{ TC "'CHAPTER 1: INTRODUCTION'" \L 1 }CHAPTER ONE

INTRODUCTION

1.1 **Background{ TC** "1.1 **Background**" \l 2 **}**

The energy the earth receives from the sun is so enormous and so lasting that the total energy consumed annually by the entire world is supplied in as short a time as a half hour. On a clear day the sun's radiation on the earth can be 1000 watts per square meter depending on the location. The sun is a clean and renewable energy source, which produces neither green-house effect gas nor noxious waste through its utilization.

Photovoltaic (PV) is a technology in which radiant energy from the sun is converted to direct current (DC) electricity. Although the scientific basis of the photovoltaic effect has been known for nearly 150 years, the modern photovoltaic cell was not developed until 1954. Only four years later the first cells were providing power for U.S. spacecraft. Some of these early systems are still operating in space today and attest to the reliability and durability of the technology.

The photovoltaic process is completely solid state and self contained. There are no moving parts and no materials are consumed or emitted. Consider the advantages that photovoltaic systems have over competing power options:

While operating, they have no moving parts and produce power silently.

They are non-polluting with no detectable emissions or odors.

They can be stand-alone systems that reliably operate unattended for long periods.

They require no connection to an existing power source or fuel supply.

They may be combined with other power sources to increase system reliability.

They can withstand severe weather conditions including snow and ice.

They consume no fossil fuels - their fuel is abundant and free.

They can be installed as modular building blocks - as your power demand increases, more photovoltaic modules may be added.

In the last decade over 100 megawatts of U.S. produced photovoltaic modules has been installed worldwide. Most systems are at remote sites where the power demand is relatively small (< 1000 watts). Photovoltaic systems are often the most economical option for this type of application.

Unfortunately solar cells are still far too expensive to produce a significant fraction of the worlds energy needs. However as shown in Figure 1.1, the cost of PV cells per watt of peak output has decreased dramatically since the 1970's (Green, 1993).

The efficiency of a solar cell is defined as the ratio of the electrical output power over the sun-light input power. Commercial silicon solar cells are typically 10-16% efficient .

Lowering the cost of photovoltaic electricity from solar cells is essential for the technology to further extend its use, especially among utilities. One promising area of research is the use of PV as the power source for pumping water. When a DC motor and pump is directly coupled to a PV generator without storage batteries. The pumped water can be used to store energy.

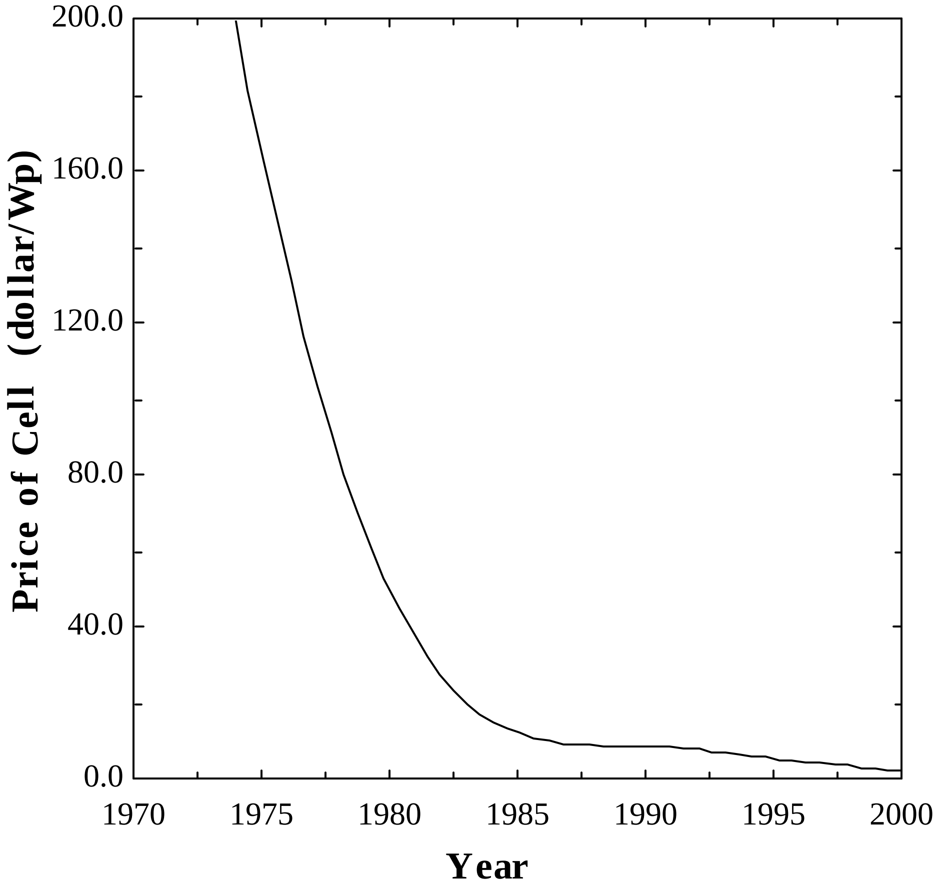

Figure 1.1 Trend of Solar Cell Manufacturing Cost **{** TC "Figure 1.1 Trend of Solar Cell Manufacturing Cost " \l 6 **}**

The use of photovoltaic power for water pumping is appropriate as there is often a natural relationship between the availability of solar power and the water requirement. The water requirement increases during hot weather periods when the solar radiation levels are highest and the output of the solar array is at a maximum. The water requirement decreases when the weather is cool and the sunlight is less intense. Photovoltaic water pumping systems (PVPS) are particularly suitable for water supply in remote areas where no reliable electricity supply is available.

Water can be pumped during the day and stored in tanks, making water available at night or when it is cloudy. The use of batteries to store electricity can also provide this capability. However there is debate within the industry whether it is better to increase the size of the array and fill a bigger tank or to use a smaller array and batteries. There is some merit in using the large array as a 25% loss is sustained by battery storage and conversion.

The fastest growing PV market segment is the thousands of photovoltaic-powered water pumps being installed in the United States and abroad each year. These applications include domestic use, water for camp, irrigation, village water supplies, and livestock watering. No single design method is suitable for the entire range of existing needs.

Livestock watering is gaining in popularity with electric utilities in the western United States. These companies are finding it much more economical to use a photovoltaic-powered pump than to maintain a distribution line to a remote pump on a ranch. Several utilities are offering a photovoltaic water pumping system as a customer service option. The many advantages of using water pumps powered by photovoltaic systems include low maintenance, ease of installation, reliability, and the capability to be matched to water usage needs. Most pumping systems do not use batteries but store the water in water tanks.

The usual elements of a PV water pumping system are:

1. Photovoltaic array - to provide the electricity supply to operate the pump. This supply could be direct current (DC), usually at 110 volts, or alternating current (AC) which is produced by inverting the DC power to AC power.

2. Pump

3. Battery storage if used - to provide electricity storage to allow pumping in cloudy conditions or at night.

4. Storage tank - normally elevated, serves a similar purpose to battery storage.

5. Maximum power point tracker (MPPT) which forces the PV array work at maximum power point and improve the efficiency of system.

6. Electronic devices to change the configuration of PV array at different radiation levels to improve the efficiency of system.

The volume of pumped water is dependent on six major factors:

1. The radiation level which is a measure of the sun's available energy,

2. The photovoltaic array area,

3. The conversion efficiency of the photovoltaic array

4. The slope the photovoltaic array.

5. The ambient temperature

6. The pump-motor -hydraulic system characteristics

The cost of photovoltaic installations is mostly dependent on the PV array area. The major disadvantages of using PV are their high installation costs and its low energy conversion efficiency. Therefore, in order to improve the cost effectiveness of PV array powered systems, the electric power generated by the PV array should be efficiently utilized.

Three different system configurations are currently in use. The first is the directly coupled system where a PV array is directly coupled to a DC motor and pump. The second system is the battery buffered PV pumping system where a battery is connected across the array to feed the DC motor driving a pump. The third system uses maximum power point tracker (MPPT) or array tracking to improve the efficiency of system. The typical range of sizes for photovoltaic-powered pumps is a few hundred watts to a few kilowatts.

Direct coupled systems, where the PV array is directly coupled to a DC motor-pump system, is shown in Figure 1.2. Such a system is simple and reliable, but the system is not continuously at its optimum operating point due to the continuous variation of solar radiation .

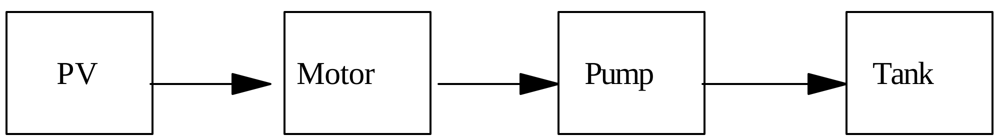

Figure 1.2 The Direct Coupled PVPS{ TC "Figure 1.2 The Direct Coupled PVPS" \l 6 }

Battery buffered systems with a storage battery is shown in Figure 1.3. In this system, a battery is connected across the PV array and the DC motor is operating at almost constant voltage, and as a result, the DC motor is operated near to its optimum operating point. This system has two advantages over the directly coupled one: First, in the battery systems, water may be pumped day and night, thus the water discharge is larger and second, the DC motor is operating at its optimum operating point, and consequently, the system efficiency is enhanced. A major disadvantage of such a system is the extra system cost and unreliability due to the battery.

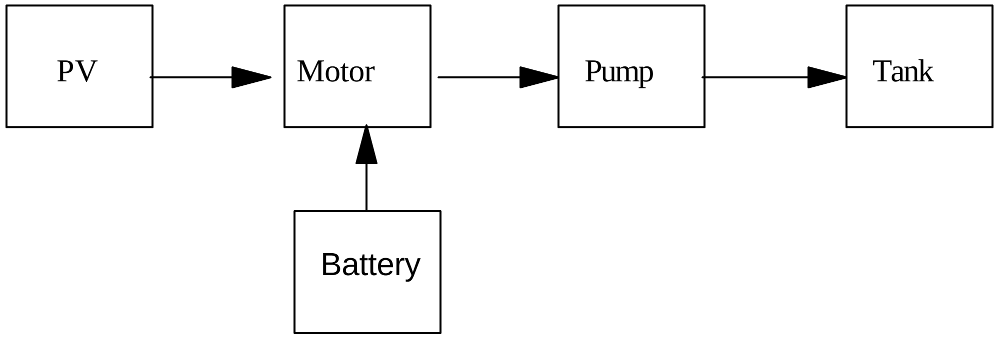

Figure 1.3 The Direct Coupled PVPS with Battery Buffer{ TC "Figure 1.3 The Direct Coupled PVPS with Battery Buffer" \l 6 }

The photovoltaic modules are often mounted on a tracking device that maximize energy production by tracking the sun from east to west each day as shown in Figure 1.4. The tracker uses little or no power and may increase water production as much as 20 to 40 percent during summer months.

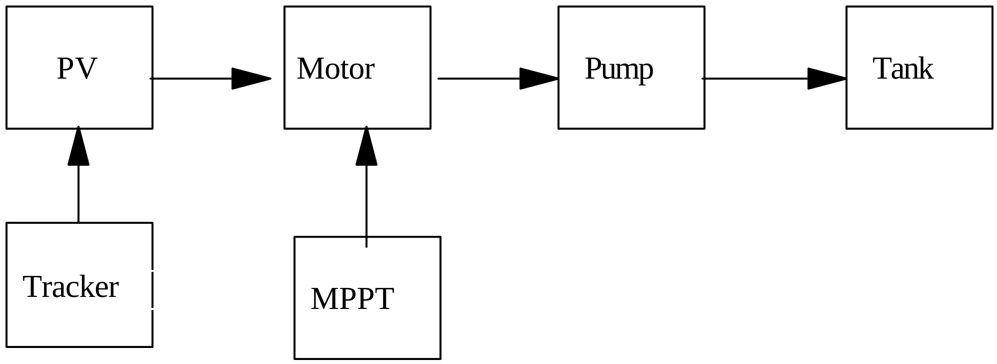

Figure 1.4 The Direct Coupled PVPS with Tracker{ TC "Figure 1.4 The Direct Coupled PVPS with Tracker" \l 6 }

1.2 Motivation for research{ TC "1.2 Motivation for research" \l 2 }

Wide spread use of PVPS is limited because the capital cost is high. To make the investment more effective, it is necessary to produce the long term performance of PVPS.

The difficulty in predicting the performance of a PV pumping system is explained as follows. When the PV array supplies sufficient electrical power, the motor produces mechanical torque and the pump draws water. Sufficient radiation must be available for a PV pumping system to start its pumping operation: this radiation level is called the radiation threshold. The threshold of PV pumping system depends on the characteristics of the system components. After the system starts up, it will pump water at a rate that depends on the intensity of the radiation. There is a nonlinear relationship between pumping rate and the radiation; at high radiation levels, the rate of increase of pumping rate with increasing radiation is smaller than an intermediate radiation levels. Both the existence of a radiation threshold and the nonlinear dependence radiation level make the analysis of a PV pumping system and prediction of its performance difficult.

Many researchers have investigated and proposed different methods for designing and optimizing the PVPS to improve the system efficiency and reduce the investment. The results of several experimental studies and theoretical analyses of PVPS have been published. Appelbaum and Bany (1979a) and (1979b) analyzed the direct coupled PV pumping system under steady state conditions. Appelbaum and Singer (1993) have examined the starting characteristics of DC motor and pump powered by PV array with/out MPPT. Roger (1979) showed that a DC motor driving a centrifugal pump represents a well-marched load for a PV array because this system utilizes most of available DC power generated by the array. Anis *et al.* (1985) reported that a load composed of a DC motor driving a constant volume pump represents a non-matched load to a PV array because the motor driving a constant volume pump requires a nearly constant current. The matching of a DC motor to a PV generator to maximize daily gross mechanical energy is reported by Saied(1989). Salashmash (1990) and Dagher have analyzed the effect of PV array configuration on the performance of PVPS. Hsiao

(1984) and Koner (1995) analyzed the performance of PVPS by varying the motor constant. Dunlop (1988) has experimentally investigated the effects of different tracking methods. In the study by Hsiao, hourly radiation data were required, leading to expensive use of computer simulation time. In the study of utilizabilty by Loxson (1994), two segments were used to represent the flow rate vs radiation, leading to the large errors between simulation results and experiment data.

Townsend (1989), Eckstein (1990), and Al-Ibrahim (1996) developed a comprehensive PV cell model for TRNSYS which use four parameters. They also developed motor, pump and MPPT models. However there is complicated nonlinear relationship among models, requiring numerical skill to deal with the models. In addition, difficult to obtain parameters for the motor and pump are required for simulation.

A conclusion is that most of the available analysis methods are based on a specific pump and motor for a specific site. Those methods are difficult to use in different locations and systems because it is difficult to get both detailed information on the components of PVPS and long-term weather information.

Another factor is that manufactures only provide data on the motor-pump combination. They never sell the motor and pump separately. Normally the parameters of motor-pump group has been optimized by manufacturers.

This study is motived by the need to develop a general method for simulating the long term performance of PVPS. The objective of this research is to develop a general method for the evaluation of long-term performance of direct coupled PVPS and PVPS with MPPT. The simulation will be done on an hourly basis, with the power assumed constant over each hour. The new method is only based on the available information of the PV module, the pump and the motor all of which are normally supplied by manufacturer. The generated weather data will be used in the new method to reduce the calculation time and the difficulty of obtaining the long-term measurement weather data.