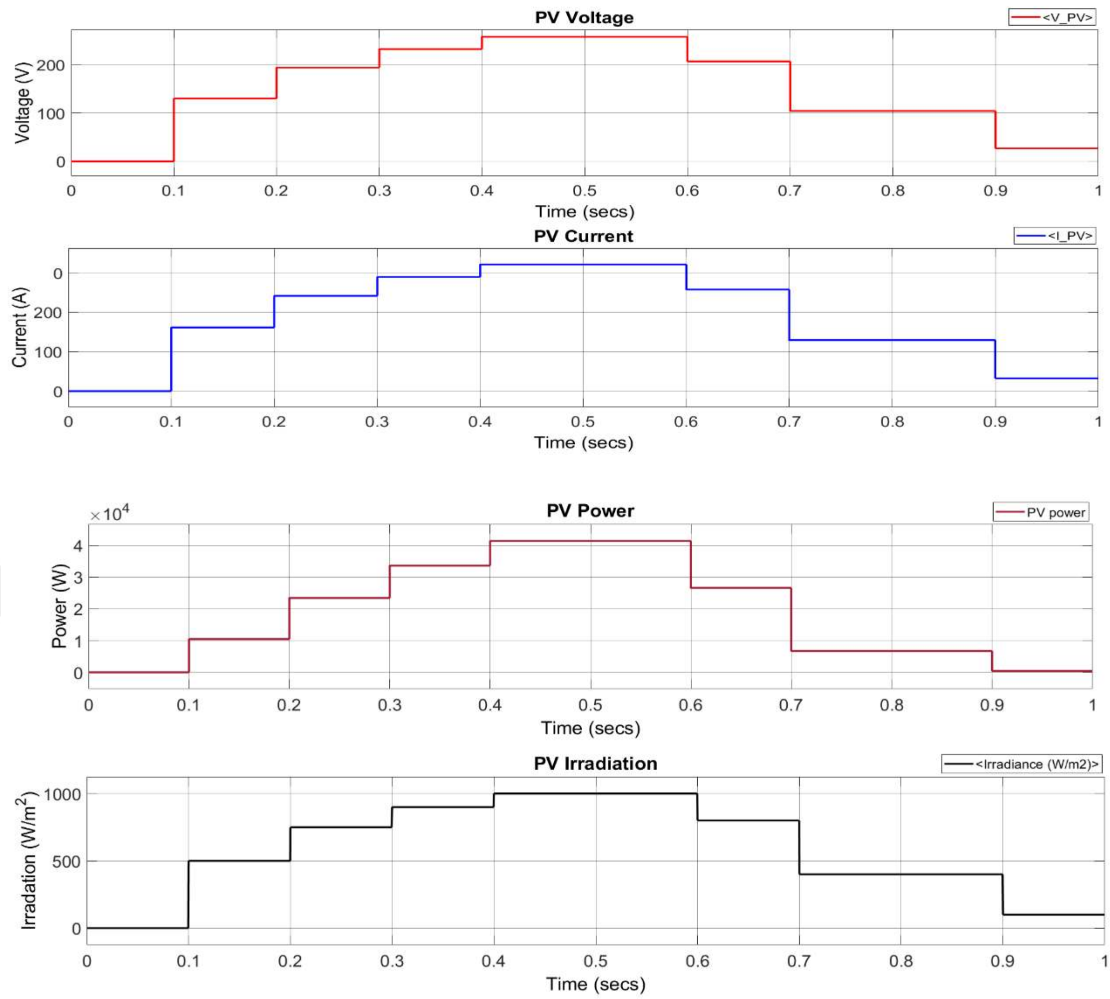

Figure 6.6 PV Voltage, Current and Power under different irradiation.

6.3 MPPT DC-DC Boost converter

Our proposed boost converter is linked to a TEG and PV array on one side and an off-grid DC-AC inverter on the other. Under standard test conditions (STC), the maximum voltage generated from renewable energy sources has a maximum input voltage of roughly 363.9 volts and a maximum output voltage of approximately 908 volts. A DC-DC boost converter's components are a switching device, a diode, an inductor, and a capacitor. In the simulation, a typical power diode and a power MOSFET switching device are selected since they are frequently used in low-to medium-power applications. The Boost converter is controlled by the MPPT P&O algorithm. Selected parameters in the boost converter: L = 0.5mH and C = 4.5mf. The Figure 6.7 shows the DC-DC boost design in Matlab.

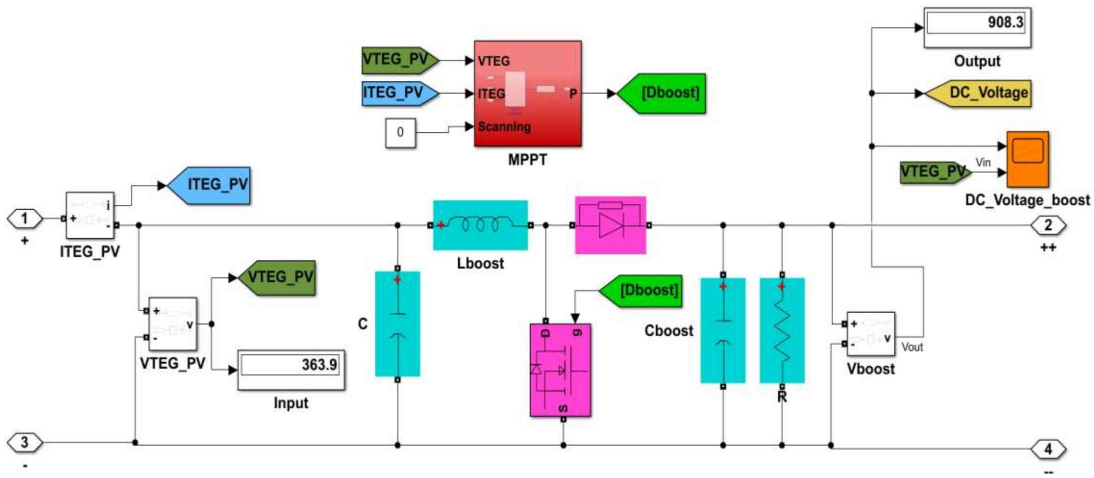

Figure 6.7 P&O Controlled MPPT boost converter.

The duty cycle in MPPT P&O algorithm shown in Table 6.3.

Table 6.3 P&O algorithm parameters

Parameters	Value
Duty cycle initial value	0.6
D limits [Upper, lower]	[0.9, 0.7]
Increment value for P&O algorithm	0.05
Measurement filter cutoff frequency	20000
Scanning mode duration	0.0005

Boost converter input and output voltage shown in Figure 6.8. Also, the duty cycle for MPPT shown in Figure 6.9.

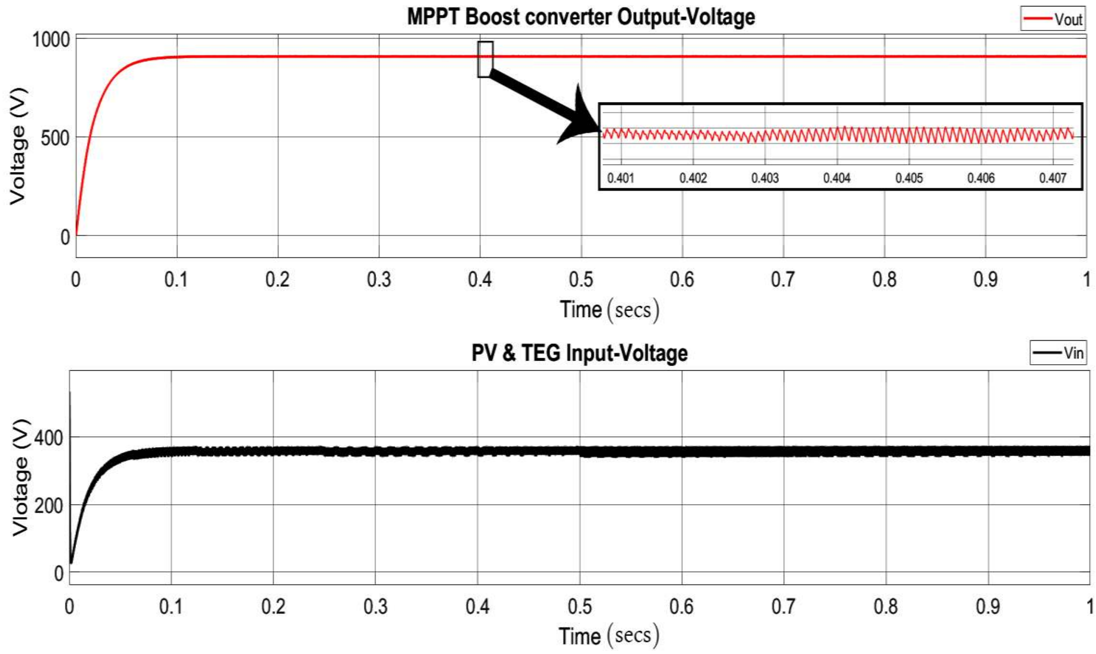

Figure 6.8 Output and input voltage for MPPT boost converter.

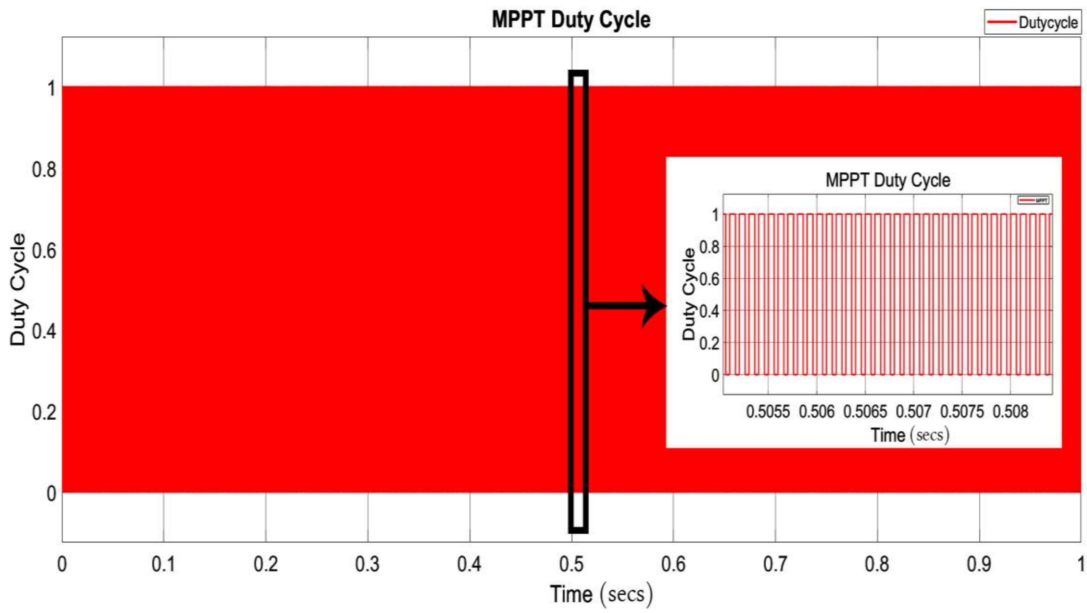

Figure 6.9 MPPT duty cycle.

6.4 Off Grid DC-AC Inverter

Off-grid inverters are designed and controlled for use in island microgrid. Pure three-phase signal voltage is generated to supply the proposed loads. Off-grid inverters are intended to operate independently and cannot be synchronized with the grid. Off-grid inverters must immediately convert DC to AC to power appliances. It must react rapidly and at or above the inverter's capacity rating. It draws electricity from the boost converter and transforms it to AC. So, Figure 6.10 shows off-grid inverter control in Simulink. Also, Figure 6.11 shows the duty cycle of our proposed inverter.

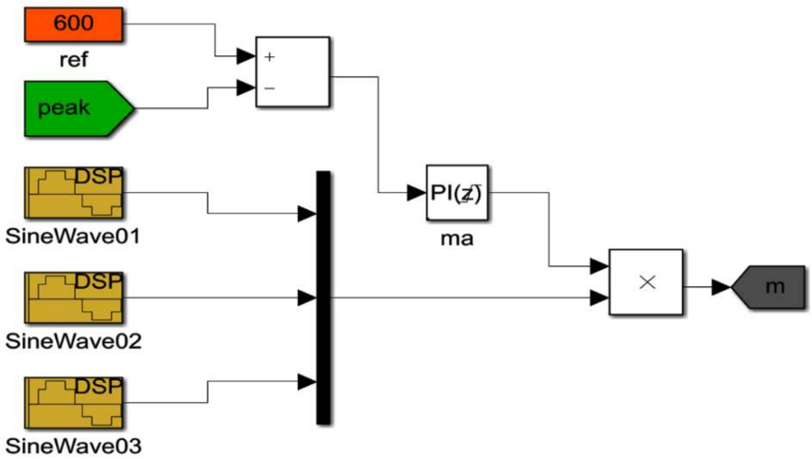

Figure 6.10 Off grid inverter control.

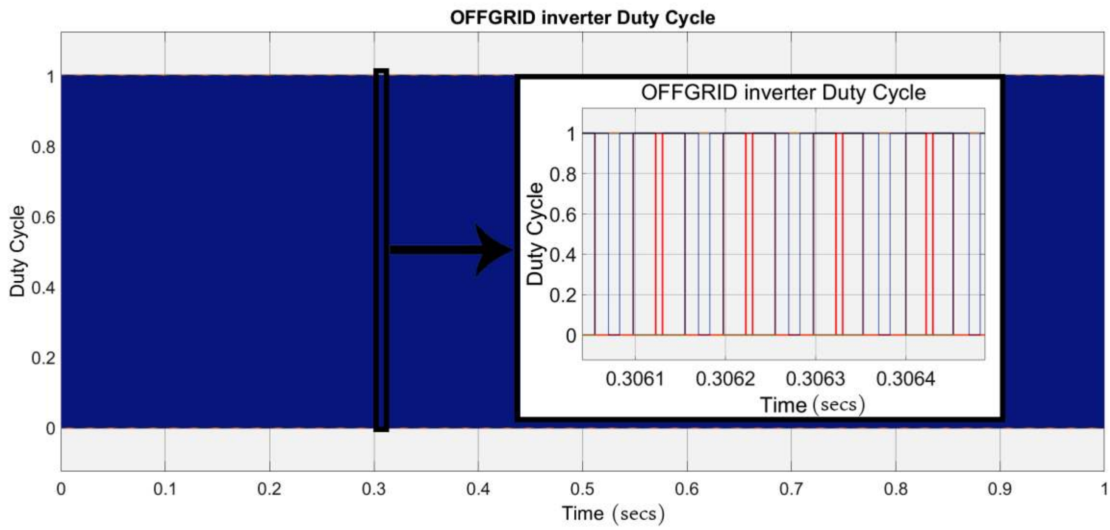

Figure 6.11 Off grid inverter duty cycle.

6.5 Loads and Energy Management

In a large scale grid, load management is usually a contingency plan of last resort. In a community microgrid, load management becomes a much more important function because there are fewer generation resources available to maintain islanded operations. Since the purpose of the community microgrid is to increase the efficiency and reliability of the power supply, the selection of controlled loads must be done carefully to ensure the necessary flexibility of the system. This study discusses the load management system. In the designing of microgrids, all loads can be divided into three types: essential loads, secondary loads, and non-essential loads.

1) Essential loads

These are the most important loads within the Microgrid, as they cannot fail for any reason. Local hospitals, clinics, and dispatch centers are examples.

2) Secondary loads

Loads that can be temporarily removed or replaced with another sources to alleviate peak loads. These are loads that can be removed when there is not enough power energy supported. Example: HVAC equipment (heaters, fans and air conditioners), hot water heating, pool filtration, washers and dryers.

3) Non-essential loads

These loads operate when there is a surplus of electrical power. These loads are dropped when there is no surplus power from renewable energy sources to maintain the stability of the microgrid and prevent a power outage. For example, residential loads and business facilities with backup generators. In the event of an initial non-essential activation, the emergency generators can be started remotely in advance, reducing the load on the microgrid system. Figure 6.12 shows the smart meters with proposed loads.

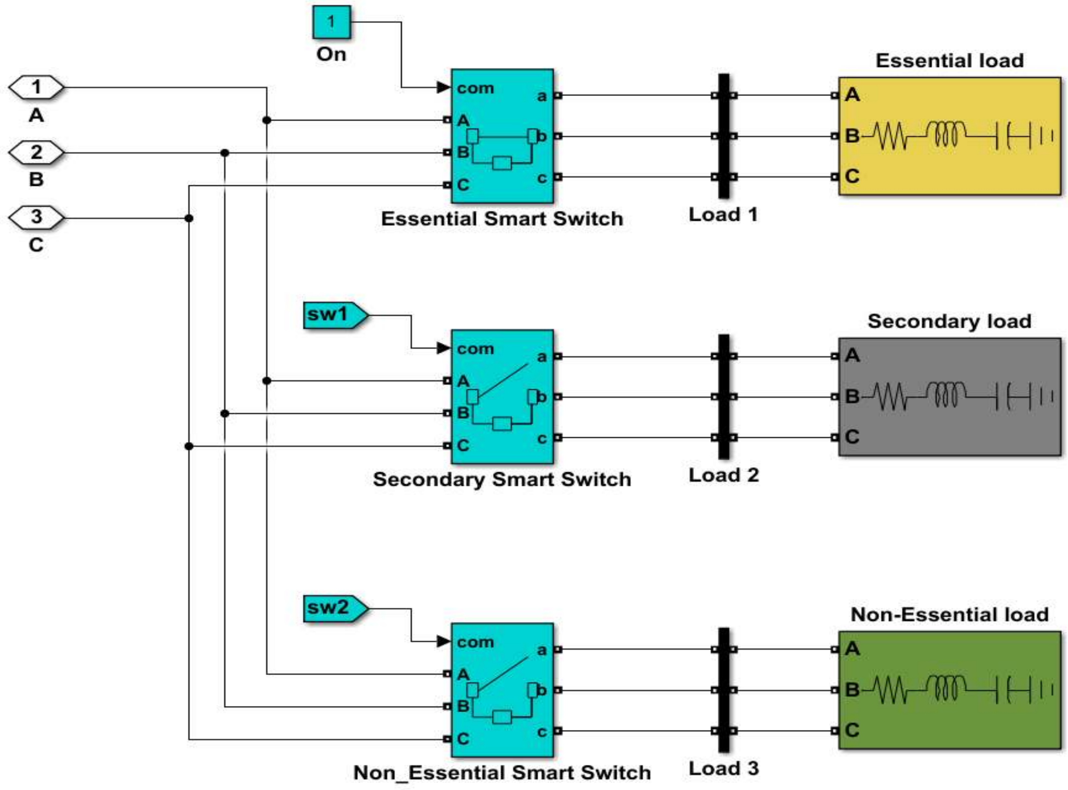

Figure 6.12 Three RLC loads design with smart meters.

In this study, a fuzzy logic controller is implemented to control our proposed loads according to available PV and TEG power supplies. The load unit system control is shown in Figure 6.13.

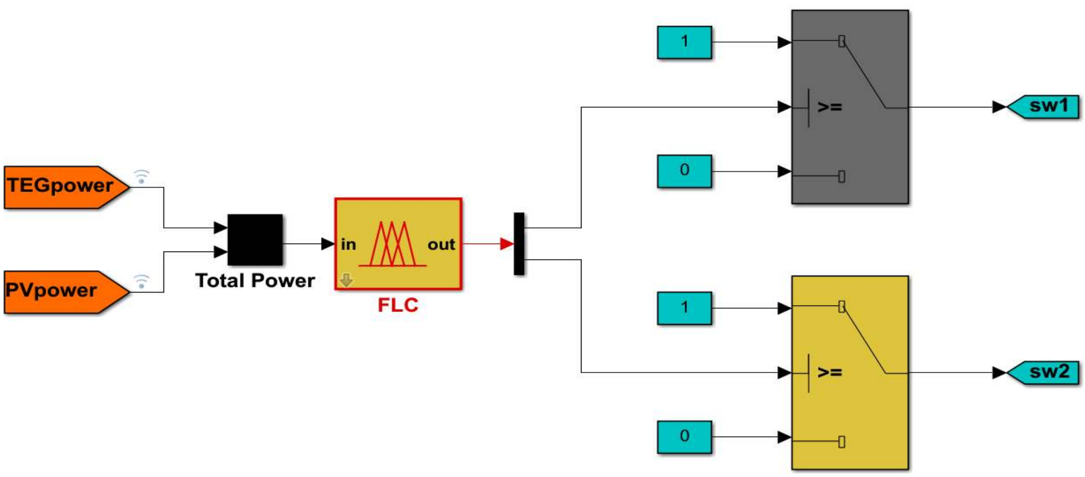

Figure 6.13 Fuzzy logic load control unit in proposed Microgrid.

In the proposed study, two fuzzy logic functions to control secondary and non-essential loads separately designed and illustrated in figure 6.14.

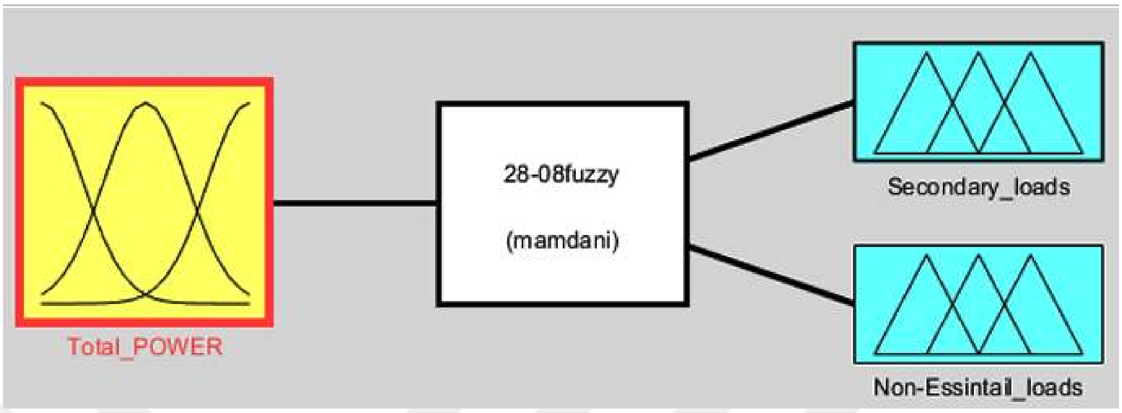

Figure 6.14 Input and output design of fuzzy logic control.

The input side of each fuzzy control has four trimf type membership functions (low – normal – high) as shown in figure 6.15.

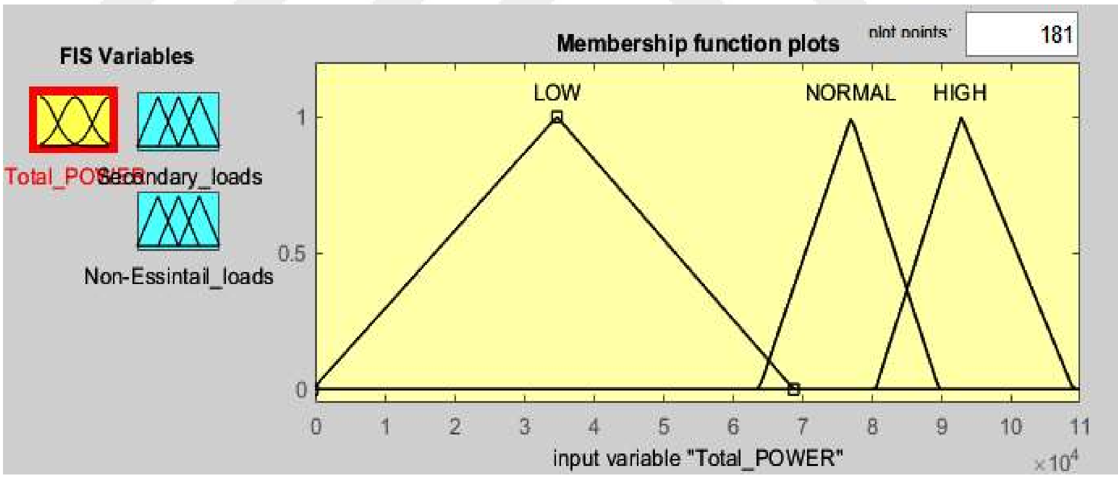

Figure 6.15 Membership function for total power in Fuzzy logic.

Figure 6.16 show the each membership has parameters to interface with the load side. On the load side, there are two memberships (ON–OFF) to control load according to available power.

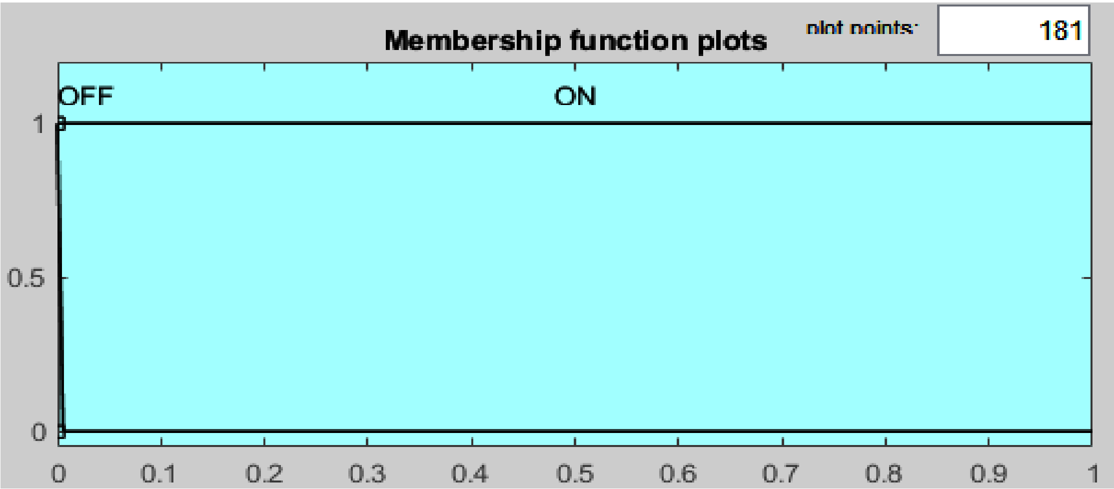

Figure 6.16 Membership functions for Secondary and non-essential load.

The fuzzy logic rule strategies depended on the amount of generated power. The Figure 6.17 illustrate the rules of proposed control.

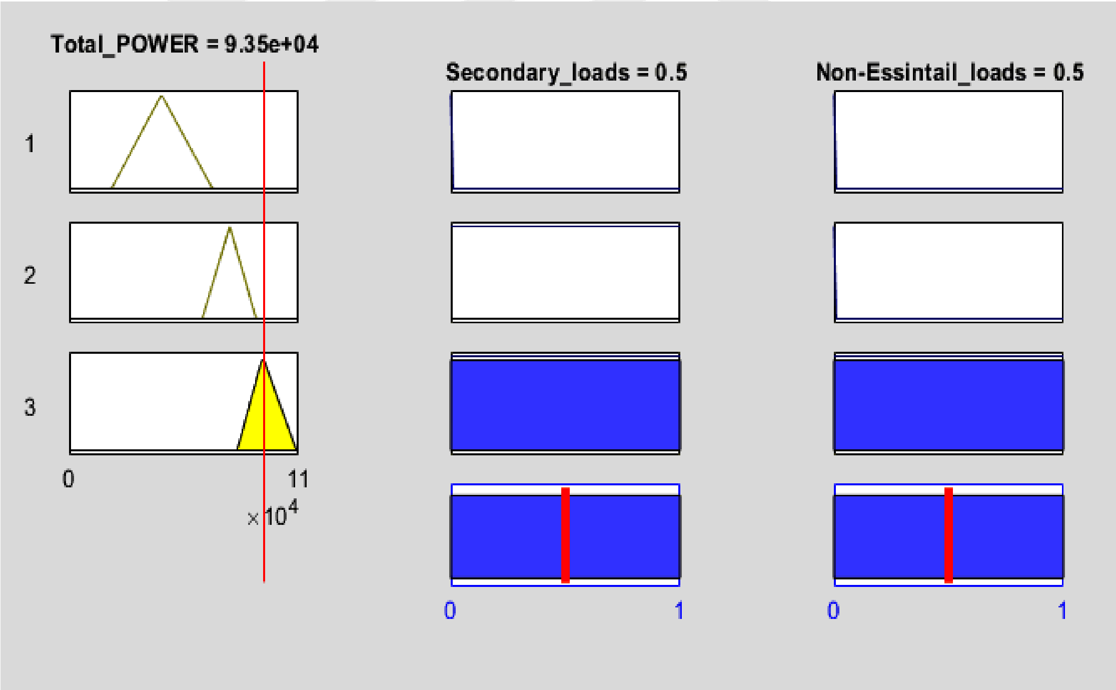

Figure 6.17 Secondary and non-essential load fuzzy logic rules with total power.

In this thesis, four scenarios applied to proposed standalone microgrid to test our island load operation according to our control algorithm.

- **Scenario 1**

In this scenario, constant photovoltaic power is generated (irradiation = 1000 W/m2) with variable TEG power (different temperatures). The figure 6.18 shown the forecasted weather of sunny day with different temperature applied on the hot side of thermoelectric generator.

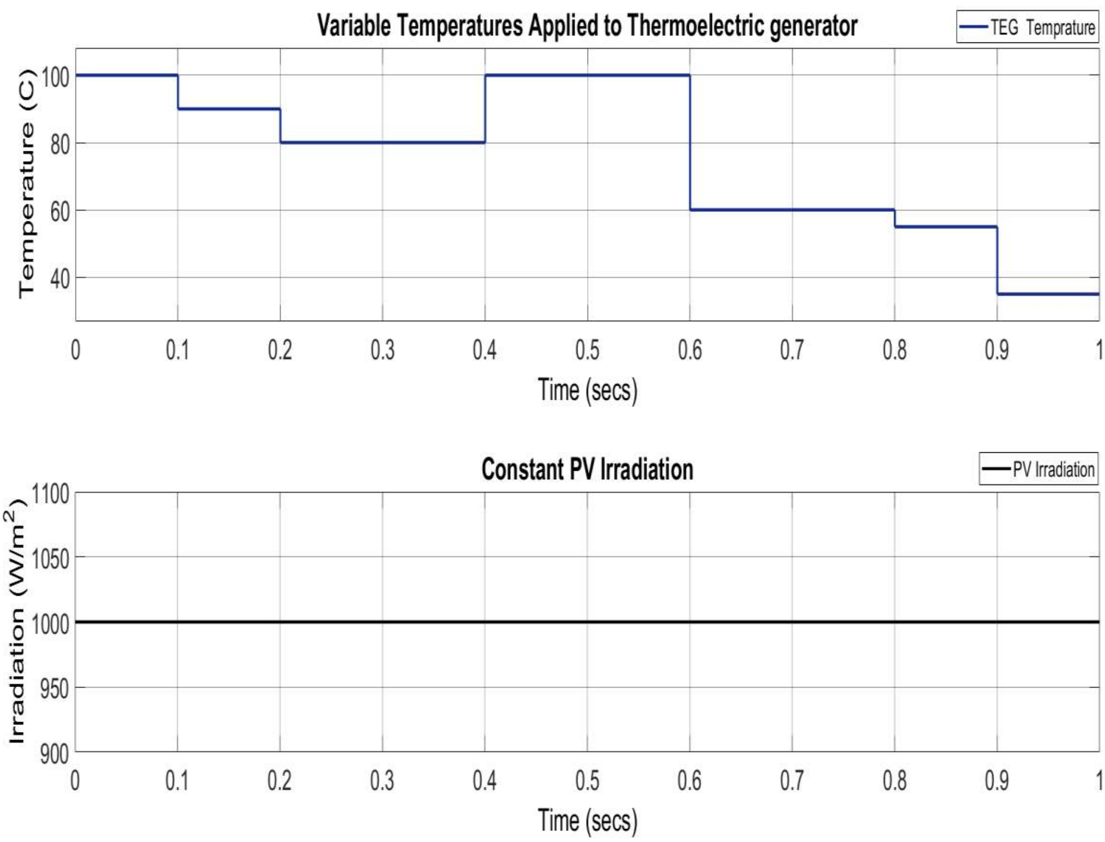

Figure 6.18 Constant photovoltaic power generated (irradiation = 1000 W/m2) with variable TEG power (different temperature).

In this scenario, the essential load in ON mode from the beginning of Simulink and also the secondary load. When the hot temperature of TEG is raised to 100 °C, the generated power increases. Then, the proposed control sends a signal to close the switch of the third load (non-essential load) Figure 6.19.

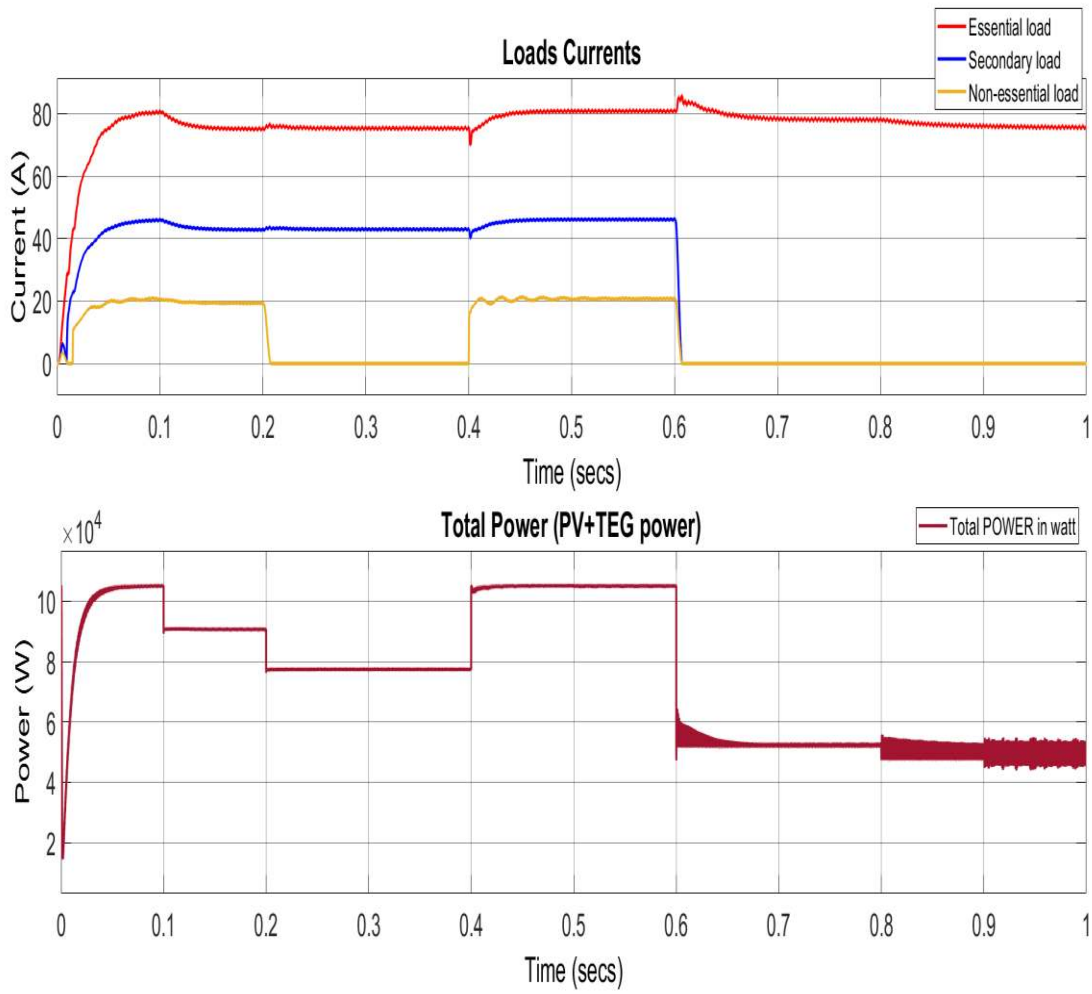

Figure 6.19 Load management in case of constant photovoltaic and different TEG power.

- **Scenario 2**

In this case, we assumed constant TEG with variable PV power. In other words, the hot temperature (100 °C) was constant and changed the PV power according to irrational change from 100, 400, 500, 800, 900 and 1000 (W/m2). Figure 6.20 shows the constant temperature in TEG and the forecasted value of PV irradiation.

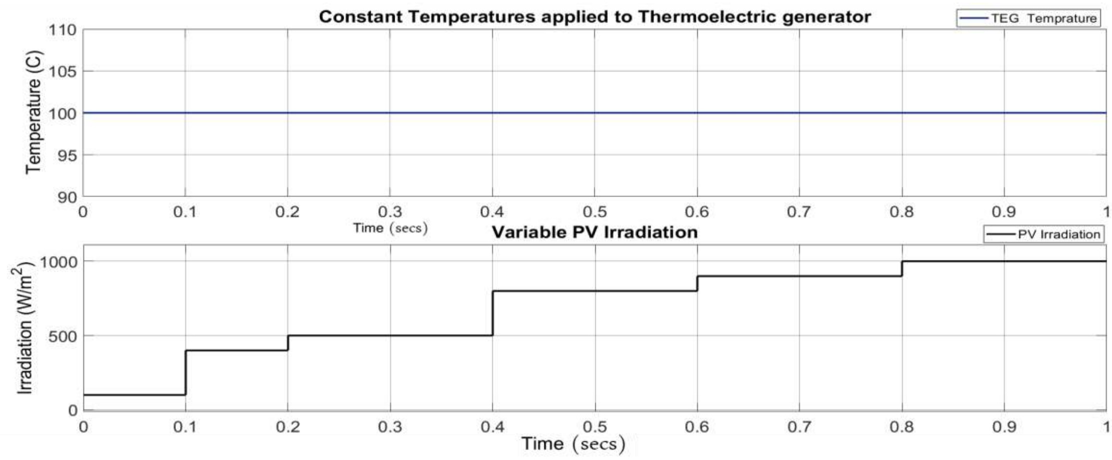

Figure 6.20 Variable photovoltaic irradiation with constant temperature applied to the hot side of TEG).

The Figure 6.21. Illustrated microgrid system operation between supply and demand essential and secondary loads in on mode. At 0.1 second the power is increased and fed the secondary loads then at 0.4 second the non-essential load is supplied directly from sources without any waste in energy.

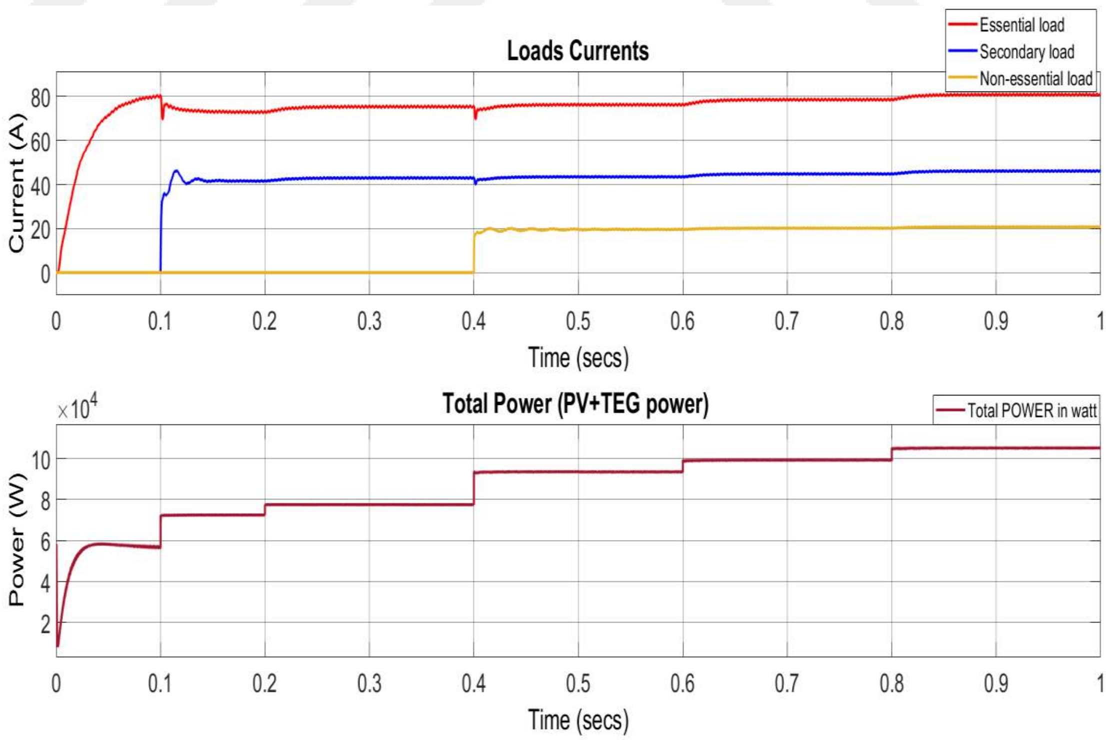

Figure 6.21 Load management in case of variable photovoltaic and constant temperature on TEG).

- **Scenario 3**

As shown in Figure 6.22, Different values of TEG hot temperature with different irradiation values are tested.

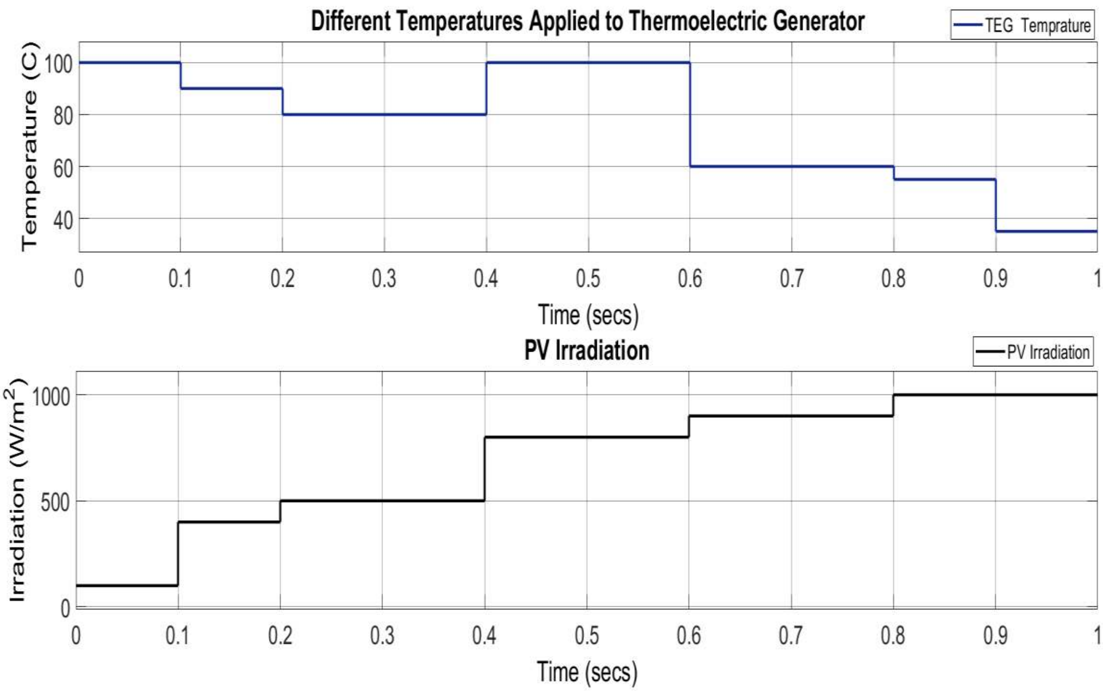

Figure 6.22 Variable photovoltaic with variable temperature on TEG.

In this case, it demonstrates the loads working according to the presented algorithm. All loads are working according to the amount of available power. In 0.4 sec, the fuzzy logic controller sends signal to feed the secondary and non-essential loads from surplus power. When the power decreased as shown in 0.6 second the secondary and non-essential loads became out of system. So, the reducing in power will shedding the loads according to proposed algorithm as shown in figure 6.23.

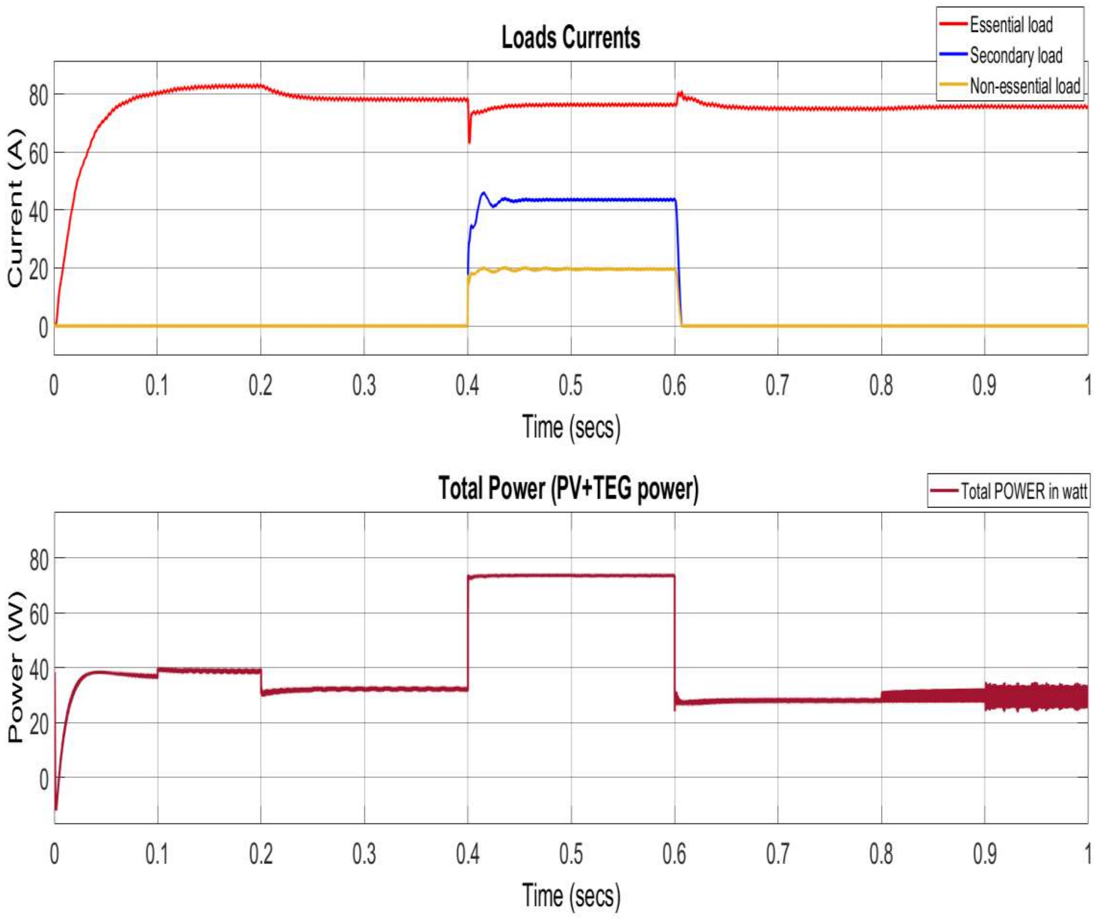

Figure 6.23 Load management in case of variable TEG with variable PV power.

- **Scenario 4**

In this scenario, as shown in figure 6.24, 100°C is applied on the hot side of the proposed TEG and 1000W/m2 of irradiation is assumed in PV.

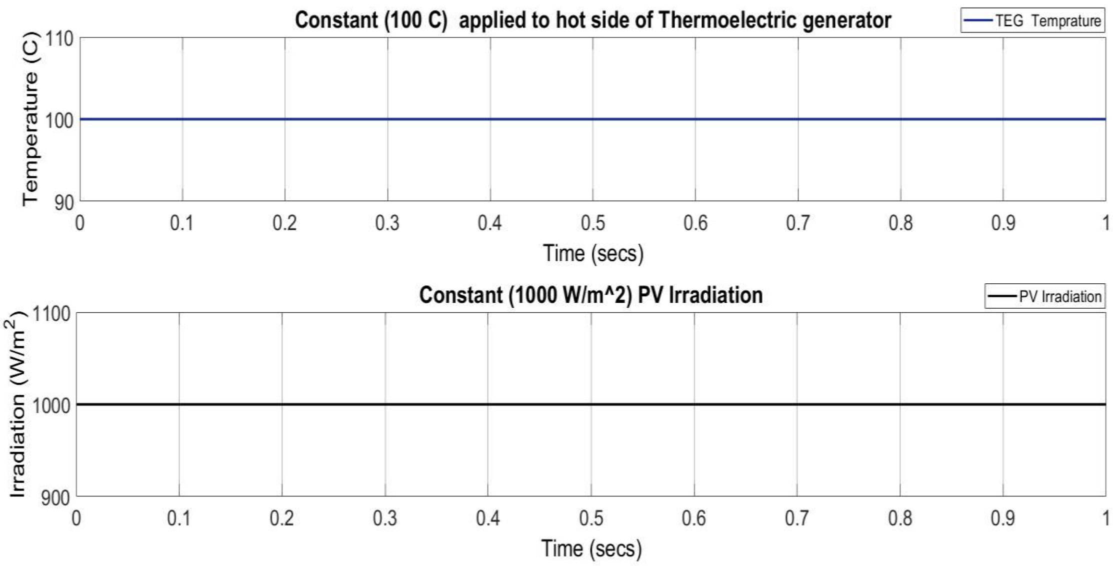

Figure 6.24 Constant photovoltaic irradiation with constant temperature on TEG.

The results in Figure 6.25 show all loads supplied from the renewable energy sources without wasting energy.

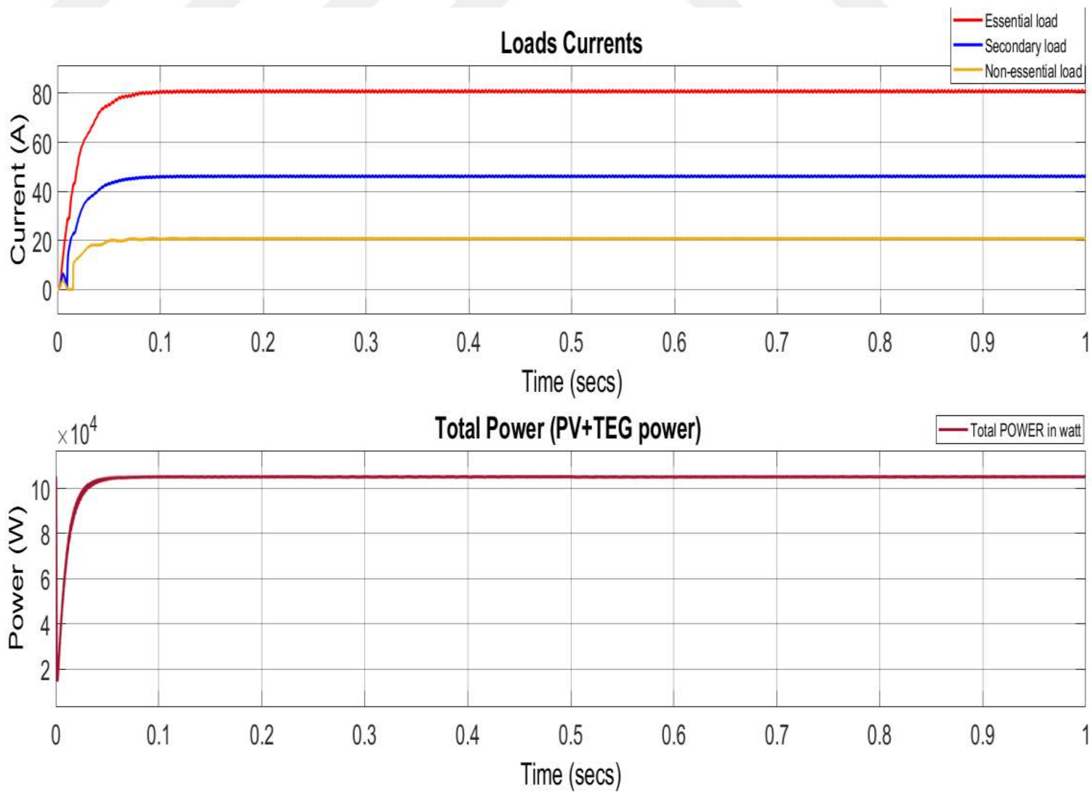

Figure 6.25 Load management in case of constant TEG with constant PV power.

All of that in constant and smooth output voltage as shown in Figure 6.26.

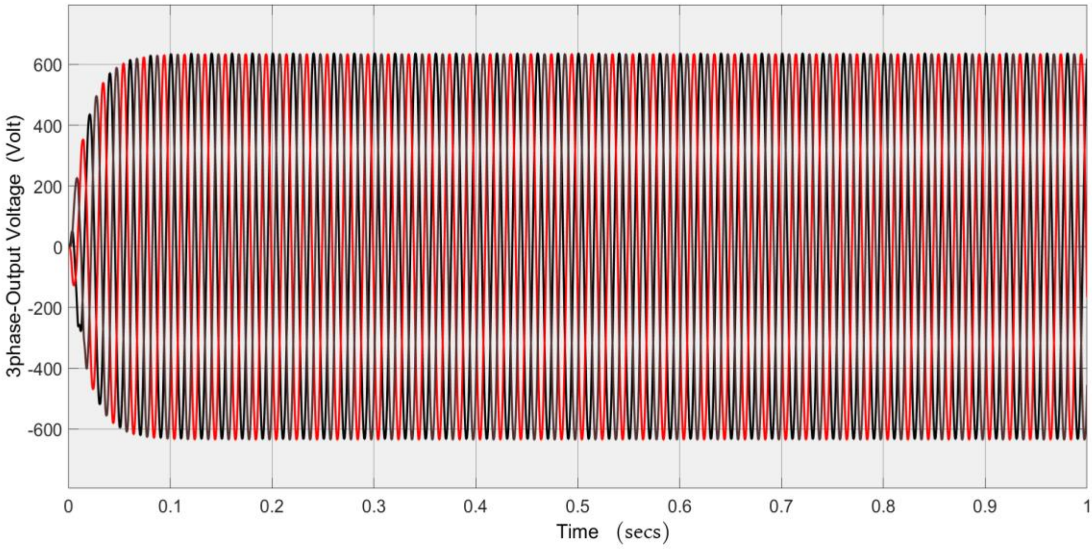

Figure 6.26 Output voltage of proposed Microgrid system in STC.

7. CONCLUSION

In this study, we implemented a standalone microgrid consisting of solar energy and a thermoelectric generator, so this study depended on renewable energy. The study was simulated using Matlab-Simulink. Our implemented microgrid was distinguished by the absence of a battery storage system, and this will reduce the cost of the microgrid. A thermoelectric generator was implemented to generate electrical energy throughout the day and for 24 hours if conditions are met. Our presented island microgrid can be implemented in remote areas that have hot springs where the hot water can be used to generate electrical energy as a natural and renewable source. Additionally, in this study, a fuzzy logic algorithm was designed to control demands based on the amount of generated power to use energy without much wasting throughout the day. Finally, we think this study has been of great benefit in managing RLC loads and maintaining the stability and efficiency of the microgrid and its protection.

8. RECOMMENDATION

In this study, we recommend our presented microgrid be implemented in areas that contain hot springs, which have natural hot water that is used to operate these thermoelectric generators. Additionally, it was also shown in the results that load management has a significant impact on the stability and efficiency of a microgrid. Therefore, any microgrid system should not be devoid of an intelligent program to manage loads, especially in isolated microgrids. Also, it is possible to improve and develop this system by using other control algorithms in addition to improving the output signals.

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