The use of Variable Speed Drives with Solar Water Pumping Systems

The use of solar photovoltaics (PV) technology as an alternative to traditional energy sources such as petrol and diesel generators to power electric water pumps has become increasingly apparent. Solar PV technology is used extensively by remote villages and farmers as the power source to pump water for domestic consumption, sanitation, livestock and irrigation.

A variable speed drive (VSD) is a piece of equipment designed to regulate the speed and rotational force (torque) of an electric motor. VSD's are becoming a standard inclusion as part of the solar water pumping system controller. This document explains is the role of VSD in solar pumping.

Solar Pumping Systems

A typical solar water pumping system contains the following equipment: a solar array, which converts sunlight into electricity; system controllers, which control the array and the pump; an electric motor, which drives the pump; and a water pump, which moves the water from a source to its delivery point.

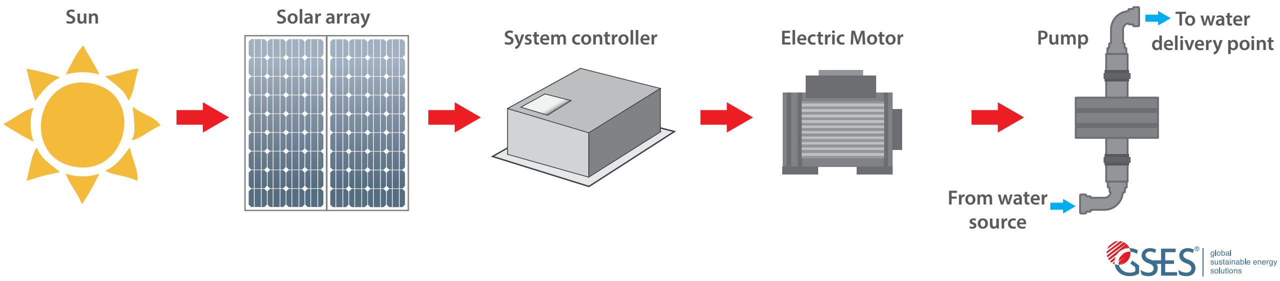

Figure 1 basic components of a solar water pumping system.

There may be other components in the pumping system, such as a battery or an AC source connected to the system controller.

Electric motors

Two main kinds of electric motors are available: DC motors and AC induction motors. While DC motors can be used for solar pumping applications, they are not as widely manufactured or used and are therefore a more specialised and expensive product, whereas AC induction motors are widely available and a cheaper product.

Currently the most widely available motor for industrial purposes is the "squirrel cage induction motor". This product has low manufacturing costs, robust construction, adaptability to submersible and flameproof applications, and its ability to accept a wide range of voltage / power ratings. Given these advantages, the use of AC induction motors to drive water pumps is an obvious choice.

Historically AC induction motors had distinct disadvantages compared to the DC motor. On start-up, the current and running speed of a DC motor can be readily controlled by use of a variable resistance in series (older technology) or a Pulse Width Modulated controller (modern). The AC induction motor relies on the supply frequency and the number of poles on the stationary winding (stator) to dictate "synchronous" speed. "Slip" or the difference between synchronous speed and actual shaft rotational speed allows induction of electrical currents into the rotor, and thus limits the motor current by means of a back electromotive force (emf) being generated into the stator as the rotor turns.

This poses the problem that on initial start-up, the rotor is not turning, and therefore there is no back emf to limit the inrush current from the supply. This leads to typical inrush currents of between 3 and 7 times the motor's full load rated current being drawn until the motor comes up to speed (generally a period of 2-10 seconds) assuming the motor is connected directly to the supply, a configuration known as Direct On Line (DOL). This set of circumstances is not suitable for a solar powered system, as it would require that the PV array is considerably oversized to provide this initial start-up current; the batteries (if used) and inverter would also have to be relatively oversized as well. A means of minimising the start-up current is to reduce the voltage required at start-up.

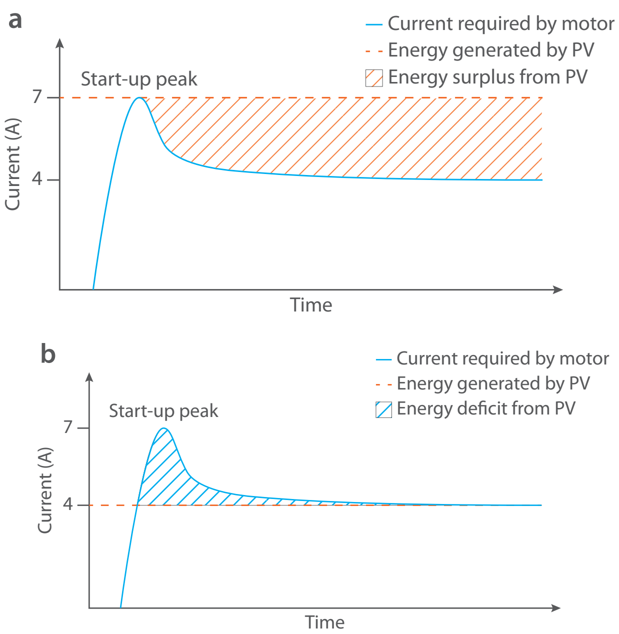

Figure 2 Motor surge current in DOL configuration would either prevent a PV array from starting the motor or result in an oversized PV array being installed

Various ingenious methods involving switching resistors / inductors / transformers etc. in and out of the motor starting circuit have been used some time with reasonable levels of success. However the rapid growth of both the power electronics and microcontroller industries since the 1980's have provided us with the Variable Speed Drive (VSD): a much more versatile and easily installed solution.

Variable Speed Drive

A variable speed drive (VSD) is a type of motor controller that controls the output of motor by varying frequency and voltage. A VSD consists of three parts:

1. AC to DC converter: It consists of 6 diodes which act as a 3 phase full wave bridge rectifier to convert AC to DC current and provide a *stiff**[1] DC voltage supply to the DC bus. In some VSDs, the diodes will be replaced by IGBT's*[2] acting as a controlled rectifier but also having the inherent ability to regenerate energy, i.e. to feed energy from the DC bus back into the AC line. These are often referred to as 4 quadrant operation or active rectifier type VSDs, and are preferable if you intend to operate from a battery inverter or other stand-alone power system due to the reduced level of line harmonics as compared to the diode rectifier VSDs.
2. DC bus: A DC bus to filter out the AC ripple using a capacitor and thereby supplies the smooth DC signal. The large capacitors also act to provide a limited amount of energy storage.
3. DC to AC converter: IGBT bridge rectifier converts the DC signal from the DC bus back to AC signal using Pulse Width Modulation (PWM) techniques and can also provide regenerative braking to slow the motor down and return energy to the DC bus from which it is either directed to a braking resistor for dissipation as heat or back to the supply in a 4 quadrant type VSD.

Some modern VSDs have been specifically designed to accommodate direct connection of the DC bus to a PV array. This has the benefit of eliminating the need for expensive additional equipment such as a battery bank and inverter, provided that it is acceptable to limit pumping to

1 Stiff voltage source: source voltage magnitude does not depend on the load connected to it.
2 IGBT's: Insulated Gate Bipolar Transistors

times of strong sunlight. It is typically possible to switch these VSDs between AC input and direct PV input modes for operation at night or in bad weather if an external AC source exists.

VSD in Solar Pumping systems

Reducing surge current at motor start-up

A VSD can provide a reduced starting voltage to the motor windings, thus reducing the starting current of the motor and giving it time to gain momentum before the full load is supplied with power. The VSD also allows the user to start and stop the pump at a controlled, programmable rate (e.g. accelerate or decelerate over a time period) while putting minimum strain on the motor. This reduces the mechanical wear of the motor as well as the start-up loads on the PV array.

Reduce energy consumption

A VSD with variable torque load can be used in water pumps to reduce the input energy requirement. As described by the affinity law, the power consumption of the pump can drop significantly with a small drop in the speed of the motor. Provided that the flow rate is acceptable, running a pump at a lower speed over a longer period of time can deliver considerable energy saving. The VSD can reduce the operating speed of the motor, allowing a smaller PV array to be installed to deliver the pumping requirement.

The ability of the VSD to control pump operation also means that in case of cloudy conditions or times of reduced solar irradiation, the motor could still run to provide deliver pumping work.

Flexibility

A VSD can be programmed to run the motor at certain speed to obtain a desired flow rate from a pump. Most VSDs come with an integrated proportional–integral–derivative (PID) controller which allows the drive to derive a set point based on actual feedback from the process e.g. from a flow transducer or tank level sensor and operate in a closed loop mode if desired.

VSD with a closed loop control offers better system control and increases the system reliability.

Cost implications

The variable speed drive reduces the cost of the system in two ways: (i) increased system efficiency and (ii) reduced operational and maintenance costs. The system efficiency is increased with the capacity to run the pump at lower speed. This can translate to a smaller solar array or the elimination of the need for batteries, inverter or a diesel generation set, which can significantly reduce the capital cost of the system. By allowing the pump to run at a lower speed, system wear and tear is reduced, increasing the lifespan of the pump and delaying replacement and accompanying costs.

Conclusion

The variable speed drive as used with a solar pumping system means that the solar PV array is more effectively matched to the pumping system in terms of installed capacity and therefore cost. The inclusion of the VSD also provides more flexibility in the control of the pumping system, allowing the pumping regime to be varied to suit the application with the least energy use.

Variable speed drives can also be retrofitted into existing solar pumping systems with an AC induction motor after evaluating the suitability of the motor, particularly its insulation rating.

GSES' Solar Water Pumping Guide provides a fundamental knowledge source for solar pumping technology and advice in system design for each application. This can be purchased at www.gses.com.au/shop

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