Master Thesis

Master's Programme in Renewable Energy System, 60 credits

Smart Student Table

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Sammanfattning:

Elevbordet är särskilt utformat för barn i speciella omständigheter. Det är en lämplig och effektiv lösning på de problem som barn står inför i flyktingläger efter att ha blivit tvingade från sina hem och skolor.

Tanken med studien är att ta fram en skiss för att skapandet av elevbordet med elproduktionen som kommer att vara lämplig för belysning och att används i dagliga skolbehov som bärbara datorer. Således kommer solcellssystemet att anslutas till en liten generator genom ett hybridsystem och när solljuset försvinner kan kraften genereras med cykeltrampor. En komplett prototyp har också tagits fram som en del av studien.

Hybridsystem har många fördelar när det gäller flexibilitet och skalbarhet i energiresurserna. Om man kombinerar två eller flera förnyelsebara energiresurser kan man välja att använda dem i full kapacitet, eftersom svagheten hos ett system är balanserat av det andra systemet.
Abstract:

The objective of this study is to develop what is called a Student table, which is designed specifically for school children in emergency circumstances, so it will be suitable for partial solutions for the problems facing children in refugee camps, who are forced to leave their homes and schools.

The idea of the study focuses on the creation of the Student table so that the generation of electricity will be suitable for lighting and illumination with the use of some electronic devices used in daily school needs like laptops, so the solar cell system will be connected to a small generator through a hybrid system. A fully functional prototype has been built as part of the study.

When the system works through the hybrid route for lighting and illumination the solar system will generate the power needed and when the sun light disappears the power can be generated by bike pedals.

The generation of electricity by the hybrid system is considered as an effective and environmentally friendly option with economic benefits.
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Chapter 1

1. Introduction

Due to the global warming and greenhouse effect, renewable energy production has a crucial importance in providing sustainable and environmentally friendly energy supply. Since most renewable energy resources are variable in nature, integrating them into grid infrastructure has a great advantage in exploiting the maximum energy from the system.

Hybrid renewable energy production is a power or electrical energy generation from more than one resource, where at least one of them is a renewable resource. Particularly, the advantage of solar and wind energy has increased their use in the hybrid system for the reason they both are abundant, emission free resources. PV and wind energy are efficient enough to supply to the grid or to use as a stand-alone system. The hybrid renewable energy system is becoming the best alternatives to increase the energy yield worldwide. They effectively take the advantage of one system over the other in terms of flexibility and scalability of the energy resources. On combining two or more renewable energy resources allows more option to use them in full capacity as the weakness of one system is balanced by the other system.

This advantage is clearly seen in the PV and wind hybrid systems, as wind and solar energy are inversely correlated, so when is high wind condition the probability of a solar insolation is less, and the opposite is true when is high solar irradiation, the wind condition is often low, moreover, these systems can be used in the development of isolated rural areas and camps.

An alternative to use wind energy in the hybrid system is to use kinetic energy from human input. This could potentially be beneficial in small setups for rural areas and camps as this provides a simple way a securing energy supply whenever needed.

Energy is the necessity for human life. It is uses in our daily activity. The solar technology has grown in recent years. for example, the solar generation rate growth was 30 percent in 2017.

1.1. Background

Solar and wind or kinetic energy resources are alternative to each other which will have the actual potential to satisfy the load demand to some extent. There are many researches in solar and wind hybrid system on utilizing the combined advantage so as deploy as much energy as possible. However, the unstable nature of the solar and wind resource makes the study a bit arduous as it needs a significant time series historical data to significantly forecast the correlation of the energy yield of the hybrid system at a particular site. The PV and kinetic hybrid energy systems have been found to be a more viable alternative to fulfill the energy demands of numerous isolated consumers worldwide.
1.2 Objective

The aim of the thesis is to develop a smart table as hybrid system, allowing for example a laptop to be powered. The electricity is a most widely used form of energy, and the table may serve many purposes.

The main source of power generation depends on the fossil fuels but in a very low scale. It is very difficult to cover the whole area specially in the rural area or in the camp area, by a limited amount of power system.

My master thesis therefore focuses on the design of an off-grid hybrid system.

This thesis specifically focuses on the analysis of electric consumption of a single smart table.

While designing this system I have collected the necessary data and information from different resources.

1.3 Scope and limitation

The thesis considers making use of renewable energy in working life.

The practical benefit of this design, especially for states that lack a produce of electricity, is studied.

Economic aspects of the proposed system are not considered.

1.4 Thesis outline.

This thesis work is divided into-chapters.

Chapter 1-

is an introduction to the study, where the problem, justification, the aim and objectives of the study are outlined.
Chapter 2-

is devoted to a theoretical discussion and literature review about the means of harnessing solar radiation and wind (or kinetic) resources for energy applications, and their use as resource for energy production and leveraging them to generate electricity.

Some techniques are also explored for the estimation of the available and extractable energy from these renewable sources and the factors that may affect their potential.

Chapter 3-

present all mechanical, electrical and electronic parts used in this design.

Chapter 2:

2.a Theoretical background and literature:

Hybrid renewable energy systems (HRES) are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in hybrid renewable energy technologies. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.
2.b. Solar resources:

Solar resource depends on geographical location of a site. The altitude and climate also affect the solar electricity generation rate. The solar potential in Baghdad in Iraq is given in Figures (1) and (2).
2.1. Solar PV system:

2.1.1 Working principle of solar cells

Elements from Group IV of the periodic table are the main semiconductors; examples include silicon (Si), germanium (Ge), and tin (Sn). They generally have four electrons-called valence electrons-in the outermost electron shell. By doping the material, a pn-junction may be created, in which a spontaneous electric field forms over the junction.

Figure (3). A pn-junction. (Source: energy by solar)

When light, or photons, from the sun hit the solar cell, the energy forces the electrons out of their holes. If this happens close enough to the electric field, the field will send the electron to the negative side(n-type) and the empty hole to the positive side(p-type), causing further disruption of electrical neutrality. If an external current path is provided, electrons will flow along the path to the positive side(p-type) to unite with the empty holes that the field sent there. This electron flow provides a current and the cell's electric field causes a voltage.

This means we now have power! as shown above in Figure (3).
2.1.2 Simple equivalent solar cell circuit

A solar cell has the same physical structure as a diode. It consists of an (n-doped) and a(p-doped) semiconductor with a depletion region meaning that a solar cell not exposed to sunlight acts quite like a diode and can be described as one in simplified fashion.

Figure (4). A solar cell’s simplified equivalent circuit

The current through the diode is (1)

\[
I = -I_D = -I_S \cdot \left( \exp \left( \frac{U_D}{m \cdot U_T} \right) - 1 \right)
\]

Where \(I_D\) is diode current

\(I_S\) is the saturation current

\(m\) is the quality factor of solar cell; \(U_T\) is temperature voltage, \(k J/k\) is the Boltzmann constant is the \(1.38 \times 10^{-23}\) and \((K)\) temperature in Kelvin. \(\epsilon\) is the electron charge.
2.1.3 Equivalent circuit single-diode model

The equivalent circuit of a PV cell. Here the model has been exemplified by a current source connected anti-parallel with a diode, and the non-idealities are shown by inserting shunt ($R_p$-parallel) and series resistances ($R_s$). The simulation model of the Photovoltaic panel depends greatly on the output current ($I$) of the PV equivalent model. Its mathematical equation is illustrated by, this equation (1).

![Expanded equivalent circuit for a solar cell (single-diode model)](image)

Figure (5). Expanded equivalent circuit for a solar cell (single-diode model)

![Influence of series resistance $R_s$ on a solar cell’s current -voltage characteristic](image)

Figure (6). Influence of series resistance $R_s$ on a solar cell’s current -voltage characteristic
Kirchhoff’s node law $0 = I_{ph} - I_D - I_p - I$ is used with the formula $I_p = \frac{U_D}{R_p} = \frac{U + I R_S}{R_p}$ for the $I - V$ curve of the solar cell’s expanded equivalent circuit:

$$0 = I_{ph} - I_S \left( \exp \frac{U + I R_S}{m U_T} - 1 \right) - \left( \frac{U + I R_S}{m U_T} \right) - I$$

Represents the output voltage and current of the PV cell and $I_{ph}$, represents the photocurrent.

(8)
2.2 Solar generator and load:

The PV modules must provide electricity that is used by the consumer with an electric load. The simplest load is an electric resistance. A straight line describes the resistance characteristic.

The relation between Resistance, Current and Voltage is called Ohm` s law, through which can be determine the value of the load:

\[ R = \frac{U}{I} [\Omega] \]

Figure (8). Solar generator with resistance

Figure (9). A solar module under various operating conditions with electrical resistance
2.2.1 Converter DC-DC

The power output of the solar module will be increased if direct current-DC-DC converter is connected between solar generator and load as shown in Figure (10) (inside the red square).

The converter generates a voltage at the load that is different from that of the solar generator. Taking up the previous resistance example, Figures (11 & 12) shows that the power output of the module increases at higher irradiances if the solar generator is operated at a constant voltage. The power output will be increased even more if the voltage increases with falling temperatures.

Figure (10). DC-DC converter

Figure (11). Dependence of current and voltage on incident sunlight levels.

Figure (12). Dependence of current and voltage on temperature for sunlight level of 1000 W/m².
2.2.2 Solar charge control

A solar charge controller manages the power going into the battery bank from the solar array. It ensures that the deep cycle batteries are not overcharged during the day, and that the power doesn’t run backwards to the solar panels overnight and drain the batteries. Some charge controllers are available with additional capabilities, like lighting and load control, but managing the power is its primary job.

Figure (13). Solar charge control

2.3. Battery storage:

The solar generators can not to be connected directly to devices off-grid; we can theoretically, but it is ineffective and impractical. Generally, more complex system is used, if there is no grid connection, storage is usually needed.

(11)
Then energy is then available when the sun is not shining, such as at night.

A distinction is made between two types of storage:

a-To cover a few hours or
b-Days during bad weather;

A more demanding task is to compensate for fluctuations in seasonal irradiation between the summer and the winter. Because such long-term storage is generally very complex and expensive, power system that run all year generally have large PV generators so that enough energy is provided in the winter, alternatively, additional generators are used, such as wind turbine or diesel generators, that is, a hybrid system.

2.3.1 Types of Batteries:

A brief overview of the different types of batteries that may be used in solar electric and backup power systems.

Batteries used in home energy storage typically are made with one of three chemical compositions: lead acid, lithium ion, Nickel cadmium and Nickel-metal hydride (NiMH). In most cases, lithium ion batteries are the best option for a solar panel system, though other battery types can be more affordable.

2.3.1.a Lead acid batteries:

Lead acid batteries are a tested technology that has been used in off-grid energy systems for decades. While they have a relatively short life lower than other battery types, they are also one of the least expensive options currently on the market in the home energy storage sector. For homeowners who want to go off the grid and need to install lots of energy storage, lead acid can be a good option.

2.3.1.a.1 Working Principle of Lead Acid Battery

When the sulfuric acid dissolves, its molecules break up into positive hydrogen ions (2H+) and sulfate negative ions (SO4—) and move freely. If the two electrodes are immersed in solutions and connected to DC supply, then the hydrogen ions being positively charged moves towards the electrodes connected to the negative terminal of the supply. The SO4— ions being negatively charged moves towards the electrodes connected to the positive terminal of the supply main (i.e., anode).
Each hydrogen ion takes one electron from the cathode, and each sulphates ion takes the two negative ions from the anodes and react with water and form sulfuric and hydrogen acid.

The oxygen, which is produced from the above equation react with lead oxide and form lead peroxide (PbO2.) Thus, during charging the lead cathode remain as lead, but lead anode gets converted into lead peroxide.

2.3.1.a.2 Chemical Effect During Discharging

When the cell is full charged, then the anode is of lead peroxide (PbO2) and a cathode is of metallic sponge lead (Pb). When the electrodes are connected through a resistance, the cell discharge and electrons flow in a direction opposite to that during charging.

The hydrogen ions move to the anode and reaching the anodes receive one electron from the anode and become hydrogen atom. The hydrogen atom comes in contacts with a PbO2, so it attacks, and forms lead sulphates (PbSO4), whitish in colour and water according to the chemical equation.

\[
PbSO_4 + 2H = PbO + H_2O
\]
\[
PbO + H_2SO_4 = PbSO_4 + 2H_2O
\]
\[
PbO_2 + H_2SO_4 + 2H = PbSO_4 + 2H_2O
\]
Each sulphates ion (SO₄⁻) moves towards the cathode and reaching there gives up two
electrons becomes radical SO₄, attack the metallic lead cathode and form lead sulphates
whitish in colour according to the chemical equation below?

\[ \text{PbSO}_4 + 2\text{H}_2\text{O} + 2\text{H} = \text{PbS}_4 + 2\text{H}_2\text{SO}_4 \]

SO₄⁻ ion moves to the anode, gives up its two additional electrons becomes radical SO₄,
react with the lead sulphates anode and form leads peroxide and lead Sulphur acid
according to the chemical equation.

\[ \text{PbSO}_4 + 2\text{H} = \text{H}_2\text{SO}_4 + \text{Pb} \]
2.3.1.a.3 Chemical Effect During Recharging

For recharging, the anode and cathode are connected to the positive and the negative terminal of the DC supply mains. The molecules of the sulfuric acid break up into ions of $2H^+$ and $SO_4^{2-}$. The hydrogen ions being positively charged moves towards the cathodes and receive two electrons from there and form a hydrogen atom. The hydrogen atom reacts with lead sulphates cathode forming lead and sulfuric acid.

The charging and discharging are represented by a single reversible equation given below.

$$\text{PbO}_2 + H_2SO_4 + \text{Pb} \rightarrow \text{PbSO}_4 + 2H_2O + \text{PbSO}_4 + \text{Electrical Energy}$$

2.3.2.b Lithium ion batteries:

Much of new home energy battery storage technologies, use some form of lithium ion chemical composition. Lithium ion batteries are lighter and more compact than lead acid batteries. They also have a higher and longer lifespan as compared to lead acid batteries. However, lithium ion batteries are more expensive than their lead acid counterparts.
2.3.3.C Nickel cadmium batteries:

The nickel–cadmium battery (NiCd battery or NiCad battery) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes. The abbreviation NiCd is derived from the chemical symbols of nickel (Ni) and cadmium (Cd).

However, this battery is increasingly unpopular because cadmium is a dangerous substance. The material used with in the battery might enter the environment after the batteries are disposed of.

Figure (19). Nickel cadmium battery parts

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2.3.4.d Nickel-metal hydride batteries (NiMH):

A nickel–metal hydride battery, abbreviated NiMH, is a type of rechargeable battery. Contain substances that are much less problematic, though small amounts of toxic substances are still added to such batteries in practice.

Alloys consisting of nickel, titanium, vanadium, zirconium, and chrome are used. The electrolyte in these batteries and in NiCd batteries is diluted caustic potash. The chemical reaction at the positive electrode is like that of the nickel–cadmium cell (NiCd), with both using nickel oxide hydroxide (NiOOH). However, the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. A NiMH battery can have two to three times the capacity of an equivalent size NiCd, and its energy density can approach that of a lithium-ion battery.

Figure (20). Nickel-metal hydride battery (NiMH) parts
2.3.5 Battery system:

The simplest battery system consists of a photovoltaic generator, a battery, and a device that consumes power. Because the photovoltaic generator has small interior resistance, the battery discharges at low levels of irradiance in the evening and overnight via the generator.

2.3.5.1 Blocking diode

A blocking diode is used between the battery and the photovoltaic generator to prevent such power losses.

At the diode, the power losses constantly occur:

\[ P_{\text{loss diode}} = I_{pv} \cdot U_D \]

![Diagram of a simple photovoltaic system with battery storage](image1)

Figure (21). A simple photovoltaic system with battery storage

![Graph showing solar module power points with a lead battery for storage with a blocking diode and 0.1-ohm line resistance without load](image2)

Figure (22). A solar generator’s power points with a lead battery for storage with a blocking diode and 0.1-ohm line resistance without load
2.3.5.2 charge control

A solar charge controller is available in two different technologies, PWM and MPPT. How they perform in a system is very different from each other. An MPPT charge controller is more expensive than a PWM charge controller, in the battery system.

2.3.5.2.a. PWM solar charge controller

A PWM solar charge controller stands for “Pulse Width Modulation”. These operate by making a connection directly from the solar array to the battery bank. During bulk charging, when there is a continuous connection from the array to the battery bank, the array output voltage is ‘pulled down’ to the battery voltage. As the battery charges, the voltage of the battery rises, so the voltage output of the solar panel rises as well, using more of the solar power as it charges. As a result, we need to make sure we match the nominal voltage of the solar array with the voltage of the battery bank. *Note that when we refer to a 12V solar panel, that means a panel that is designed to work with a 12V battery. The actual voltage of a 12V solar panel, when connected to a load, is close to 18 VMP (Volts at maximum power). This is because a higher voltage source is required to charge a battery. If the battery and solar panel both started at the same voltage, the battery would not charge.

A 12V solar panel can charge a 12V battery. A 24V solar panel or solar array (two 12V panels wired in series) is needed for a 24V battery bank, and 48V array is needed for 48V bank. If we try to charge a 12V battery with a 24V solar panel, we will be throwing over half of the panel’s power away. If we try to charge a 24V battery bank with a 12V solar panel, we will be throwing away 100% of the panel’s potential and may drain the battery as well.

Figure (23). 12V Solar Panel with PWM charge Controller charging a low 12V battery.

Figure (24). 24V Solar Panel with PWM charge Controller charging a low 12V battery.

(19)
2.3.5.2.b. MPPT solar charge controller

An MPPT solar charge controller stands for “Maximum Power Point Tracking”. It will measure the Vamp voltage of the panel, and down-converts the PV voltage to the battery voltage. Because power into the charge controller equals power out of the charge controller, when the voltage is dropped to match the battery bank, the current is raised, so we are using more of the available power from the panel. We can use a higher voltage solar array than battery, like the 60-cell nominal 20V grid-tie solar panels that are more readily available. With a 20V solar panel, we can charge a 12V battery bank, or two in series can charge up to a 24V battery bank, and three in series can charge up to a 48V battery bank. This opens a whole wide range of solar panels that now can be used for the off-grid solar system.

2.4 Inverters:

An inverter is basically a converter that converts DC to AC power.

Inverter circuits can be very complex, so the objective of this project is to present some of the inner workings of inverters without getting lost in some of the fine details.

A voltage source inverter (VSI) is one that takes in a fixed voltage from battery as a dc power supply and converts it to a variable-frequency as an ac supply.

Figure (25). 12V Solar Panel with MPPT charge Controller charging a low 12V battery

Figure (26). 20V Solar Panel with MPPT charge Controller charging a low 48V battery.
2.4.a. B2-bridge

A B2-bridge is a very simple way to create an inverter circuit, as shown in Figure (27), below. It's consisting of four valves connected to the alternating current grid via a transformer.

At regular intervals, valves 1 and 3 are opened, followed by 2 and 4, to produce a roughly rectangular alternating current in the transformer.

Valves 1 and 2 can also be replaced with non-controllable diodes so that only half of the components need to be controlled.

Figure (27). H-bridge (B2)

Figure (28). An idealized power curve for a semi-controlled B2 bridge
2.4.b. B6-bridge

A B6-bridge is consisting of six valves connected to the alternating current grid via a transformer, used in the inverter circuit to generate 3-phase power.

In this circuit, the valves are opened cyclically so that alternating current and voltage is produced in 3-phase shifted by a third period each.

![Diagram of B6-bridge](image)

Figure (29). Six pulse bridge(B6)

2.5.1. PWM (Pulse Width Modulation):

In inverters that use pulse width modulation, one of the circuits such as b2 and b6-is used. Here, the valves are not only opened and closed once every half-wave, but several times to produce pulses of different widths, as shown in Figure (30).

(22)
Figure (30). A curve from pulse width modulation

the quality of sine wave is much better than that of rectangular waves from inverter, specifically there are fewer undesirable harmonics.

For this reason, most inverters now used have PWM.

2.5.2. H5 or HERIC circuit (Highly Efficient and Reliable Inverter Concept):

For high efficiency, other circuit concepts are used in addition to the bridges described above.

Single-phase inverter sometimes has an H5 or HERIC circuit.

They are based on the concept of H bridges.

Other transistors ensure that choke current can be drawn off during switching in the freewheeling phase, which reduces switching losses.
Figure (31). Highly efficient inverter circuits. Left H5 topology, right: HERIC topology

2.6. Synchronous Generator and Motor:

The synchronous generator is a synchronous electro-mechanical machine used as a generator and consists of a magnetic field on the rotor that rotates and a stationary stator containing multiple windings that supplies the generated power. The rotors magnetic field system (excitation) is created by using either permanent magnets mounted directly onto the rotor or energized electro-magnetically by an external DC current flowing in the rotor field windings.

2.6.1. Components of a Synchronous Generator

The stator part: – The stator carries the three separate (3-phase) armature windings physically and electrically displaced from each other by 120 degrees producing an AC voltage output.

The Rotor part: – The rotor carries the magnetic field either as permanent magnets or wound field coils connected to an external DC power source via slip rings and carbon brushes.
2.6.1.a Construction the simple of Synchronous Generator

The example above shows the basic construction of a synchronous generator which has a wound salient two-pole rotor. This rotor winding is connected to a DC supply voltage producing a field current, \( I_f \). The external DC excitation voltage which can be as high as 250 volts DC, produces an electromagnetic field around the coil with static North and South poles. When the generators rotor shaft is turned by the external torque, the rotor poles will also move producing a rotating magnetic field as the North and South poles rotate at the same angular velocity as the (assuming direct drive). As the rotor rotates, its magnetic flux cuts the individual stator coils one by one and by Faraday’s law, an emf and therefore a current is induced in each stator coil.

The stator winding is, as shown above, a function to the magnetic field intensity which is determined by:

1- the field current

2- the rotating speed of the rotor

3- the number of turns in the stator winding.

As the synchronous machine has three stator coils, a 3-phase voltage supply corresponding to the windings, A, B and C which are electrically 120 degrees apart is generated in the stator windings and this is shown above.

(25)
2.6.1.b. The Speed of a Synchronous Generator and Motor

The frequency of the output voltage depends upon the speed of rotation of the rotor, in other words its “angular velocity”, as well as the number of individual magnetic poles on the rotor.

In our simple example above, the synchronous machine has two-poles, one North pole and one South pole. In other words, the machine has two individual poles or one pair of poles, (North-South) also known as pole pairs. As shown in the equation below.

\[ f = \frac{P \cdot N_s}{2 \cdot 60} = \frac{P \cdot N_s}{120} \text{ Hz} \]

Where \( f \) is the frequency

\( P \) is the number of poles,

and \( N_s \) - the synchronous speed.

In a synchronous motor, its angular velocity is fixed by the frequency of the supply voltage, so is commonly known as the synchronous speed. Then for a-pole synchronous generator the speed of rotation of the prime mover (external mover represents the prime mover) to produce the required frequency output of either 50Hz or 60Hz of the induced emf will be:

At 50Hz

<table>
<thead>
<tr>
<th>Number of Individual Poles</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational Speed (rpm)</td>
<td>3,000</td>
<td>1,500</td>
<td>750</td>
<td>500</td>
<td>250</td>
<td>167</td>
<td>125</td>
</tr>
</tbody>
</table>

At 60Hz

<table>
<thead>
<tr>
<th>Number of Individual Poles</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational Speed (rpm)</td>
<td>3,600</td>
<td>1,800</td>
<td>900</td>
<td>600</td>
<td>300</td>
<td>200</td>
<td>150</td>
</tr>
</tbody>
</table>

Table (1). The relation between number of individual poles and rotational speed at the (50Hz and 60Hz)
So, for a given synchronous generator designed with a fixed number of poles, the generator must be driven at a fixed synchronous speed to keep the frequency of the induced emf constant at the required value, either 50Hz or 60Hz to power mains appliances. In other words, the frequency of the emf produced is synchronized with the mechanical rotation of the rotor.

2.7.1 Permanent Magnet Synchronous Generator (PMSG):

As its name implies, in a permanent magnet synchronous generator (PMSG), the excitation field is created using permanent magnets in the rotor. The permanent magnets can be mounted on the surface of the rotor, embedded into the surface or installed inside the rotor. The air gap between the stator and rotor is reduced for maximum efficiency and to minimize the amount of rare earth magnet material needed, or vice versa where the stator part has permanent magnet and the rotor contains the windings. Permanent magnets are typically used in low power, low cost synchronous generators.

![Figure (33). (PMSG)](image-url)
2.7.2 Permanent Magnet Synchronous motor (PMSM):

As its name implies, the permanent-magnet motor. As with most motors, the synchronous motor (SM) has two primary parts. The non-moving is called the stator and the moving, usually inside the stator, is called the rotor. SM can be built in different structures.

To enable a motor to rotate two fluxes are needed, one from the stator and the other one from the rotor. For this process several motor configurations are possible. From the stator side three-phase motors are the most common.

There are mainly two ways to generate a rotor flux.

One uses rotor windings fed from the stator and the other is made of permanent magnets and generates a constant flux by itself. To obtain its current supply and generate the rotor flux, a motor fitted out with rotor windings require brushes. The contacts are, made of rings and do not have any commutator segment, the lifetime of both the brushes and the motor may be similar. The drawbacks of this structure, maintenance needs and lower reliability, are then limited. Replacing common rotor field windings and pole structure with permanent magnets put the motor into the category of brushless motors. It is possible to build brushless permanent magnet synchronous motors (PMSM) with any even number of magnet poles. Motors have been constructed with 2 to 50 or more magnet poles. A greater number of poles usually create a greater torque for the same level of current. In the case of embedded systems where the space occupied is important, a PMSM is usually preferred to an AC synchronous motor with brushes. In high-speed regions a point is reached where the supply voltage is maximum, and the rotor field must be weakened as an invert to the angular speed. In the high-speed region also called the field-weakening region, while a PMS motor needs an angle shift to demagnetize the stator windings, the SM with rotor windings maintains maximum efficiency by regulating the rotor currents and then the flux. For high-speed systems where high efficiency is required, AC synchronous motors with rotor windings may be a good compromise.
2.8. The Direct Current Generator Design (Permanent Magnet):

DC generators work by rotating or passing the coils past the magnets (or magnets past the coils) with the magnet circuit in two ways.

Firstly, feeding some of the generators output power back into its own field coils to make an electromagnet which can be precisely controlled or

Secondly, to use permanent magnets to generate the magnetic flux rather than current in a coil of wire.

The advantage of permanent magnets is that no field supply is needed as the magnetic field is permanently excited reducing costs, and it also means that there is no power loss in the magnetic field winding, which helps to increase the generators efficiency.

2.8.1 Construction the simple to DC Generator

The commutator segments in a dc generator replaces the continuous slip rings of the AC generator and is the main difference in their construction.
The commutator mechanically reverses the armature coil connections to the external circuit producing a pulsating voltage. The output voltage is pulsating because it does turn “ON” or “OFF”, but it never reverses polarity like AC voltages and currents. Then since the polarity across the generators terminals remains constant, the output voltage is DC.

As well as permanent magnet generators, DC generators can also have a wound field coil to produce the required magnetic field. The names used to describe these types of dc generator depends upon the relationship and interconnection of each of the magnetic field coils with respect to the armature.

The two basic types of field winding excitation used for dc generators are called:

1- self excitation
2- separate excitation,

So, depending upon which form of field excitation is used, the dc generator is classed as either

1-a “self-excited generator” or
2-b “separately-excited generator”

2.8.2 Type of DC Generator

The two basic connections for a self-excited DC machine are

a- The “Shunt Wound DC Generator”, were the field winding constructed with relatively many turns of small high resistance wire used to limit current flow through the field, is connected in parallel, or shunt with the armature.

b- The “Series Wound DC Generator”, were the field winding is made with relatively few windings turns of very large wire of very low resistance is connected in series with the armature. Each type of DC generator construction has its own set of advantages and disadvantages and which one you use depends upon the application.
Chapter 3

The human being could be a great mercy to our environment, at the same time, he could be a great harm for his environment.

Because of bad human behavior and the increased incidence of natural disasters due to the bad effects of global warming on weather and climate a lot of people are victims of bad human act.

A lot of innocent people especially children are victims of wars and hundreds of thousands are forced to leave their homes and live in refugee camps.

My research is designed to help children at school age who live in refugee camps to get the necessary electricity for their daily school needs in an economic way that is environmentally friendly.

The objective of this study is to develop what is called a Student desk which is designed specifically for school children in such circumstances, so it will be suitable for partial solutions for the problems facing children in refugee camps who are forced to leave their homes and schools.

The idea of the study focuses on the creation of the (Student desk) so that the generation of electricity will be suitable for lighting and illumination with the use of some electronic devices used in daily school needs like laptops.

So, the solar cell system will be connected to a small generator through a hybrid system.

When the system works through the hybrid principle for lighting and illumination the solar system will generate the power needed and when the sun light disappears the power can be generated by a bike like mover.

The generation of electricity by the hybrid system is considered as an effective and environmentally friendly option with economic benefits.

I hope that the following study will help people who are in great need for such power in such circumstances.

3.1 Mechanical and electronic parts of project:

We will explain briefly the mechanical and electronic parts with the use of pictures that illustrate the parts mentioned above.
3.1.a Mechanical parts

The spinning bicycle is the main mechanical part in my design. It has been modified to the student table so that the pedals of the bicycle are used to move the spinner disk which in turn drives a small generator that is interlock with the disk in a simple way as shown in the pictures below.

In this design, I took into consideration the relocation and change of this table so where the table can be divided and transferred in the form of parts and then re-linked.

Figure (37). Side view of the design
3.1.b Electrical and electronic parts

3.2.100W 12V Mono Solar Panel:

![Solar Panel Image]

Figure (38). Front view the solar panel

3.2.1 Why Monocrystalline?

Panels come in two different forms: monocrystalline and polycrystalline. The individual solar cells are made from silicon. Monocrystalline cells are cut from a single solid piece of silicon crystals. On polycrystalline panels, several silicone crystals are bonded together.

Monocrystalline panels are significantly more power efficient. They produce up to 30% more power and can handle a wider range of light angle. This means that will be generating power earlier in the day, and later into the night.

3.2.2 Features

1. High efficiency solar panel
2. Guaranteed power output
3. Strictly quality control
4. Excellent performance in harsh weather
5. Waterproof
6. Life span up to 25 years
7. Low degradation
8. Recycling aluminum frame
3.2.3 PV module specification

<table>
<thead>
<tr>
<th>Type:</th>
<th>100W Mono Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>100W</td>
</tr>
<tr>
<td>Open Circuit Voltage ($U_{OC}$)</td>
<td>21.6V</td>
</tr>
<tr>
<td>Short Circuit Current ($I_{SC}$)</td>
<td>6.17A</td>
</tr>
<tr>
<td>Output Tolerance</td>
<td>±3%</td>
</tr>
<tr>
<td>Maximum/Peak Voltage ($U_{MPP}$)</td>
<td>17.3V</td>
</tr>
<tr>
<td>Maximum/Peak Current ($I_{MPP}$)</td>
<td>5.78A</td>
</tr>
<tr>
<td>Temperate coefficient of ($I_{SC}$)</td>
<td>(0.10 +/-0.01) %/°C</td>
</tr>
<tr>
<td>Temperate coefficient of ($U_{OC}$)</td>
<td>(0.38+/-.01) %/°C</td>
</tr>
<tr>
<td>Temperate coefficient of power ($U_{OC}$)</td>
<td>-0.47 %/°C</td>
</tr>
<tr>
<td>Temperature range</td>
<td>(-40°C to +80°C)</td>
</tr>
<tr>
<td>Number of Cells:</td>
<td>36 Cells</td>
</tr>
<tr>
<td>Panel Size</td>
<td>541mm(w)x1210mm(h)x35mm(d)</td>
</tr>
<tr>
<td>Power output warranty</td>
<td>5 year-95%/10 year-90%/ 25 year-80%</td>
</tr>
</tbody>
</table>

Table (2). PV module specification table.

3.2.4 Efficiency ($\eta$):

A solar cell’s Efficiency $\eta$ is the product of MPP output $P_{MPP}$ so, the efficiency can be determined through the equation below.

$$\eta = \frac{P_{MPP}}{E \cdot A} = \frac{FF \cdot U_{OC} \cdot I_{SC}}{E \cdot A}$$

where $P_{MPP}$ is maximum power output, $E$ is irradiance, $A$ is solar cell’s area, $FF$ is fill factor, $U_{OC}$ is open-circuit voltage and $I_{SC}$ is short-circuit voltage.

($FF$) The fill factor can be determined through the equation below.

$$FF = \frac{P_{MPP}}{U_{OC} \cdot I_{SC}} = \frac{U_{MPP} \cdot I_{MPP}}{U_{OC} \cdot I_{SC}}$$

where, $U_{MPP}$ is maximum power point voltage and $I_{MPP}$ is maximum power current.

Usually efficiency is indicated under standard test conditions. Table (3) shows the maximum efficiency and typical fill factors for various cells and modules.

3.2.4. a. Maximum power point (MPP).

A solar cell’s maximum power point can be determined at a specific voltage. Figure (39) shows the output-voltage characteristic along with the current-voltage characteristic.

The voltage $U_{MPP}$ at the MPP is less than $U_{OC}$, and the current $I_{MPP}$ is less than the $I_{SC}$.
The current and voltage both depend upon Irradiance and Temperature. The output $P_{\text{MPP}}$ is calculated as follows: 

$$P_{\text{MPP}} = U_{\text{MPP}} \cdot I_{\text{MPP}} < U_{\text{OC}} \cdot I_{\text{SC}}$$

where $I_{\text{SC}} \approx I_f = c_o \cdot E$. If the cell is short-circuited, the terminal at the solar cell is equal to zero, and $U_{\text{OC}} \sim \ln(E)$.

The MPP output cells and modules is usually determined under standard test conditions (STC) where ($E=1000 \text{ W/m}^2, \theta = 25^\circ \text{C}$, and spectral AM 1.5g) to facilitate comparisons.

Because solar modules are always having a lower output under natural conditions, $W_p$ (watts-peak) is often the designation used for finding from the measurement.

The parameters of solar modules are therefor also determined under (NOTC_s) normal operating the temperature. Because an irradiance and temperature effect on the solar cell, the measurements are taken at (NOCT) a normal operating cell temperature.

For example, ($E=800 \text{ W/m}^2, \theta = 20^\circ \text{C}$, and spectral AM 1.5g) and a wind velocity of $1 \text{ m/s}$

Generally, the (NOCT) is around 45$^\circ$C.

![Graph showing I-V and P-U curves with MPP](image.png)

Figure (39). A solar cell’s I-V and P-U curves with MPP

<table>
<thead>
<tr>
<th>Cell/module type</th>
<th>$\eta_{\text{max cell,lab}}$</th>
<th>$\eta_{\text{max cell,series}}$</th>
<th>$\eta_{\text{max module,series}}$</th>
<th>$\text{FF module,series}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-Si</td>
<td>25.0%</td>
<td>22.9%</td>
<td>20.4%</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table (3). Maximum efficiencies and fill factors various cell technologies.
3.3. How to Design Solar PV System:

Example: A project has the following electrical appliance usage:
Two 5Watt LED lamp with used 5 hours per day.
One 80Watt Laptop used for 5 hours per day.
The system will be powered by 12 Vdc, 100 Wp PV module.

1. Determine power consumption demands

Total appliance use = (10 W x 5 hours) + (80 W x 5 hours)
= 450Wh/day
Total PV panels energy need = 450 x 1.3
= 585 Wh/day.
The factor 1.3, is the assumed loss ratio in the system.

3.3.1. Size the PV modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced needs. The peak watt (Wp) produced depends on size of the PV module and climate of site location.

We must consider “panel generation factor” which is different in each site location. For Iraq, the panel generation factor is 6.25.

kWh/m²/day (∫₇ₑ: Average daily sum of global irradiation per square meter received by the modules of the given system. In Baghdad is the solar radiation is one of the highest in the world. The panel generation factor used below to determine the sizing of PV modules, is calculated with PVGIS as follows.)

(36)
3.3.2 Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Location: 33°18'46" North, 44°21'41" East, Elevation: 40 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 1.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 14.9% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.6%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 28.8%

<table>
<thead>
<tr>
<th>Month</th>
<th>$E_d$</th>
<th>$E_m$</th>
<th>$H_d$</th>
<th>$H_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>3.65</td>
<td>113</td>
<td>4.71</td>
<td>146</td>
</tr>
<tr>
<td>Feb</td>
<td>4.27</td>
<td>120</td>
<td>5.64</td>
<td>158</td>
</tr>
<tr>
<td>Mar</td>
<td>4.72</td>
<td>146</td>
<td>6.43</td>
<td>199</td>
</tr>
<tr>
<td>Apr</td>
<td>4.48</td>
<td>134</td>
<td>6.33</td>
<td>190</td>
</tr>
<tr>
<td>May</td>
<td>4.65</td>
<td>144</td>
<td>6.75</td>
<td>209</td>
</tr>
<tr>
<td>Jun</td>
<td>4.76</td>
<td>143</td>
<td>7.07</td>
<td>212</td>
</tr>
<tr>
<td>Jul</td>
<td>4.73</td>
<td>147</td>
<td>7.12</td>
<td>221</td>
</tr>
<tr>
<td>Aug</td>
<td>4.87</td>
<td>151</td>
<td>7.33</td>
<td>227</td>
</tr>
<tr>
<td>Sep</td>
<td>5.03</td>
<td>151</td>
<td>7.40</td>
<td>222</td>
</tr>
<tr>
<td>Oct</td>
<td>4.33</td>
<td>134</td>
<td>6.12</td>
<td>190</td>
</tr>
<tr>
<td>Nov</td>
<td>4.00</td>
<td>120</td>
<td>5.32</td>
<td>160</td>
</tr>
<tr>
<td>Dec</td>
<td>3.68</td>
<td>114</td>
<td>4.76</td>
<td>148</td>
</tr>
<tr>
<td>Yearly average</td>
<td>4.43</td>
<td>135</td>
<td>6.25</td>
<td>190</td>
</tr>
<tr>
<td>Total for year</td>
<td>1620</td>
<td>2280</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4). PVGIS estimates of solar electricity generation

$E_d$: Average daily electricity production from the given system (kWh)
$E_m$: Average monthly electricity production from the given system (kWh)
$H_d$: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m²)
$H_m$: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m²)
Figure (40). PV Estimate Graph

Figure (41). Irradiation Estimate Graph.

(38)
3.3.3 Total Wp of PV panel capacity

\[
\text{Needed} = \frac{585 \text{Wh/day}}{6.25 \times 10^3 \text{ Wh/day/m}^2} \times (1000 \text{Wp/m}^2)
\]

3.3.4 Number of PV panels needed = 93.6 / 100

\[
\text{Number need} = 93.6 \text{ Wp} = 0.939 \text{ modules}
\]

Actual requirement is 1 module
So, this system should be powered by at least 1 modules of 100 Wp PV module.

3.4. Inverter sizing:

Total Watt of all appliances = 10 + 80 = 90 W.
For safety, the inverter should be considered 25-30% bigger size.
The inverter size should be about = 1.3 x 90 W = 117 W or greater.

3.5. Battery sizing:

Total appliances use = (10W x 5 hours) + (80 W x 5 hours)
Nominal battery voltage = 12 V
Days of autonomy = 2 days

\[
\text{Battery Capacity(Ah)} = \frac{\text{Total Watt hours per day used by appliances}}{0.85 \times \text{nominal battery voltage}} \times \text{Days of autonomy}
\]

\[
\text{Battery Capacity} = \frac{[(10W \times 5\text{ hours}) + (80W \times 5\text{ hours})]}{(0.85 \times 12)} \times 2
\]

Total Ampere-hours required 88.2 Ah
So, the battery should be rated 12 V 100Ah for 2-day autonomy.
3.6. Solar charge controller sizing:

PV module specification
Pm = 100Wp
Vm = 16.7 Vdc
Im = 6.6 A
Voc = 20.7 A
Isc = 7.5 A

Solar charge controller rating = (1 strings x 7.5 A) x 1.3 = 9.75 A

So, the solar charge controller should be rated 10 A at 12 V.

3.7. The wiring between the panel and the solar regulator between the regulator and battery:

The wire section is chosen based on the capacity of the panel and their voltage and current of the charge as well as the length of the distance between the panel and the solar system.

Example:

1 meter to 5 meters = 2 x 4 millimeters
6 meters to 10 meters = 2 x 6 millimeters
11 to 15 meters = 2 x 8 millimeters
16 to 20 meters = 2 x 10 millimeters

The larger the distance the wire is, the more wire the wire decreases, the less voltage is lost in the wire and the charging efficiency increases (and the cost increases, of course).

Therefore, wire clip factor is very important in solar and preferably not to exceed the distance of 10 meters.

3.7.1 PV Wire Gauge Guide

Here is a guide to choosing the right wire gauge (thickness) for your amp rating plus your wire length.

To determine the size of solar wire needed, just look at the AMPS in the left column and select the amp rating of your solar system. Next follow the same row over to the approximate length of PV wire we will be using. Then, follow the column up to the yellow box at the top which will be the AWG number wire we will need. AWG is a system of labeling wires that has been used for many years in the USA. AWG numbers get smaller, as the wire length increases.
3.7.2 Electricity wires losses

Losses in solar PV wires must be limited, DC losses in strings of solar panels, and AC losses at the output of inverters. A way to limit these losses is to minimize the voltage drop in cables. A drop voltage less than 1% is suitable and in any case, it must not exceed 3%.
Figure (42). Solar PV wires.
3.7.3. Calculate voltage drop and energy losses in a wire

AC and DC electrical wire voltage drop and energy losses.

3.7.3.a. Voltage drop

Voltage drop is given by the following formula:

\[
\Delta U = b \cdot \left( \rho_1 \frac{L}{S} \cos \varphi + \lambda \cdot L \sin \varphi \right) \cdot I_b
\]

Where:

U: Voltage of the DC or AC system (V)

This is phase-phase voltage for 3-phase system; phase-neutral voltage for single-phase system.

Example:

- For western European countries a 3-phase circuit will usually have a voltage of 400 V, and single-phase 230V.
- In North America, a typical three-phase system voltage is 208 volts and single-phase voltage is 120 volts.

NB: for DC voltage drop in photovoltaic system, the voltage of the system is \( U = U_{\text{mpp}} \) of one panel x number of panels in a series.

\( \Delta U \): voltage drop in Volt (V)

\( b \): length cable factor, \( b = 2 \) for single phase wiring, \( b = 1 \) for three-phased wiring.

\( \rho_1 \): resistivity in ohm. \( mm^2/m \) of the material conductor for a given temperature. At 20 celcius degree °C the resistivity value is 0.017 for copper and 0.0265 for aluminum.

Note that resistivity increases with temperature. Resistivity of copper reaches around 0.023 ohm. \( mm^2/m \) at 100 °C and resistivity of aluminum reaches around 0.037 ohm. \( mm^2/m \) at 100 °C.

Usually for voltage drop calculation according to electrical standards it is the resistivity at 100°C that is used (for example NF C15-100), which may be calculated according to,

\[
\rho_1 = \rho_0 \cdot \left[ (1 + \alpha(T_1 - T_0)) \right],
\]

where \( \rho_0 \) is the resistivity at 20°C \( (T_0) \) and \( \alpha \) = Temperature coefficient per degree C and \( T_1 \) - is the temperature of the cable.

(43)
Note that from experience, a wire with a correct sizing should not have an external temperature over 50°C, but it can correspond to an internal temperature of the material around 100°C.

$L$: simple length of the cable (distance between the source and the appliance), in meters ($m$).

$S$: cross section of the cable in $mm^2$

$\cos \varphi$: power factor, $\cos \varphi = 1$ for pure resistive load, $\cos \varphi < 1$ for inductive charge, (usually 0.8).

$\lambda$: reactance per length unit (default value 0.00008 ohm/m)

$\sin \varphi$: sinus ($a \cos (\cos \varphi)$).

$I_b$: current in Ampere (A)

NB: For DC circuit, $\cos \varphi=1$, so $\sin \varphi=0$.

Voltage drop in percent is given by:

$$\Delta U (\%) = (100) \cdot \frac{\Delta U}{U_0}$$

Where:

$\Delta U$ is the voltage drops in V and,

$U_0$ is the voltage between phase and neutral (example: 230 V in 3-phase 400 V system).

### 3.7.3.b. Energy losses

Energy losses in a cable are mainly due to resistive heating of the cable.

It is given by the following formula:

$$E = a \cdot R \cdot I_b^2$$

Where, $E$ energy losses wires in (W)

$a$ is the number of lines coefficient ($a =1$ for single line, $a = 3$ for 3-phase circuit),

$R$ is the resistance of one active line,

$I_b$ current in Ampere (A).
The resistance $R$ is given by the next formula:

$$R = b \cdot \rho_1 \cdot \frac{L}{S}$$

where $b$ is the length cable factor ($b=2$ for single phase wiring, $b=1$ for three-phased wiring), and $\rho_1$ is the resistivity of the material conductor. The resistivity at wire temperature 20°C is 0.017 for copper and 0.0265 for aluminum in ohm. $mm^2/m$. At 100 °C, the resistivity of copper reaches around 0.023 ohm. $mm^2/m$, and the resistivity of aluminum reaches around 0.037 ohm. $mm^2/m$.

$L$ is the simple length of the cable (distance between the source and the appliance), in meters ($m$), and

$S$ is the cross section of the cable in $mm^2$.

NB: for direct current the energy losses in percent is equal to the voltage drop in percent.

Figure (43). Example of voltage drop losses according to wire cross section for a PV system of 3 kWp with 50 m of solar DC string cable
3.8. Solar Charge Controller:

![Solar Charge Controller Diagram](image)

Figure (44). Photovoltaic battery system with a shunt controller

Charge controllers generally monitor voltage. Specifically, they measure the battery's voltage $U_b$.

If the voltage drops below the lower limit for voltage of deep discharge (around 10.7 V for a 12 V lead battery), switch $S_2$ separates power consumers from the battery.

Once the battery has recovered that is, once the battery’s voltage has reached a minimum level device are reconnected. Switch $S_1$ stops the battery from being charged further if its voltage exceeds its cutoff level (around 13.7 V for a 12 V lead battery).

3.8.1 Features

- LCD display
- All necessary protections equipped
- Adjustable controlling parameter of the system
- With double USB ports charge
- Automatically recognizing day/night
- Temperature compensation
- Dual mosfet reverse current protection, low heat production
- Solar controller has been specifically designed to meet the needs of the rural electrification market. The low cost resulted from using the latest electronic technology and high-volume manufacturing.
The solar controller’s electronics are protected with moisture-tight coating, minimizing damage from humidity and from nesting insects.
Solar controller is fully automatic and requires no adjustments or user selections.

3.8.2 Specification
High Quality
Material: PC
Size: 150*78*35mm
Model NO: KLD1220
Rated Voltage: 12V/24V
Rated Current: 20A
Working Temperature: -35°C to +60°C
Application: Home, Industrial, Commercial
Standby Current: <10mA
Float voltage: 13.7V (default value, adjustable)
Discharge cutoff voltage: 10.7V (default value, adjustable)
Discharge recovery voltage: 12.6V (default value, adjustable)

3.9. DC 24V 36V 48V 60V 72V 84V 96V 108V - 12V 20A Voltage Converter:

In the modern world of electronics, there are three different basic approaches available for the process of DC-to-DC conversion. These are the linear approach, the switching approach, and the charge pump approach.

(47)
A DC-to-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).

DC to DC converters are used in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored energy is drained.

Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage or highest voltage battery thereby saving space instead of using multiple batteries to accomplish the same thing.

3.9.1 Specification

Type: DC Converter
Output Current: 20A Max
Output Voltage: 12V DC (Max 12.8v)
Short circuit protection
Over temperature protection
Weatherproof sealing
Size: 120mm x 52mm x 35mm (not including mounting tabs)

Suitable for 24V-108V battery pack electric vehicles.

3.9.2 Connections

1. Red Wire: 24-108V DC Input (usually connect the + pole of the Rear light)
2. Yellow Wire: 12V DC Output (connect the + pole of the 12V light)
3. Black Wire: either connect Ground Wire Or not connect (12V light - pole and Rear light- pole)
3.10. Watt Meter with Special Heavy GA Wire Wind Generator Solar DC inline

This meter is great to use as an inexpensive way to spot check renewable energy system for power production measures eight parameters:

- Volts - Real time
- Volts - Minimum
- Amps - Real time
- Amps - Peak
- Watts - Real time
- Watts - Peak
- Amps/Hour
- Watts/Hour

Figure (46). Watt Meter
3.11. PM Synchronous Machen:

The inside of a wheel is displayed below in Figure (47).
This is where the motor is housed, it’s a 3 phase AC motor. Some of you may be thinking “why would you use an AC motor on a DC system?” This is because AC motors have greater control over their start up torque and are generally more efficient at higher power requirements.

The permanent magnets in a Permanent Magnet Direct Current motor (PMDC) are always mounted side-by-side with alternating pole-faces pointed towards the stator-poles. Because of this, they will always have an even number of magnets.

Also, we see 30 powerful permanent magnets.

The brushless design reduces friction which makes it maintenance effective.

### 3.11.1 Features

36V DC Low Speed Permanent Magnet Alternator

- 30 powerful permanent magnets.
- *Reaches 12 volts at 75 RPM*
- *Reaches 24 volts at 150 RPM*
- *Reaches 36 volts at 200-250 RPM*

Zero cogging

Stator hand wound for low RPM output

For charging 12, 24 and 36V battery systems may be applied

\[
 r.p.m = \frac{120 \cdot f}{P} = \frac{120 \cdot 50Hz}{30} = 200 \text{ r.p.m}
\]

\( f \) is the frequency,

\( P \) is the Number of poles, and

\( r.p.m \) is the velocity.
3.12. Three Phase Bridge Rectifier for 12V, 24V, 48V up to 1000V Wind Turbine Generators:

This method that has been used to convert AC to DC is the use of a bridge rectifier diodes converter.

We can use a similar bridged to convert DC to AC, (this system is called an inverter). When operated as a converter to produce DC, the machine is run off an AC line.

Figure (48). 3-Phase Bridge Rectifier
3.12.1 Three-phase full-wave rectification

Figure (49). A flow diagram of a wind turbine generator charging a 12-volt battery. From Windy Nation Inc.

Figure (50). 3-phase full-wave rectification: (A) Schematic diagram, (B) Input/output voltage waveforms

(53)
3.12.2. DC Filtering Methods

The pulsating direct current produced by both single-phase and three phase rectifier circuits is not pure DC. A certain amount of AC ripple is evident in each type of rectifier. For many applications, a smooth DC output voltage, with the AC ripple removed, is required. Circuits used to remove AC variations of rectified DC are called filter circuits.

![Diagram of DC filtering methods](image)

The output of a rectifier has a DC value and an AC ripple value, as shown in the figure above. To gain a relative index of the amount of AC variation, the ripple factor of a rectifier output waveform may be determined.

\[
 r = \frac{V_{r(rms)}}{V_{dc}}
\]

where,

- \( r \) is the ripple factor,
- \( V_{r(rms)} \) is the \( rms \) value of the AC component and,
- \( V_{dc} \) is the average value of the rectified DC voltage.
Another index used to express the amount of AC ripple is the percent of ripple of a rectified DC voltage. Ripple percentage is expressed as:

\[
\% \text{ ripple} = \frac{V_{r\text{rms}}}{V_{dc}} = 100
\]

**Sample Problem:**

Given: A power supply has an AC input of 26 \(V_{(\text{rms})}\) and a p-p ripple of 1.5 V at its output, as measured with an oscilloscope.

Find: DC voltage output of the power supply.

Solution:

\[
V_{dc} = V_{\text{max}} - \frac{V_{r\text{p-p}}}{2} = (26V \times 1.41) - \frac{1.5V}{2}
\]

\[
V_{dc} = 36 \text{ V DC}
\]

A full-wave rectified voltage has a lower percentage of ripple than a half-wave rectified voltage. When a DC supply must have a low amount of ripple, a full-wave rectifier circuit should be used a ripple factor.
3.13. Inverter DC/AC 600W:

![Inverter DC/AC 600W](image)

**Inverter technology**

The discussion has assumed that all devices consuming power run on direct current DC from the solar control system. Power from the grid, however, is alternating current. An off-grid inverter is required to run common appliances connected to an off-grid PV system, so the inverter is connected after the battery, because the inverter is generating 230V AC power from 12V DC battery. Fully sine wave inverter for all kinds of applications. This inverter can be used as a power inverter in the small solar systems. Device is employed for any normal AC appliances that input does not exceed performance of inverter. As an example of using the usual appliances in a camp.

**3.13.1 Features**

- Use your ordinary 230V devices in the car, boat or caravan!
- Smaller inverter that converts 12V DC (DC) to 230V AC voltage (AC).
- The converter is connected by means of battery terminals (included).
- Provides 600 W power (up to 1200 W power output).
The converter has a modified sine wave and is provided with overvoltage short circuit protection, two built-ins 35 A fuses and cooling fan.

Next to the 230 V socket there is a power switch.

**Conclusion:**

A hybrid system can reliably produce electricity for a house or a camp. These small or distributed solar systems are often installed by houses or camps to reduce their electricity costs and, the hybrid system gives a more reliable solution for remote areas lacking electrical grid.

A- Hybrid System Advantages

Stores solar or low cost (off-peak) electricity.

Allows use of solar energy during peak times (self-use or load-shifting)

Power available during a grid outage or blackout

Enables from the energy independence

Reduces power consumption from the grid (reduced demand)

B- Hybrid System Disadvantages

Higher cost than grid-feed solar. Mainly due to the high cost of batteries.

More complex installation requires more room and higher install cost.

Battery life of 7-15 years.

May limit how many appliances you can run at the same time (depending on the type of hybrid inverter and its capability).
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