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Simulation of a Stand-alone Hybrid PV-Diesel Systems for Critical Island Loads

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Abstract:

Micro-grid is an effective solution to increase the power distribution reliability by using renewable energy sources or hybrid with a diesel generator. In this research, a hybrid energy system using a solar power system designed for extraction of 100 kW at peak power, at standard condition 1000 W/m2 and 25 ˚C with a diesel generator designed 500 KVA at peak power is simulated for a standalone microgrid utilities. For extraction maximum power, the duty ratio of a converter is adjusting based on the specific value of maximum power point (MPP) voltage of the PV array. Thus, the DC voltage of the inverter side is kept constant to meet the grid specifications, e.g. 400 V and 50 Hz. The PV array is modelling by nonlinear equations which describe the effect of real irradiance levels for the Western Desert in Egypt on DC voltage. The solar power system is designed in an actual location with a diesel generator, supplying a three-phase load of about 300 KW contain 60 KW of critical police loads and 240 KW of normal police loads. Due to the fluctuations in solar irradiance, load sharing between the PV system and the diesel generator is controlled. The load sharing is verified numerically by the Newton-Raphson method for a three-bus ring distribution system. Numerical and simulation results show the capability of the designed PV system to share the load with the diesel generator over the year.

The proposed system helps to achieve security and stability, especially in border and remote places due to the high cost of connecting these places with the public network, as well as the difficulty of maintaining diesel generators and delivering fuel. Due to the sunny climate of the Western Desert in Egypt, so the hybrid energy system with any renewable sources helping in increase generation capacity for any future extension loads power requirements without increase the storage units of diesel generator, reduce maintenance of diesel generator, increase the lifetime of diesel generator, helping to keep the environment clean, maintains reliable electricity to the consumer and can be portable from place to another without any additional cost.

***Keywords**: PV system, boost converter, voltage source control, three-level inverter, diesel generator, hybrid energy system, and load sharing.*

I. INTRODUCTION

Renewable energy refers to clean energy that comes from natural sources or can't run out or endless like solar, wind, hydro, geothermal, biomass energy [1]. Renewable resources technology is extremely used globally to generate electricity, for economic reasons, environmentally, friendly techniques, and support the public network development. Nowadays, renewable resources get the presidency's interest in electricity generation while preserving the environment, which suitable for a standalone distributed generation system and remote rural area, where the traditional grid connection is absent or costs a lot of money to produce continuous and stable electricity [2–4].

Day energy demand increase due to population outbreak the day, which affect conventional sources. The main amount in generation electricity comes from fossil fuels [5]. Generally, after generating electricity by fossil fuel is exhausting. The renewable sources become the only way to compensating the future energy demand. On the other hand, generating electricity by the non-renewable sources or fossil fuel emits harmful gases and pollutes the environment [6].

One of the renewable resources is solar energy. Producing electricity by a photovoltaic cell is an important alternative for conventional energy "fossil fuels". It is a reliable technique and plays an important role in CO_2 emissions mitigation. Although the initial cost for installing a photovoltaic system is extremely high, the running cost is very low [7].

In the paper, the proposed hybrid energy system consist of a PV system as the main source using real irradiance levels and temperature at the Western Desert in Egypt with a diesel generator as a backup source to feed loads contain normal and critical, the main configuration features are low specific inverter cost and robust, high efficiency and easy maintenance.

There are many scientific researchers have already been done in this field, come up with many techniques that achieving the best optimization for renewable energy generally and the PV system epically, also discussed the different methods of solar system control to maximize output voltage and efficiency and how to overcome the problems like harmonic, low frequency and voltage stability while load sharing. In the proposed system complete what the researchers ended up and customized techniques to achieve a hybrid energy system with some characteristics as lightweight and portable and reducing the initial finances while keeping efficiency and output high as possible and the possibility of enlarging the system by adding more sources or batteries if necessary.

II. Solar Energy

Solar user's demands determine how solar energy is simple or complex. Solar energy produces a direct current "DC", which travels in one direction to loads. The majority of solar energy is on availability at the markets, as a before the silicon-crystalline modules was suitable for residential and commercial solar systems using, which consist of multiple strings of solar cells, wire in series positive to negative, and mount in an aluminum frame [8]. The cell size determines the amperage amount as in large cell has a high value of amperage. Early crystalline modules are using a

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monocrystalline with round-shaped cells, the manufacturing process is more efficient, but is an expensive process. Today's poly-crystalline with a square or rectangular-shaped cells is the suitable source for crystalline, as the manufacturing process is cheap and wastes less material, but has a less efficient [9]. A series string has value of the sum module voltages. Each module has the same voltage and current. The module negative side connects to the positive side of the next module. The source circuit or combiner box is the sum voltage of each string, as string positive lead connects to a negative lead at the end of each string. The positive leads connect to an individual fuse and the negative leads connect to a negative busbar at an enclosure. The combiner box is showing in Fig. 1 [10].

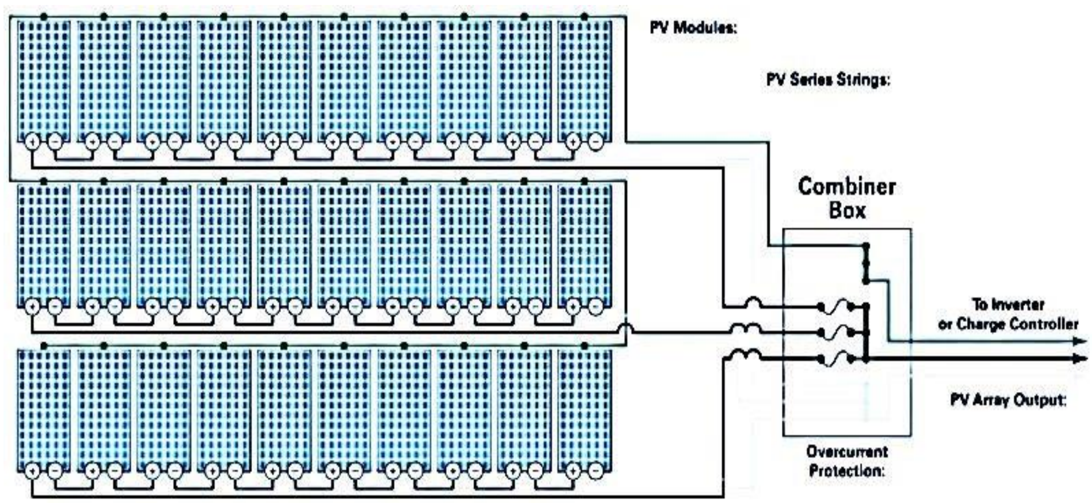

Fig. 1 A combiner box has series modules and in parallel strings to max voltage and current.

For widespread PV system hybrid applications, some issues like technical requirements from the power system side need to be achieved to ensure the PV system safety and reliability, identified for a stand-alone microgrid interconnection and solved the interconnect problems such as islanding detection, harmonic distortion, FACT, and electromagnetic interference. Control and protection function from maximum power tracking, inverter current control, and power factor control devices work correctly. PV system maintenance, life spa, and reliability is strong recommending through a long-term operation, in addition to reducing initial cost, size, and weight. PV inverters must be operated at the unity power factor. To meet the load of (300 kW), the propose PV system configuration has three strings of the subsystem. Each one consists of 7 branches in parallel. Each branch consists of 19 PV panels in series. The PV module characteristic is giving in Table. 1.

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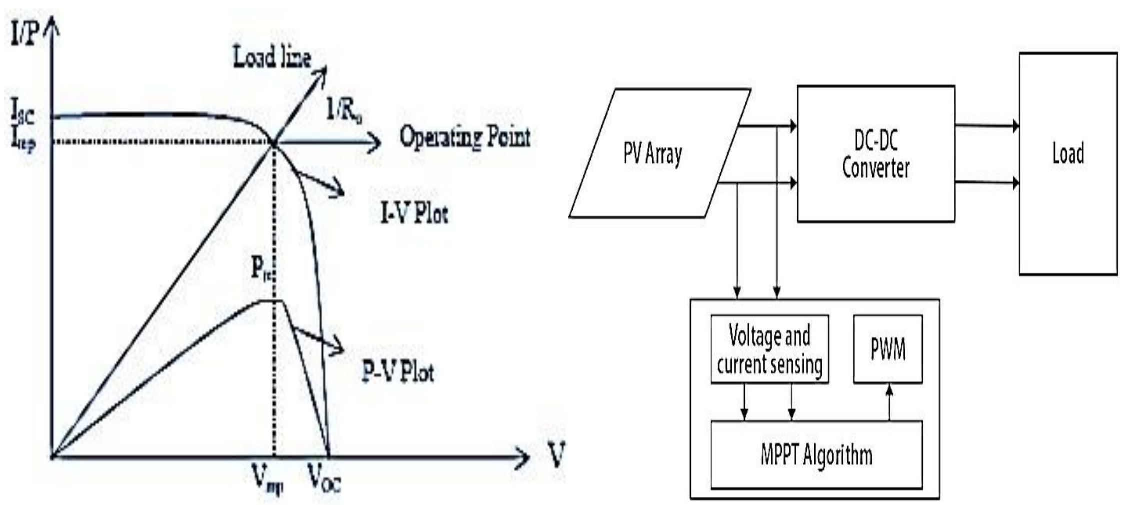
Table. 1 Solar module specification in the proposed system.

Parameters at standard condition (1000 W/m2 and 25 ˚C)	**Unit**	**Specificatio n**
Nominal power for a PV panel	W	266
Open circuit voltage V_{oc}	V	38.6
Short circuit current I_{sc}	A	9.03
The voltage at MPP V_{MPPT}	V	31.6
Current at MPP I_{MPPT}	A	8.44
Number of panels (for on branch) in series	panel	19
Number of panels (branch) in parallel each branch includes 19	branch	7

The output power of PV module panels depends on solar irradiation that falling on it. The relation is linear between output power and the intensity of solar irradiation. Unfortunately, solar irradiation availability is not constant throughout the day. From intersection P/V curve, I/V curve and load line used to reach the maximum power output of PV modules with high efficiency illustrated in Fig. 2 (a). The MPPT algorithm generates the current magnitude at the MPP and used the converter as DC step-up voltage transformer then to the inverter to convert DC to AC to feed loads shown in Fig. 2 (b).



(a) (b)

Fig. 2 a) MPPT point resulting from intersection load with I-P /V curve.

b) Block diagram show power flow of PV-system feeding Loads.

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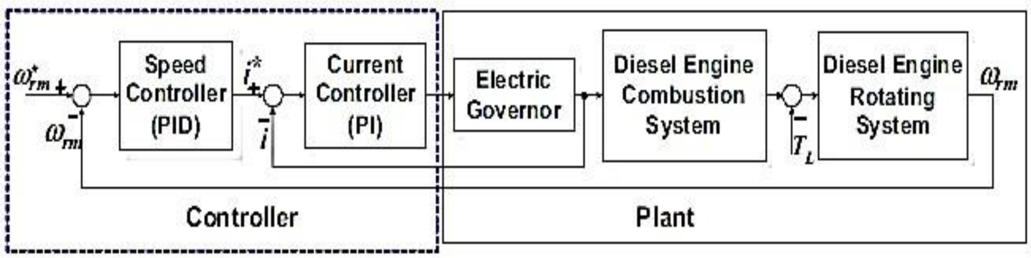
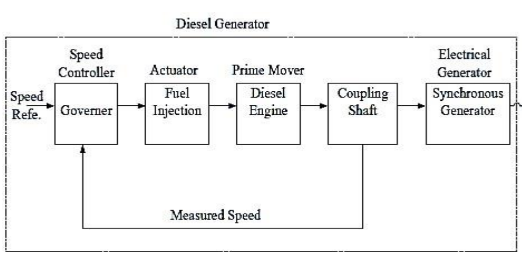
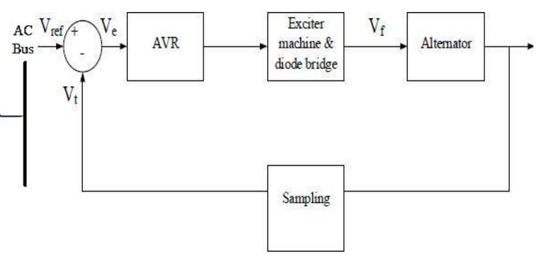
III. Diesel Generator

Diesel generators currently use in heavy load mobile and stationary power generation units, because of its characteristic's like high output torque, size flexibility, and durability. In rural areas, the most load power requirements for the diesel engine, when couple to a synchronous machine operating in parallel with renewable source using for power supply and providing light. Diesel generator consists of an engine, a governor, an excitation, and a synchronous generator. A speed regulator and an actuator are the major units for controlling output power. A diesel engine unit converts heat energy to mechanical energy, then a governor converts mechanical energy into electrical energy automatically to control engine speed by format the fuel intake. Speed governor keeps the turbine operating at its designed speed, and speed governor output is a throttle signal that controls the fuel going into the engine as shown in Fig. 3 (a), (b), and (c) [11-12].



(a)





(b) (c)

Fig. 3 a) Block diagram of diesel generator control.

b) Excitation control scheme. C) Governor control scheme.

One of the most important elements for diesel engine work is the high temperature inside the diesel generator combustion chamber, as air at high pressure enter through the input filter. Because of compressed air heat the small fuel droplets spray with the compressed air, and then burn fuel molecules vaporizes from the surface of the droplets of the compressed air. Fuel-burning has a delay due to the vaporization process [12]. Combustion gas pressure in the chamber cause a quick extension for the cylinder which effect on the piston to go outward due to the sudden pressure, and the developed power transfer to crankshaft because of compression ratio is high illustrated in fig. 4, the diesel engine works at maximum thermal efficiency [13]. The principle of diesel engine work is keep diesel generator speed constant by using governor which control speed regulation by managing the air/fuel ratio that is injected into the combustion chamber by using servo motor device. The servomotor uses a PID controller.

An automatic voltage regulator is using for adjusting the excitation current to control terminal voltage. Excitation system has a main function at synchronous generator control field current to manage terminal voltage. In this paper excitation system at simulation is modelled to keep synchronous machine behavior accurate in the study of synchronous machine performance at all disturbances of power system stability. Excitation system model is suitable for diesel generator that connecting to hybrid AC/DC stand-alone microgrid.

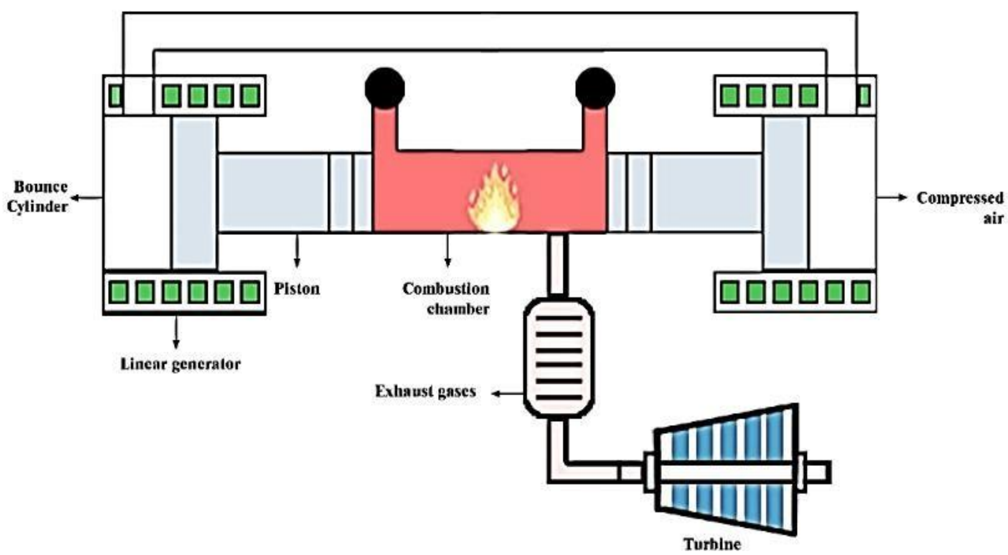


Fig. 4 Diesel generator interior including the combustion chamber and the power flow.

The benefits of using renewable energy with diesel generators are reduction of fuel transportation costs, issues associated with fuel storage, the operating time in fuel consumption, emissions, clean generation, improves the runtime, diesel generator life-time, and efficiency. Solar and other renewable sources are integrating with diesel generator helping to reduce the fuel consumed in diesel generator.

IV. Hybrid Energy System

Particularly, hybrid energy systems develop a combination of PV with a diesel generator as a portable can move from place to other easily. Besides, output power of hybrid energy system offer a clean, an efficient power, and more cost-effective than individual diesel generator. Due too increasingly in solar energy researches, hybrid renewable energy become the best solution for offgrid or remote power generation. In this paper, a PV system connecting to a diesel generator and operates hand in hand to feed the desired load shown in Fig. 5.

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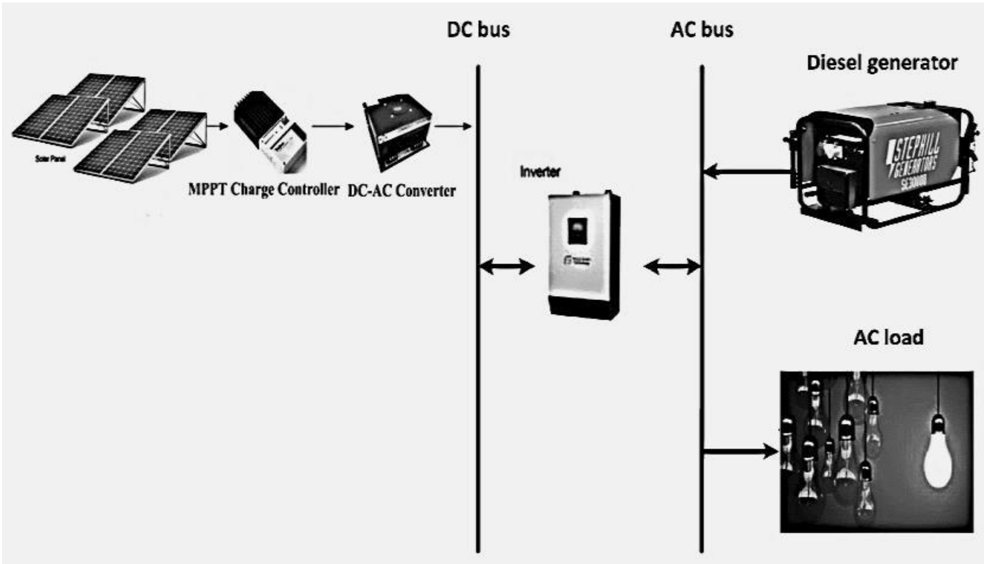

Fig. 5 A simple shape for connecting of hybrid energy system.

V. Proposed Hybrid Energy System

The model block has total output power is consisting of a 100 kW of PV system with a 500 KVA of a diesel generator to feed load power contain critical load has 60 KW and normal load has 240 KW. The intensity of sunlight control power available from the PV system, which controls the availability of PV system to feed the microgrid or make diesel generator share load power requirements during the day and year. The function written in MATLAB performs the power flow and determines which source feeds the load power requirements. A MATLAB program is used to simulate the real system of photovoltaic energy with a diesel generator and distribute the electrical to loads. The simulations model works in three cases first, only PV system feed loads, second, Load sharing between PV system with a diesel generator and third, Failure system because of increasing loads than a generation from both two sources. The simulation results perform a costeffective analysis and predict the ecological impacts of the hybrid power system [14-15]. The costeffective analysis calculates the fuel consumed, the energy per gallon of fuel supplied, the total fuel cost, and calculate energy pay back time [EPBT], simple pay back time [SPBT] for the PV array. The model optimizes the hybrid power system performance by Maximum Power Point Tracking [MPPT], that provides power system modeling with all the information shown in Fig. 6.

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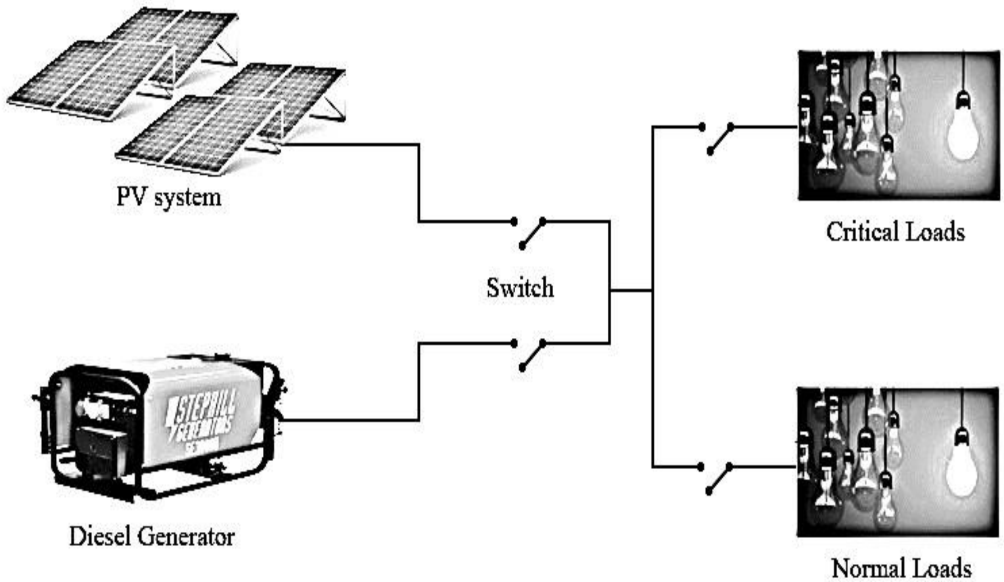

Fig. 6 switching algorithm for controlling load power source.

When load power requirement is less than the PV power source capacity, the switching algorithm is switch ON only PV system. And if the load power requirement is greater than the PV power source capacity, the switching algorithm is switch ON PV system and diesel generator to share the load power requirement. Finally, if the load power requirement exceeds the PV power and diesel generator source capacity, the switching algorithm is to switch OFF the diesel generator and disconnect all loads, except critical loads supplied from the PV system.

The input parameters consist of data files that obtained from the actual situation. The model uses sensors at actual locations like the sunlight insolation amount, incident upon the PV array, charge and discharge level of the batteries if it exists, and operating parameters of the diesel generator according to this information. Processing signals by using AC/DC converters to transmit data which some information solar insolation values, electrical load, and temperature that improve to develop the model and also to find out the efficiency and the fuel amount using for the diesel generator. These parameters are very sufficient to any hybrid power system for analyzing and determining the above elements. An extension of the country's tendencies to use renewable energy to preserve the environment.

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A. Derivation of Solar Cell Mathematical Equation

A figure 7 illustrate the equivalent circuit for lad current mathematical equation [15], [16].

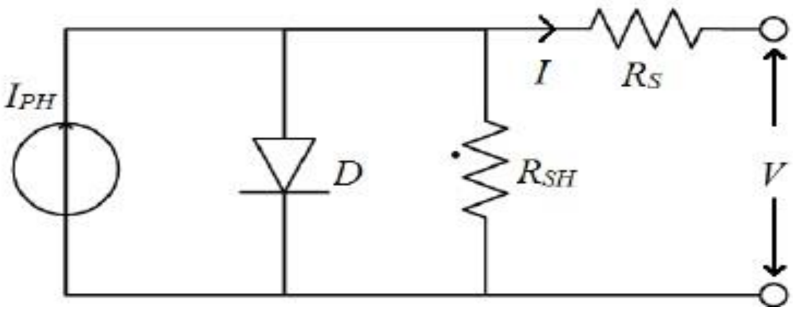

Fig. 7 An equivalent circuit for photovoltaic cell.

The load current equation is given below [10]

$$\mathrm{I} = I_{PH} - I_s\left(e^{\frac{q(V+I_{RS})}{NkT}} - 1\right) - \frac{(V+I_{RS})}{R_{SH}} \qquad \mathrm{A} \qquad (1)$$

As I is load current, I_{PH} is photocurrent, I_s is diode saturation current, q is the absolute value of electron charge = 1.60×10-19 C, V is cell terminal voltage, N is diode ideality factor, k is the Boltzmann's constant =1.38 ×10-23 J/K, T is cell temperature, R_S and R_{SH} are series and shunt resistance respectively. The solar cell behavior depends on these parameters directly.

$$I_{PH} = [I_{sc} + K_i(T - T_{ref})]\,\frac{B}{1000} \qquad \mathrm{A} \qquad (2)$$

As I_{sc} is short circuit current, K_i is temperature coefficient of short circuit current, T is cell temperature, T_{ref} is reference temperature, and B is solar irradiation in [W/m^2]. In this paper, the solar irradiation varies from 400 to 1000 [W/m^2] [6]. The effect of varying temperatures on PV array can be achieved from a mathematical expression. Note, I_{PH} is an important parameter which differentiates from one diode to another and increase with T.

$$I_s = I_{RS}\left(\frac{T}{T_{ref}}\right)^{\frac{3}{N}} e^{-\frac{qV_t}{NK\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}} \qquad \mathrm{A} \qquad (3)$$

$$I_{RS} = \frac{I_{sc}}{e^{\frac{q(E_{go})}{AK}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}} \qquad \mathrm{A} \qquad (4)$$

$$R_s \leq 0.001\,\frac{V_{oc}}{I_{sc}} \quad \& \quad R_p \geq 100\,\frac{V_{oc}}{I_{sc}} \qquad (5)$$

$$\mathrm{THD} = \frac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_1} = \frac{\sqrt{I_1^2 + I_2^2 + \cdots I_n^2}}{I_1} \qquad (6)$$

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As I_{RS} is the diode reverse saturation current, V_t is thermal voltage, T is cell temperature, T_{ref} is reference temperature, B is solar irradiation in [W/m^2], and after mathematical manipulation of the above equations, the following equation is yielded

$$V_{panel} = C_1 i_n \left[1 - C_2 (I_{panel} I_{RR} - C_3 I_{RR})\right] - C_4 I_{panel} I_{RR} \quad V \quad (7)$$

As V_{pv}, I_{pv}, C_1, C_2, C_3, C_4 are parameters that have been derived from the panel coefficient; I_{RR} is the solar Irradiance. For the proposed PV array design in this paper, the values of C_1 , C_2 , C_3, and C_4 are 2.27, 2210433.245, 0.009027, and 0.04, respectively. Equation (7) is a nonlinear one. It describes the effect of irradiance on the PV array voltage. To find out the voltages generated from the solar panel directly, making the voltage V_{dc} fixed on the boost converter.

By using MATLAB code, the results for PV array voltage for the two extreme values of the irradiance level.

Where irradiance equal to 1000 W/m^2:

V_{panel}=31.61 V, and I_{panel}=8.44 A ⟶ P_{panel}=266 W

Where irradiance equals 400 W/m^2:

V_{panel}=29.7374 V, and I_{panel}=3.376 A ⟶ P_{panel}=100.394 W

The purpose of deriving the formula for the PV voltage is obtained the value of the voltage $_{pv}$ that acts as an input to the Boost converter. This process makes it easier to calculate the directcurrent voltage V_{DC} after the Boost converter. Also, the DC-Link capacitor can be calculated.

Where irradiance equal to 1000 W/m^2, I_{RR} = 1 P.U, and for one string has 7 branches:

V_{PV}=N_s V_{panel} =19*31.61 = 600.6 V ⟶ P_{pv}=V_{PV} $I_{PV} I_{RR}$= 600.6*8.44 A*7*(1) =35.488 kW

Where irradiance equal to 400 W/m^2, I_{RR} = 0.4 P.U, and for one string has 7 branches:

V_{PV}=N_s V_{panel} =19*29.73=564.88 V ⟶ P_{pv}=V_{PV} $I_{PV} I_{RR}$= 564.8*8.44 A*7*(0.4) =13.352 kW

Where: N_s is panel series number, I_{RR} is the solar irradiance. From equation (7) and table. 2 above, the number of panels in series 19 panels and the number of branches in parallel 7 branches so, the table. 3 illustrate PV array results at irradiance (400 and 1000) W/m^2.

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The solar irradiance effects on generation have been taken into account so that the voltages and currents generated from the solar panel are affected by solar irradiance. Consequently, the power generated is affected by the change of solar irradiance shown in Fig. 8.

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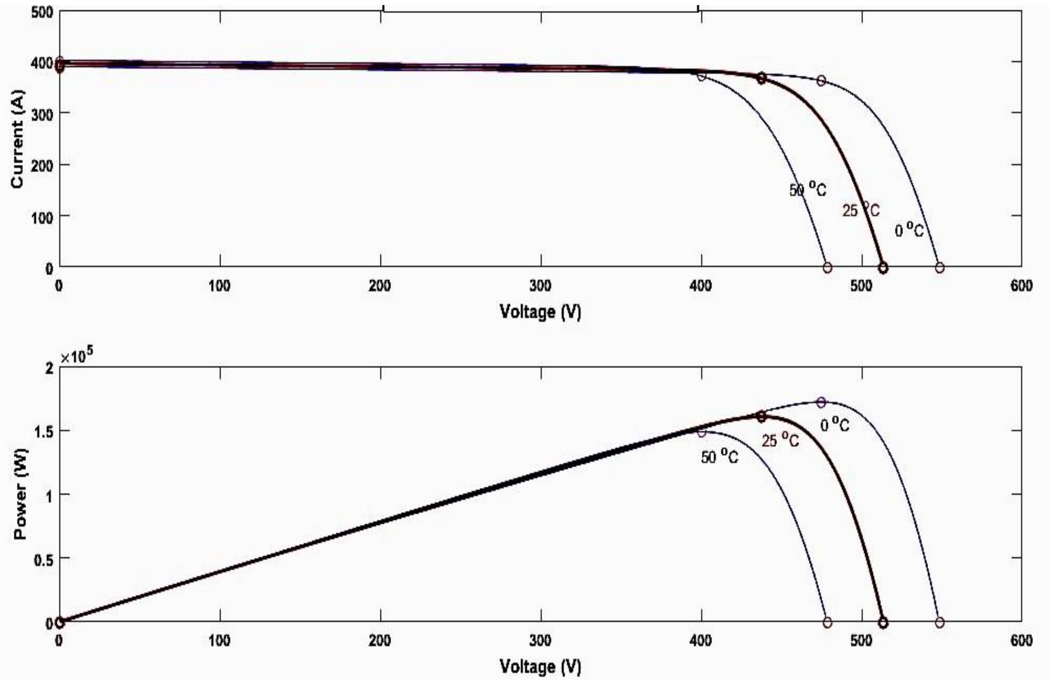

Fig. 8 Output current- power/voltage attitude with temperature changing and the effect on P/ I value.

B. Boost converter module

There are two main types of photovoltaic systems; stand-alone and grid-connected. In general, with a grid-connected system, the inverter transforms the output DC voltage from the solar panels into the AC voltage. The PV system produces the optimum and maximum capacity for PV arrays by using the maximum power point tracker (MPPT) technique, which is usually linked to a DCDC converter, to make the output power at maximum. The maximum power point (MPP) track is controlled by transforming the variable voltage to the maximum DC voltage, then converting the fixed voltage to alternating by the inverter. It can realize by one of the following techniques Perturb and Observe technique [P&O], Incremental Conductance Technique [ICT], Constant Reference, Current-Based Maximum Power Point Tracker" [17-18].

In this paper, a Constant Reference method is the one, which is common MPPT technique that compare the PV array power and current with a constant reference, under specific atmospheric conditions. The resulting of difference signal (error signal) is using to drive a power conditioner, which interfaces the PV array to the load as -shown in Fig. 9.

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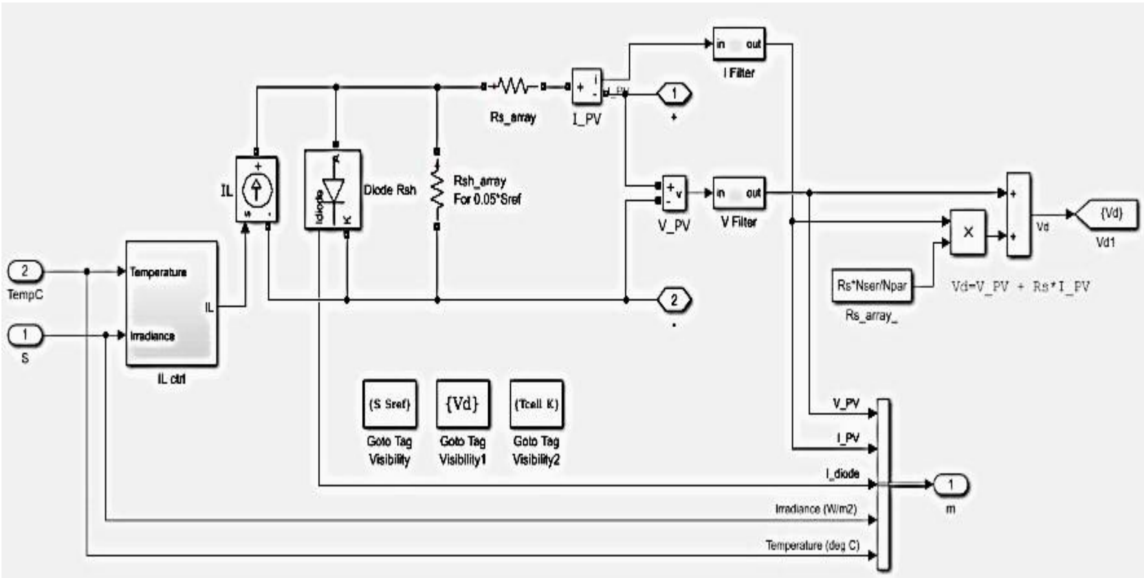

Fig. 9 Proposed model of PV-system in MATLAB simulink

Boost converter help to overcome disadvantages and get an accurate point for operation by step up DC input voltage to be great at the output voltage. The device consists of at least from two semi-conductor switches, a diode acts as a freewheeling diode ensuring the path of current during the off state to another switch, a transistor connects with the source in series. The inductor reduces the ripple in voltage and current respectively at output converter stage. The basic principle of the converter operation is consists of two states, in on state a switch close increasing the inductor current, and in off state a switch open, resulting in a decrease in the inductor current. The equation which describes the boost converter performance is given by the following equations [10].

$$V_{dc} = \frac{V_{pv}}{1-D} \quad \text{V} \tag{8}$$

$$I_{dc} = (1-D)I_{pv} \quad \text{A} \tag{9}$$

Equation (8) is then divided by Equation (9) to obtain

$$R_{in} = (1-D)^2 R_o \quad \Omega \tag{10}$$

Where: D is duty cycle ratio for boost converter and $[t_{on} = D * T_s, t_{off} = (1-D) * T_s]$.

By using MATLAB code, the results for PV array and DC voltage for Boost converter voltage are given in Table. 2

Table. 2 the results for PV array and boost converter at irradiance (400 &1000) W/m^2.

Parameters	Unit	Specification	
Irradiance I_{RR}	W/m^2	400	1000
PV array Voltage	V	564.88	600.4
PV array Current	A	23.6	59.08
PV array Power	KW	13.35	35.5
Duty ratio D	-	0.273	0.2274
DC-Voltage	V	777	777
DC-Current	A	17.18	45.652
DC-Power	KW	13.352	35.488

The results indicate PV system voltages (V_{PV}) before using boost converter are variable due to solar irradiance levels change. To fix this problem maximum power point tracking (MPPT) technique for the boost converter by adjusting the duty ratio (D), shown in fig. 10.

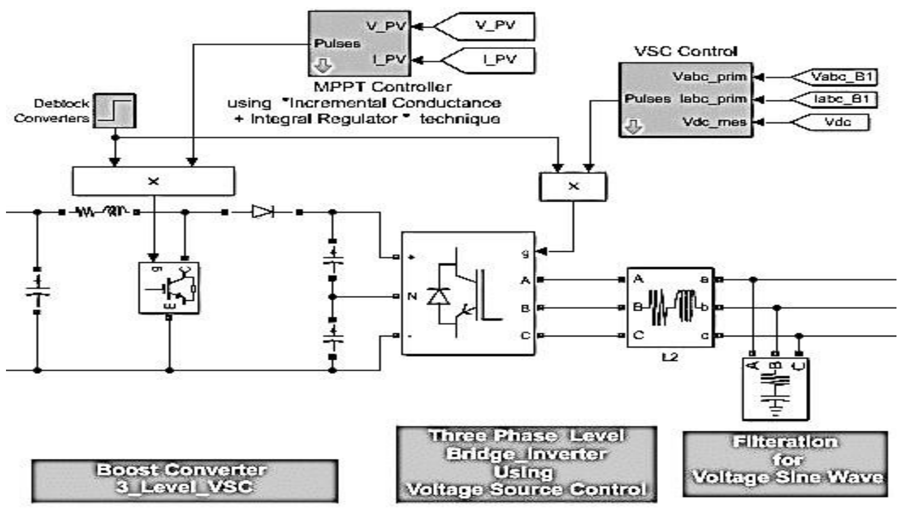

Fig. 10 Boost Converter, 3-Ph Inverter with Filter in MATLAB simulink that used in the paper

Alternating Current (AC) Power almost uses for all industrial, commercial, and residential user. However, the biggest issue with AC cannot store for future uses. Therefore, AC is converting to DC, store in batteries and ultra-capacitors, Whenever AC power is needed, and DC is again converted into AC. The device that converts DC into variable AC is called Inverter. The AC variation can be in the voltage magnitude, phase's number, frequency, or phase difference, and the role of the inverter is not just to convert DC/AC power, but also with high efficiency at low cost. There are many classification types based on source, output characteristics, number of output level, load type, control technique "different PWM technique".

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C. Three-Phase PWM Inverter

In this paper, the Three-phase voltage-source with pulse width modulation PWM inverter describe by the following equation, then LCL-Filter connects for reducing the harmonics from the inverter current that injecting to the micro-grid [18].

$$V_{LL,MS} = 0.6124\, m\, V_{dc} \quad (11)$$

Where: m is modulation index, {m = $V_{peek\ Control\ Signal}$ / $V_{peek\ Triangle\ Signal}$ }

From above description, the proposed PV system is configured, also the efficiency for boost converter and three phase inverters take into account as shown below:

Total power for PV system has three strings at 1000 W/m^2.

$P_{PV\ system}$ = 35.488*3 = 106.464 kW

The efficiency of the Boost converter and inverters are = 0.98*0.97 = 0.9506.

$P_{PV\ system}$ = 106.464 kW * 0.9506 = 101.204 kW Total

power for PV system has three strings at 400 W/m^2.

$P_{PV\ system}$ = 13.352 * 3 * 0.9506 = 38.077 kW.

In industrial load, three-phase ac supply using six transistors and six diodes as shown in below Fig. 11 [8-10].

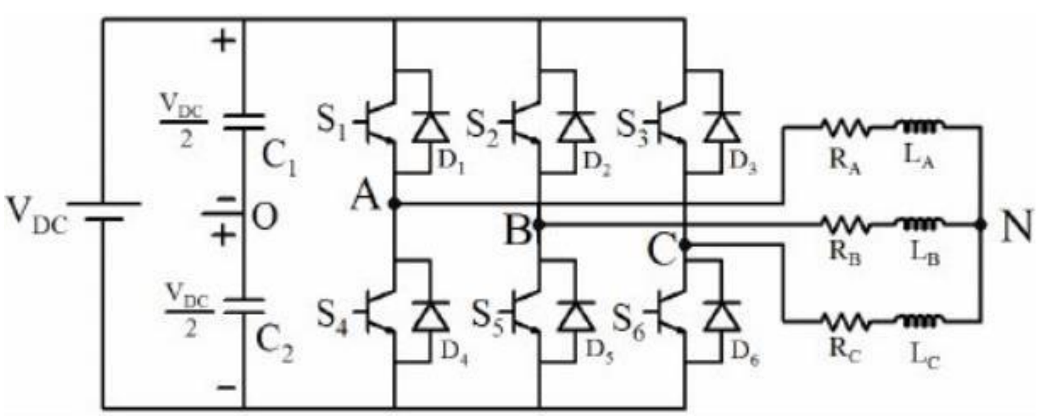

Fig. 11 A three-phase voltage source inverter.

There are two types of power electronic switch losses conduction means ON state loss, and switching loss means OFF state loss at the switch. Generally, the conduction loss is greater than the switching loss. Solar inverter divide into two type's transformer and transformerless type.

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Transformer solar inverter helps boost voltage produced by the solar panels. It has a simple design, but heavy and less efficient in converting energy. Transformerless solar inverter has a digital, lighter, faster, and efficient percentage of 95% to 99%. The output voltage waveform has two components the fundamental and harmonic components. Harmonic components can be filtered at the output side by using high-frequency filter. So many different techniques have been proposed and put into practice to avoid the harmonic content. These techniques require sophisticated gating circuits and controls. Sinusoidal pulse-width modulation (SPWM) and space vector modulation (SVPWM) are two of these techniques.

VI. Simulation of the Suggested Hybrid Energy System

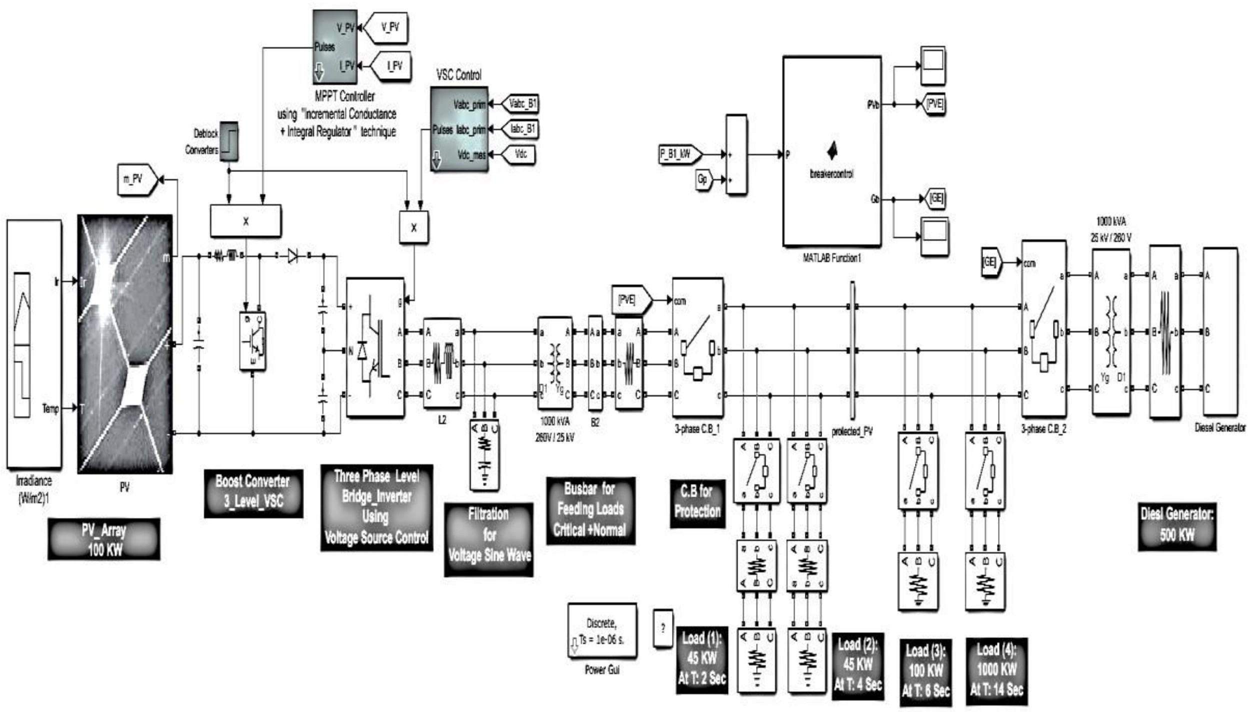

Fig. 12 A stand-alone hybrid energy system in MATLAB simulink.

The system is represented by three buses in the MATLAB program where the PV system connects to the bus bar, the diesel generator connects to another bus bar and a load (normal and critical) connects to both bus bars. System performance is building an appropriate simulink model as shown in Fig. 12. A typical selected day for each season considers for detail simulation. The results are shown in Table. 3. It is clear from the results obtained that the load sharing between the solar energy and diesel generator is varied according to the irradiance variations for each time of the selected days.

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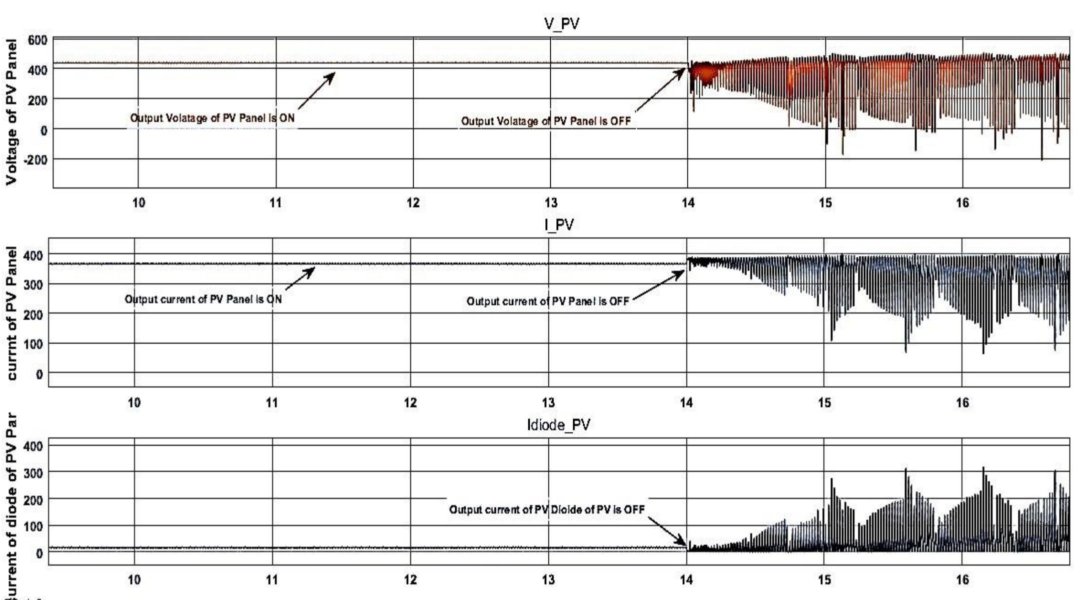
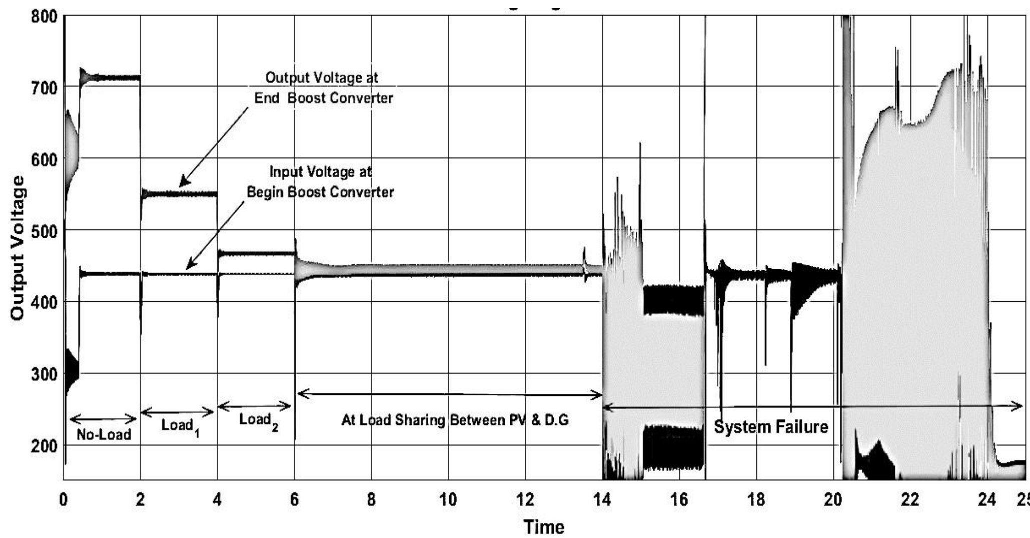
Table. 3 simulation results for 4 seasons in the year, one day for each season

Seasons	Day	Time		PV Generation kW
Spring	24/3/2020	8:00 am	3:30 pm	96.89
		3:30 pm	4:00pm	58.71
Summer	1/7/2020	8:30 am	9:00 am	58.71
		9:00am	3:30pm	96.89
		3:30 pm	4:00pm	56.18
Autumn	3/10/2020	8:00 am	9:00 am	54.08
		9:30am	2:00pm	96.89
		2:00pm	4:00pm	50.93
Winter	31/12/2020	8:00 am	9:00 am	23.92
		9:00am	10:00am	38.46
		10:00am	11:00am	45.71
		11:00am	1:00pm	52.82
		1:00pm	2:00pm	47.69
		2:00pm	3:00pm	34.25
		3:00pm	4:00pm	20.23

The results obtained by PV panel simulation is shown in Fig. 13 (a), which illustrate output voltage and current during three cases (only PV system, Both PV system and diesel generator, and failure system), before using boost converter which is raised DC voltage illustrated in Fig. 13 (b) to help make the most of PV panels output voltage to keep the voltage at a high level for increasing efficiency by using a three-phase level inverter. Besides, reducing waste energy which resulting from transferring, low maintenances, exceeding from a lifetime of PV panel. The current of PV panel diode represents bypass diode is connecting in parallel with PV cell provide a low resistance path that allows current to flow in one direction only.



(a)



(b)

Fig.13 a) Output voltage and current form PV panels.

b) Output voltage before and after using Boost Converter.

A three-phase PWM inverter is the final step that exploits the DC output voltage of the boost converter to AC voltage suitable to meet critical and normal loads with the highest efficiency for PV panels. Fig. 14 (b) shows the output voltage of the inverter before and after adding a filter in the output stage. The output is a pure sinusoidal waveform to reduce harmonic.

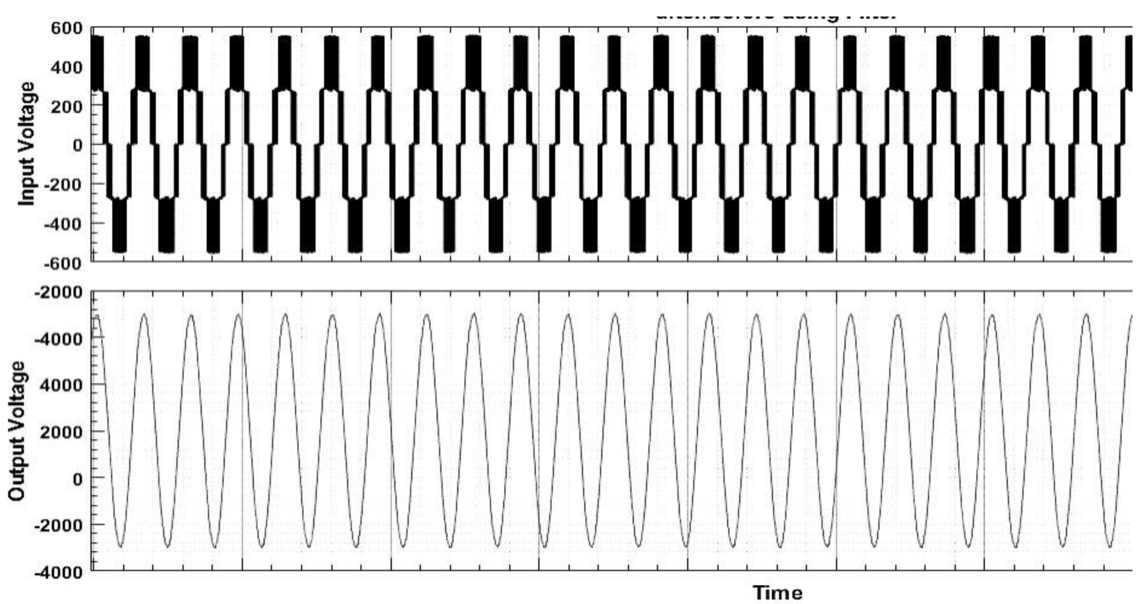


Fig. 14 Three-phase output voltage PWM inverter before and after using filter

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The diesel generator is considered a second source that achieves reliability and continuous for stand-alone micropower generation and distribution grid. In the designed hybrid energy system diesel generator is programmed to share load power requirements when increasing than PV system capacity. Here, diesel generators start load sharing and continuous until loads power requirements become greater than PV system and diesel generator capacities, so the system is the failure or in other solution make any source of both systems feed only critical loads power requirements. Fig. 15 is shown the performance of the diesel generator through load sharing and failure system for output three-phase voltage and current.

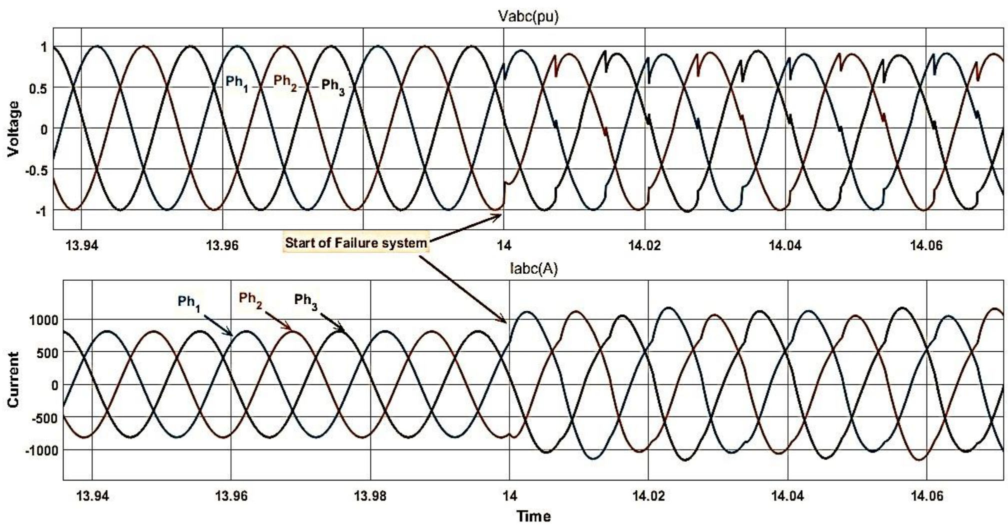

Fig. 15 A diesel generator characteristics through load sharing and system failure.

From the load side, Fig. 16 illustrates the point of the waveform for three-phase V/I waveform during PV system only and both systems PV and diesel generator and how system deal with the changing of feeding source.

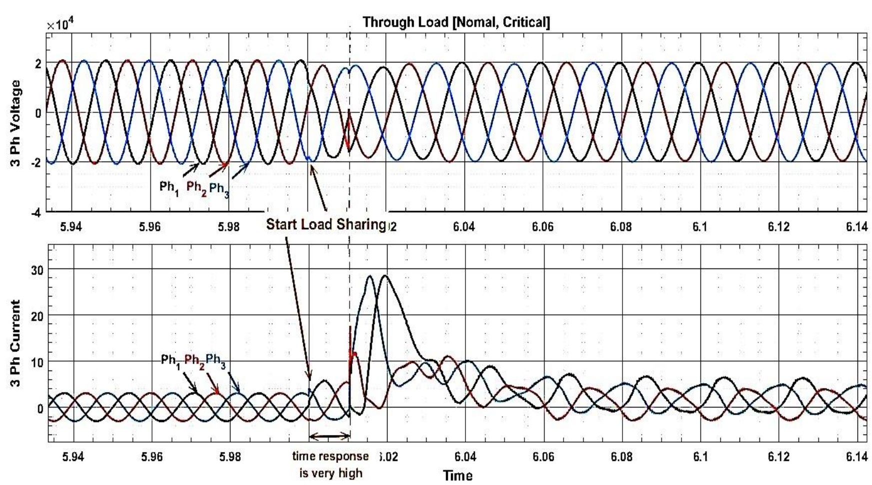

Fig.16 The waveform of three-phase voltage and current during load sharing.

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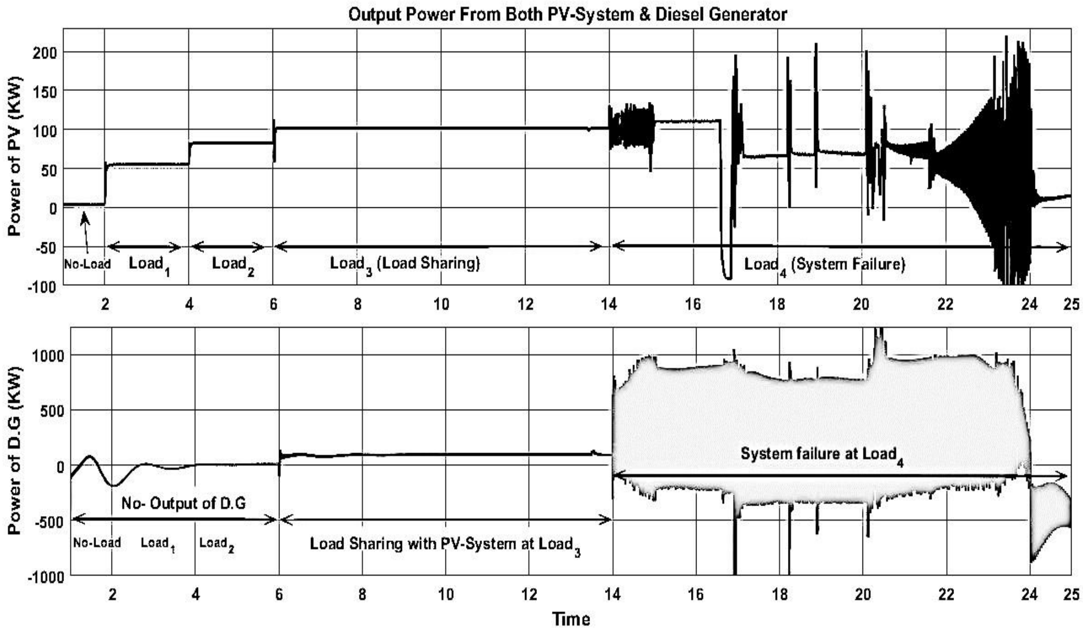
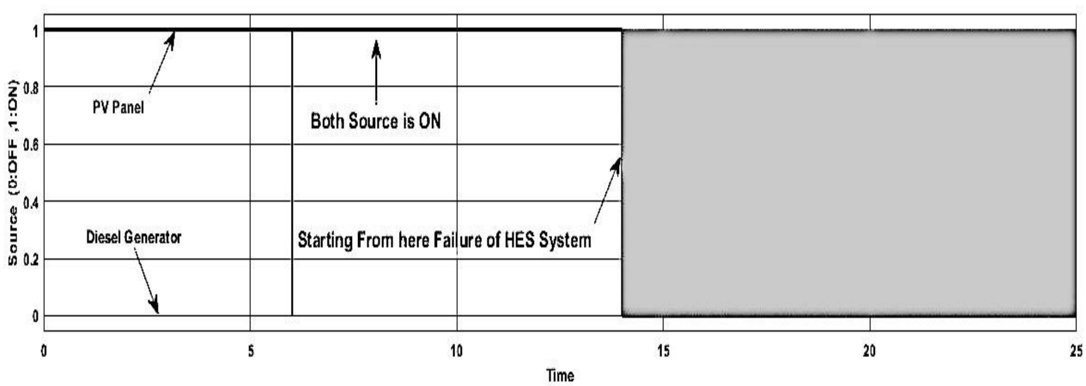
To ensure that the designed system of a stand-alone hybrid energy system is working correctly through three cases programmed in MATLAB. Fig. 17 (a), (b) show the output power of PV and diesel generator first at no-load, second at load 45 K, third at load 90 KW, fourth at load 190 KW, and finally at load 1190 KW. Fig. 17 (b) illustrates the period in which any source is working means which source is ON or OFF.



(a)



(b)

Fig. 17 a) Final output power of PV system and diesel generator.

b) The time where PV system and the diesel generator are ON and OFF.

VII. Discussion of results

A MATLAB program is used to simulink the designed system as it runs actually on any day of the year to appear if is working correctly or not with changes in solar radiation during the day. The purposed system has three cases depending on loads capacity, first PV system only feeds the load power requirements as the capacity of loads in limit with a PV system, second both PV system and diesel generator feed the load power requirements as the capacity of load in limit with both systems and third case system failure as the load capacity become greater than both sources.

Three main points must be discussed first, boost converter waveform showed how to raise DC voltage that outcome from PV modules to reduce the harmonic and low frequency which affected on PV system efficiency based on MPPT Controller using incremental conductance with integral regulator technique and made the mission of inverter by the way smoothly and with low facts and harmonic. Second, used an LCL filter after a three-phase PWM inverter to make a pure sinusoidal waveform feeding AC loads with high efficiency for output. Third, at load sharing between both PV system and a diesel generator that illustrated in Fig. 16 and Fig. 17 during step uploads power requirements.

VIII. CONCLUSION

In the purposed hybrid energy system, a stand-alone microgrid for police critical loads where locate in remote and border areas based on PV- diesel generator systems is successfully constructed. The MPPT controller performance is satisfactory under variable irradiance. The converter and the inverter unit has successfully maintains the power quality as the standard.

In operation, PV system works as the main source to feed loads during the daytime, and the diesel generator cooperates main source to achieve the system power balance. Simulation results in many scenarios have validated the proposed stand-alone microgrid structure flexibility and the energy management strategy.

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