Active and Reactive Power Control for PV based Water Pumping System

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Abstract— The scarcity of fossil fuels and lack of electrification of several rural areas in developing countries like India has encouraged the use of renewable energy sources in recent times. The solar photovoltaic power is of great relevance in areas where electric lines are not yet laid. Since agriculture is generally the main source of income in most of rural India, irrigation is one of the biggest challenges. PV powered pumping systems have gained popularity in the past few decades. The nature of the load demands an active and reactive power control in standalone systems powered by renewable sources. There are several techniques to achieve active and reactive power control in a microgrid. In this paper a technique to control PQ is employed to a PV powered composite load and results are evaluated using MATLAB/SIMULINK**.**

Keywords*- Active power, Boost converter, Induction motor, Inverter, Reactive power*

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I. INTRODUCTION

One of the most important and widely accepted applications of photovoltaic(PV) standalone systems is for water pumping. A particularly in rural area, where solar irradiation is in abundance but a supply from the national grid is lacking. Low power pumps ranging from 200–2000W are generally employed in PV pumping systems. They are employed in several places for supplying water for livestock or domestic purposes. They are also used for water and energy conservation such as low head drip irrigation systems[1]. The energy utilization efficiency of PV panels is often quite low. This efficiency can be significantly improved even in commercial photovoltaic pumping systems by employing suitable algorithms for maximum power point tracking. The choice of motor for rural irrigation is generally a squirrel cage induction motor. The renewable source in this paper supplies to a load that is composite. An induction motor operating in parallel with a static RL load is considered. Since the system consists of both a static and dynamic load, both active and reactive power is needed to be controlled in particular scenarios. Although some work has been carried out previously by with a grid connected PV system, not much has been done in case of a standalone system which is powering a composite load. This paper aims at providing a novel active and reactive power control strategy in the case of a standalone system considering the requirements of static and dynamic loads.

A. PV Panel

The basic generation unit in a PV system is the Photovoltaic cell. These cells are connected in series and parallel to increase the voltage and current respectively and consequently output power of the PV panel. The single-diode mathematical model is applicable to simulate silicon photovoltaic cells which consist of a photocurrent source denoted by Iph, a nonlinear diode D, internal resistances Rs in series and Rsh connected in shunt. The equivalent circuit is shown in Fig. 1.

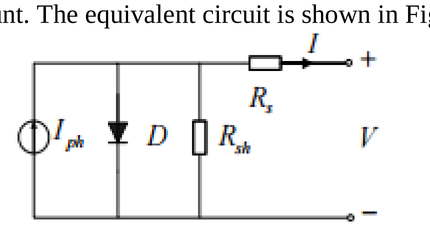

Fig. 1. Single diode model of PV cell

The mathematical relationship between the output current I and output voltage V in the single-diode equivalent circuit can be described as:

I=Iph-Is(e^(((qV+IRs))/ΔkT)-1)-(V+IRs)/Rsh (1)

where, Iph is photocurrent; Is is diode saturation current; q is coulomb constant (1.602e-19C); k is Boltzman's constant (1.381e-23 J/K); T is cell temperature (K); A is P-N junction ideality factor; Rs and Rsh are intrinsic series and shunt resistances. The PV panel characteristics of power and current are non linear with varying conditions of solar irradiance and temperature.

B. DC-DC Boost converter

In Figure. 2. the circuit diagram of a dc-dc boost converter is shown. The voltage output of the converter is equal to or greater than the input voltage.

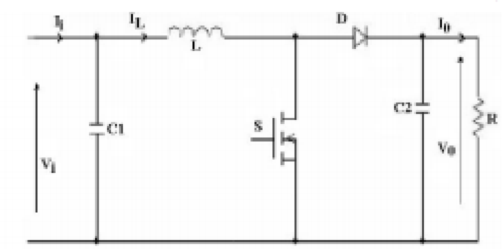

Fig. 2. Boost converter circuit

The relationship between output voltage Vo and input voltage Vi is given by

Vo/Vi=(1/(1-D)) (2)

The duty cycle D of the switch is increased or decreased which causes the voltage change. Two modes of operation are present. The first when the switch is closed. In this mode the inductor is charged through the switch with the same polarity as the source. The charging current is assumed to be linearly varying. The diode restricts the flow of current from the source to the load. The load demand is met by the discharging of the capacitor. The second mode is when the switch is open. The diode is in forward biased condition. The inductor discharges. The inductor and source together charge the capacitor and meets load demands. The load current is assumed constant throughout the operation as it is very small. For designing the inductor and capacitor the following equations are used:

For inductor

L=(Vo*D)/(ΔI*f) (3)

For capacitor

C=D/(R*(ΔVo⁄Vo)*f) (4)

Where R is load resistance, f is the switching frequency and ΔVo/Vo is the output ripple voltage.

C. Induction Motor

Induction motors are used in pump applications worldwide. The model of a typical Induction model was taken[17]. They are versatile and cost-effective. Although the induction motors manufactured are designed to operate at 400V, for this demonstration, an induction motor that has a rating of 1kVA and operates at 100V is chosen.

D. RL load

A three phase RL load with R of 1kΩ and L of 1mH is connected in parallel to the Induction motor load.

II. PROPOSED METHODOLOGY

A. PV Module

The PV model chosen is the Kyocera KC200GT which is readily available in the MATLAB/SIMULINK library. The Maximum power point at 1000W/m^2 of the KC200GT is 200W. To generate a power of 100kW at STC, 125 strings were connected in parallel with 4 panels in each string. The IV characteristics and power v/s voltage curves of the designed PV module with the MPP marked for various values of irradiance is shown in Fig. 3.

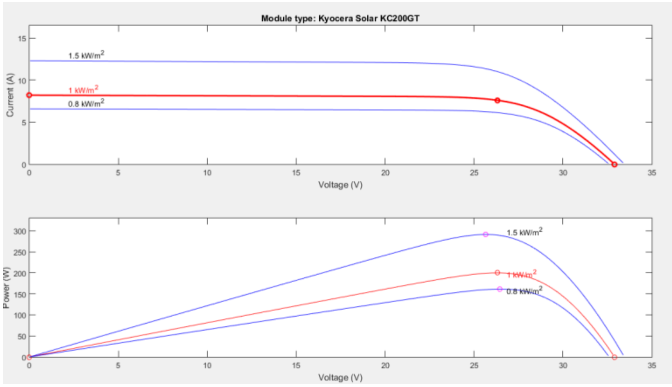

Fig. 3. The I-V and P-V characteristics of PV panel for various values of irradiance

The PV module is provided with a simple Perturb and Observe based Maximum Power Point tracking module. The algorithm for the MPPT module is as shown in Fig. 4

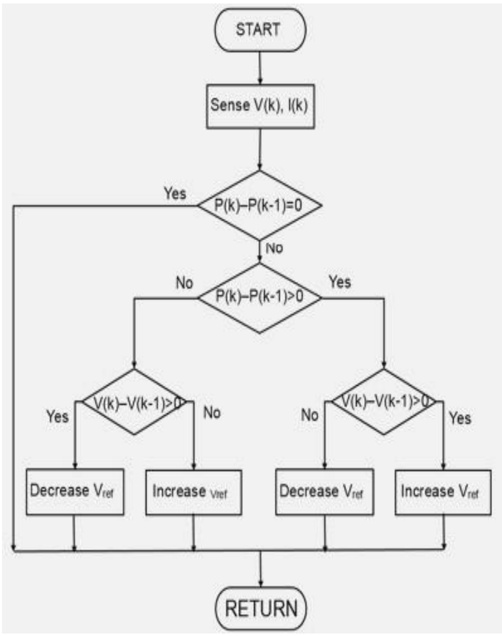

Fig. 4. P and O algorithm for MPPT

B. Battery charging and discharging

In order to make the system standalone and self sufficient a lead acid battery which is capable of providing back up for up to one hour in absence of adequate irradiance was chosen. The MATLAB SimPowerSyetms library battery model was taken. Care is taken that the battery SOC is always between 20% and 80%. When the PV panel generates excess power compared to load demand, the battery is charged up to 80%. When there is a shortage of PV power generation, the battery discharges and supplies the load requirement.

C. Inverter

An oversized inverter was designed in order to ensure that it is capable of supplying both active and reactive power required by the load. The control loop used to achieve this consists of Proportional Integral controllers which are fed with errors in both AC and DC power, voltage in order to control the active reactive power.

III. SIMULATION RESULTS

The simulation was carried out in MATLAB/SIMULINK. The results were observed for motor torque load of 100% of maximum torque load. The settling time is noted to be 3.2 seconds. The diagram of the proposed model is as shown in Fig. 5. The various subsystems are subsequently shown in the figures that follow.

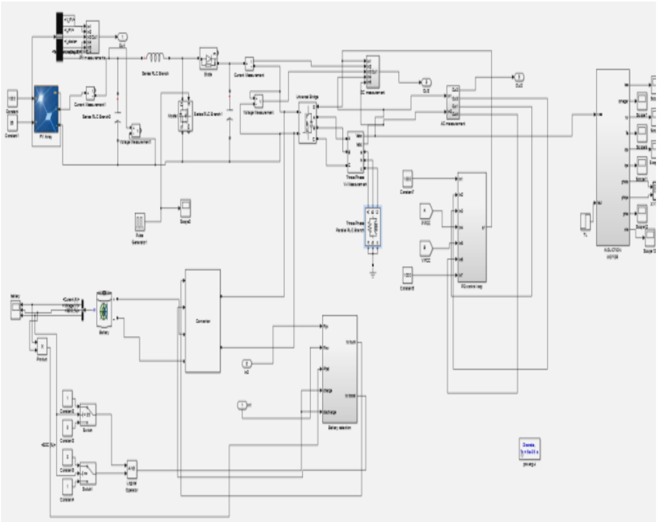

Fig. 5. PV panel with MPPT powering a composite load

The selection criteria for battery are demonstrated in Fig. 6 below. The battery converter is shown in Fig.7. The converter connected to the battery either operates in buck or boost most while the battery is in charging or discharging state respectively.

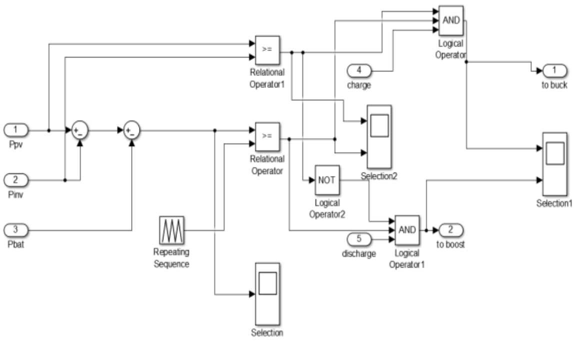

Fig. 6. Battery converter buck and boost mode control

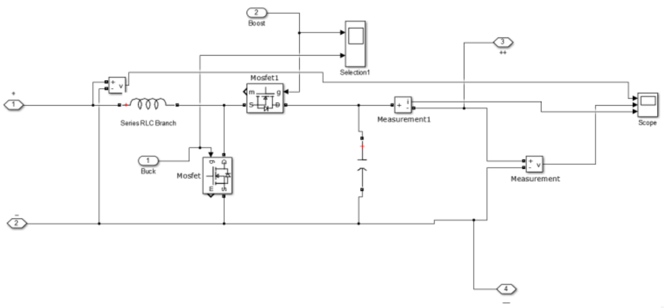

Fig. 7. Battery converter

The active and reactive power is controller based on the demand of the loads. The reference values are chosen depending on the type of load and demand. The control loop for active reactive power control is shown in Fig. 8. This loop provides the six pulse signal required for the inverter MOSFETs.

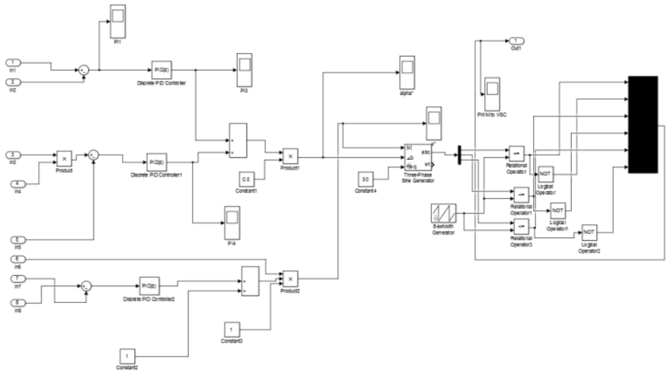

Fig. 8. Active and reactive power control loop

The output voltage, current, power, irradiance and temperature of the PV panel is shown in Fig. 9

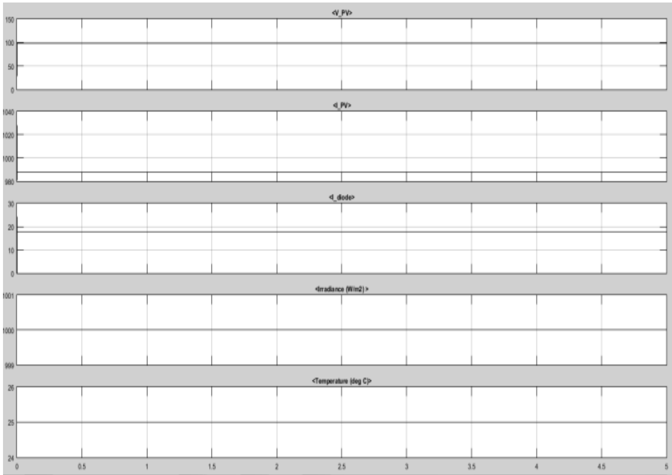

Fig. 9. PV panel output, irradiance and temperature

Fig. 10 shows the output power of the DC converter connecting the PV panel and battery to load.

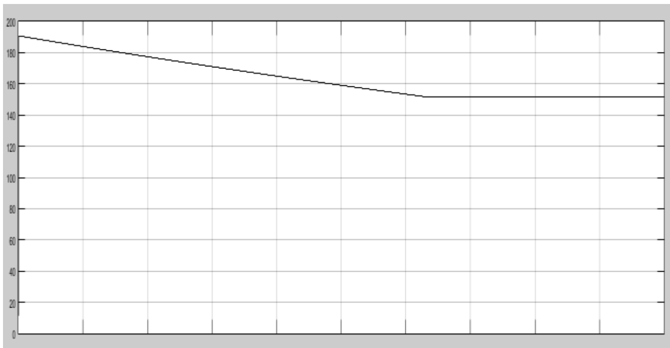

Fig. 10 Output power of the DC-DC converter

The output voltage and current of the three phase inverter when PV panel is generating excess power than load requirement is shown in Fig. 11

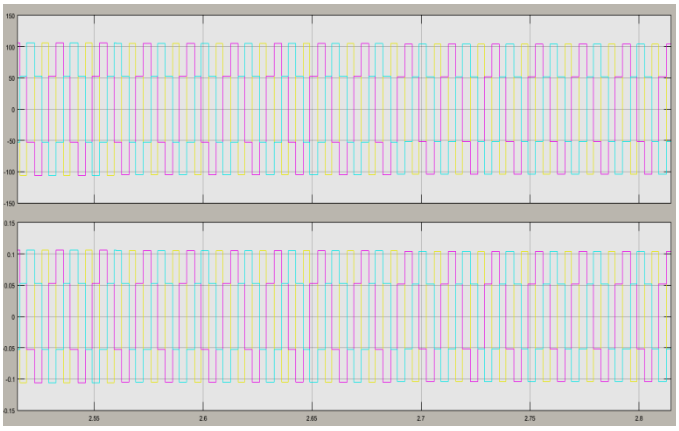

Fig. 11 Output voltage and current of inverter

The active and reactive power as measured at the output of the inverter is shown in Fig. 12 and Fig. 13 respectively.

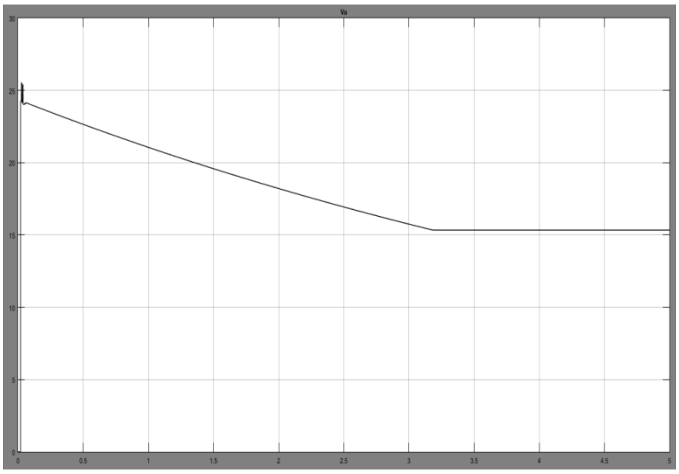

Fig. 12 Active power as measured at output of inverter

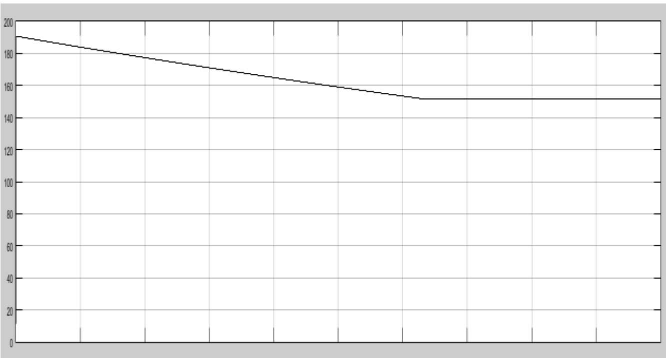

Fig. 13 Reactive power as measured at output of inverter

IV. CONCLUSION

The active and reactive power control methodology was applied to a standalone system consisting of composite load. The induction motor torque was varied and the control loop was observed to be effective. The MATLAB/SIMULINK simulation results demonstrate results for a model that can be implemented for an agricultural water pumping system powered by PV panel with battery backup of up to 1 hour.

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