2. Literature Review

2.1. Previous Works:

Several works have been done in the area of sun tracking system, among them; these are the most recent researches:

Study undertaken during fall 2011 at the Appalachian State University Solar Research Laboratory in Boone shown in figure (2.1). The study conclude that there is a statistically significant power increase when using the single axis tracker compared to a fixed mount ranging from 15% at the lower range to 19% for the upper range. At the highest irradiance the tracker offers a significant increase in performance. [11]

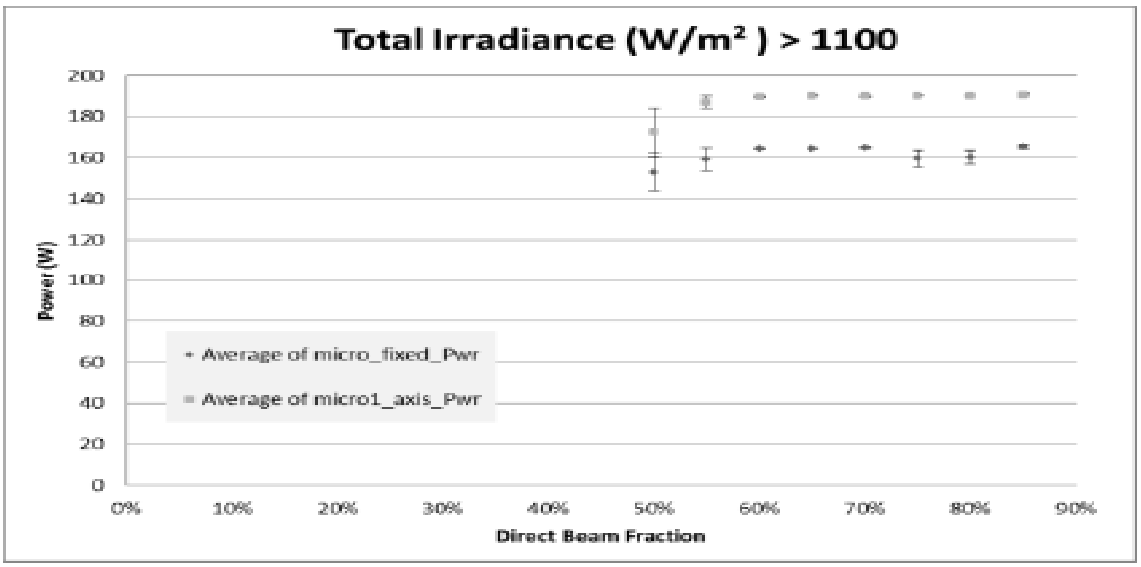

Figure (2.1) (Power relations, fixed panel vs. single axis)

Another work of using phototransistors covered with a small plate to act as a shield to sunlight, as sensor as well as driver as shown in Figure (2.2) below:

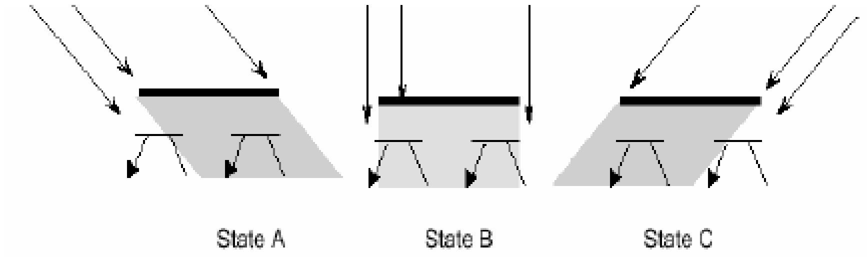

Figure (2.2) (shielded phototransistors at different angles of sun light)

When morning arrives, the tracker is in state A from the previous day. The left phototransistor is turned on, causing signal to turn the motor continuously until the shadow from the plate returns the tracker to state B. As the day slowly progresses, state C is reached shortly, turning on the right phototransistor. The motor turns until state B is reached again, and the cycle continues until the end of the day or until the minimum detectable light level is reached.

(World Academy of Science, Engineering and Technology 41 2008)

A dual axis solar tracking system depends upon the proportional between the error and the movement of the panel:

C(t)=Kp e(t) .[10]

2.2. Photovoltaic

Photovoltaics, also called solar cells, are electronic devices that convert sunlight directly into electricity. The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest growing renewable energy technologies and it is expected that it will play a major role in the future global electricity generation mix. Solar PV systems are also one of the most “democratic” renewable technologies, in that their modular size means that they are within the reach of individuals, co-operatives and small-businesses who want to access their own generation and lock-in electricity prices[1].

2.2.1 PV technology offers a number of significant benefits, including:

I-Solar power is a renewable resource that is available everywhere in the world.

II-Solar PV technologies are small and highly modular and can be used virtually anywhere, unlike many other electricity generation technologies.

III-Unlike conventional power plants using coal, nuclear, oil and gas; solar PV has no fuel costs and relatively low operation and maintenance (O&M) costs. PV can therefore offer a price hedge against volatile fossil fuel prices.

V-PV, although variable, has a high coincidence with peak electricity demand driven by cooling in summer and year round in hot countries.

A PV system consists of PV cells that are grouped together to form a PV module, and the auxiliary components (i.e. balance of system - BOS), including the inverter, controls, etc. There are a wide range of PV cell technologies on the market today, using different types of materials, and an even larger number will be available in the future[3].

PV cell technologies are usually classified into three generations, depending on the basic material used and the level of commercial maturity:

2.2.2 First-generation:

PV systems (fully commercial) use the wafer-based crystalline silicon (c-Si) technology, either single crystalline (sc-Si) or multi-crystalline (mc-Si).

Silicon is one of the most abundant elements in the earth‘s crust. It is a semiconductor material suitable for PV applications. Crystalline silicon is the material most commonly used in the PV industry, and wafer-based c-Si PV cells and modules dominate the current market. This is a mature technology that utilizes the accumulated knowledge base developed within the electronic industry. This type of solar cell is in mass production and individual companies will soon be producing it at the rate of several hundred MW a year and even at the GW-scale[3].

The manufacturing process of wafer-based silicon PV modules comprises four steps:

I. Polysilicon production;

II. Ingot/wafer production;

III. Cell production; and

V. Module assembly.

Crystalline silicon cells are classified into three main types depending on how the Si wafers are made. They are:

a-Monocrystalline (Mono c-Si) sometimes also called single crystalline (sc-Si);

b-Polycrystalline (Poly c-Si), sometimes referred to as multi-crystalline (mc-Si); and

c-EFG ribbon silicon and silicon sheet-defined film growth (EFG ribbon-sheet c-Si).Commercial production of c-Si modules began in 1963 when Sharp Corporation of Japan started producing commercial PV modules and installed a 242 Watt (W) PV module on a lighthouse, the world's largest commercial PV installation at the time (Green, 2001). 7 While a mature technology, continued cost reductions are possible through improvements in materials and manufacturing processes, and from economies of scale if the market continues to grow, enabling a number of high-volume manufacturers to emerge [3].

2.2.3 Second-generation:

PV systems (early market deployment) are based on thin-film.

After more than 20 years of R&D, thin-film solar cells are beginning to be deployed in significant quantities. Thin-film solar cells could potentially provide lower cost electricity than c-Si wafer-based solar cells. However, this isn't certain, as lower capital costs, due to lower production and materials costs are offset to some extent by lower efficiencies and very low c-Si module costs make the economics even more challenging. Thin-film solar cells are comprised of successive thin layers, just 1 to 4 μm thick, of solar cells deposited onto a large, inexpensive substrate such as glass, polymer, or metal. As a consequence, they require a lot less semiconductor material to manufacture in order to absorb the same amount of sunlight (up to 99% less material than crystalline solar cells). In addition, thin films can be packaged into flexible and lightweight structures, which can be easily integrated into building components (building-integrated PV, BIPV). The three primary types of thin-film solar cells that have been commercially developed are[3]:

I-Amorphous silicon (a-Si and a-Si/μc-Si);

II-Cadmium Telluride (Cd-Te); and

III-Copper-Indium-Selenide (CIS) and Copper-

2.2.4 Third-generation:

Third-generation PV technologies are at the precommercial stage and vary from technologies under demonstration (e.g. multi-junction concentrating PV) to novel concepts still in need of basic R&D (e.g. quantum-structured PV cells). Some third-generation PV technologies are beginning to be commercialized, but it remains to be seen how successful they will be in taking market share from existing technologies. There are four types of third-generation PV technologies [3]:

I-Concentrating PV (CPV);

II-Dye-sensitized solar cells (DSSC);

III-Organic solar cells; and

V-Novel and emerging solar cell concepts.

2.2.5 THE EFFECT OF LIGHT ON SILICON:

When light strikes a silicon crystal, it may be reflected, be absorbed, or may go right through. Let's concentrate on the light that is absorbed. Usually when light of relatively low energy is absorbed by a solid, it creates heat without altering the electrical properties of the material. That is, low-energy light striking a silicon crystal causes atoms of silicon to vibrate and twist in their bound positions, but do not break loose. Similarly, electrons in bonds also gain more energy and are said to attain a higher energy level. Since these energy levels are not stable, the electrons soon return to their original lower energy levels, giving off as heat the energy they had gained. Light of greater energy can alter the electrical properties of the crystal. If such light strikes a bound electron, the electron is torn from its place in the crystal. This leaves behind a silicon bond missing an electron and frees an electron to move about in the crystal. A bond missing an electron, rather picturesquely, is called a hole. An electron free to move throughout the crystal is said to be in the crystal's conduction band (Figure 2.3), because free electrons are the means by which electricity flows. Both the conduction-band electrons and the holes play important parts in the electrical behavior of PV cells. Electrons and holes freed from their positions in the crystal in this manner are said to be light-generated electron-hole pairs. A hole in a silicon crystal can, like a free electron, move about the crystal. The means by which the hole moves is as follows: An electron from a bond near a hole can easily jump into the hole, leaving behind an incomplete bond, i.e., a new hole. This happens fast and frequently-electrons from nearby bonds trade positions with holes, sending holes randomly and erratically throughout the solid. The higher the temperature of the material, the more agitated the electrons and holes and the more they move [5].

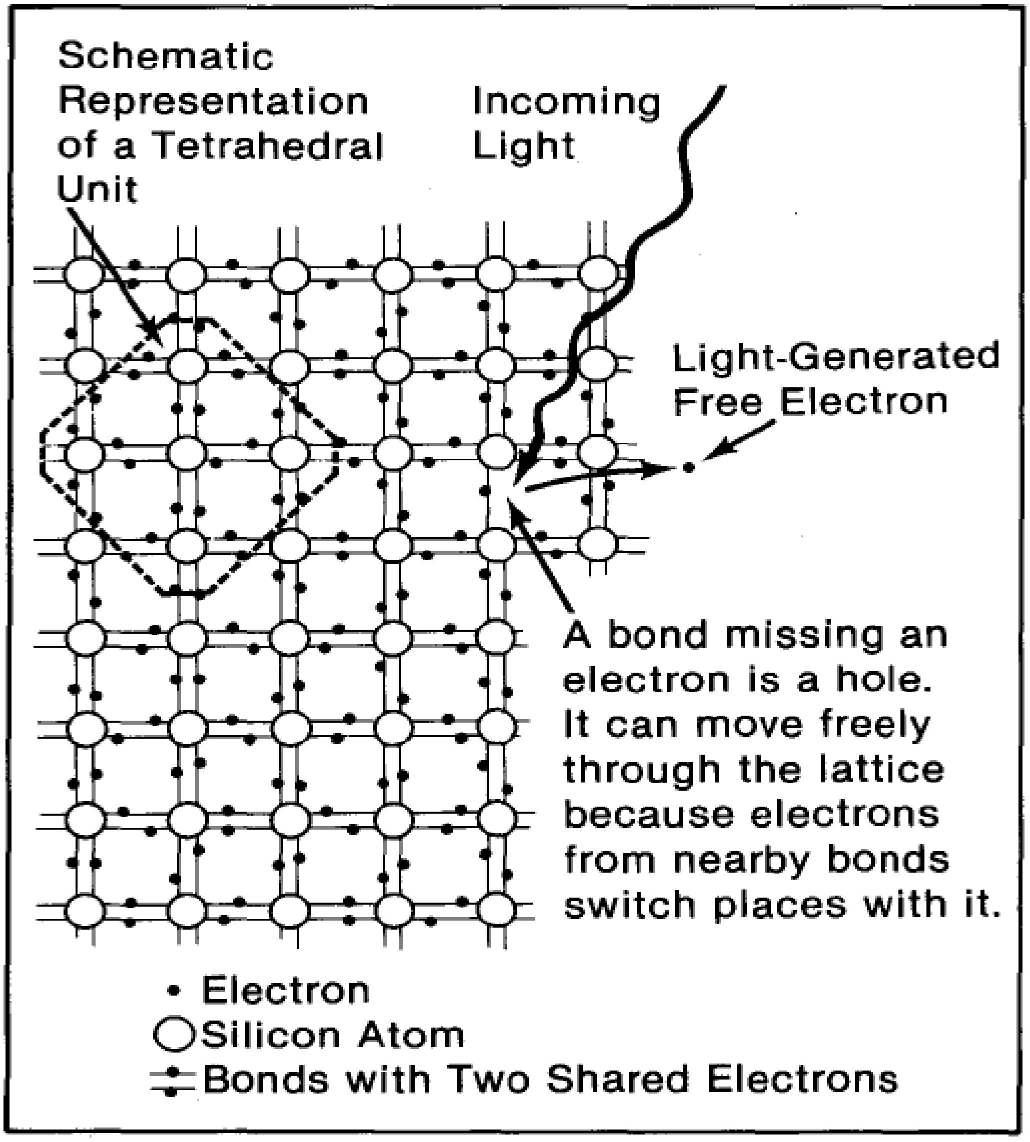

Figure (2.3) Effect of light power on silicon crystal

2.2.6 THE POTENTIAL BARRIER:

The Function of the Barrier A PV cell contains a barrier that is set up by opposite electric charges facing one another on either side of a dividing line. This potential barrier selectively separates light-generated electrons and holes, sending more electrons to one side of the cell, and more holes to the other, Figure (2.4). Thus separated, the electrons and holes are less likely to rejoin each other and lose their electron 'The barrier is called "potential" because it is an electrical phenomenon

having to do with how much energy a particle (electron or hole) would "potentially" gain if that particle encountered the barrier and were accelerated.
10 Basic Photovoltaic Principles and Methods [5].

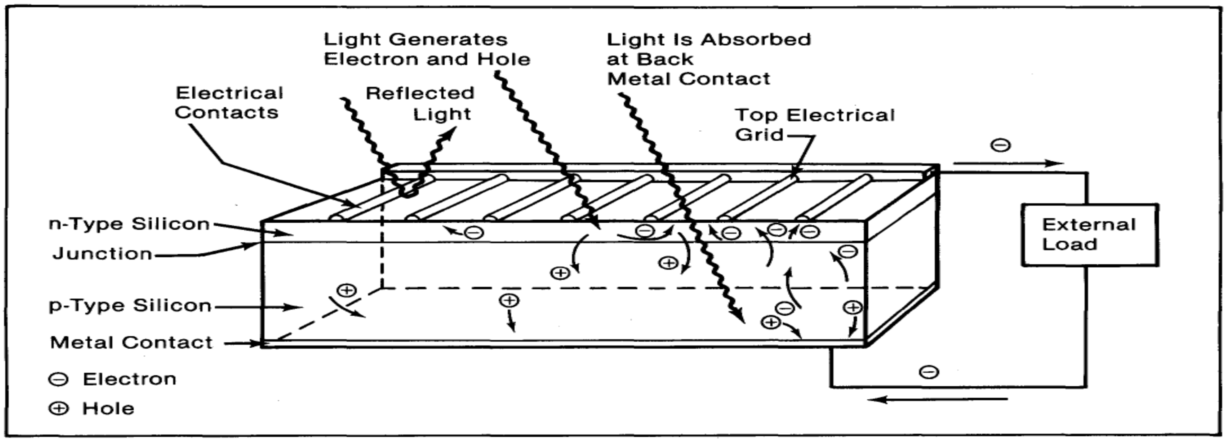

Figure (2.4) the effect of Light incident on the a cell

2.3. Light Dependant Resistor:

A Light Dependent Resistor (LDR, photoconductor, photocell, or photo resistor.) is a device which has a resistance which varies according to the amount of light falling on its surface, when light falls upon it then the resistance changes.
Light dependent resistors or LDRs are often used in circuits where it is necessary to detect the presence of light, or the ambient level of light, often to create a light triggered switch.
Different LDR's have different specifications, a typical LRD has a resistance in total darkness of 1 MOhm, and a resistance of a couple of kOhm in bright light (10-20kOhm @ 10 lux, 2-4kOhm @ 100 lux). It is not uncommon for the values of resistance of an LDR to be several megohms in darkness and then to fall to a few hundred ohms in bright light. With such a wide variation in resistance, LDRs are easy to use and there are many LDR circuits available. LDRs are made from semiconductor materials to enable them to have their light sensitive properties.

Many materials can be used, but one popular material for these LDR's is cadmium sulphide (CdS).

To understand how an LDR works, It is first necessary to understand that an electrical current consists of the movement of electrons within a material. Good conductors have a large number of free electrons that can drift in a given direction under the action of a potential difference. Insulators with a high resistance have very few free electrons, and therefore it is hard to make the them move and hence a current to flow.

An LDR is made of semiconductor material with a high resistance. It has a high resistance because there are very few electrons that are free and able to move - the vast majority of the electrons are locked into the crystal lattice and unable to move. Therefore in this state there is a high LDR resistance [3].

As light falls on the semiconductor, the light photons are absorbed by the semiconductor lattice and some of their energy is transferred to the electrons. This gives some of them sufficient energy to break free from the crystal lattice so that they can then conduct electricity. This results in a lowering of the resistance of the semiconductor and hence the overall LDR resistance.

The process is progressive, and as more light shines on the LDR semiconductor, so more electrons are released to conduct electricity and the resistance falls further.

Figure (2.5) shows the description and dimensions of LDR [2].

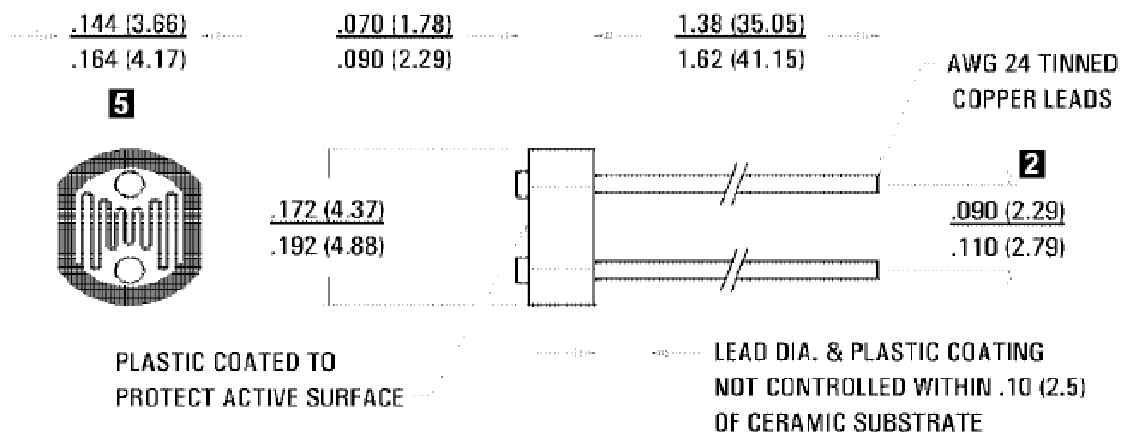

Figure (2.5) LDR. Description and dimensions.

The sensitivity of a photo detector is the relationship between the light falling on the device and the resulting output signal. In the case of a photocell, one is dealing with the relationship between the incident light and the corresponding resistance of the cell. As in Figure (2.6).

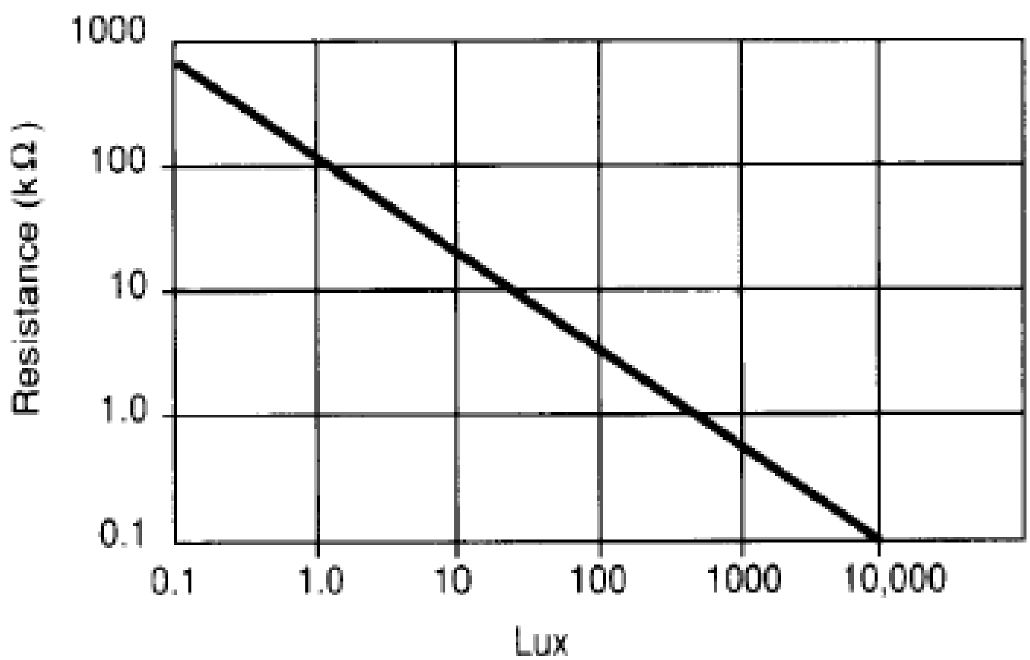

Figure (2.6) sensitivity of LDR.

2.4. Stepper Motor Theory

A step motor is a constant output power transducer, where power is defined as torque multiplied by speed. This means motor torque is the inverse of motor speed. To help understand why a step motor's power is independent of speed, we need to construct (figuratively) an ideal step motor. An ideal step motor would have zero mechanical friction, its torque would be proportional to ampere-turns and its only electrical characteristic would be inductance. Ampere-turns simply mean that torque is proportional to the number of turns of wire in the motor's stator multiplied by the current passing through those turns of wire. Anytime there are turns of wire surrounding a magnetic material such as the iron in the motor's stator, it will have an electrical property called inductance. Inductance describes the energy stored in a magnetic field anytime current passes through this coil of wire. Inductance (L) has a property called inductive reactance, which for the purposes of this discussion may be thought of as a resistance proportional to frequency and therefore motor speed. According to Ohm's law, current is equal to voltage divided by resistance. In this case we substitute inductive reactance for resistance in Ohm's law and conclude motor current is the inverse of motor speed. Since torque is proportional to ampere-turns (current times the number of turns of wire in the winding), and current is the inverse of speed, torque also has to be the inverse of speed.In an ideal step motor, as speed approaches zero, its torque would approach infinity while at infinite speed torque would be zero. Because current is proportional to torque, motor current would be infinite at zero as well.Electrically, a real motor differs from an ideal one primarily by having a non-zero winding resistance. Also, the iron in the motor is subject to magnetic saturation, as well as having eddy current and hysteresis losses. Magnetic saturation sets a limit on current to torque proportionally while eddy current and hysteresis (iron losses) along with winding resistance (copper losses) cause motor heating [2].

2.4.1 Speed-Torque Curve Basics

In the previous section it was shown that motor torque varies inversely with speed. This then is the motor's natural speed-torque curve. Below a certain speed, called the corner speed, current would rise above the motor's rated current, ultimately to destructive levels as the motor's speed is reduced further. This can be seen in Figure (2.7) [4].

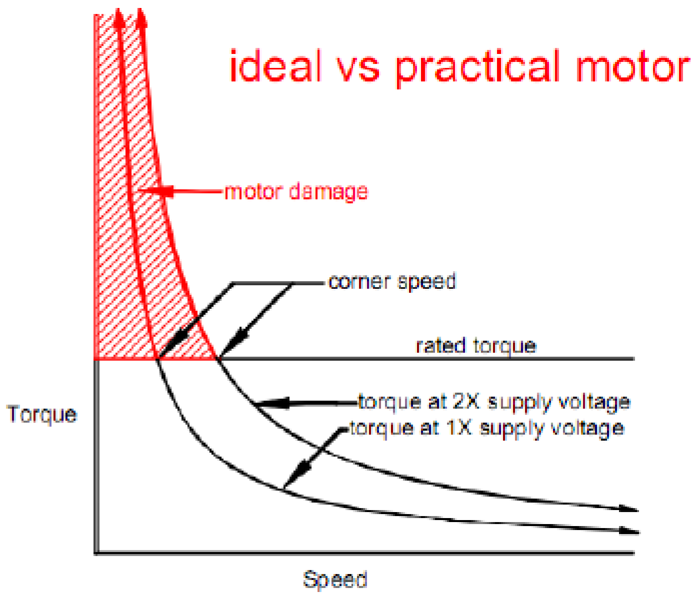

Figure (2.7)

2.4.2 Motor Power Basics

The motor power output (speed times torque) is determined by the power supply voltage and the motor's inductance. The motor's output power is proportional to the power supply voltage divided by the square root of the motor inductance.

If one changes the power supply voltage, then a new family of speed-torque curves result. As an example, if the power supply voltage is doubled then a new curve is generated; the curve now has twice the torque at any given speed in region 2. Since power equals torque times speed, the motor now generates twice as much power as well. This is illustrated in Figure (2.8) [4].

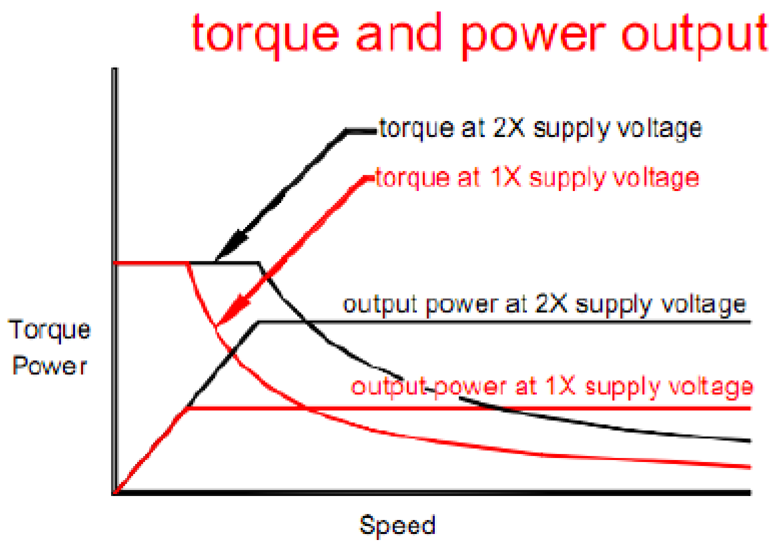

Figure (2.8)

2.4.3 Motor Connections:

Step motors have four, six or eight wires; older motors may have five wires, but they will not be covered here.Four-wire motors are the simplest to connect and offer no connection options. Simply connect one winding to the terminals labeled "Phase A" and "Phase /A" and connect the other winding to the terminals that say "Phase B" and "Phase /B". If it is unknown which wires belong to which phase, simply use an ohmmeter and test which wires have continuity. The ones that have continuity will belong to the same phase; if the motor turns the wrong direction when connected just swap "Phase A" and "Phase /A". A typical four wire motor connection is illustrated in Figure (2.9).Six-wire motors are the most common. There are two connection options: Full-winding and halfwinding shown in Figure (2.10) [4].

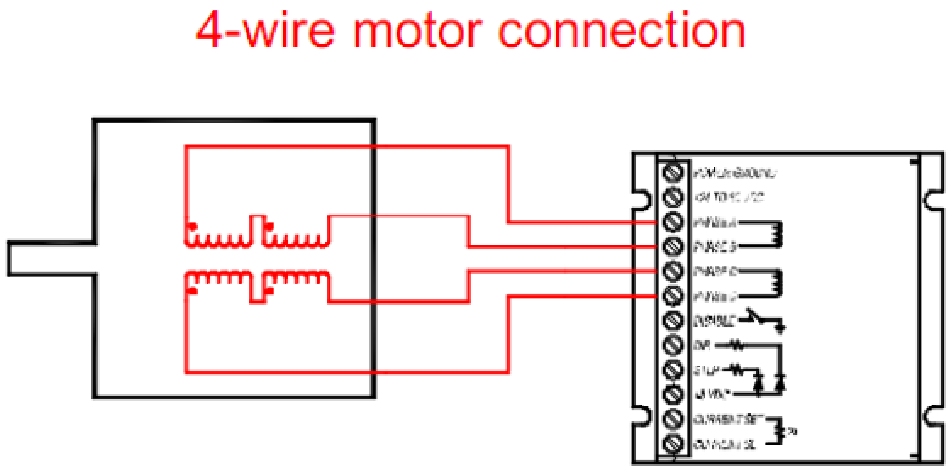

Figure (2.9)

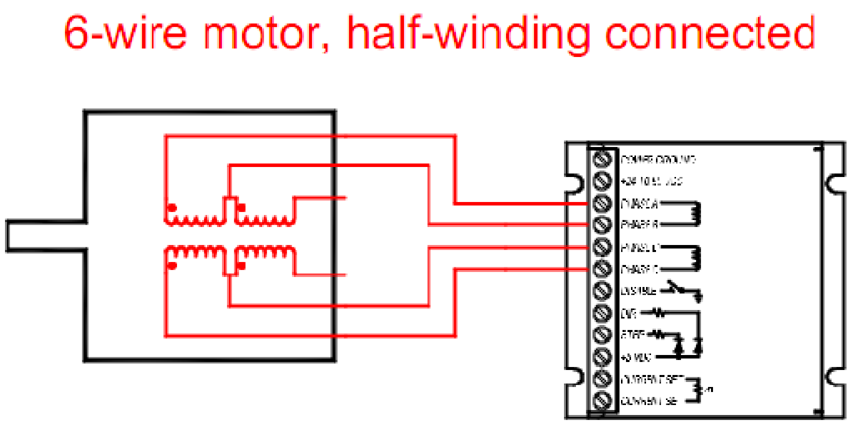

Figure (2.10)

2.4.4 Switching Sequence:

The stepper motor can be operated in three different stepping modes, namely, full-step, half-step, and microstep.

I - Full-Step:

The stepper motor uses a four-step switching sequence, which is called a full-step switching sequence which is already described above.

II - Half-Step:

Another switching sequence for the stepper motor is called an eight-step or half-step sequence. The switching diagram for the half-step sequence is shown in Fig. 3. The main feature of this switching sequence is that you can double the resolution of the stepper motor by causing the rotor to move half the distance it does when the full-step switching sequence is used. This means that a 200-step motor, which has a resolution of 1.8°, will have a resolution of 400 steps and 0.9°. The half-step switching sequence requires a special stepper motor controller, but it can be used with a standard hybrid motor. The way the controller gets the motor to reach the half-step is to energize both phases at the same time with equal current [7].

<u>WAVE STEPPING</u>

The wave stepping sequence is shown below.

STEP	L1	L2	L3	L4
1	H	L	L	L
2	L	H	L	L
3	L	L	H	L
4	L	L	L	H

Wave stepping has less torque then full stepping. It is the least stable at higher speeds and has low power consumption.

<u>FULL STEPPING</u>

The full stepping sequence is shown below.

STEP	L1	L2	L3	L4
1	H	H	L	L
2	L	H	H	L
3	L	L	H	H
4	H	L	L	H

Full stepping has the lowest resolution and is the strongest at holding its position. Clock-wise and counter clockwise rotation is accomplished by reversing the step sequence.

STEP ANGLE

The step angle, the number of degrees a rotor will turn per step, is calculated as follows:

$$\text{Step Angle}\,(\Theta_S) = \frac{360^\circ}{S}$$

$$S = mN_r$$

$$m = \textit{number of phases}$$

$$N_r = \textit{number of rotor teeth}$$

2.4.5 DC MOTORS VS. STEPPER MOTORS:

Stepper motors are operated open loop, while most DC motors are operated closed loop.

I. Stepper motors are easily controlled with microprocessors, however logic and drive electronics are more complex.

II. Stepper motors are brushless and brushes contribute several problems, e.g., wear, sparks, electrical transients.

III. DC motors have a continuous displacement and can be accurately positioned, whereas stepper motor motion is incremental and its resolution is limited to the step size.

IV. Stepper motors can slip if overloaded and the error can go undetected. (A few stepper motors use closed-loop control.)

V. Feedback control with DC motors gives a much faster response time compared to stepper motors.

2.4.6 ADVANTAGES OF STEPPER MOTORS:

I. Position error is noncumulative. A high accuracy of motion is possible, even under open-loop control.

II. Large savings in sensor (measurement system) and controller costs are possible when the open-loop mode is used.
III. Because of the incremental nature of command and motion, stepper motors are easily adaptable to digital control applications.
IV. No serious stability problems exist, even under open-loop control.
V. Torque capacity and power requirements can be optimized and the response can be controlled by electronic switching.
VI. Brushless construction has obvious advantages.

2.4.7 DISADVANTAGES OF STEPPER MOTORS:

I. They have low torque capacity (typically less than 2,000 oz-in) compared to DC motors.

II. They have limited speed (limited by torque capacity and by pulse-missing problems due to faulty switching systems and drive circuits).

2.5 Stepper drivers

The direction of rotation is determined by applying the pulses to either the clockwise or counterclockwise drive circuits. Rotor displacement can be very accurately repeated with each succeeding pulse. Stepping motors are generally operated without feedback, which simplifies the control circuit considerably. One of the most common stepper motor drive circuits is the unipolar drive, shown in Figure (2.11). This circuit uses bifilar windings and four Darlington transistors to control the direction of rotation and the stepping rate of the motor [7].

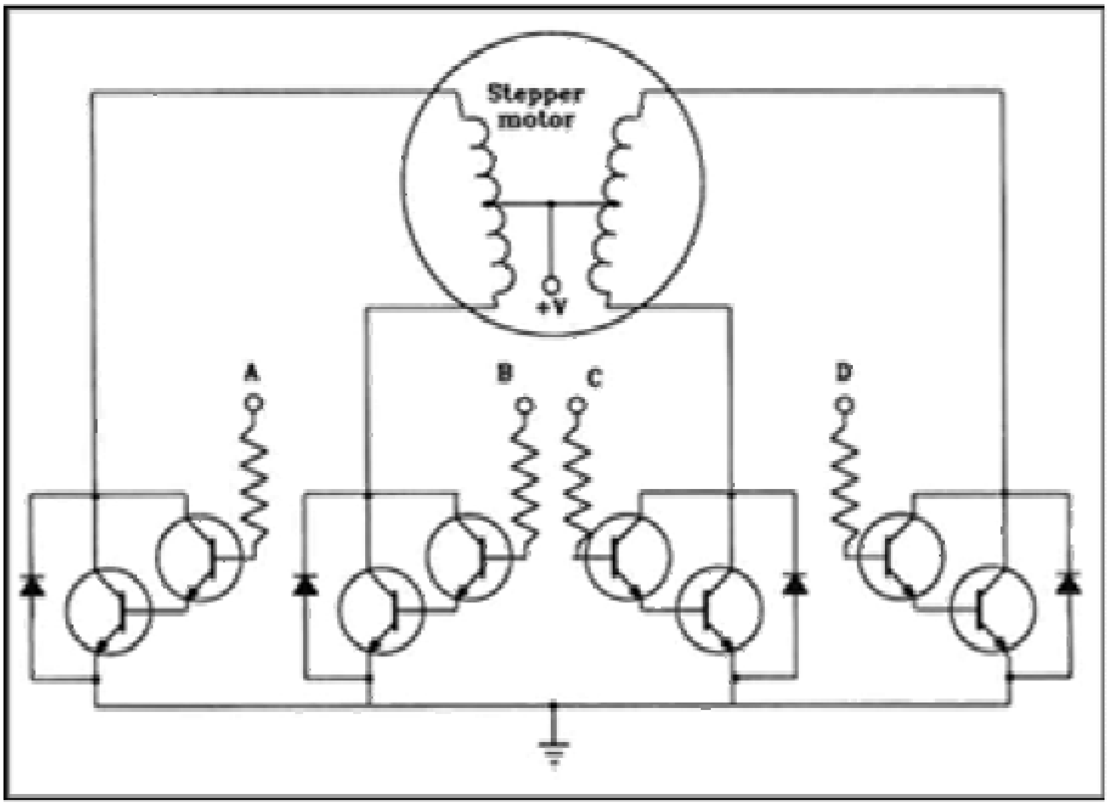

Figure (2.11) Unipolar stepper motor drive.

2.5.1 Drive requirements:

The operating speed range of stepping motors is proportional to the phase resistance . As the phase resistance can be controlled by changing the forcing resistance, it is possible to operate stepping motors at very high speeds using the simple drive circuits with a large forcing resistance. However, the supply voltage must also be increased to maintain the phase current at its rated value when the motor is stationary, and consequently a large dc power supply is needed. For small motors this may be a perfectly satisfactory method of obtaining a wide speed range, because the size of

power supply is unimportant. A large supply voltage and phase resistance are only required when the motor is operating at high speeds. If the motor is stationary the phase currents dissipate High-speed operation 81 a substantial part of the supply output in the series forcing resistance, and the heat produced can cause problems if the forcing resistances cannot be cooled. The simple series forcing resistance is therefore an inefficient method of improving the speed range; power is wasted in the resistances at low speeds so that the mechanical output power (torque × speed) can be improved at higher speeds [7].

Current flows into the motor provided the voltage applied to the phase can overcome the induced voltage, see figure (2.12). If the motor is to operate at a higher speed then the induced voltage is larger and the applied voltage must also increase, so that current flows into the winding over the extended speed range. Increases in applied voltage must be accompanied by proportional increases in phase resistance if the winding current is to be limited to its rated value when the motor is stationary. This argument reveals that the phase voltage is the fundamental factor in determining the speed range of the motor, and the function of the series resistance can then be regarded as 'current-limiting', rather than 'forcing'. At the highest speeds the phase current is low, so the voltage drop across the series resistance is small and
the applied voltage balances the induced voltage [7].

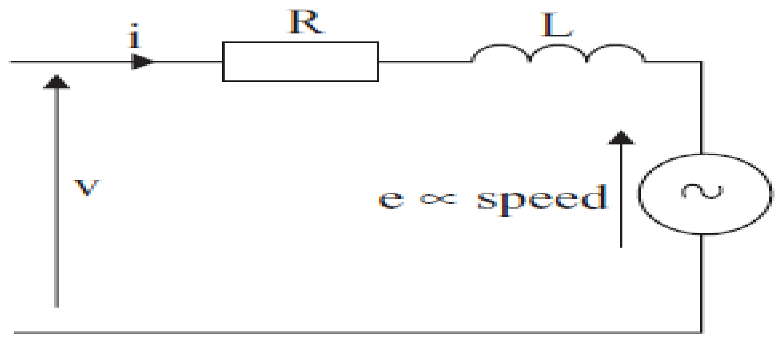

Figure (2.12) Circuit model for one phase

The drive circuit requirements are now clarified: a large supply voltage is needed at high speeds, but the phase current at low speeds must be limited without the power wastage associated with the simple series resistance method of current-limiting.