MODELLING AND SIMULATION OF PHOTOVOLTAIC WATER PUMPING SYSTEM

MUSADDIQ SAIYED[1], YASHIT TITA[2]
[1]PG Scholar, [2]Assisatnt Professor
[1]Electrical Department
LDRP-ITR, Gandhinagar, Gujarat, India

Abstract: This paper deals with the modelling of simple and efficient water pumping system. It provides the study of its equivalent circuit. This system uses maximum power point tracking algorithm to maintain maximum power at output in any atmospheric condition. Each subsystem is modelled in order to get whole system that works efficiently. This simulation works on ideal data and real time data. The module voltage is given to boost converter that further connected to DC motor and pump. The final result validate that MPPT can significantly increase the conversation efficiency of the system.

INRODUCTION

Water resources are essential for satisfying human needs, ensuring health, food production, restoration of ecosystem as well as social and economic development. However, according to UN World Water Development Report in 2015[1], by 2050, agriculture will need to produce more food globally. This will require huge amount of water. Remote water pumping systems are a key component in meeting this need.

In this paper, a simple but efficient photovoltaic water pumping system is modelled. It provides theoretical studies of photovoltaics (PV) and its modeling techniques. It also investigates in detail the maximum power point tracker (MPPT), a power electronic device that significantly increases the system conversation efficiency.

WATER PUMPING SYSTEM AND PHOTOVOLTAIC POWER

A water pumping system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive. Windmills have been installed traditionally in such areas; many of them are, however, inoperative now due to lack of proper maintenance and age. Today, many stand-alone type water pumping systems use internal combustion engines. These systems are portable and easy to install. However, they have some major disadvantages, such as: they require frequent site visits for refueling and maintenance, and furthermore diesel fuel is often expensive and not readily available in rural areas of many developing countries.

The consumption of fossil fuels also has an environmental impact, in particular the release of carbon dioxide (CO2) into the atmosphere. CO2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations. Good examples include large-scale grid-connected wind turbines, solar water heating, and off-grid stand-alone PV systems. The use renewable energy for water pumping system is, therefore, a very attractive proposition. [2]

PV systems are highly reliable and are often chosen because they offer the lowest life-cycle cost, especially for applications requiring less than 10KW, where grid electricity is not available and where internal-combustion engines are expensive to operate. If the water source is 1/3 mile (app. 0.53K*m*) or more from the power line, PV is a favorable economic choice.

ENERGY STORAGE ALTERNATIVES

Among many possible storage technologies, the lead-acid battery continues to be the workhorse of many PV systems because it is relatively inexpensive and widely available. In addition to energy storage, the battery also has ability to provide surges of current that are much higher than the instantaneous current available from the array, as well as inherent and automatic property controlling the output voltage of the array so that loads receive voltages within their own range of acceptability. [3]

While batteries may seem like a good idea, they have a number of disadvantages. The type of lead-acid battery suitable for PV systems is a deep-cycle battery, which is different from one used for automobiles, and it is more expensive and not widely available. Battery lifetime in PV systems is typically three to eight years, but this reduces to typically two to six years in hot climate since high ambient temperature dramatically increases the rate of internal corrosion. Batteries also require regular maintenance and will degrade very rapidly if the electrolyte is not topped up and the charge is not maintained. They reduce the efficiency of the overall system due to power loss during charge and discharge. Typical battery efficiency is around 85% but could go below 75% in hot climate from all those reasons, experienced PV system designers avoid batteries whenever possible. [4]

For water pumping systems, appropriately sized water reservoirs can meet the requirement of energy storage during the downtime of PV generation. The additional cost of reservoir is considerably lower than that incurred by the battery equipped system.

A PROPOSED MODULE

The experimental water pumping system proposed in this thesis is a stand-alone type without backup batteries. As shown in Figure 1-1, the system is very simple and consists of a single PV module, a maximum power point tracker (MPPT), and a DC water pump. The size of the system is intended to be small; therefore, it could be built in the lab in the future. The system including the subsystems will be simulated to verify the functionalities.

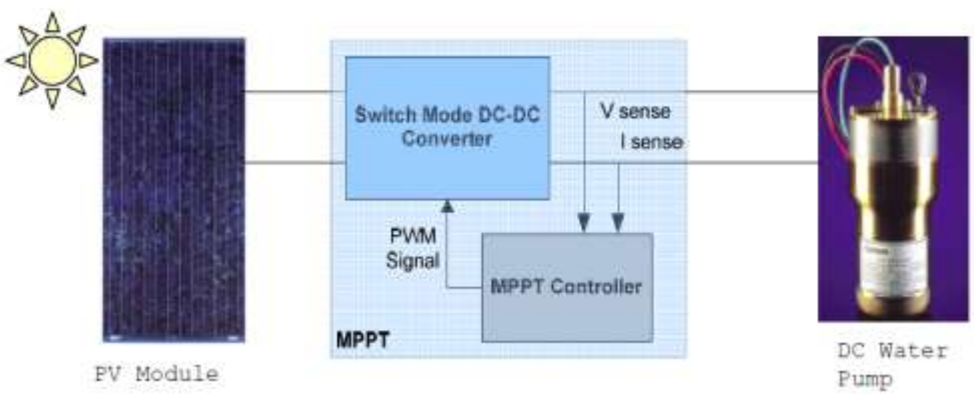

Figure 1: Block diagram of the proposed PV water pumping system

There are different sizes of PV module commercially available (typically sized from 60W to 500W). Usually, a number of PV modules are combined as an array to meet different energy demands. For example, a typical small-scale desalination plant requires a few thousand watts of power. The size of system selected for the proposed system is 250W, which is commonly used in small water pumping systems. Each module provides a maximum power of 250W, therefore the proposed system requires 4 parallel and 2 series strings that gives approximate 2000W of power.

MAXIMUM POWER POINT TRACKER

The maximum power point tracker (MPPT) is now prevalent in grid-tied PV power systems and is becoming more popular in stand-alone systems. It should not be confused with sun trackers, mechanical devices that rotate and/or tilt PV modules in the direction of sun. MPPT is a power electronic device interconnecting a PV power source and a load maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. MPPT is made up with a switch-mode DC-DC converter and a controller. For grid-tied systems, a switch-mode inverter sometimes fills the role of MPPT. Otherwise, it is combined with a DC-DC converter that performs the MPPT function. [4]

PERTURB AND OBSERVE METHOD

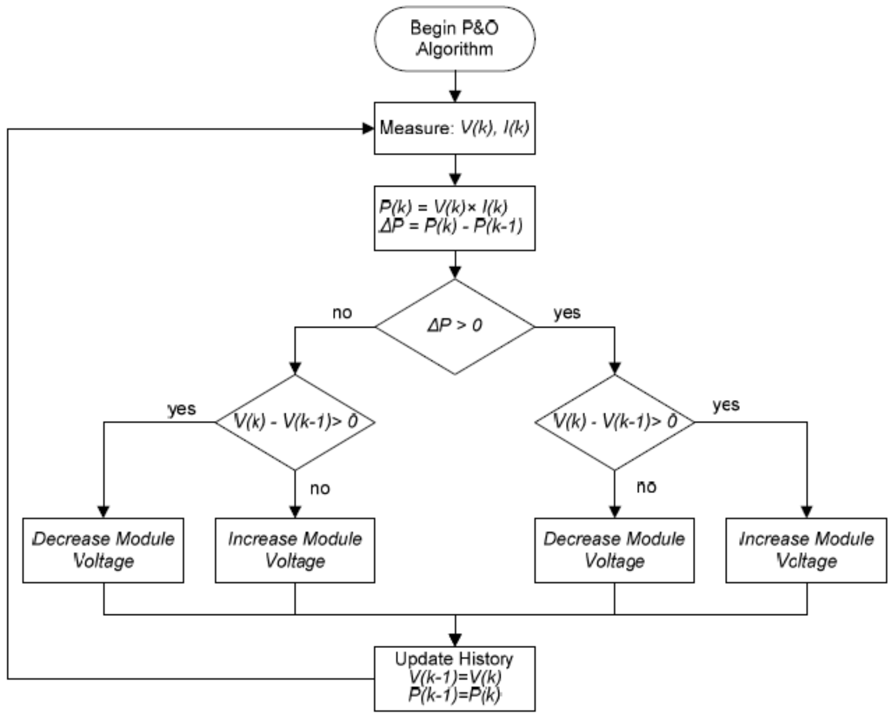

Figure 2: Flow chart of Perturb and Observe algorithm

There are some limitations that reduce its MPPT efficiency. First, it cannot determine when it has actually reached the MPP. Instead, it oscillates the operating point around the MPP after each cycle and slightly reduces PV efficiency under the constant irradiance condition [5]. Second, it has been shown that it can exhibit erratic behavior in cases of rapidly changing atmospheric conditions as a result of moving clouds

Assume that the operating point is initially at the point A and is oscillating around the MPP at the irradiance of 250W*/m2*. Then, the irradiance increases rapidly to 500W*/m2*. The power measurement results in a positive _*P*. If this operating point is perturbing from right to left around the MPP, then the operating point will actually move from the point A toward the point E (instead of B). This happens because the MPPT cannot tell that the positive _*P* is the result of increasing irradiation and simply assumes that it is the result of moving the operating point to closer to the MPP. In this case the positive _*P* is measured when the operating voltage has been moving toward the left; the MPPT is fooled as if there is a MPP on the left side. If the irradiance is still rapidly increasing, again the MPPT will see the positive _*P* and will assume it is moving towards the MPP, continuing to perturb to the left. [6]

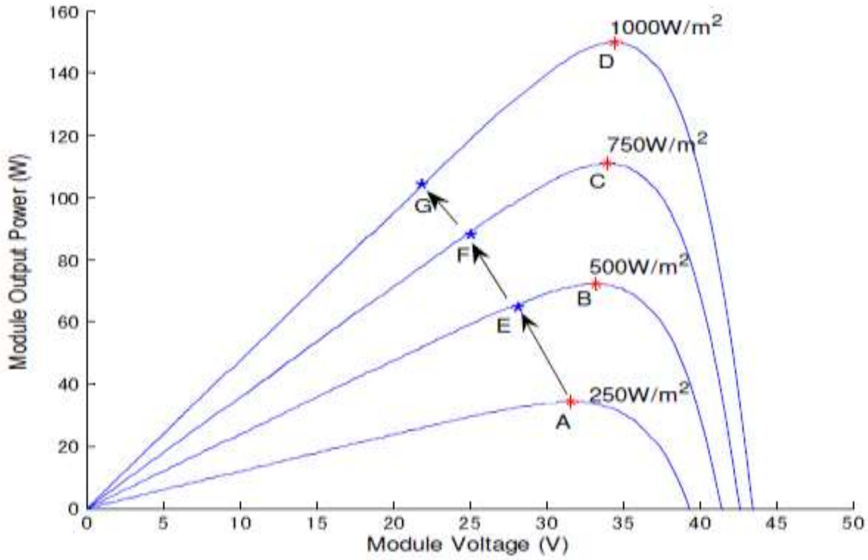

Figure 3: Erratic behavior of the P&O algorithm under rapidly increasing irradiance

Modeling of DC Water Pump

A 5HP,240V,1750 RPM motor is used in this application.

SIMULINK is chosen for this purpose because it offers a tool called "SimPowerSystems" which facilitates modeling of DC motors with its DC machine tool box. The model is then put into the MATLAB simulation designed in the previous section, replacing the resistive load.

The flow rate of water in positive displacement pumps is directly proportional to the speed of the pump motor, which is governed by the available driving voltage [7]. They have constant load torque to the pump motors, and it is expressed by the total dynamic head in terms of its equivalent vertical column of water; for example, vertical lift and friction converted to vertical lift.

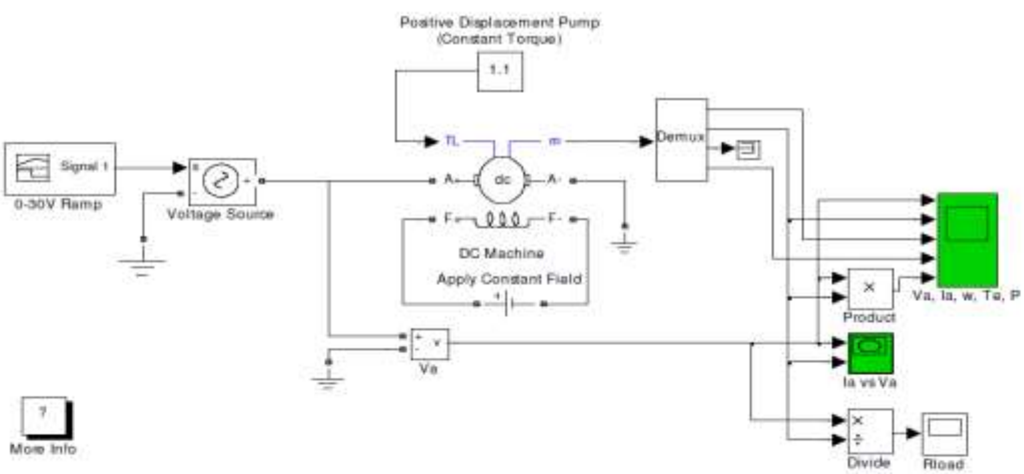

Figure 4: SIMULINK model of permanent magnet DC pump motor

MATLAB SIMULINK AND SIMULATION RESULT

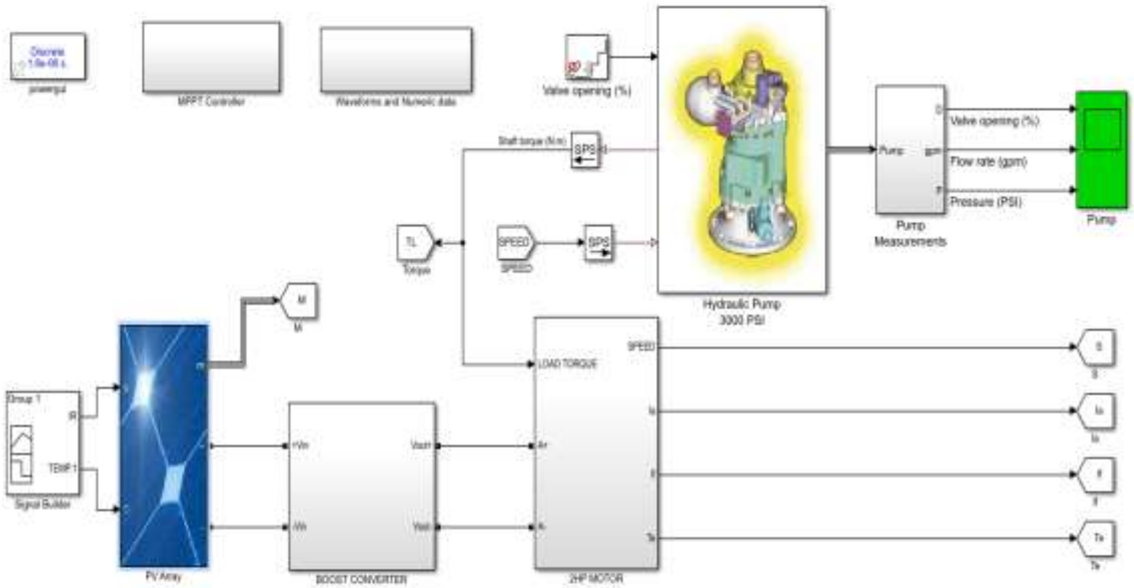

Figure 5: FULL SYSTEM FROM INPUT TO OUTPUT

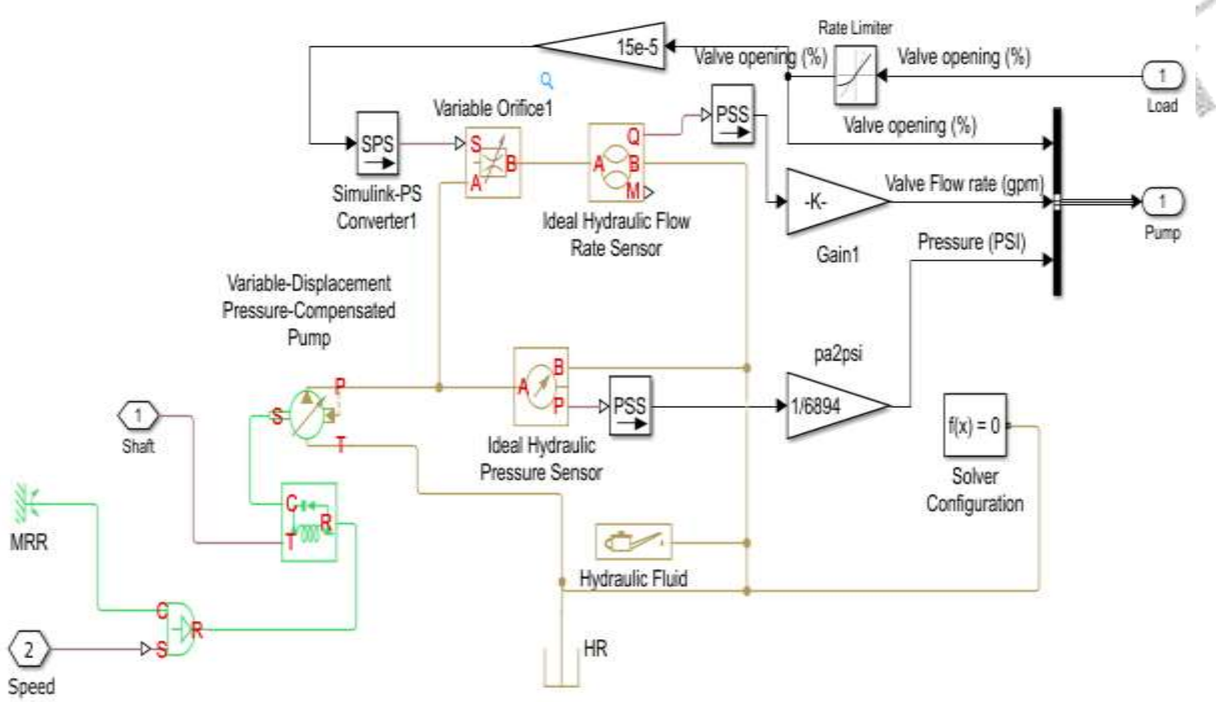

Figure 6: A hydraulic pump Simulink model

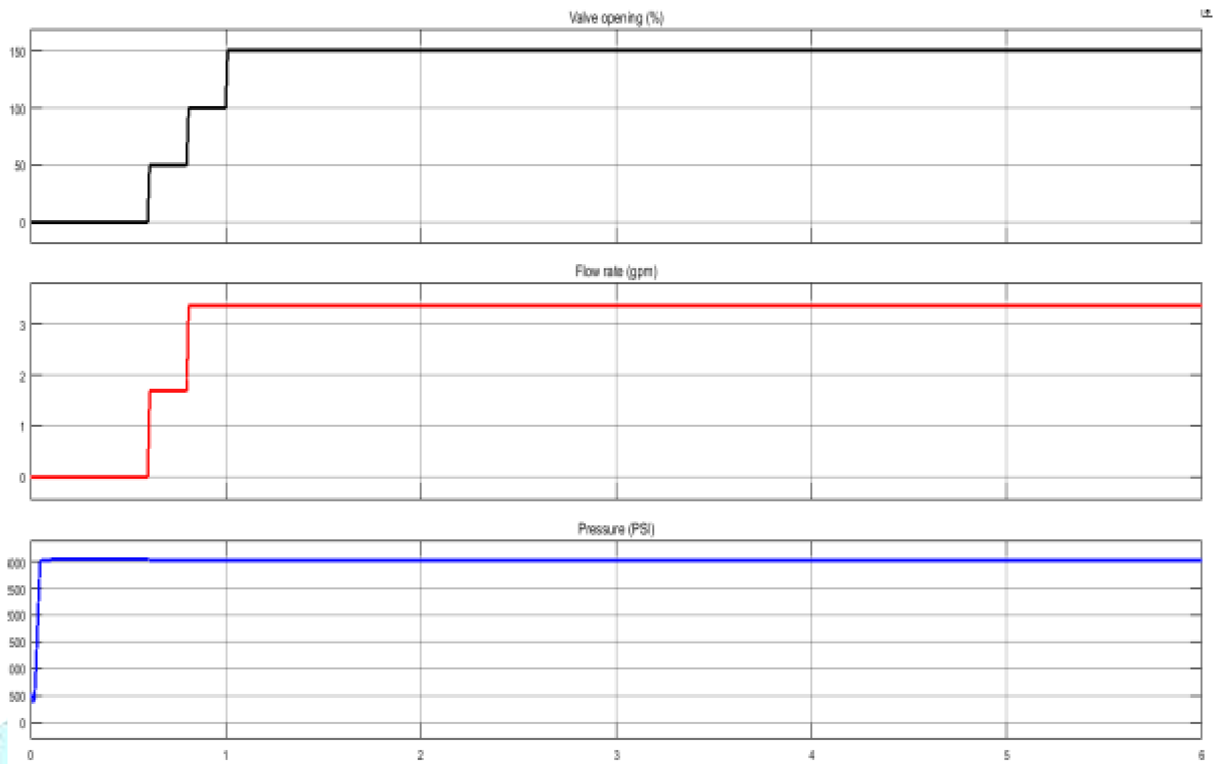

Figure 7: Waveforms of Pump

1. **Valve opens in three time periods**
2. **Flow rate of a water**
3. **PSI (pounds per square inch)**

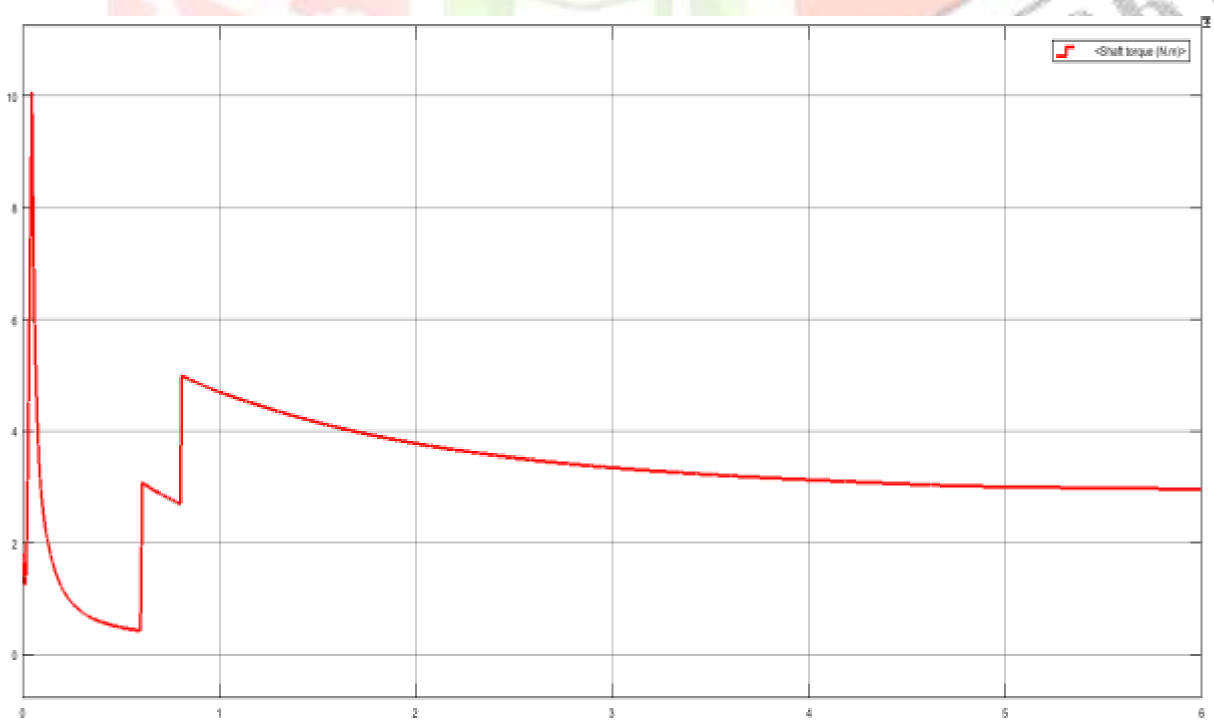

Figure 8: Shaft torque

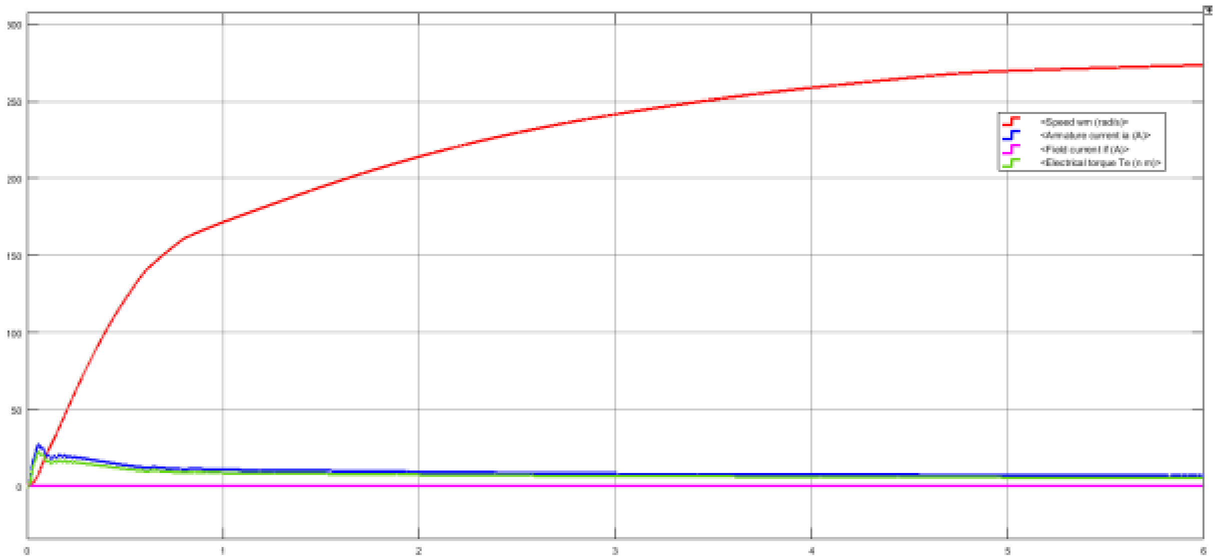

Figure 9: Motor Characteristics

The results show that MPPT offers significant performance improvement. It enables to pump up to 87% more water than the system without MPPT. Even if the efficiency of converter is set to 90%, it can still pump 67% more water than the system without MPPT.

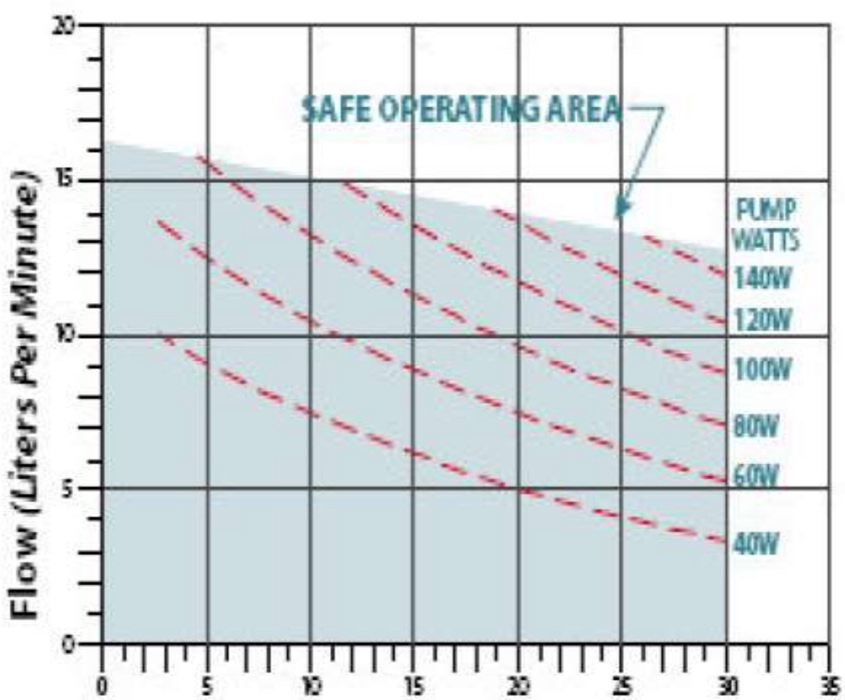

Figure 10: Water pump performance chart

CONCLUSION

Issues of energy and global warming are some of the biggest challenges for humanity in the 21st century. Energy is so important for everyone, and in fact, taking control of the world's supply of oil is one of the most important national agenda for United Sates. The world is getting divided into two groups: the countries that have access to oil and natural gas resources and those that do not. In contrast, renewable energy resources are ubiquitous around the world. Especially, PV has a powerful attraction because it produces electric energy from a free inexhaustible source, the sun, using no moving parts, consuming no fossil fuels, and creating no pollution or greenhouse gases during the power generation. Together with decreasing PV module costs and increasing efficiency, PV is getting more pervasive than ever.

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