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Stand Alone PV Based Single Phase Power Generating Unit for Rural Household Application

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Abstract:

Access to energy is essential to reduce poverty. In Tanzania electricity is available to about 24% of the population; 93% of rural households lack access to electricity. Most of these houses are sparsely populated; this makes national grid extension to such areas economically unviable. Solar home systems present a huge promise for these areas but, most of the villagers do not think of solar photovoltaic (PV) system as a cost effective solution to electricity shortage. Aiming at stressing the applicability of solar PV technology in Tanzania, this paper presents a design and costing of a stand-alone solar PV system for a Tanzanian rural household; highlighting some common mistakes done in sizing, installing and maintaining solar home systems.

The design is done in two different fashions:
(i) The entire system sized as a single system. (ii) The system divided into three subsystems or phases. So an economic designing of a PV based power generation system require an energy storage element in the form of battery For rural household applications where power supply required throughout a varies widely with change in atmospheric conditions thereby choosing battery for energy storage scheme is an effective choice. Rural Household applications generally involve ac power driven appliances while output power of PV or battery is dc in nature.

Introduction:

PV systems meant for acting as a power supply require an auxiliary power source in form of battery, super capacitor, fuel cell, wind generator or maybe grid, if possible. Output power of PV modules vary widely with changes in solar irradiation and temperature.

PV systems meant for small or low power applications generally exhibit relatively high power capacity at high level of irradiation and very low power capacity at low level of irradiation. So an economic designing of a PV based power generation system require an energy storage element in the form of battery For rural household applications where power supply required throughout a varies widely with change in atmospheric conditions thereby choosing battery for energy storage scheme is an effective choice. Rural Household applications generally involve ac power driven appliances while output power of PV or battery is dc in nature. Hence, there is a need for efficient and reliable electrical power conversion system. For supplying power to ac loads, there is requirement for an inverter which must be fed with a 400V dc link to give 230 V (rms) voltages at the output of inverter.

Four Stage Conversion System:

In Fig. 1, the configuration from [1], [3] has four power stage converters with two DC links whose voltages are to be maintained for desirable outputs. This kind of configuration requires at least five controlled switches on the dc side. The input dc stage to inverter is generally having a high step up gain (transformer coupled) converter, due to limitation of voltage boosts of conventional boost converters. Generally transformer coupled boost converters have minimum two controlled switches. Hence at least two controlled switches are required to provide a high voltage dc link to the inverter. The bidirectional battery converter also requires two controlled switches for carrying a bidirectional current.

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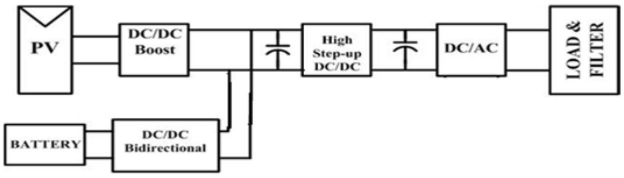

Fig.1. Four Stage Configuration with Two Controlled DC Link

Three Stage Conversion System:

The configuration shown in Fig. 1 requires a transformer coupled configuration for high step up gain which requires minimum three switches on the dc-dc stage along with four separate switches for the inverter, but this configuration has cascaded battery connection, which is not a preferable solution as for every change in load, the corresponding change in dc link voltage would disturb the battery charging/discharging current. Frequent disturbances in battery charging/discharging current puts stresses on the battery and reduces battery life [7].

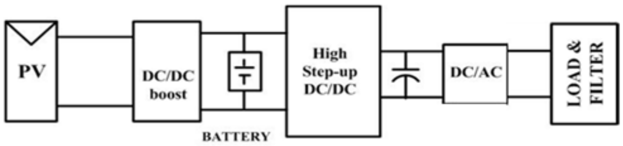

Fig.2.Three Stage Configuration with Cascaded Battery

Fig. 2 depicts a three stage configuration, where two high step up transformer coupled dc-dc converters, are required to maintain the 400V dc link[1], [2], [3], [4], [6]. In this case, both the high step up converters, mainly of transformer coupled configuration, requires the battery charger to be bidirectional. Bidirectional high step-up/step-down converters require minimum four controlled switches and high step-up converter for PV requires minimum two controlled switches. In total, it demands six switches for the DC stage along with four inverter switches.

Converter Topology Configuration:

The work of the thesis a converter configuration using a half bridge boost converter [5], [8], [9] along with a bidirectional buck-boost dc-dc converter for the dc power conversion stage and a single phase VSI for connecting to ac loads. Moreover, additional converters can be integrated with any of the two the dc links. The work of this thesis includes integrating a bidirectional dc dc boost converter with the primary side dc link. Using this converter configuration, high boost of PV voltage and battery current control can be realized using only four controllable switches.

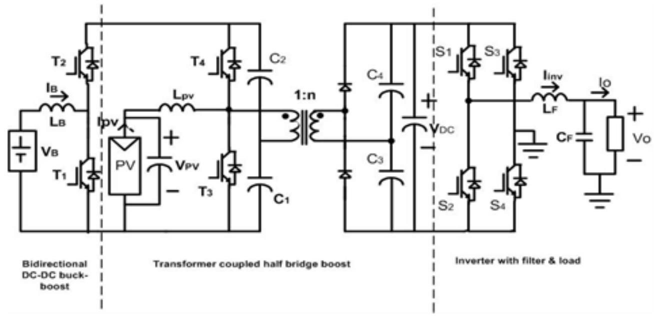

Fig.3. Converter Configuration with Half-Bridge Boost Converter

MPPT Algorithm- Incremental Conductance:

The MPPT algorithm that is being used for generating current reference for PV is incremental conductance, which has been found to perform faster than other methods. In this method, the slope of the conductance (-dI/dV) is checked and a current reference is generated for the PV converter. The logic diagram explaining the method for determining the current reference is shown in Fig. 4.

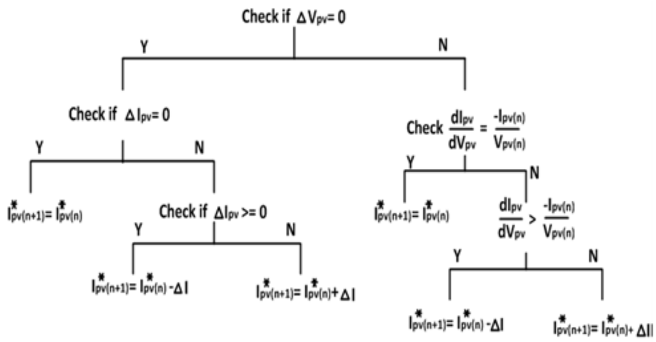

Fig 4: MPPT Algorithm - Incremental Conductance Method

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Simulation Results:

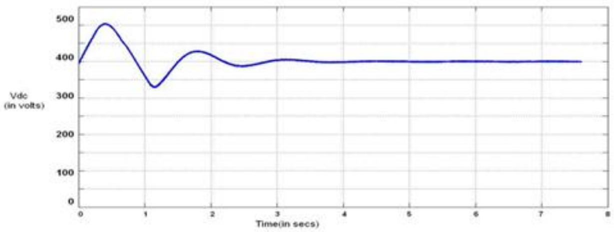

Fig. 5. DC link voltage at MPPT

Case 2: Step Change in Load in MPPT Mode of Operation

In this mode, PV operates at MPP at 0.5 kW/m2 solar insolation with Impp = 16A, delivering maximum power and the battery converter maintains the DC link voltage by taking a charging current less than that specified by SOC controller [9].

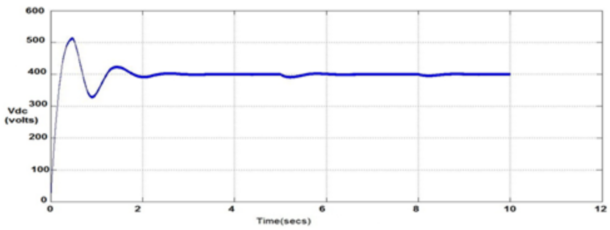

Fig. 6. DC Link Voltage Variation under Load Changes

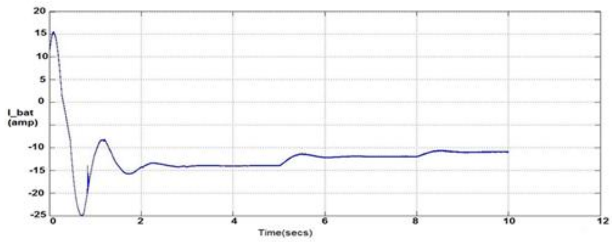

Fig. 7. Battery Current at MPPT Operation under Load Changes

Initially, the dc link voltage stabilizes at 400V by the control action performed by the battery converter which takes in a charging current of 14A while PV continues to operate a MPP with I mpp of 16A. At 5 second, an increment in load takes place, which causes a fall in dc link voltage.

As battery converter is controlling the dc link voltage, a fall in dc link voltage triggers the battery current to increase (Fig. 11) for supplying the extra load demand by restoring the dc link voltage at 400V [10], [11].

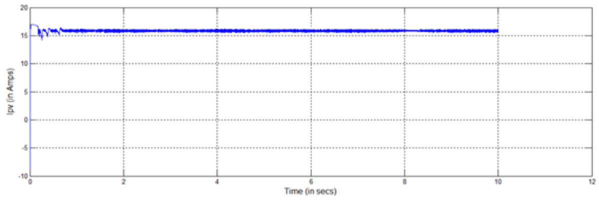

Fig. 8. PV Operating at MPPT and Delivering Constant Current

Case 3: Non-MPPT Mode of Operation

In this mode, PV operates at a operating point other than MPP, delivering the power required by load and charges the battery with a constant current specified by SOC. PV operates at 0.4 kW/m2 and the load connected is 200W, 50VAr. PV maximum power point current Impp is 13 A. The maximum battery charging current is taken as 4 Amps.

Case 4: Step Change in Load in Non-MPPT Mode of Operation

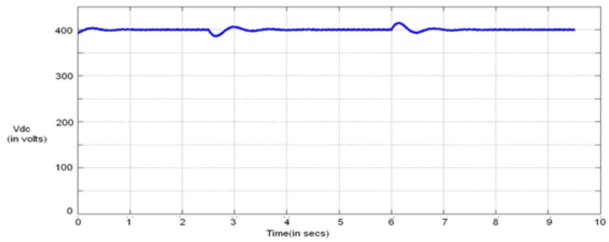

Fig. 9. DC Link Voltage Variation under Non-MPPT Mode

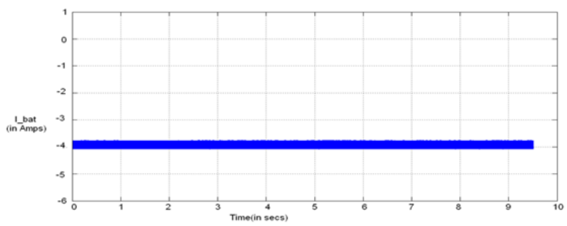

Fig. 10.Constant Battery Charging current

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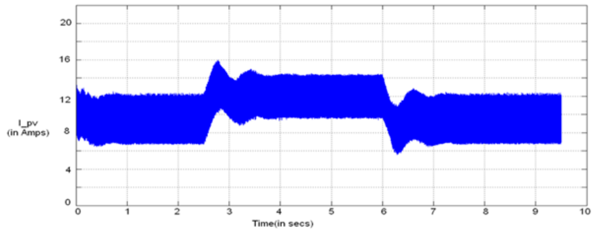

Fig.11. PV Current Variation with Load Changes in Non-MPPT Mode

In this case, initially PV operates at current of 10A, and the battery charging current is maintained at 4A (specified by SOC). At 2.5 seconds, a load change of 100W takes place, which causes the dc link voltage to fall. As PV is maintaining the dc link voltage, with fall of dc link voltage PV current increases to a new value to restore the dc link voltage [12].

Case 5: Change in Operating Mode from MPPT to Non-MPPT Mode and back caused by Step Change in Solar Insolation

In this mode, initially PV operates in MPPT mode at 0.5 kW/m2 with Impp = 31A. The load connected is a 1kW, 100 MVAr load. The battery takes a charging current of 10A, which is less than the maximum charging current . While an increase in solar insolation at 5 second causes change in operating mode from MPPT to Non-MPPT.

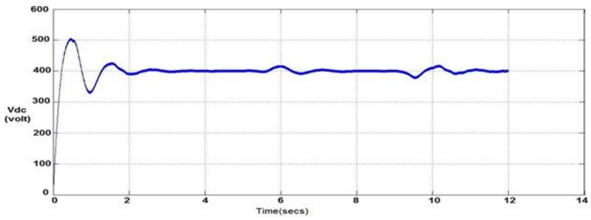

Fig. 12. DC link voltage Variation under Solar Insolation Changes

The dc link voltage is initially maintained by the battery converter at 400V. At 5 second solar insolation gets a step change to 0.9kW/m2, which changes the operating mode to Non- MPPT mode of operation as the PV MPPT power at this level of insolation is higher than that required. The dc link voltage is now maintained by the PV converter [8].

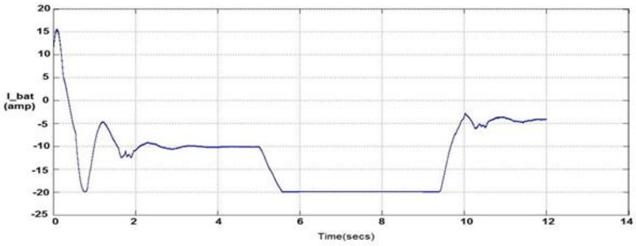

Fig. 13. Battery Current Variation under Solar Insolation Changes

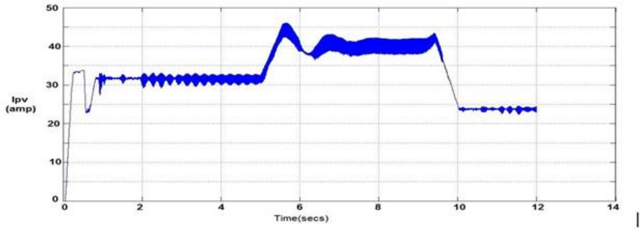

Fig. 14. PV Current Variation under Solar Insolation Changes

Conclusion:

The task of this master thesis is to develop a reliable, efficient and reduced stage configuration for PV based stand alone power generating unit with a control method for the converter configuration. From the above chapters and from the results of the simulation, it can be observed that the converter configuration, with some reduction in the number of controlled switches and the control method, has the ability to operate successfully under different operating conditions.

In MPPT mode of operation, the half bridge boost converter has the ability to operate the PV at MPPT successfully while the battery converter is capable of responding quickly to maintain the dc link voltage. In non-MPPT mode of operation, the battery converter charges the battery with a constant current while PV maintains the load demand by maintaining the dc link voltage and by supplying the power necessary to charge the battery with a constant current. The control method has successfully performed under various load change and solar insolation level changes.

Observation of these results depict that the control method is robust enough to maintain the dc link voltage for the inverter while controlling the battery charging/discharging in a reliable manner.

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