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Title:

Energy management system for hybrid renewable energy system

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ABSTRACT

Conventional power system is mainly based on fossil fuel power plant. The latter is huge source of pollution while its primary energy, fossil fuel, is being rapidly depleted. However, some remote loads and villages cannot benefit from this electric energy for the raison that there is no network. Renewable off-grid electricity supply is one alternative that has gained attention especially for those types of load or villages. The aim of this project is to present an optimal hybrid energy system to meet the electrical demand in a reliable and sustainable manner for an off-grid remote village.The proposed system is composed of Photovoltaic source, diesel generator and battery storage. In fact, solar energy source alone cannot meet the requirement of micro-grids or remote loads in terms energy. Therefore, diesel and a battery are associated to store and supply power when there is excess and lack of power respectively.Anenergy management system to control the hybrid system is proposed. It is built based on three goals which are: (i) energy demand satisfaction; (ii) system cost reduction; and (iii) reduction of gas emission.Obtained results have showed that the proposed energy management system accurately uses solar energy source to minimize operation of Diesel and battery.

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General introduction

At the time unfortunately up to 1,2 billion people have no access to electricity according to the Global Tracking Framework published by the World Bank (World Bank, 2017)[1]. Eighty per cent of these people live in rural areas, in Asia and Africa in particular. Although great progress has been made in developing countries towards rural electrification over the past 20 years, there is still a lot to improve. Access to electricity is a vital enabler for social development, public health problems tackling. 100% global electrification is therefore an absolute priority for many global organizations and governments. The problem is: supplying electricity to remote areas is far from being easy business. Two options can be considered: connection to an existing grid or design of a local micro-grid.

The second choice is often the most appropriate for remote locations where building a grid connection would be complex and very expensive. Many micro-grids already supply electricity to remote communities and they are most of the time powered by diesel or gas generator sets. It appears now that fossil fuel power generation is not the optimal solution for remote micro grids. Hybrid power plants including distributed generation (fossil fuel genset + renewable energy source) and energy storage system are often more appropriate for two main reasons;

- Hybrid power plants allowing reduction fossil fuel appears therefore to be a better solution for providing electricity in remote locations,
- Design of hybrid power plants for isolated systems is lesser expensive solution.

A micro-grid can be supplied by different types of renewable energy resources (RE) and micro-power plants such as hydropower. However, in this report, we will concentrate on the micro-grids that are supplied by solar PV sources backed with a battery electric storage system (BESS). Such hybrid micro-grids allow generation energy to meet demand by synchronizing RE technologies with existing diesel generators. The bidirectional nature of the power flow on the BESS can charge an electrical battery storage system whenever excess energy is available from a renewable source or using a diesel generator. It can act as a direct current–alternating current (DC–AC) converter whenever energy is required from the battery. [2], as part of a control strategy, at the time the demand load exceeds the supply capacity of the diesel generator.

The report will investigate the energy management of hybrid system that will be used to feed power to remote load with known load profile. Therefore, the report is organized as follows:

Chapter 1 presents Hybrid renewable energy system in general while chapter 2 deals with control of the components of the HRES. Simulation of the whole system and results discussion are presented in chapter 3. Cost analysis and comparison using well known dedicated software “HOMER” are investigated in chapter 4.

1.1. Introduction

Recently, Hybrid Renewable Energy Systems (HRES) have gained reputable popularity, and gained huge interest among research studies for modelling, simulation, and optimization. This is a system which combines two or more renewable energy sources. The main drivers of a HRES are costs associated with conventional/traditional energy systems, reduction of emissions, negative impact on health and environment and optimization of systems [3, 4]. The current global deviation from fossilized remains of dead plants and animals (which are considered non-renewable resources) formed over extensive heat and pressure formation on the earth over millions of years [5] to renewable resources has further enhanced research in this area. The HRES also have the potential for energy balancing of systems, stability, and reliability for areas with little or no access to electricity, with the design and modeling of the HRES unique to each case study. Ongoing research and investigation persists in improving its efficiency, performance, and integration with renewable energy sources such as solar, wind and other renewable energy technologies. However, the design is usually aimed at solving an optimization problem. An exact one-size-fits-all solution is not realistic, due to the number of dynamic variables, complexities, and non-linearity in performance of systems. Therefore, the defining terms for optimal solution in a case study vary as a function of energy balance and management, support of existing infrastructure, optimal sizing of system and component parts, control strategies, and so on as stipulated by location and researcher [5].

1.2. Types of micro-grid

According to IEEE standards a micro-grid is a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A micro-grid can connect and disconnect from the grid to enable it to operate in either grid-connected or island mode. Additionally, the micro-grid's operational controls need to be fully coordinated when connected to the main power grid or while islanded, requiring additional equipment, communications and control applications. There are three main types of micro-grids, remote, grid-connected and networked[6].

1.2.1 Remote Micro-grids

Also known as off- micro-grids, they are physically isolated from the utility grid and operate in island mode at all times due to the lack of available and affordable transmission or distribution (T&D) infrastructure nearby. For these remote scenarios, renewables, such as wind and solar, typically provide a more economic and environmentally sustainable DER solution for the micro-grid operator. Additionally, many remote micro-grids are considering battery energy storage systems for backup power in lieu of conventional generators.

1.2.2 Grid-connected micro-grids

These micro-grids have a physical connection to the utility grid via a switching mechanism at the point of common coupling (PCC), but they also can disconnect into island mode and reconnect back to the main grid as needed. In grid-connected scenarios, a micro-grid that is effectively integrated with the utility service provider can provide grid services (e.g., frequency and voltage regulation, real and reactive power support, demand response, etc.) to help address potential capacity, power quality and reliability, and voltage issues on the utility grid.

In islanded scenarios, local voltage and frequency controls are required within the micro-grid and can be provided by energy storage (e.g., battery, flywheel) or a synchronous generator (e.g., CHP, natural gas, fuel cell diesel). Due to its ability to perform multiple functions for grid services and emergency backup power, battery energy storage systems have been gaining popularity for micro-grids that need to operate in both grid-connected and island modes. When serving a relatively small geographic area, grid-connected micro-grids demonstrate economic viability for educational campuses, medical complexes, public safety, military bases, agricultural farms, commercial buildings and industrial facilities.

1.2.3 Networked Micro-grids

These systems, also known as nested micro-grids, consist of several separate DERs and/or micro-grids connected to the same utility grid circuit segment and serve a wide geographic area. Networked micro-grids are typically managed and optimized by a supervisory control system to operate and coordinate each grid-connected or island mode at different tiers of hierarchy along the utility grid circuit segment. Community micro-grids, smart cities and new utility adaptive protection schemes (e.g., closed-loop self-healing) are examples of networked micro-grids.

1.3. Need for Hybrid Energy Systems

One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extension is costly and the cost of fuel increases. Recent research and development in Renewable energy sources have shown excellent potential, as a form of supplementary contribution to conventional power generation systems.

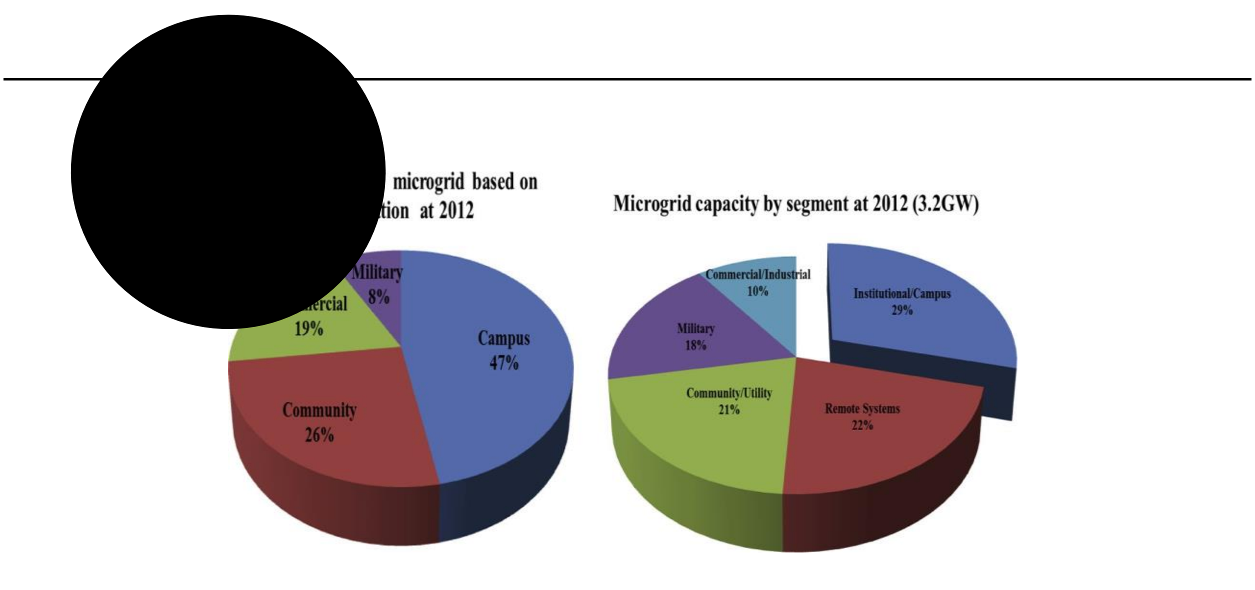


Fig. 1.1 The classification of micro-grid based on application

In order to meet sustained load demands during varying natural conditions, different energy sources and converters need to be integrated with each other for extended usage of alternative energy. Renewable energy sources, such as photovoltaic, wind energy, or small scale hydro, provide a realistic alternative to engine-driven generators for electricity generation in remote areas. It has been demonstrated that hybrid energy systems can significantly reduce the total lifecycle cost of standalone power supplies in many situations, while at the same time providing a more reliable supply of electricity through the combination of energy sources [7].

Solar and wind energy are non-depletable, site dependent, non-polluting, and possible sources of alternative energy choices. Many countries with an average wind speed in the range of 5–10 m/s and average solar insolation level in the range of 3–6 KWh/m2 are pursuing the option of wind and PV system to minimize their dependence on fossil-based non-renewable fuels. A merging of solar and wind energy into a hybrid generating system can attenuate their individual fluctuations, increase overall energy output, and reduce energy storage requirement significantly. It has been shown that because of this arrangement, the overall expense for the autonomous renewable system may be reduced drastically [8].

Nowadays, the integration of PV and wind system with battery storage and diesel backup system is becoming a viable, cost-effective approach for remote area electrification. Wind and solar systems are expandable, additional capacity may be added as the need arises. Moreover, the combination of wind and solar PV system shrinks the battery bank requirement and further reduces diesel consumption [8].

The prospects of derivation of power from hybrid energy systems are proving to be very promising worldwide. The use of hybrid energy systems also reduces combustion of fossil fuels and consequent CO_2 emission which is the principle cause of greenhouse effect/global warming. The global warming is an international environmental concern which has become a decisive factor in energy planning. In wake of this problem and as a remedial measure, strong support is expected from renewables such as solar and winds. The PV–wind hybrid energy system using battery bank and a diesel generator as a back-up can be provided to electrify the remotely located communities (that need an independent source of electrical power) where it is uneconomical to extend the conventional utility grid. All possible advantages of a hybrid energy system can be achieved only when the system is designed and operated appropriately [8].

1.4. Pre-feasibility Analysis of Hybrid Energy Systems

Climate conditions determine the availability and magnitude of wind and solar energy at a given site. Pre-feasibility studies are based on the weather data (wind speed, solar insolation) and specific site load requirements. Appropriate weather data are required to calculate the performance of an existing system or to predict energy consumption or energy generated from a system during the design stage. The global whether data could be obtained from internet and other sources like local metrological station. The global weather pattern is taken from NASA surface metrological station shown in Figs 1.2 and 1.3. In Fig 1.2 the red and yellow indicate high wind energy is available while the blue colors reflect lower wind energy potential zone. Fig 1.3 shows the World Solar Energy Potential. Wind and solar hybrid system can be designed with the help of these global weather patterns, for any location all over the world. Deciding on the best feasible solution will need to be done, on a site-to-site basis. Some sites can be best serviced by mains or grid power, others by generators, and some by combinations of the renewable energy solutions described above [7].

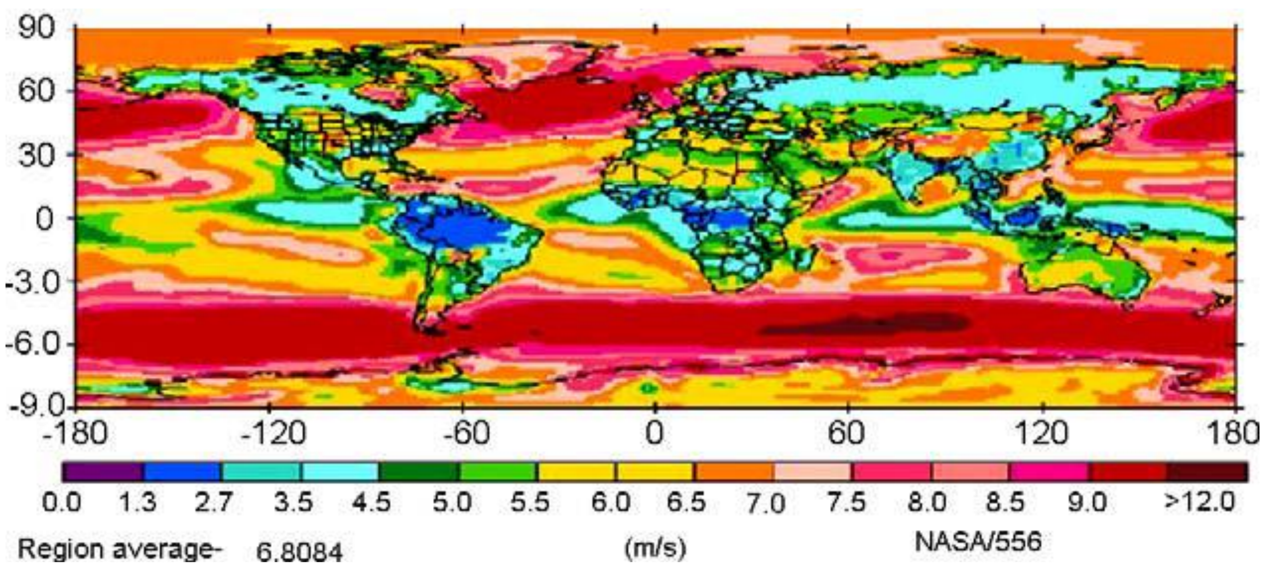


Fig. 1.2 Global wind energy potential

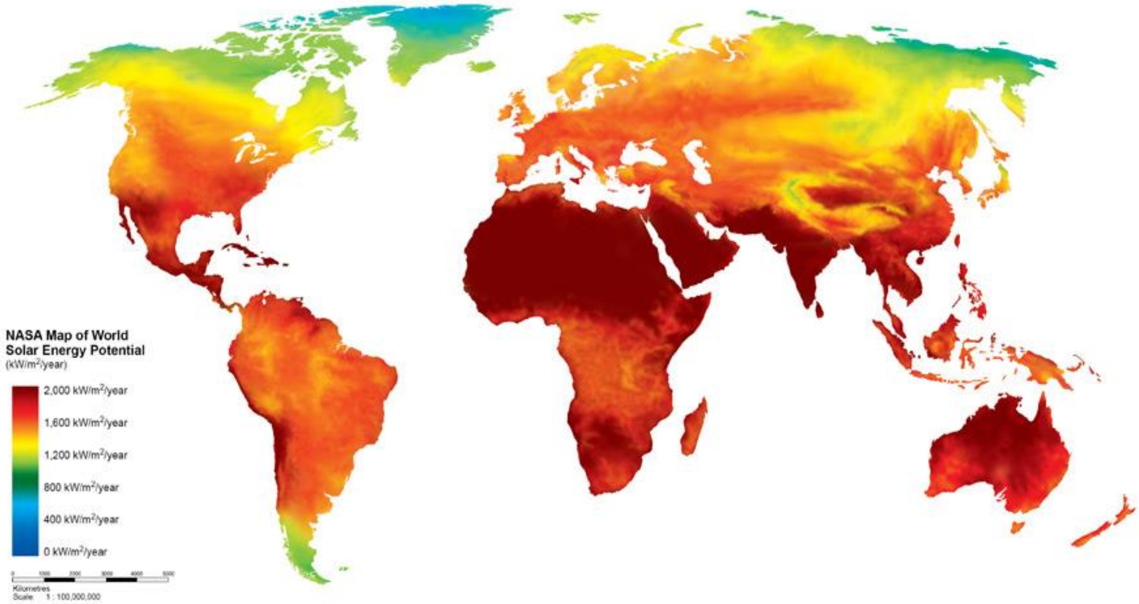


Fig. 1.3.Map of World Solar Energy Potential.

Some researchers used data from metrological stations for prefeasibility study and hybrid energy system design. The combination of PV and wind in a hybrid energy system reduces the d emands on the battery bank and diesel. The feasibility of the hybrid PV / wind energy system is s trongly dependent on the site's solar radiation and the potential for wind energy.

Various feasibility and performance studies are reported to evaluate option of hybrid.PV/wind energy systems. Photovoltaic array area, number of wind machines, and battery storage capacity play an important role in operation of hybrid PV/wind–diesel system while satisfying load [7].

1.5. Technical configuration of hybrid power system

Following various configurations, the hybrid system can be designed to effectively utilize the renewable energy sources available locally and serve all power appliances**.**

There are three accepted types of hybrid system technological configurations according to the voltage and the load combination. These are as follows:

- AC-coupled hybrid power systems.
- DC-coupled hybrid power systems.
- Mixed-coupled hybrid power systems

1.5.1 AC-coupled hybrid power systems

The majority of the electric loads since last century have been operated with AC power. So, the standard choice for commercial power systems is ultimately an AC distribution system, an AC micro-grid system is connected with a medium voltage distribution line at the point of PCC. The distributed generations, storage devices and loads are attached with a common bus base at the distribution networks. During the grid-tied mode, the system voltage and frequency are maintained by utility grids while energy storage devices, nonrenewable DGs and adjustable loads with control techniques help to keep standard voltage and frequency level during islanded mode[9].

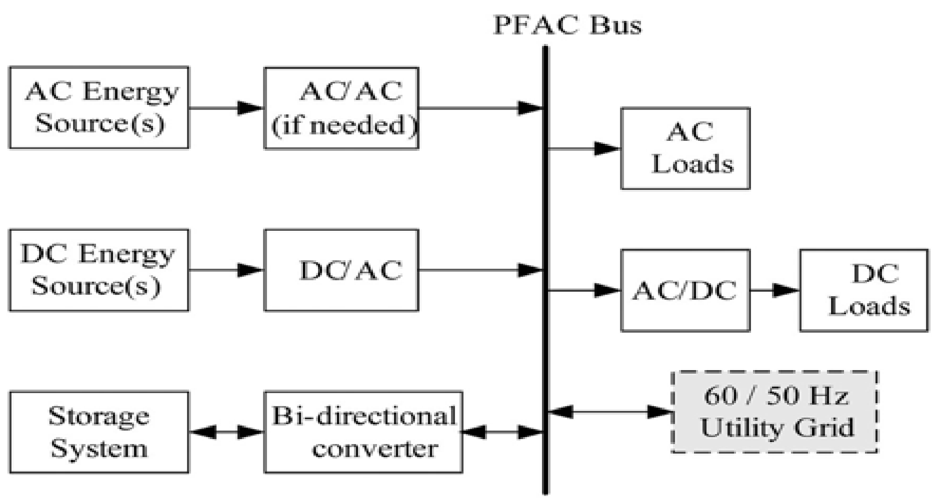


Fig .1.4 Schematic diagram of a AC-coupled hybrid energy system.

1.5.2 DC-COUPLED HYBRID POWER SYSTEMS

In a DC microgrid, energy storage and a large percentage of the sources and the loads are interconnected through one or more DC busses. Nonetheless, AC buses or some sort of DC to AC converter are still necessary due to the fact that some sources and loads cannot be directly connected to DC[10].

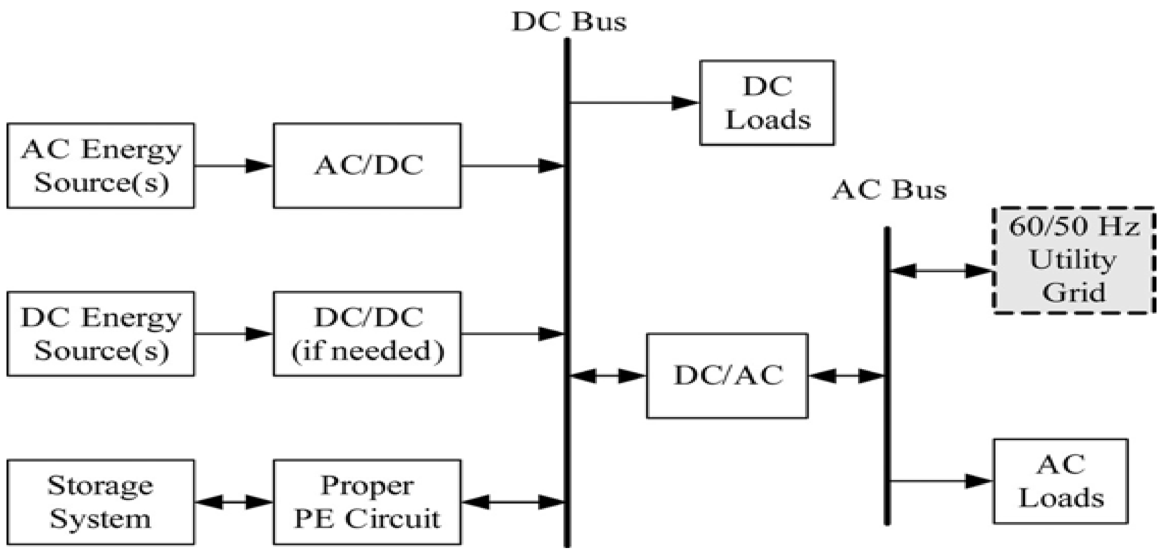


Fig .1.5 Schematic diagram of a DC-coupled hybrid energy system.

1.5.3 MIXED-COUPLED HYBRID POWER SYSTEMS

It is also possible to combine AC-coupled and DC-coupled hybrid power systems and form mixed hybrid power system. With this type of configuration, some of the renewable energy sources (PV-array, in this case) are connected with the battery bank at the DC-bus and other RESs (wind turbine, in this case) are connected with the generator at the AC-bus.

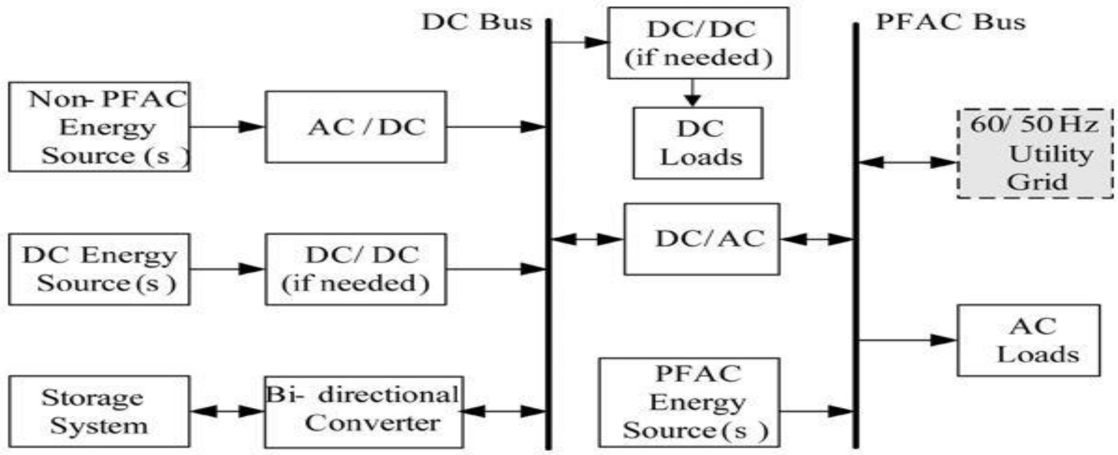


Fig .1.6 Schematic diagram of a hybrid-coupled hybrid energy system

1.6. Modeling of hybrid renewable energy system (HRES) components

For size optimization, modelling of hybrid energy system components is a significant step to providing its performance under different situations. The modeling of different hybrid energy system components are given below:

1.6.1 Solar PV system

The analysis of PV system starts by the modeling and the analysis of the PV module. The latter is generally composed of series and /or parallel PV cells. Therefore, the modeling of PV module is based on the equivalent electrical circuit of the solar cell. The performance of this latter is normally evaluated under the STC. To satisfy the requirement of temperature and insolation in STC, the test usually needs specified environment and some special testing equipment, such as an expensive solar simulator [16]. This section provides the mathematical model of PV module.

The PV module being modeled by single diode circuit is described by the following I-V equation:

$$I = I_{PV} - I_S\left(exp^{\frac{V + R_S I}{aV_{Th}}} - 1\right) - \frac{V + R_S I}{R_P} \quad \text{………………………………………(1)}$$

Where: I_{PV} is the light-generated current. It is function of the irradiance, environment temperature and a gain provided by the manufacturer.

$$I_{PV} = I_{PV\_ref}\left[1 + \frac{k_i}{100}\left(T - T_{ref}\right)\right] \quad (2)$$

And Is is the diode saturation current being expressed by following equation:

$$I_S = \frac{I_{SC\_ref} + k_i\left(T - T_{ref}\right)}{exp\left[\frac{V_{OC\_ref} + k_V.\left(T - T_{ref}\right)}{a.V_{Th}}\right] - 1} \quad (3)$$

The different parameters in the model of the PV module need to be estimated using one of the identification methods as described in [16]. Varying the temperature and the irradiance will result in different current or power output of the PV module, as shown in Fig. 1.7.

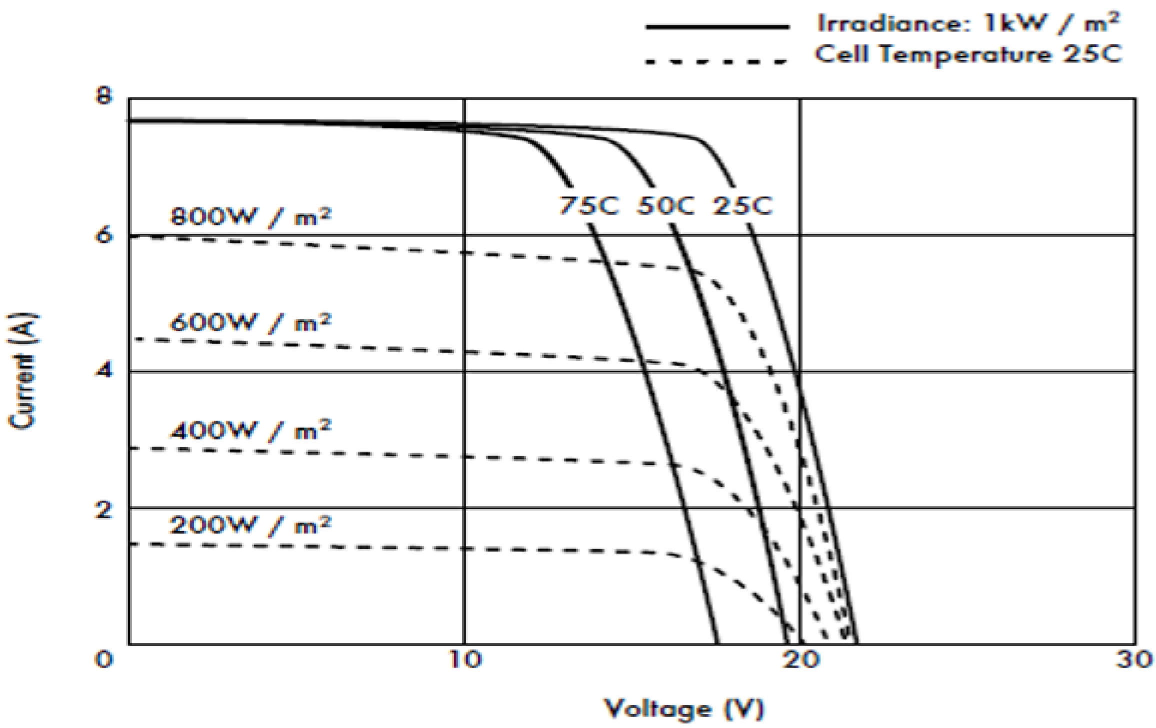


Fig .1.7 Different IV curves, the current (A) changes with irradiance and the voltage (V) changes with temperature .

1.6.2 BATTERY BANK SYSTEM

The energy production and its consumption depending on number of batteries and state of the battery connected at any given time. When the battery is charging, power generation exceeds the load demand. Then availability of power in the battery bank at a specified time is expressed by the given Eq. (4):

$E_{Batt}(t) = E_{Batt}(t - 1) + E_{EE}(t) \times \eta_{CC} \times \eta_{CHG}$..(4)

where, $E_{EE}(t)$ is the extra energy available from all the systems, η_{CC}as the charging controller efficiency, and η_{CHG}as the battery charging efficiency.

The quantity/state of charging the battery are expressed by the given Eq. (5):

$SOC_{min} \leq SOC(t) \leq SOC_{max}$..(5)

where, $SOC_{min}$is the value of minimum SOC; and SOC_{max}as the maximum value of SOC assumed as 1. Minimum value of SOC is obtained using the following Eq. (6),

$SOC_{min} = 1 - DOD$………………………………………………………………………………(6)

DOD :depth of discharge [7,17].

1.6.3 Modeling of Diesel Generator

To attenuate shortfalls in energy production during periods of poor sunshine, photovoltaic systems require a backup diesel generator for increased system availability and minimum storage requirements. The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the engine generator to be installed, following two cases should be considered:

1. If the diesel generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load
2. If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than CAh, where CAh is the ampere hour capacity of the battery.

Overall efficiency of diesel generator is given by

$\eta_{over-all} = \eta_{breakthermal} \times \eta_{generator}$…………………………………………………………(7)

Here $\eta_{breakthermal}$ is brake thermal efficiency of diesel-engine. Normally, diesel generators are modeled in the control of the hybrid power system in order to achieve required autonomy. It is observed that if the generator is operated at 70–90% of full load than it is economical. In the absence of peak demand, diesel generators are normally used for meeting load requirements and for battery charging.

The hourly fuel consumption of DG is assessed using the following equation (8) :

$$D_f(t) = \alpha_D P_{Dg}(t) + \beta_D P_{Dgr} \quad \ldots\ldots(8)$$

where, $D_f(t)$ is the hourly fuel consumption of DG in L/h, P_{Dg} is the average power per hour of the DG, kW, P_{Dgr} is the DG rated power, kW, α_D and β_D are the coefficients of the fuel consumption curve, L/kWh, these coefficients have been considered in this book as 0.246 and 0.08145, respectively [16].

1.7. Conclusion

Sustainable, environmentally friendly and renewable sources such as wind and solar can create a more energy-efficient economy. Solar and wind energy sources can be pooled to form a hybrid renewable energy grid with other sources. Hence, greater efficiency in power production can be achieved by making the best use of their advantages to overcome their limitations

2.1. Introduction

Control unit is one of major component of micro-grid. The flow of power from generation to the load centers should be monitored, controlled and managed properly. Besides, conventional controllers used in conventional electric power system to maintain power quality (voltage, frequency and sin wave within limit), renewable energy sources use new controllers that improve their efficiency. Maximum power tracking controller is one of the most known one.

This chapter is devoted to describe controllers being used by renewable energy sources included in the proposed HRES.

2.2. Control of HRES components

2.2.1 Maximum power point tracking

MPPT concept is very unique to the field of PV systems which involves the application of power electronics filed. This concept can be seen as an alternative to the intermittence issue related to most of renewable energy sources. In other words, power delivered by renewable energy source is randomly available.

As discussed before the solar cells has an IV and PV curves such that (P = IV) [18]

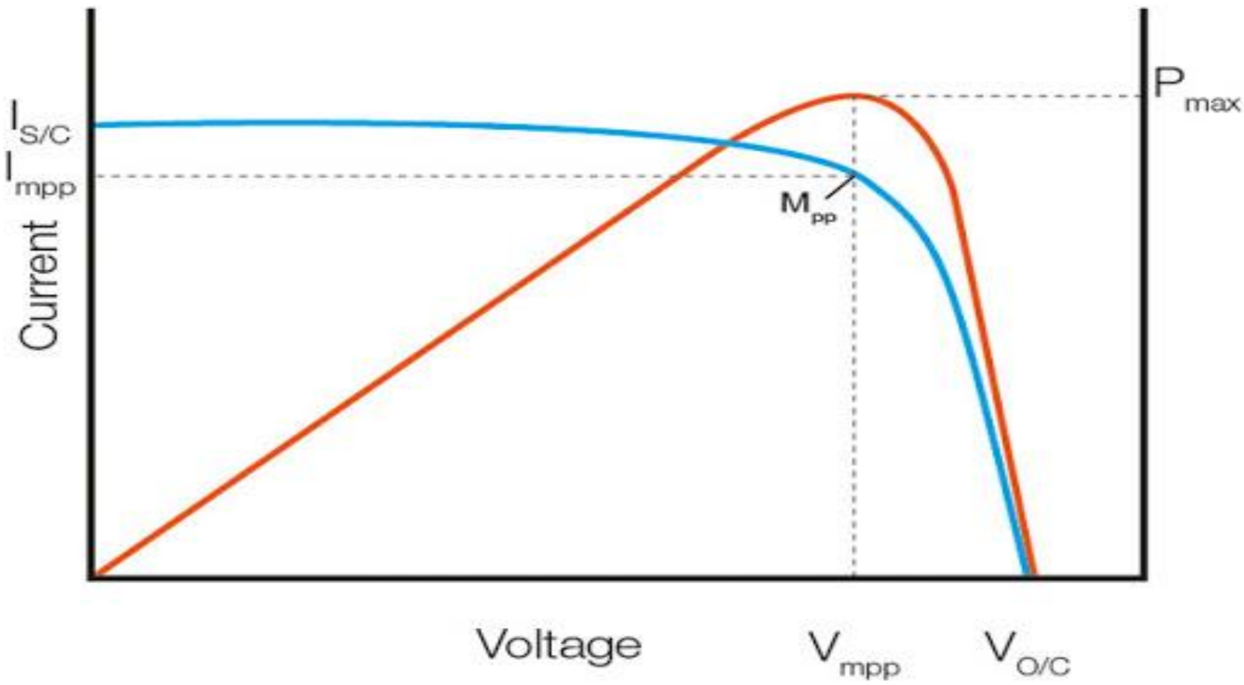


Fig 2.1 Maximum power point on IV & PV curves

To get this maximum power point "MPP", the module has to be forced to operate at MPP and the simplest way to do this is to force the voltage of the PV module to be" $V = V_{MPP}$" this process called the maximum power point tracking MPPT.

MPPT controller is nothing but hardware implementation of MPPT algorithm. There are several algorithms to track the MPP they are also called the MPPT techniques[19]:

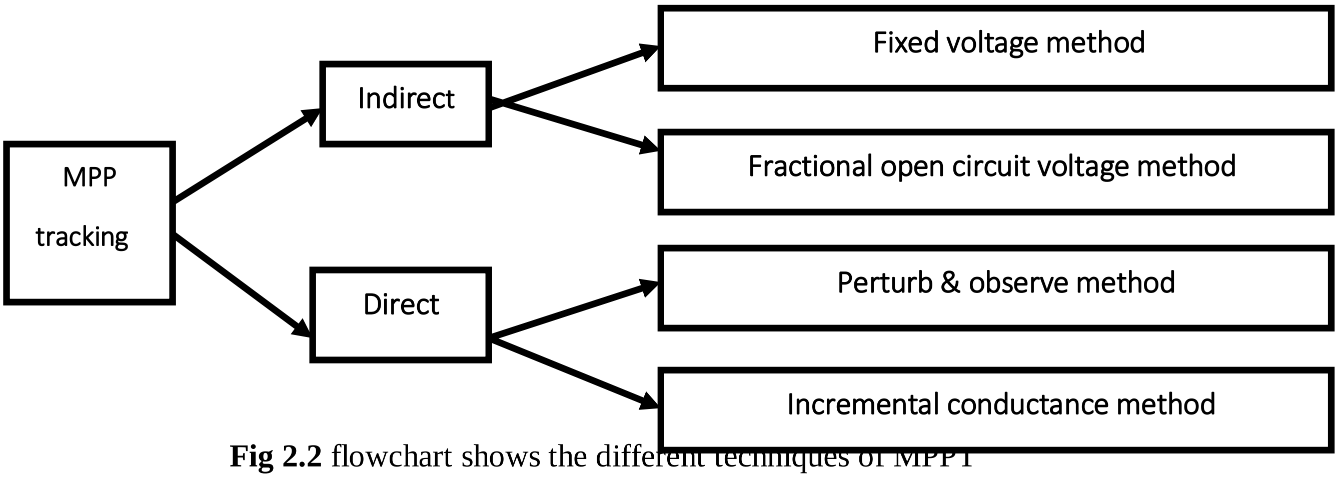


Fig 2.2 flowchart shows the different techniques of MPPT

2.2.1.1 Direct MPPT methods

The direct MPPT is more accurate & faster than the indirect MPPT

A- Perturb & observe method

This method works with increasing and decreasing the voltage as shown in figure below:

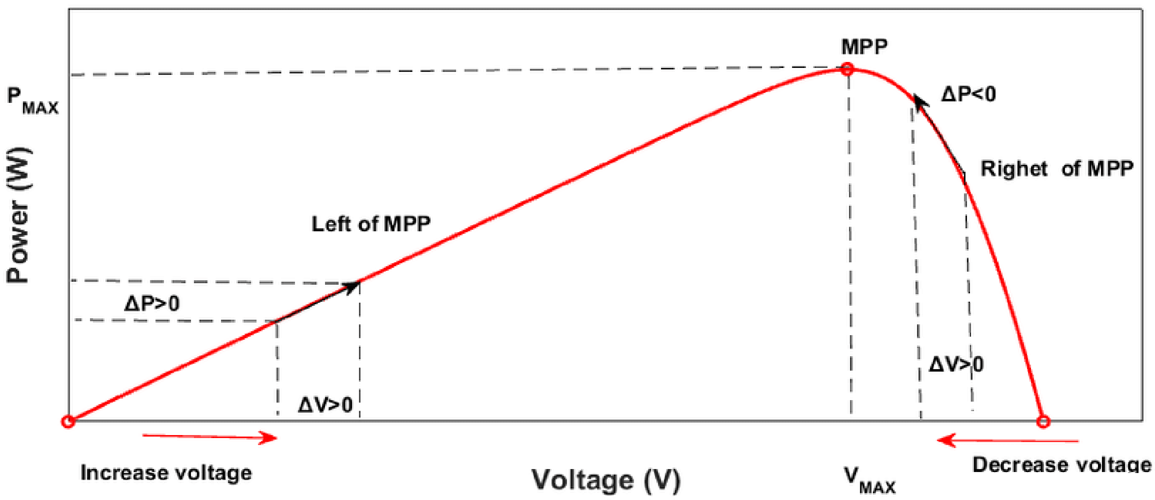


Fig 2.3 The P&O behavior to track the MPP

- If increase in voltage leads to increase in power this means that the operating point is to the left of the MPP & hence further the voltage perturbation is required towards the right to reach the MPP

- If the increase of voltage leads to a decrease in power this means that the operating point is to the right of the MPP & hence further voltage perturbation towards to the left to reach the MPP

B- Incremental conductance method

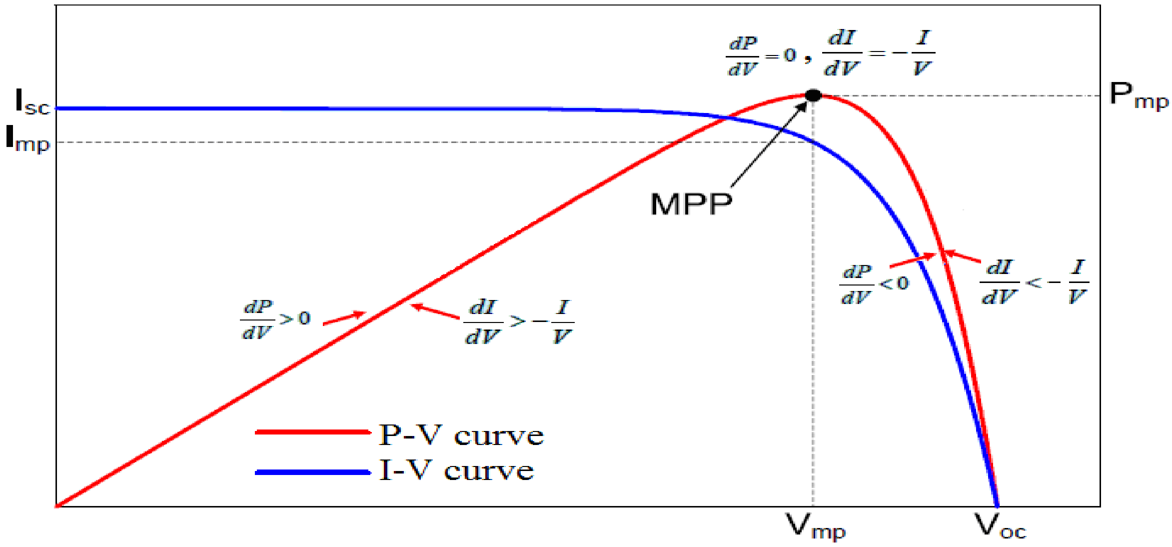


Fig 2.4 The incremental conductance method behavior to track the MPP

The instantaneous conductance: "$\frac{I}{V}$"

The incremental conductance: "$\frac{dI}{dV}$"

As shown in fig 2.4 at MPP the slop of the PV curve $\frac{dP}{dV} = 0$

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} = I + V\frac{dI}{dV} \quad (9)$$

In general the algorithm imposes a voltage on PV module at every iteration measures the incremental change in conductance and compares it with the instantaneous conductance and decides if the operating point is to the left or to the right of MPP:

- At the MPP

$$-\frac{I}{V} = \frac{dI}{dV} \quad (10)$$

- The operating point is to the left of the MPP this means

$$-\frac{I}{V} < \frac{dI}{dV} \quad (11)$$

- The operating point is to the right of the MPP

$$-\frac{I}{V} > \frac{dI}{dV} \qquad (12)$$

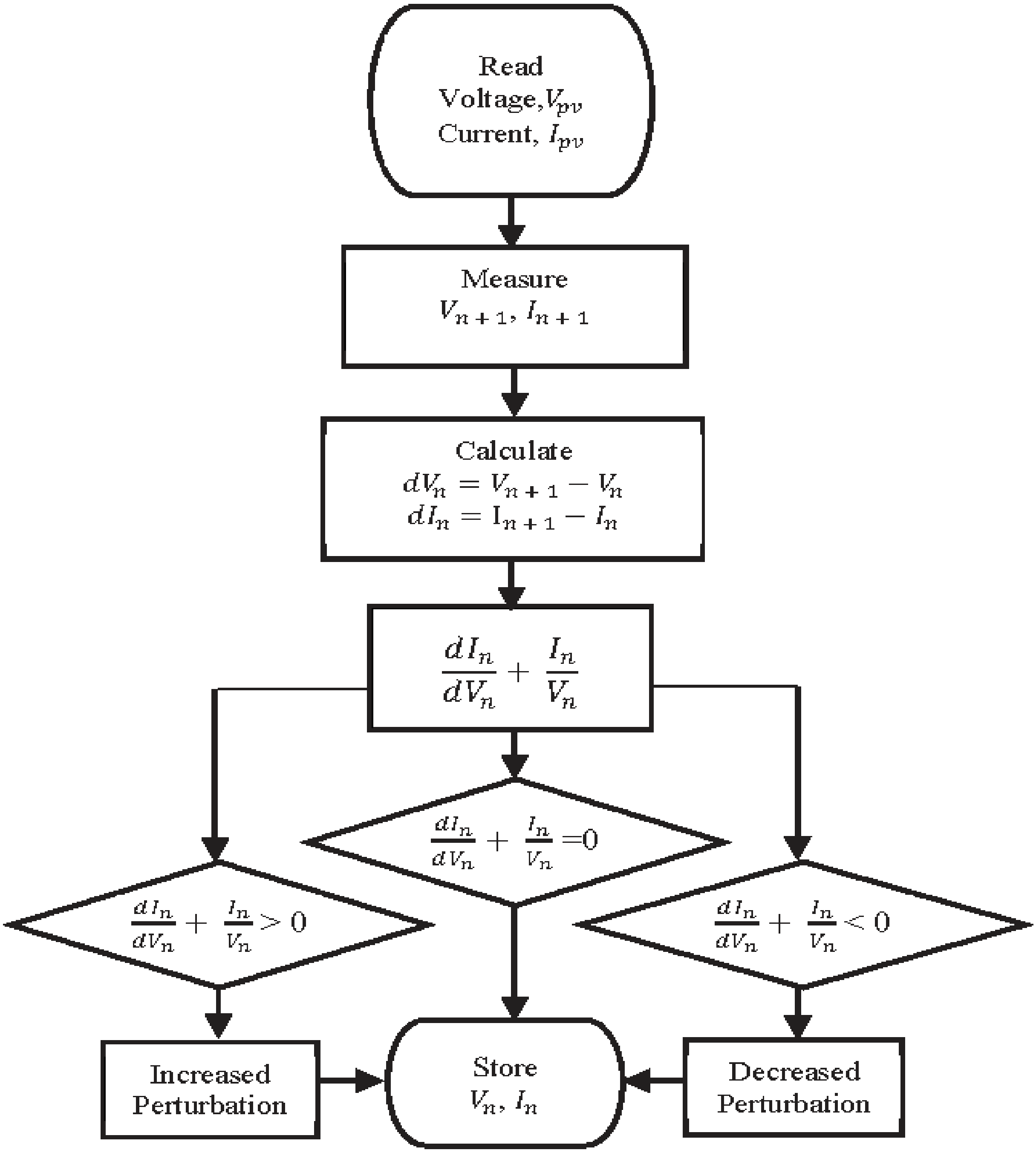


Fig 2.5 flowchart describes the incremental conductance method

2.2.2 Voltage source converter

Photovoltaic system needs to use inverter as power conversion device of the DC output of the PV array into AC power. The inverter can be controlled by a pulse width modulation control technology the following structure explain the control of the inverter [20, 21]:

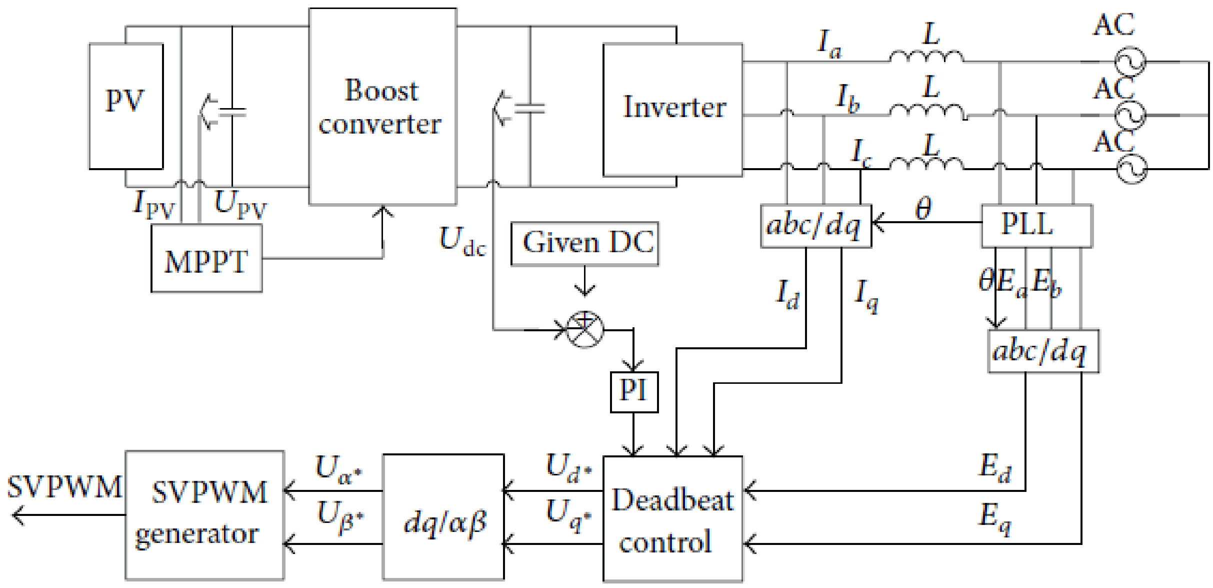


Fig 2.6 Structure of three-phase photovoltaic, grid connected DG source.

The entire system is composed of a maximum power tracking MPPT controller, DC voltage controller, and AC current PI deadbeat controllers. The control system uses the double-loop control structure of voltage outer loop and current inner loop. The voltage outer loop can keep DC voltage stable, and the current inner loop is used to improve the rapidity of the system[22].

2.2.2.1 Phase-locked loop

A very important and necessary feature of DG side converter control is the DG synchronization. The synchronization algorithm is able to detect the phase angle of DG voltage in order to synchronize the delivered power. The purpose of this method is to synchronize the inverter output current with the DG voltage, in order to obtain a unity power factor.

The inputs of the PLL model are the three phase voltages measured on the DG side and the output is the tracked phase angle[23, 24].

2.2.3 Automatic voltage regulator"AVR"

Any diesel generator contains synchronous generator to convert the mechanical power to an electrical power. The terminal voltage of the synchronous generator can be affected by various disturbing factors (speed, load, power factor, and temperature rise), so that special regulating equipment is required to keep the voltage constant, even when affected by these disturbing factors.

2.2.3.1 Excitation system

The system which is used for providing the necessary field current to the rotor winding of the synchronous machine, such type of system is called an excitation system. In other words, excitation system is defined as the system which is used for the production of the flux by passing current in the field winding. The excitation system consists of an exciter and AVR see figure 2.7

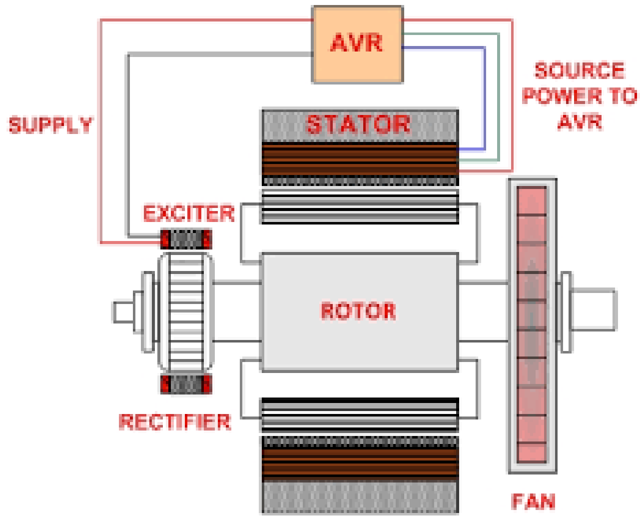


Fig 2.7 Excitation system of SG

2.2.3.2 The simplified model for AVR

As shown in Figure 2.8, the AVR controller compares the generator output terminal voltage with the set reference voltage, and, as per the error signal, it changes the field excitation of the generator to maintain constant terminal voltage.

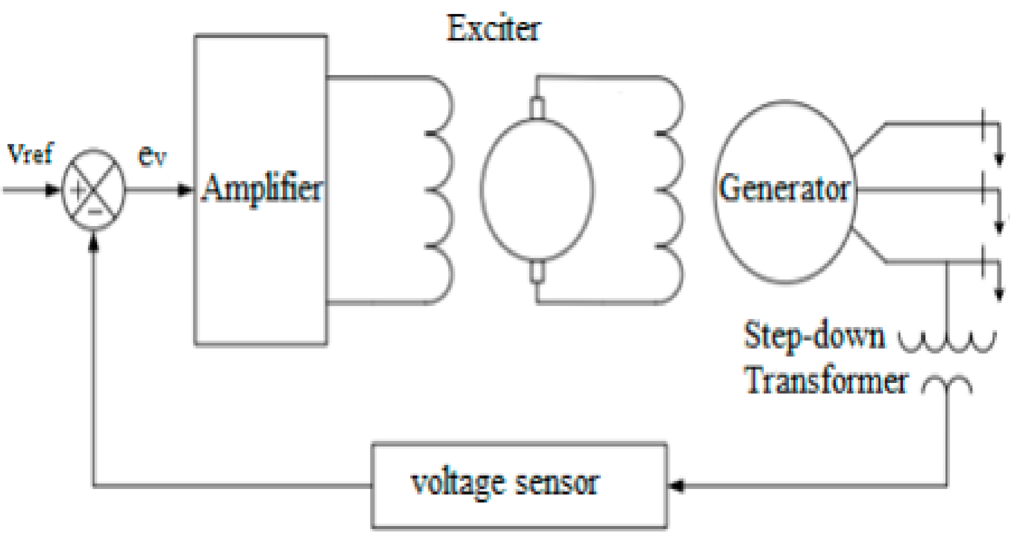


Fig 2.8A typical arrangement of a simple automatic voltage regulator (AVR)

This AVR performs as a feedback control system that receives the feedback signal from potential and current transformers placed at the output terminals of the generator. The potential transformer continuously observes the voltage variations in the alternator, while the current transformer feeds the current signal to the controller circuit. The potential transformer feeds a comparator to calculate the error by comparing its output voltage value with the reference or nominal voltage, and the resulted signal (voltage error) is fed to the field windings of an alternator after due amplification.

Moreover, an exciter is employed in order to bridge the comparator and field windings. Generally, the AVR system is composed of four basic components: sensor, amplifier, exciter, and generator. The linear mathematical model for each basic component of the AVR is shown in Figure 2.9

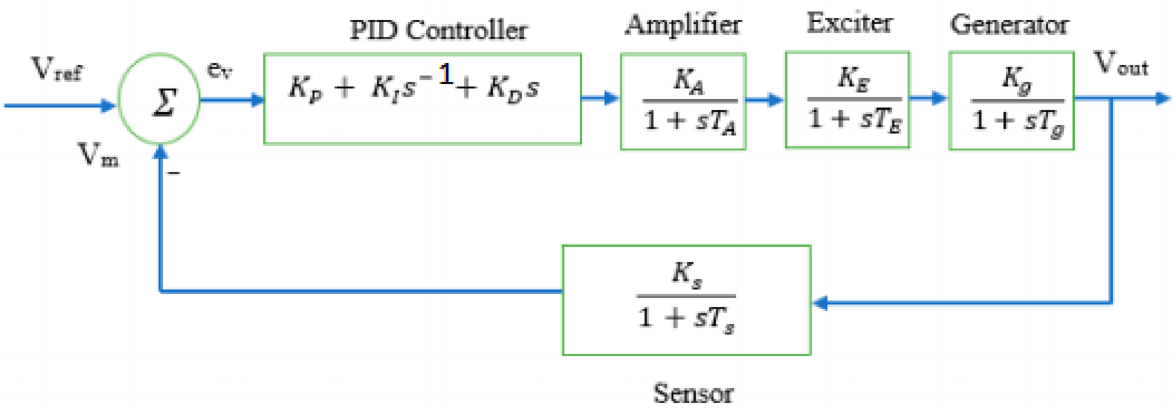


Fig 2.9 Block diagram for an AVR system

The following table shows the parameters limits

	Transfer function	Parameter limits
PID controller	$K_p + \frac{K_i}{s} + K_d s$	$0.2 \le K_p, K_i, K_d \le 2.0$
Amplifier	$\frac{K_a}{1 + sT_a}$	$10 \le K_a \le 40$ $0.02 \le T_a \le 0.1$
Exciter	$\frac{K_e}{1 + sT_e}$	$1 \le K_e \le 10$ $0.4 \le T_e \le 1.0$
Generator	$\frac{K_g}{1 + sT_g}$	K_g depends on load (0.7-1.0) $1.0 \le T_g \le 2.0$
Sensor	$\frac{K_s}{1 + sT_s}$	$0.001 \le T_s \le 0.06$

Table 2.1 different parameters limits for the block diagram of the AVR [26]

2.3 Conclusion

This chapter presented a comprehensive overview of micro-grid control strategies. The control of HRES is always considered as challenge due to the uncertainties of the renewable energy sources “solar power, wind energy, etc.” and controlling the inverter to synchronize it with DG. This chapter suggested some schemes to control the different components of the HRES to be balanced system, synchronized, and generate constant voltage and frequency.

3.1. Introduction

This chapter presents the simulation of the hybrid renewable energy system. The studied system includes photovoltaic panels, synchronous diesel generator, and a battery for storage energy .The PV panels are connected to the common DC bus by a boost converter. The battery is connected by a bi-directional DC/DC converter, and then integrated into a variable AC load via a common DC/AC inverter where the diesel generator is the main power source. A simulation study has been carried under different weather conditions (sunny and gloomy day) while maintaining power quality at a satisfactory level. In order to achieve the maximum power, a MPPT algorithm is applied for the photovoltaic panels .The modeling and simulation of the whole system has been performed under Matlab/Simulink environment(MATLAB 2018).By other words, it can be stated that the main components in the studied Micro-grid are:

- a diesel generator " acting as the base power generator"
- a 50kW PV array " to produce renewable energy"
- a battery " storage unit to save the extra power of the PV array "

The simulation is performed in three main cases presented within this chapter sections:

- only the diesel generator (DG)with variable load
- PV array + DG during both sunny and gloomy days with variable load
- Battery + PV array + DG with variable load

3.2. Diesel generator supplying variable load

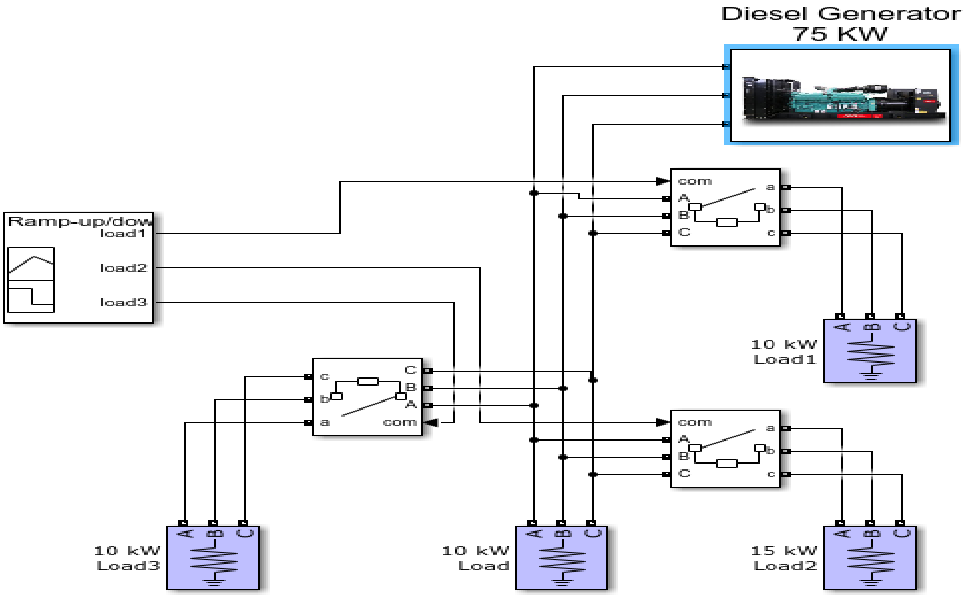
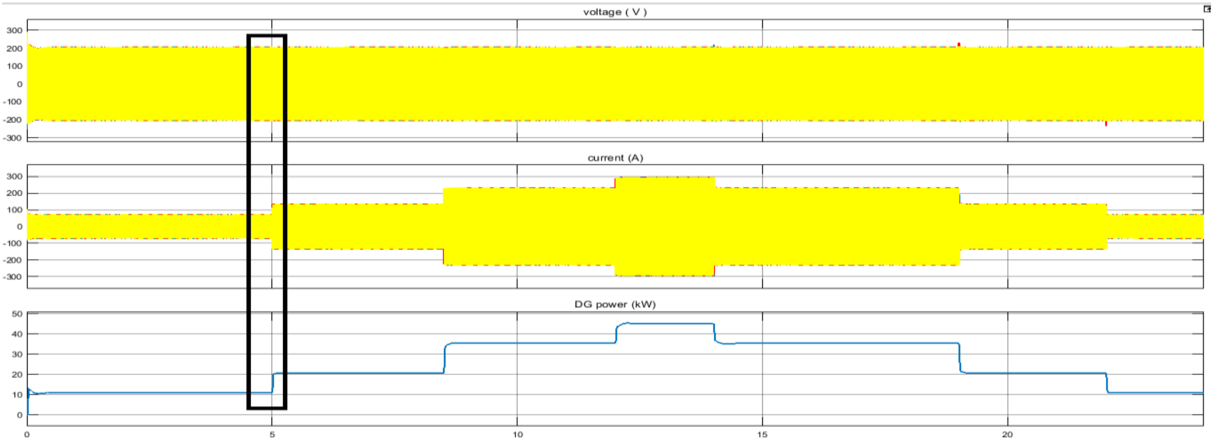


Fig 3.1 Simulink model for diesel generator supplying variable load

3.2.1.Description

- The diesel synchronous generator works with an excitation system to control the output voltage through the automatic voltage regulator (AVR) to maintain the generator output terminal voltage at a set value under varying load. The principal of how the AVR works can be explained simply that it senses the voltage at the power-generating coil and comparing it to a stable reference. The error signal is then used to adjust an average value of the field current.
- In this section only the performance of the AVR is tested where the diesel generator is connected with variable load. The variable load model is realized by using four constant loads (3 loads of 10 kw and 1 load of 15 kw) connected through breakers, which will play the role of varying the total load by connecting and disconnecting some loads through received control signal as shown in Figures 3.1 and 3.3.

3.2.2. Results



Zoom in:

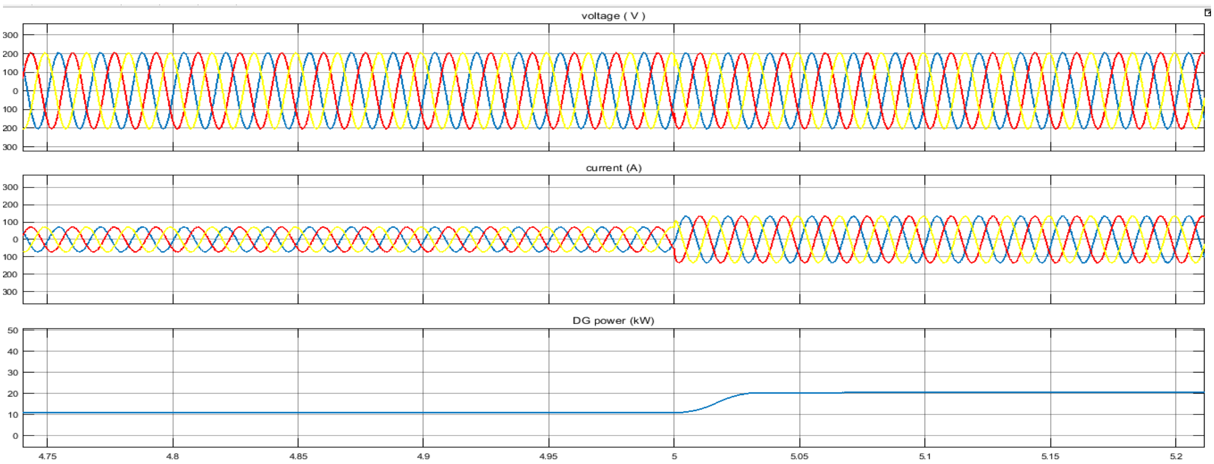


Fig 3.2 the output of DG (voltage V, current A and power kW)

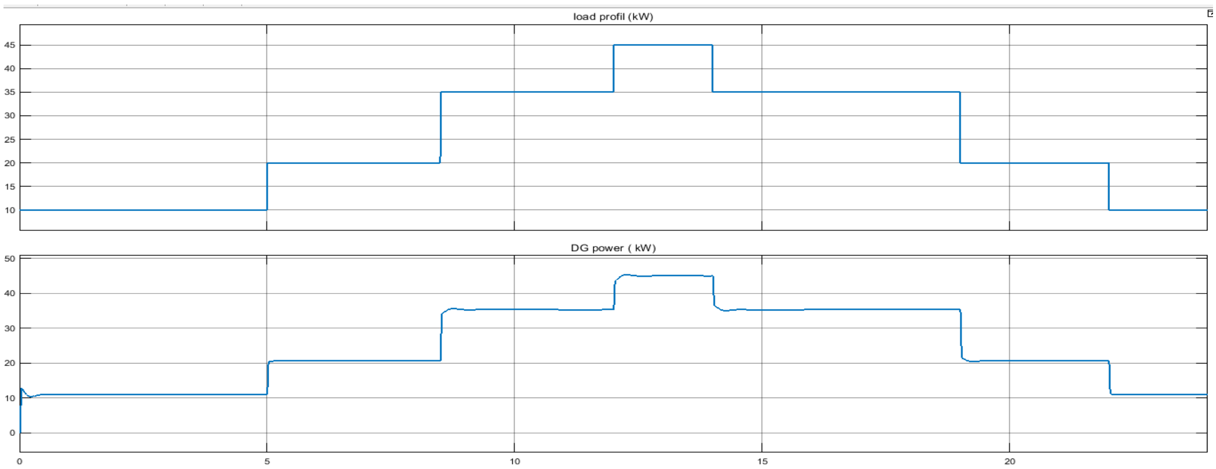


Fig 3.3 comparing the load demand with the power supplying by the DG

As it is shown in Figure 3.2 and 3.3, the results prove that the AVR is working perfectly such that when load power is varying the voltage stays constant and the current changes to satisfy the load power demand.

3.3. PV + DG

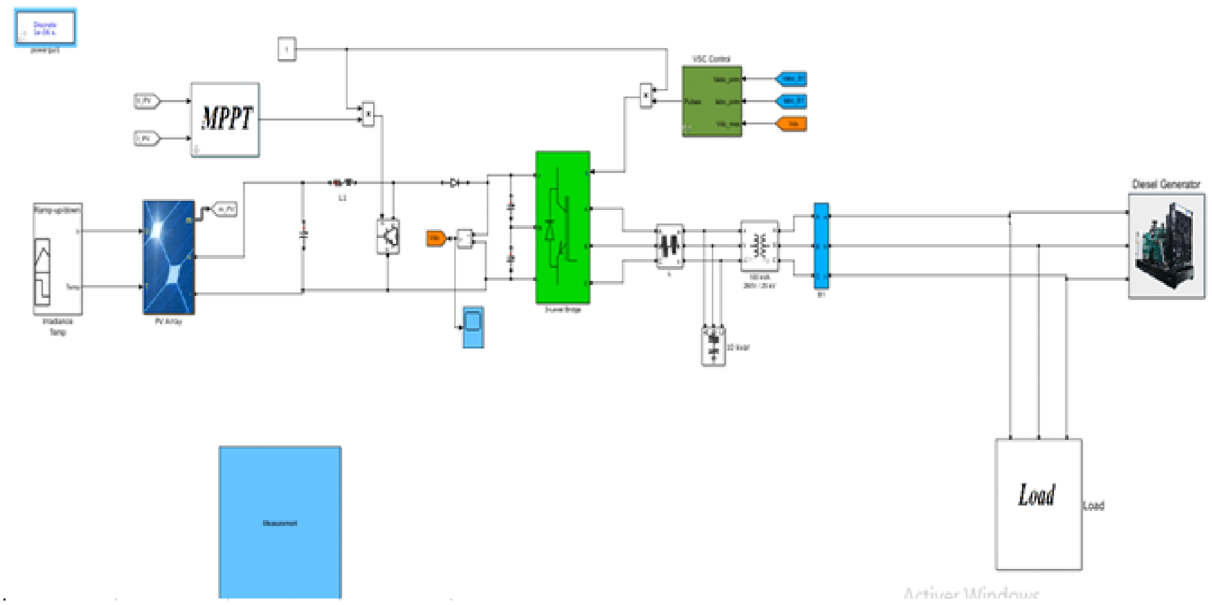


Fig 3.4. Simulink model for hybrid PV, DG system

3.3.1.Description

In this case of the PV + DG system, The DC-DC boost converter and the Voltage Source Converter (VSC) link a 50-kW PV array to the 75kW DG as it is shown in Figure 3.4.The implemented Maximum Power Point tracker (MPPT) to the boost converter uses the 'incremental conductance + Integral Regulator' method

The detailed model components are as follows:

- PV array that provides up to 50kW at sunlight (1000 W / m^2)
- DC-DC boost converter to step up the voltage at the PV output (273.5 V DC at maximum power) to 500V DC. Duty cycle switching is controlled by the MPPT controller that uses the 'Incremental Conductance + Integral Regulator technique. In order to produce the necessary voltage for extracting full power from the PV array.
- VSC uses two control loops, which are external control loop to regulate the dc link voltage to 500V and the internal control loop which regulates the active and reactive currents of the DG. It is worthy to mention that the **PLL** to synchronize the inverter with the DG
- Filter to eliminate harmonics.

3.3.2. Results

A. Sunny day

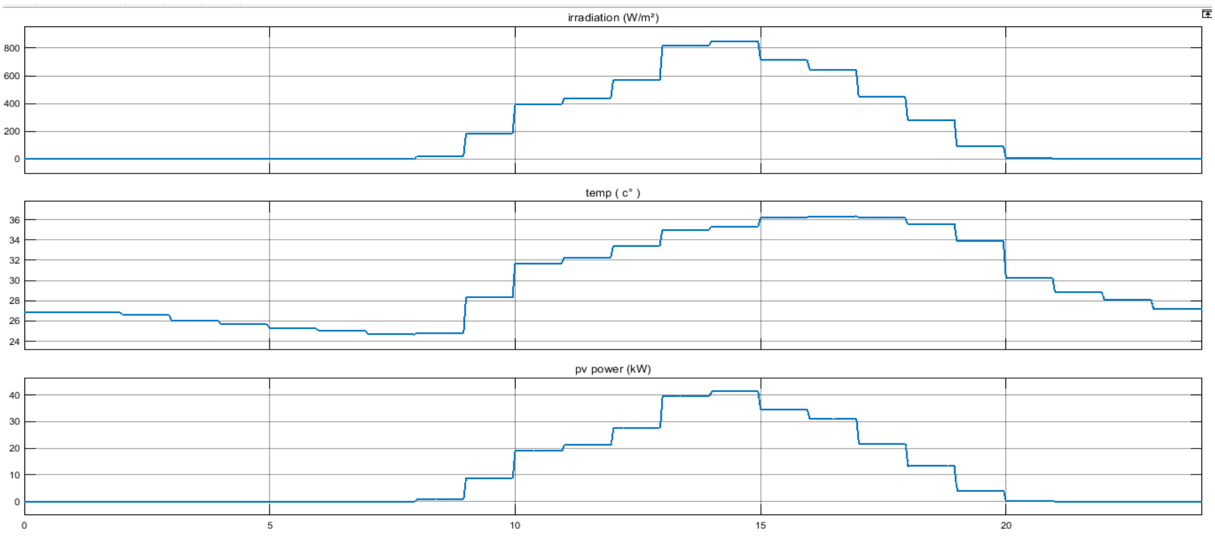


Fig 3.5 PV array power for a given data

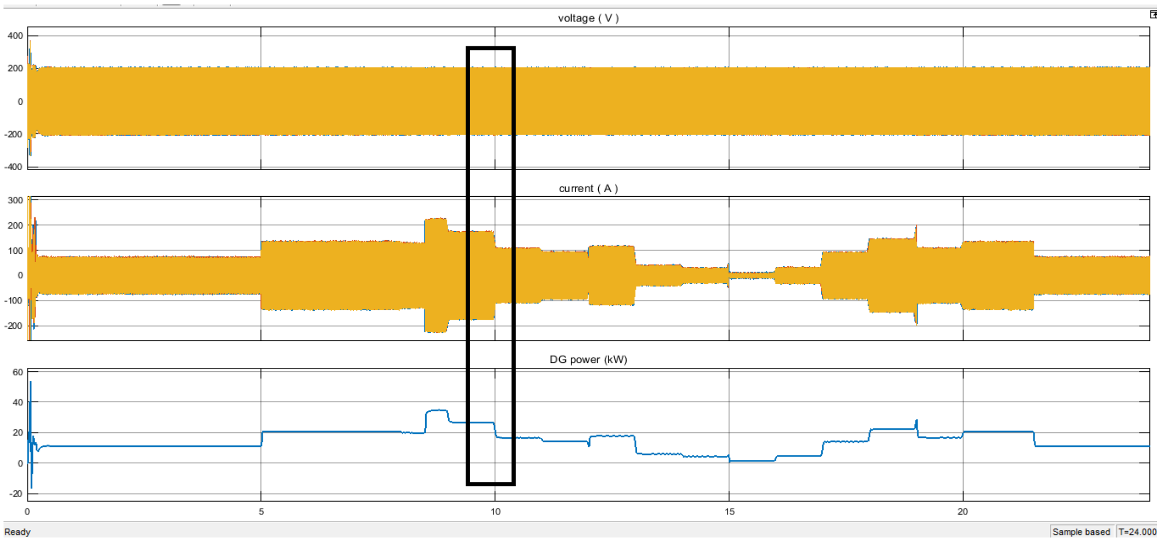
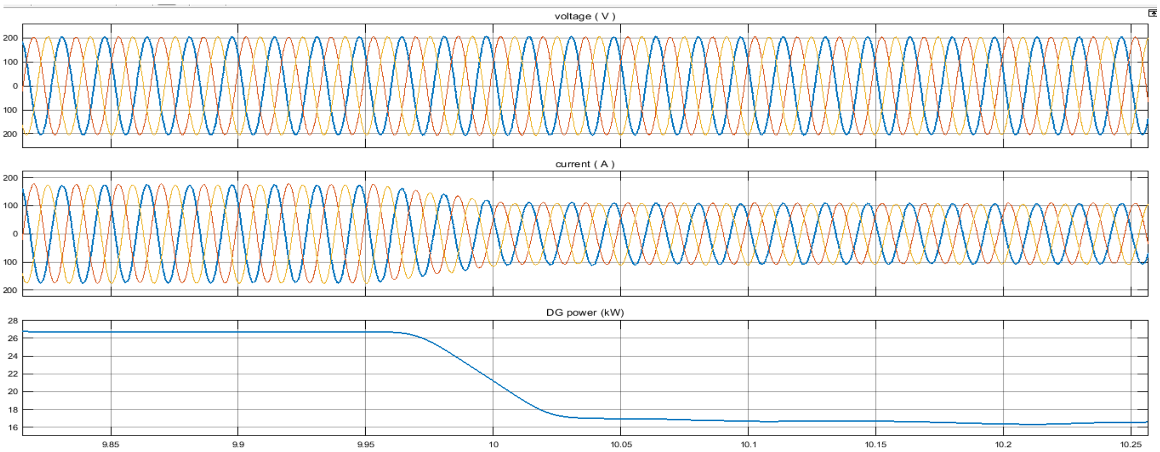


Fig 3.6 the outputs of diesel generator " voltage , current , power"

zoom in:



Comment: during the variation of power of the diesel generator, the voltage stays constant due to the AVR

General result for sunny day

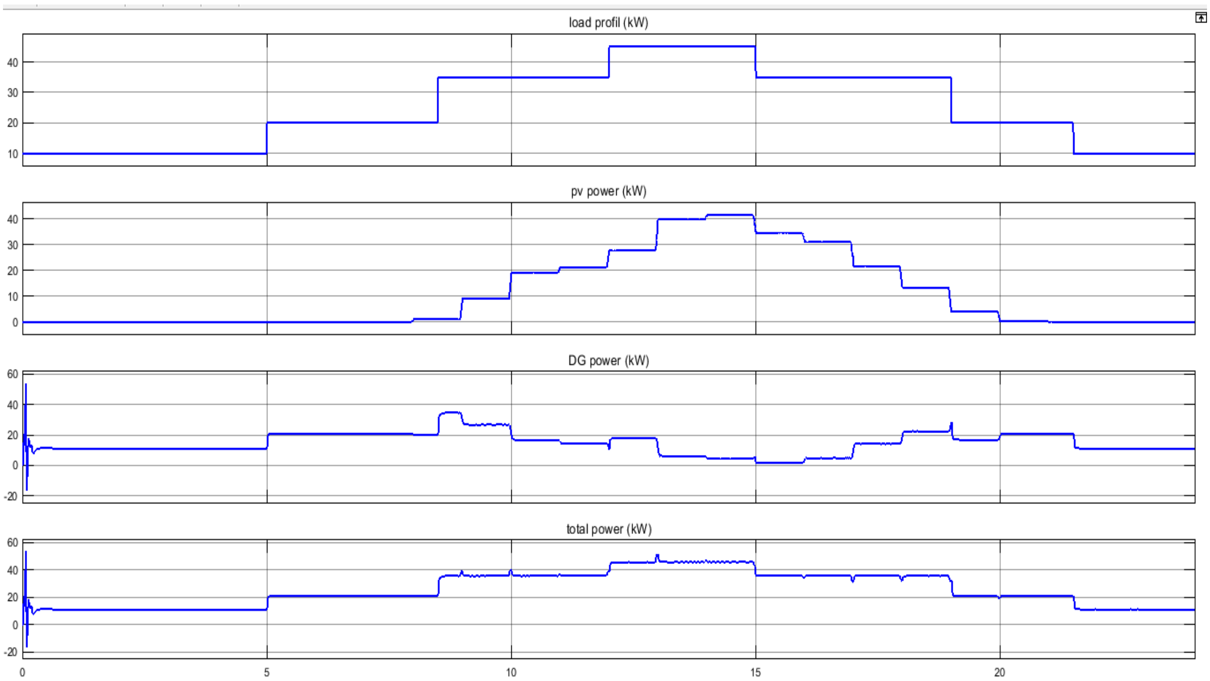


Fig 3.7 management of power for sunny day

During the first 7 hours of morning when there is no sun light “irradiation = 0W/m² “ the output of the PV is zero and the only source of power is the diesel generator , but when the irradiation rises “ PV power begin increasing” the diesel generator power decreases accordingly. Hence, the management system works perfectly, the latter system manage the power sharing between the two power sources where all the produced power satisfies the load demand giving the priority to the power obtained from the renewable sources to be fed directly to the load to reduce the conception of the diesel generator to the fossil fuels.

- At the night the diesel generator returns to be the only source of power because there is no power coming from the PV arrays
- The power produced by the DG is reduced compared to the first system. Therefore , can say that the 2nd system is more economic comparing to the previous one.

B. Cloudy day

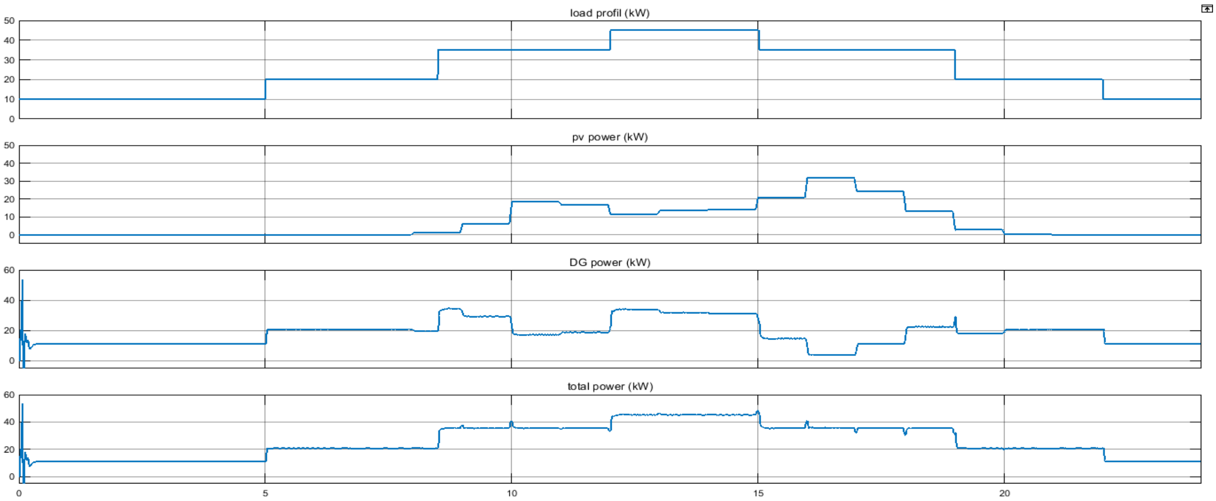


Fig 3.8 management of power for cloudy day

In the case of the cloudy day, the power produced from the PV arrays is less than the case of the sunny day. That is, the diesel generator provides more power comparing to the case if sunny day, this leads to consume more fuel comparing to the case of sunny day. However, it is still better economically when the only source is the diesel generator. Again the total power produced by the system is satisfying the load profile “PV power + DG power = load demand “

3.4. PV + DG + Battery

In this section, energy storage system ESS is added to take into consideration the case when the power produced by the PV arrays is greater than the load demand ($P_{PV} > P_{LOAD}$). Hence, the extra power will be stored in the ESS which is presented by batteries in our case.

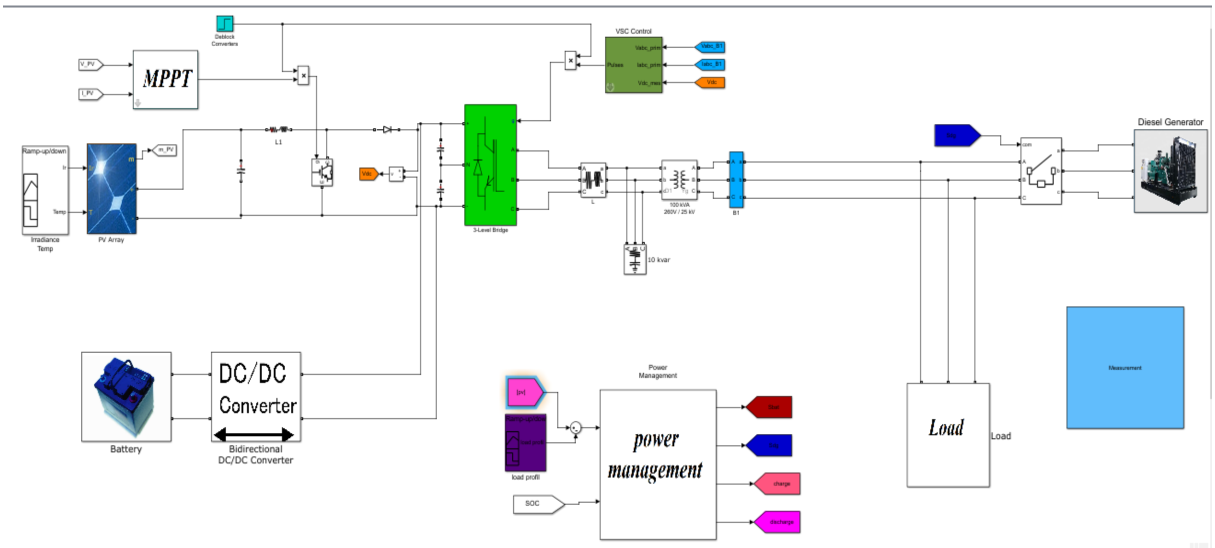


Fig 3.9 Simulink model for hybrid PV, Battery and DG System

3.4.1 Description

- The storage unit "Battery "is connected to the DC bus via bidirectional converter to charge and discharge the battery.
- The management of the power of this case is shown in the following flowchart of "proposed management system":

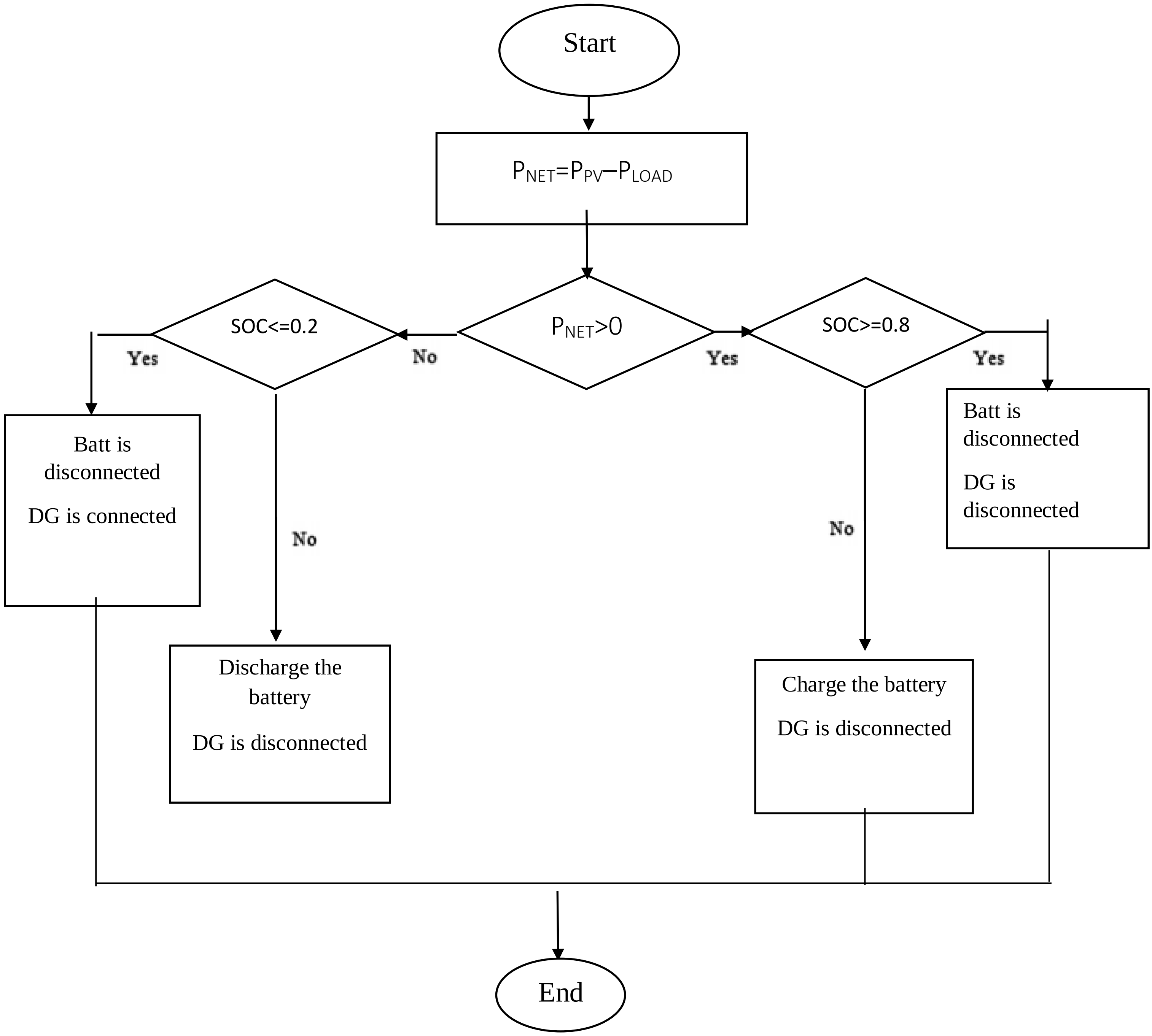


Fig 3.10. Power management flowchart of the hybrid system

The management system, shown in Figure 3.10, is designed to reduce the conception of the fossil fuel by the DG as much as possible, Furthermore, the state of charge (SOC)of the battery should be within the range of [20%, 80%] because this is the appropriate operation condition of the battery. Hence, the reliability (life time) of the system will not be effected.

3.4.2. The results

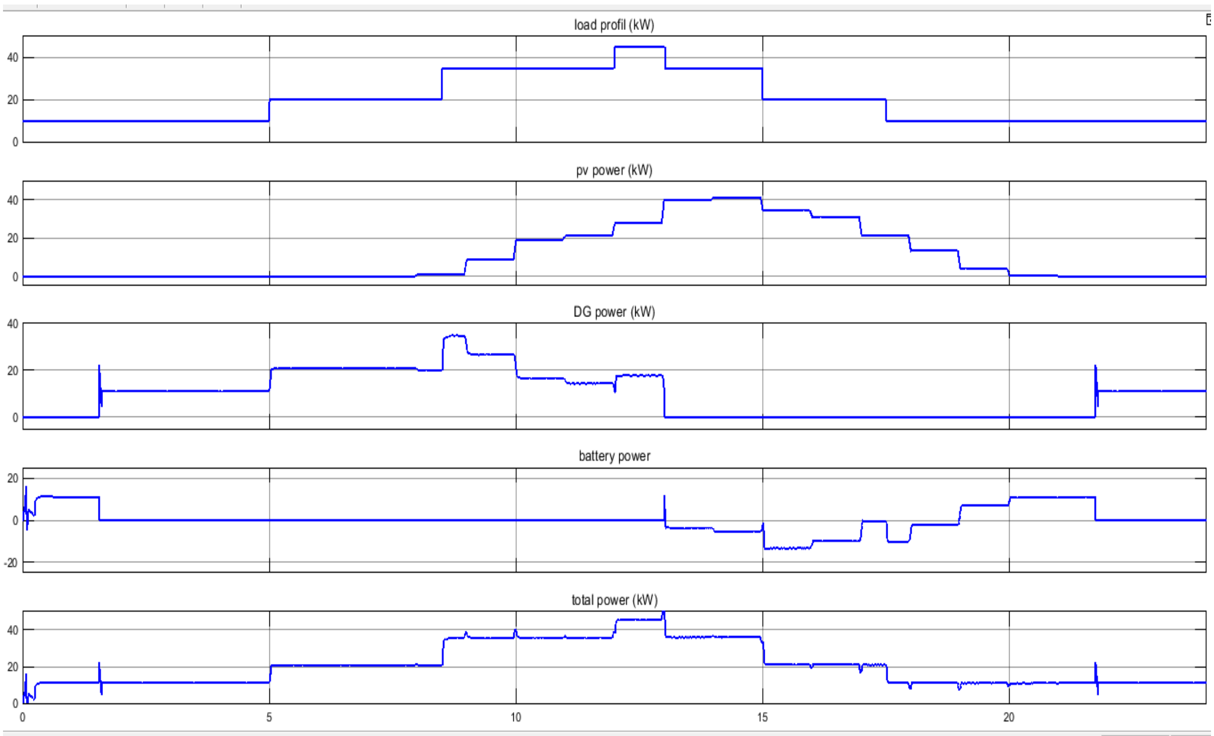


Fig 3.11 Power change for PV,DG and Battery

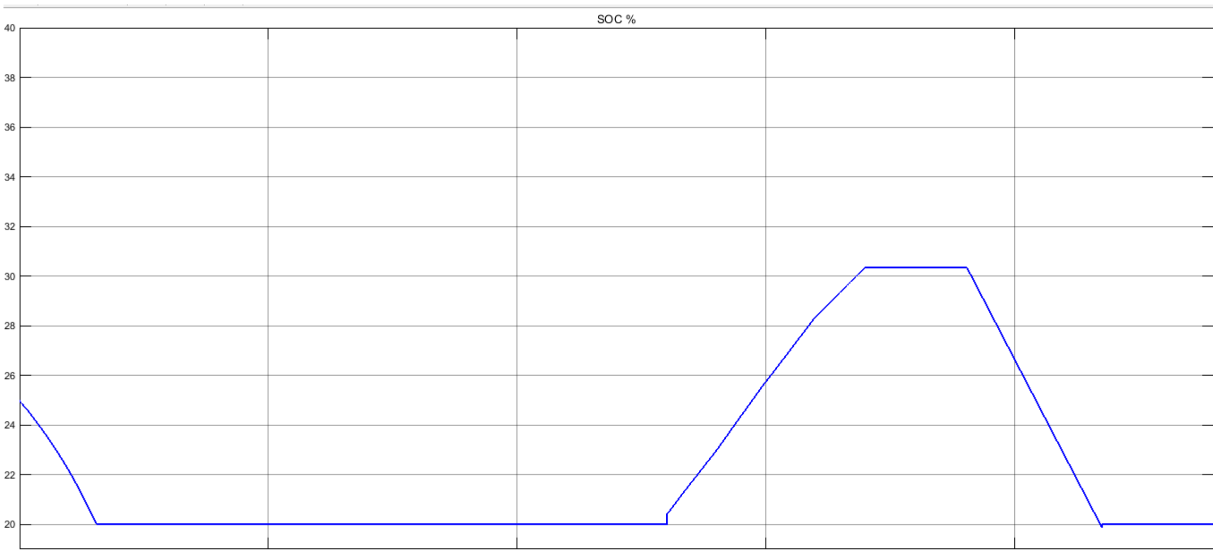


Fig 3.12 the state of charge of the battery

Comment:

- As shown in the results the sum $P_{PV}+P_{BAT}+P_{DG} = P_{LOAD}$ is preserved at any time
- The state of charge didn't fall under 20 %
- The results can be clarified within the following points according to time progress :
  - at the beginning battery is the only source of power "battery is discharging mode $P_{BAT}>0$" "
  - when SOC = 20% the battery is disconnected and the DG is connected to be the only source of power until the irradiation goes up Then, the amount of power generated by DG reduced by the same amount produced by PV arrays P_{PV} ($P_{DG}=P_{LOAD}-P_{PV}$)
  - at the moment when $P_{PV}>P_{LOAD}$ the DG is disconnected and that extra power ($P_{EXTRA}=P_{PV} - P_{LOAD}$) fed to the battery " see state of charge , it is increasing". However, when P_{PV} start decreasing ($P_{PV}<P_{LOAD}$) the battery discharge to compensate the difference of powers between the load and the PV arrays ($P_{LOAD}=P_{PV}+P_{BATT}$)
  - the battery keep discharge until SOC =20% it will be disconnected from the micro-grid and the DG will connected to be the only source of the power.

3.5 Conclusion

In this chapter, simulation and control of a Micro-grid system consisting of diesel generator, photovoltaic array, and battery for storage energy are implemented under Matlab/Simulink environment. The aim of this system is to extract the produced power by (PV)system to the electrical network (load),and manage the system without errors of power or of synchronization or any electrical error. It is noteworthy that the storage energy is assured by batteries, and the connection of these systems is achieved through a DC bus, in addition to that a control with PLL is applied to ensure the synchronization of system. By comparing the results of the three systems we can see that we reduce the consumption of the fossil fuels as much as possible

4.1. Introduction

HOMER software developed by the National Renewable Energy Laboratory (NREL), USA, is considered to be one of the most powerful tools for optimizing HESs by performing a system's techno-economic analysis with a lifetime project of a certain number of years[27].. With HOMER you can address various technologies such as PV, wind turbine, hydrokinetic, hydropower, biomass, conventional generator, battery, flywheel, super capacitor, and fuel cell. HOMER can model both the LF (load following) strategy and the CC (cycle charging) strategy for controlling the operation of the generator and the energy storage, Both of these strategies make economic dispatch decisions; they choose the most economical way to serve the load at each time step. HOMER simulates hundreds or even thousands of all possible combinations of the energy system and then ranks the results according to the least-cost options that meet the load requirements[28]. HOMER allows the user to input a profile of hourly power consumption and match renewable energy generation with the load required. It enables a user to analyze micro-grid potential, peak penetration of renewables, the ratio of renewable sources to total energy, it has a powerful optimizing function which is useful for determining the cost of different energy project scenarios. This functionality enables cost minimization and scenario optimization based on different factors. To use HOMER, the input model must be provided which describes the technology options, the cost of the components and the availability of resources. HOMER uses these inputs to simulate various system configurations, or component combinations, and produces results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays the simulation results in a wide range of tables and graphs that help to compare configurations and assess their economic and technical merits.

In this project we use homer to compare our system (PV + diesel + battery) with other systems, especially the old system which is based only on diesel generator and shows how our system is more economical and nature friendly.

4.2. Methodology

SUCCESSFUL EVALUATION OF ANY RENEWABLE ENERGY PROJECT REQUIRES APPROPRIATE CRITERIA TO BE APPLIED IN THE SELECTED AREA TO ENSURE ACCURATE ANALYSIS OF THE OPERATIONAL BEHAVIOR OF THE DIFFERENT SCENARIOS. IN THE CURRENT WORK THE FOLLOWING FRAMEWORKS OF ANALYSIS ARE ADOPTED:

- SITE SPECIFICATIONS SELECTED AND THE LOAD DEMAND DATA
- METROLOGICAL DATA (TEMPERATURE AND SOLAR RADIATION)
- THE COMPONENTS OF HYBRID POWER SYSTEM
- OPERATIONAL CONTROL SYSTEM

4.2.1 SPECIFICATION AND LOAD PROFILE OF THE SELECTED SITE

The remote rural village selected as a case study in this research is located at Debba, Kalaa, Relizane, Algeria. The village consists of 20 households with a total population of around 60 people. Water-wells and hand pumps are the principal water sources in the area. The village has no grid access, and this situation may open up new opportunities for the use of stand-alone HESs to supply electricity to the area. As with most remote rural areas, the village's residential units require low power supplies for electrical appliances and lighting. Figure 4.1shows the village households' total daily load profile. And the seasonal profile shows in Figure 4.2 . A random variability of 5 per cent is considered for step-by - step time and day-to-day analyses to provide greater reliability. Electricity consumption is low during the first hours of the day (00:00–06:00), since the people are asleep. From 06:00 to 07:00, the load profile shows an increase as most people are either ready to go to school or work. Then the load profile decreases again, as most members of the family are outdoors and continue until 14:00 when people return home. The load profile shows a continuous increase starting at 14:00 and the maximum is recorded from 19:00–21:00 as most people are present in their homes; then the load decreases, referring to the beginning of sleep time. There is a daily total energy demand of 165.59 kWh / day, a daily average of 6.9 kW and a peak power load of 23.31 kW.

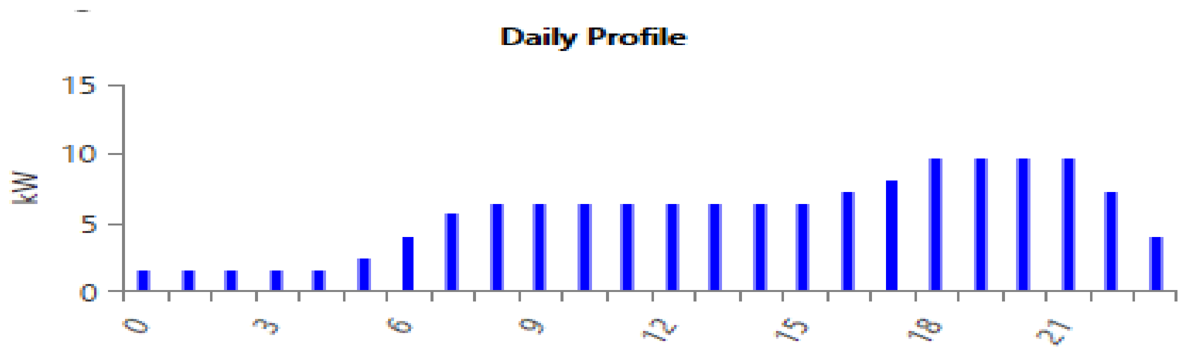


Fig4.1 The total daily load profile of the village's households

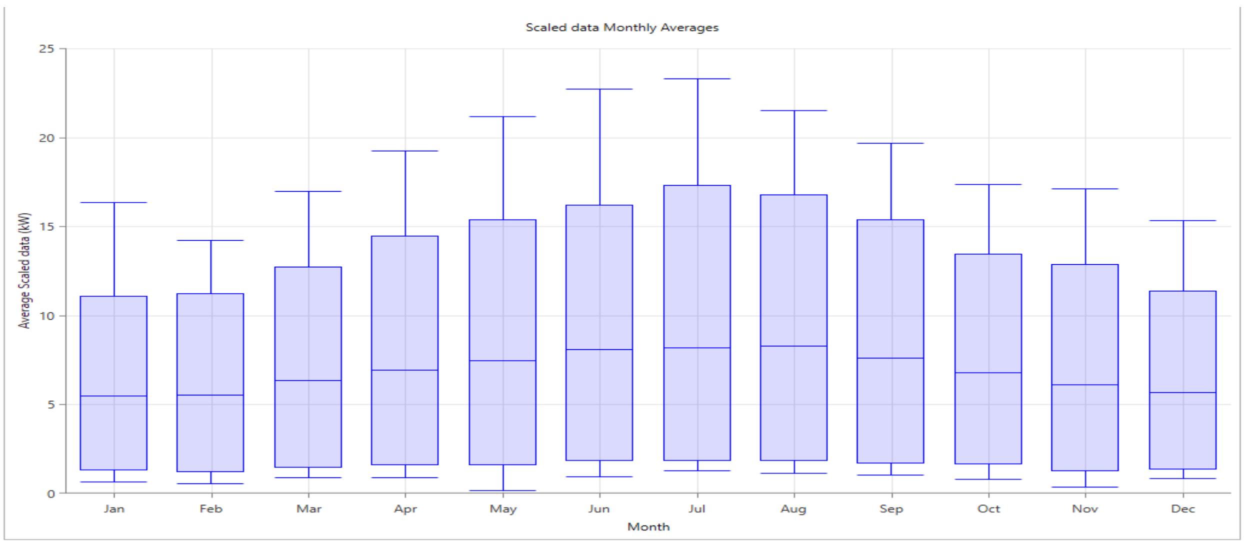


Fig4.2 The seasonal profile

4.2.2 Solar Resource and Temperature

Solar radiation and ambient temperature are the two parameters with the most profound effects on the output PV power. In this framework, HOMER software uses the monthly average global horizontal radiation and ambient temperature as input parameters. The following points explain the solar radiation and ambient temperature data in the selected site, which were obtained from the NASA website [29].

- The solar radiation and clearance index data for the selected village (35°44.7'N, 0°33.5'E) are presented in Figure 4.3. The annual average solar radiation is 4.80 kWh/m^2/day, maximum solar radiation (7.16 kWh/m^2/day) is recorded in June, and the minimum solar radiation (2.31 kWh/m^2/day) is recorded in December. The amount of solar radiation received by the area is relatively high, which indicates that the solar energy system is an attractive power source.

- The ambient temperature plays a vital role in the performance of PV modules. Therefore, accurate measurement of ambient temperature data is essential. The monthly average ambient temperature for the chosen area is illustrated in Figure 4.4. The summer season shows the highest ambient temperature, at 28.64˚C in July, and the winter season records the lowest ambient temperature, at 9.59˚C in January. In HOMER software, the ambient temperature is taken into consideration when calculating the output PV power.

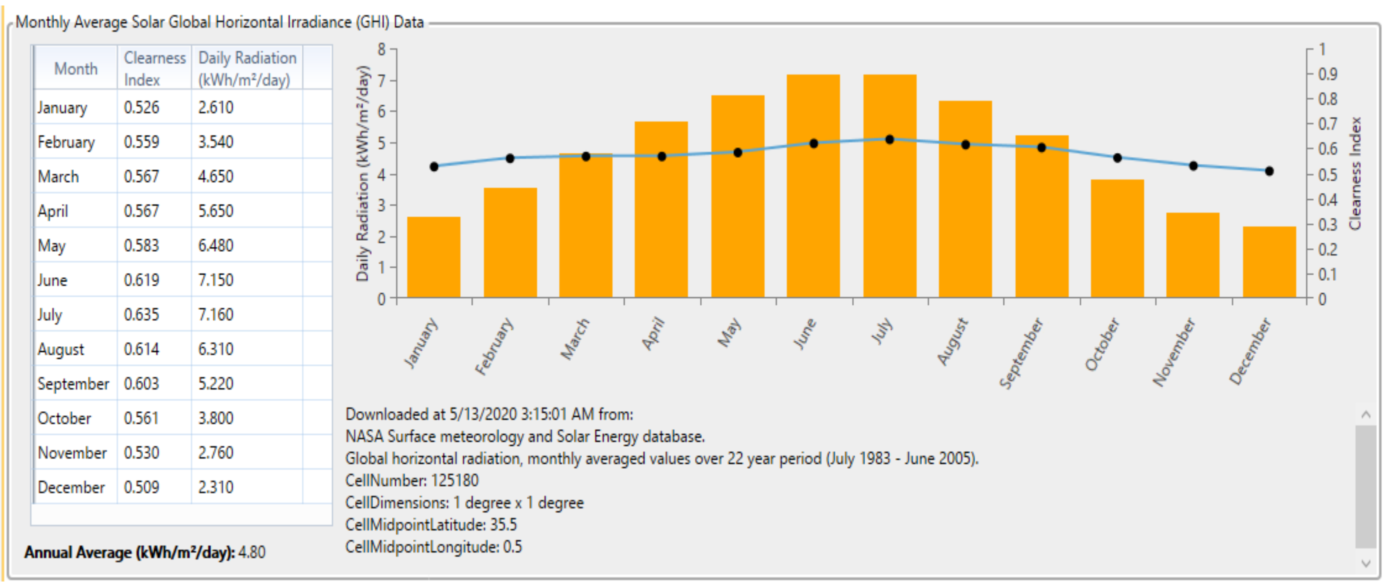


Fig4.3 Monthly average solar global radiation and clearance index of the village.

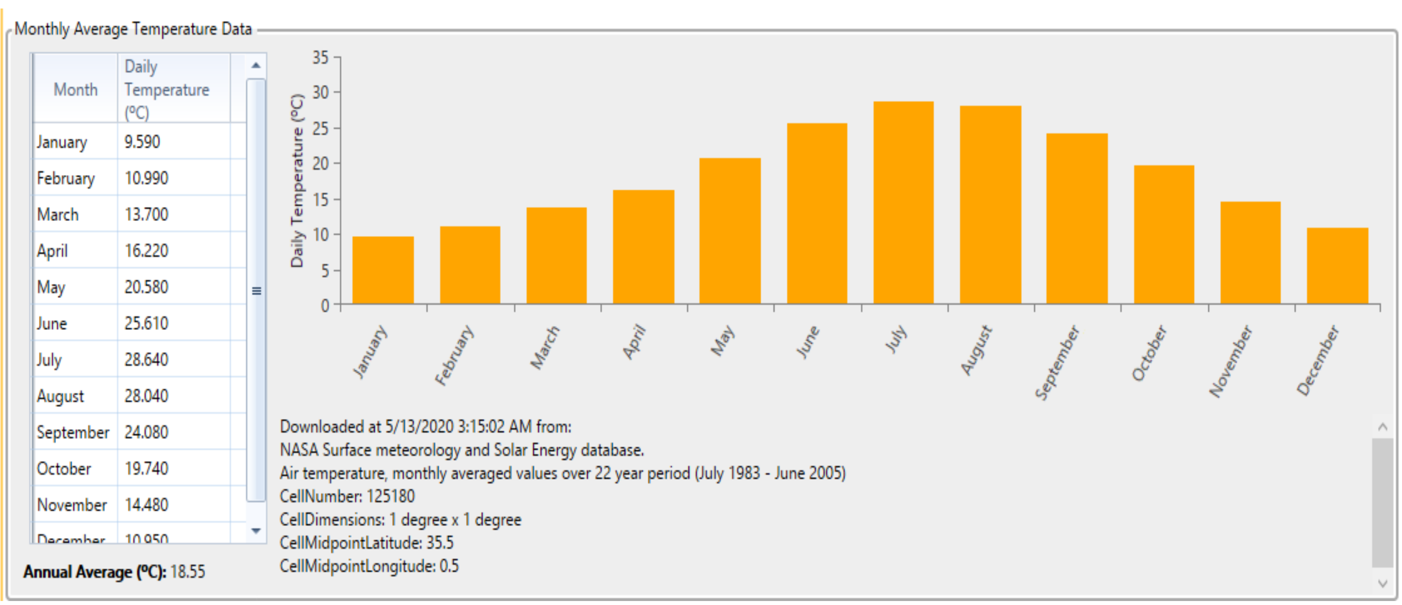


Fig 4.4 Monthly average temperature of the village.

4.2.3 System Components

The proposed HES consists of four components in this research , the PV system, the diesel generator, the converter and the batteries. Figure 4.5 illustrates a schematical diagram of the proposed HES. The parameters of techno-economic input for all HES components are explained in detail in the Table 4.1 Note that the homer has given the technical parameters and costs of the components In terms of capacity, the optimizer lets HOMER find the optimum sizes for system components.

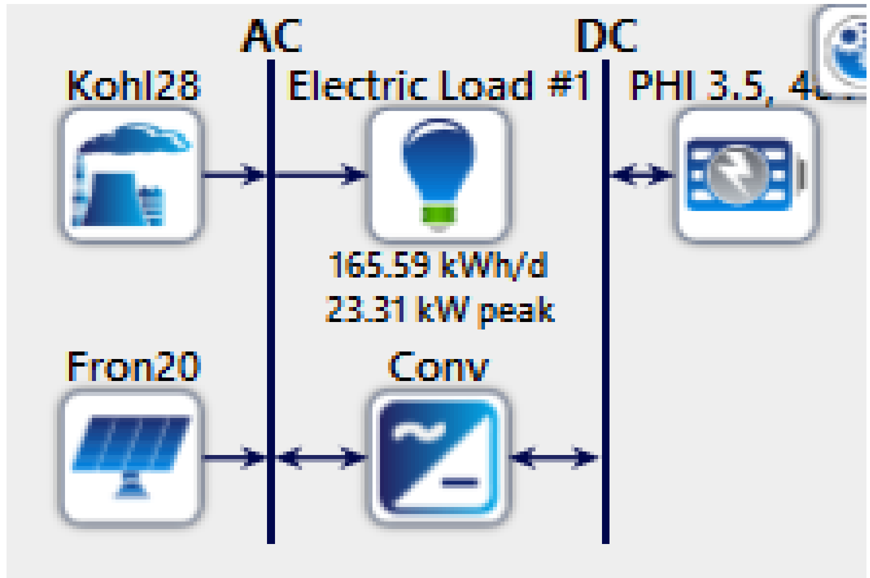


Fig 4.5 Schematic diagram of PV/diesel/battery (HES).

Description	***Specification***
Abbreviation	Fron20
Panel type	Flat plate
Rated capacity (Kw)	20
Temperature coefficient	-0.41
Operation temperature	45
efficiency	17.3%
Operating and maintenance cost ($)	3000
Cost of replacement ($)	10
Capital cost	3000
Life time (years)	25

Table4.1.athe parameters of the PV array [30]

Description	***Specification***
Diesel generator	Kohler 28 kw prime
Fuel curve interrupt (L/h)	0.5
Fuel curve slope (L/h/kw)	0.329
Capital cost ($)	1000
Operating and maintenance ($)	2
Cost of replacement ($)	1000
Life time (h)	15000

Table 4.1.b the parameters of the DG [31]

Description	***Specification***

Model	Simpliphi PHI
Nominal capacity (kwh)	3.53
Nominal voltage (v)	51.2
Capital cost ($)	3000
Cost of replacement ($)	3000
Life time (years)	10

Table 4.1.c the parameters of the batteries [32]

Description	***Specification***
Efficiency	90% for inverter and 85% for rectifier
Cost of capital ($)	550
Cost of operation and maintenance ($)	5
Cost of replacement ($)	450
Life time (years)	15

Table 4.1.d the parameters of the converter [33]

Table 4.1 Input parameters and costs of different components.

4.2.4. Control Strategy

The two control methods of the hybrid PV/diesel/battery system are the LF and CC dispatch strategies. In this project, the LF strategie is presented for PV/diesel/battery HES .The implementation of these strategies in practice can be done using a suitable controller, such as microcontroller, PLC, FPGA, etc.

4.2.4.1 Load Following Strategy

Figure 4.6 shows the flowchart of the LF dispatch strategy for the PV/diesel/battery HES. The system operation of this model can be classified into three cases as follows:

- The first case is when the output PV power is equal to the load power. Here, the PV power meets the load demand, the batteries do not draw any energy, and the generator stays off. In this case, no excess power exists.

- The second case takes place when the output PV power is higher than the load power. The PV feeds the load resulting in excess power. In this case, the excess power will be damped if the battery is fully charged. In the case where the battery is not fully charged, the excess PV power is used to charge the battery. The generator also does not work in this case.

- The last case is when the PV power is lower than the load power. The two possible subcases are as follows:

- If SOC = SOC_{min}, the generator works to feed the net load (load minus renewable power). The generator provides only enough power to satisfy the net load without charging the battery. It is important to mention that if the minimum generator loading output power is higher than the net load, the generator works to feed the load and the excess power from the PV charges the battery.

- If SOC >SOC_{min}, a cost of discharging the battery is computed and compared with the cost of turning on the generator that operates only to serve the net load. If the battery discharging cost is higher than the cost of turning on a generator, then the battery would not be discharged while the generator runs and produce enough power to meet the load demand without charging the battery. Otherwise, the battery is discharged. The following equations explain the cost of each decision:
- The cost of discharging the batteries is calculated using the following equation [34]:

$$C_{disch} = C_{batt,wear} \qquad (7)$$

$C_{batt,wear}$ is the battery wear cost ($/kWh), which is given by [8]:

$$C_{batt,wear} = \frac{C_{batt,rep}}{Q_{lifetime}\, N_{batt} \sqrt{\eta_{rt}}} \qquad (8)$$

where $C_{batt,rep}$ is the battery replacement cost ($), N_{batt} is the number of batteries in the storage bank, Q_{life} is the single battery throughput (kWh), and η_{rt} is the battery round trip efficiency (%).

The cost of turning on the generator ($/kWh), in which the generator operates only to serve the net load, is calculated using the following expression [35]:

$$Cgen = \frac{F_{con} F_{price}}{L_{served} G_{output}} + \frac{C_{gen,rep}}{L_{served} G_{lifetime}} + \frac{C_{gen,O\&M}}{L_{served}} \qquad (9)$$

where F_{con} is the fuel consumption (L/hour), F_{price} is the fuel price ($/L), L_{served} is the total load to be served, G_{output} is the generator output (kW), $C_{gen,rep}$ is the replacement cost of the generator ($/kWh), $G_{lifetime}$ is the generator lifetime, and $C_{gen,O\&M}$ is the O&M cost of the generator.

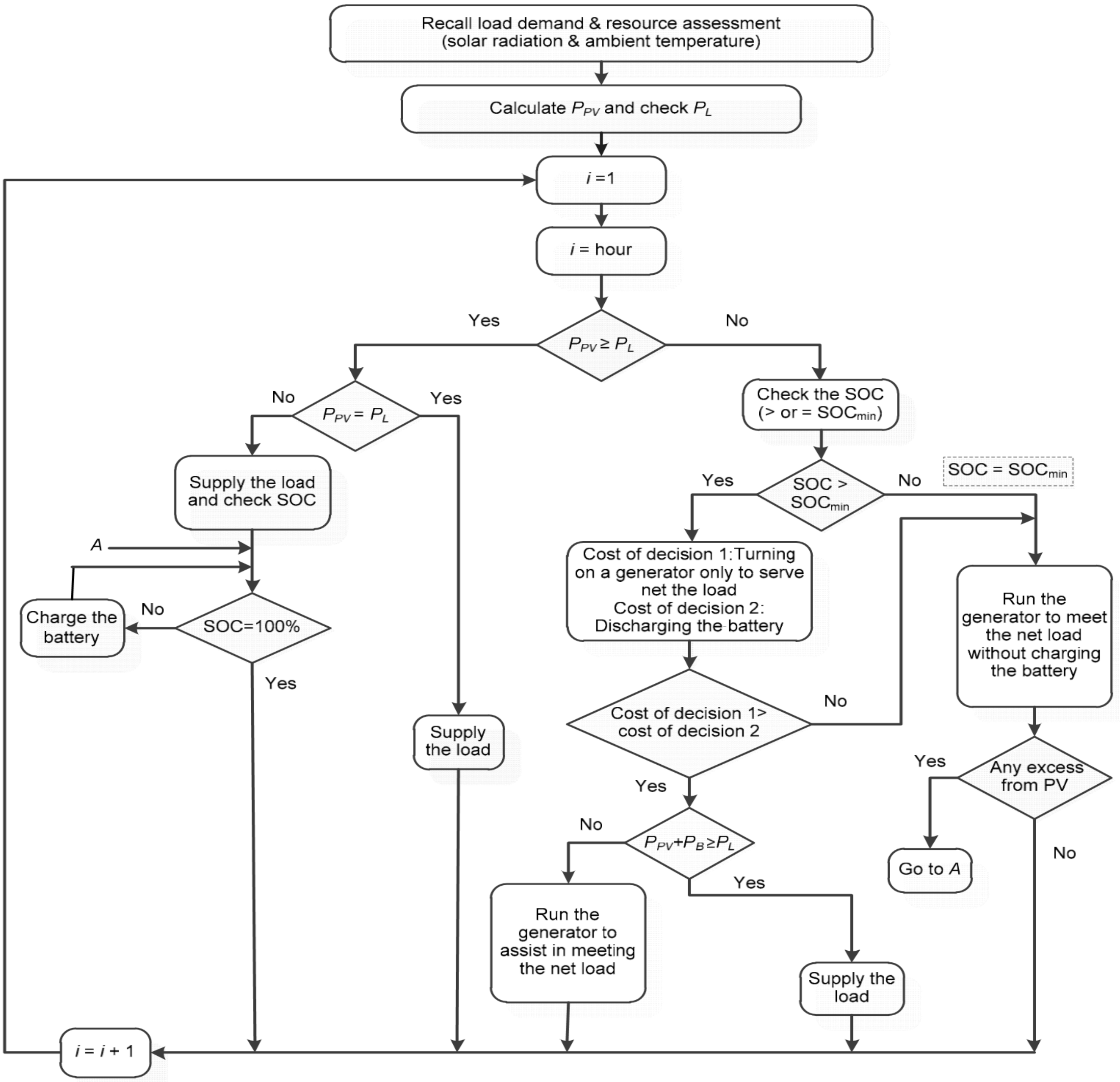


Fig 4.6 Load following (LF) dispatch strategy for the PV/diesel/battery HES

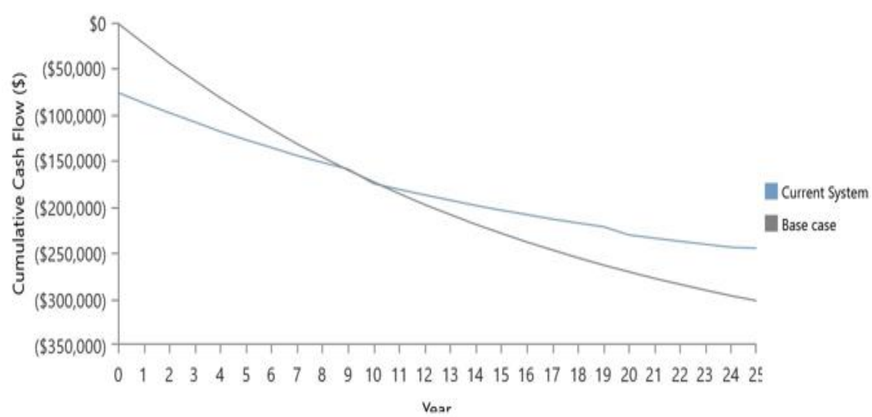
4.2.5 Result and Discussion

Figure 4.7 shows the results of three deffernts systems given by the HOMER. The base system w hich is based only on the diesel generator and the second system which is (pv + battery) the third one is our system (pv + diesel + battery), as you can see in the figure the optimization results of t his configuration show that the (pv + battery + diesel) is considered an optimal solution because of its low NPC which is the net present cost (or life cycle cost);, the NPCof a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system as a whole.

Architecture										Cost			
				Fron20 (kW)	Fron20-Inv. (kW)	Kohl28 (kW)	PHI 3.5, 48V	Conv (kW)	Dispatch	NPC ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)
						28.0			LF	$301,951	$23,280	$1,000	$17,520
				20.0	20.0	28.0			LF	$359,956	$23,126	$61,000	$17,712
				20.0	20.0	28.0	5	30.0	LF	$244,931	$13,068	$76,000	$9,204

Fig 4.7 Optimization Result

Figure 4.8 is the cumulative cash flow curve, where the grey curve represents the basic case where only the diesel generator is used.as for the blue curve it represents our system , we can see that the difference in cost over time , the basic system is less expensive in the be



ginning, and this is normal because the cost of the equipment used in our system is higher , b ut with the passage of time and the increase in fuel consumption in the basic system, the diff erence in thecost begins to appear, As it appears that our system is more economic .

FFig 4.8 cumulative cash flow

4.2.6. Gas emission

The hybrid renewable system would save about 36,27 kg/yr of carbon dioxide in one year in operation compared to a stand-alone diesel generator system. Emission of other toxic gases such as carbon monoxide and sulphar dioxide will be reduced mentioned in table 2 and 3.

Pollutant	Quantity	Unit
Carbon Dioxide	75,809	kg/yr
Carbon Monoxide	413	kg/yr
Unburned Hydrocarbons	20.8	kg/yr
Particulate Matter	24.8	kg/yr
Sulfur Dioxide	185	kg/yr
Nitrogen Oxides	388	kg/yr

Table 4.2 Emission by stand-alone diesel generator system

Pollutant	Quantity	Unit
Carbon Dioxide	39,537	kg/yr
Carbon Monoxide	215	kg/yr
Unburned Hydrocarbons	10.9	kg/yr
Particulate Matter	12.9	kg/yr
Sulfur Dioxide	96.7	kg/yr
Nitrogen Oxides	203	kg/yr

Table 4.3 Emission by Hybrid and Stand-alone system

4.3 Conclusion

This study examined the use of solar hybrid system in comparison to diesel generator. The results showed that the solar PV hybrid reduce fuel consumption, hence there is fuel conservation which means reduced carbon emissions and The running hours of the generators .The result from the HOMER shows that PV, Diesel Generator with battery and converter is most economical solution, HESs prove to be more reliable and economical than single energy source systems (diesel generator).

General Conclusion

Nowadays, modern nations produce the majority of their power using conventional energy generation technology, based on fossil fuel, nuclear or waterfall. These power plants generate power at large scale and dominate power systems almost all around the world.

However there is trend everywhere to turn to clean, renewable and sustainable energy sources. So far their utilization is somehow limited to micro-grids, islanded hybrid power systems or grid-connected small power plants. Our project aimed to design and optimize an off-grid hybrid renewable energy system (HRES) for a remote island load, where no grid extension is available. The study considered one type of renewable energy resource, namely solar source that knows an extensive use across the word.

It is determined that using a hybrid system to power isolated places is far better than using the diesel only power generation system, especially in areas where there is no utility power. The economic analysis of hybrid PV/diesel and battery stand-alone systems carried out in this investigation verifies the predictions for the brilliant future of hybrid energy technology for remote areas. From the environmental analysis on pollutant emission, the hybrid PV/diesel system is preferred over diesel generators. The designed hybrid system minimizes the diesel operational hours, thus reducing fuel consumption, which significantly reduces environment pollution.

Through this study, it has been demonstrated that the use of hybrid PV/ diesel system with battery could achieve significantly lower NPC as well as reduction of green house gas emissions as compared to a standalone diesel system. It is concluded that, the hybrid PV/diesel system has a high potential and deserves to be further investigated for use in power generation of remote loads or villages.

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