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Maximum Power Point Tracking Algorithm Performance Assessment of Grid-Assist Photovoltaic System

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Abstract- A common challenge for all conventional MPPT algorithms is how to obtain the optimal current and voltage operating points automatically to maximize PV output power under variable atmospheric conditions. This paper discusses the assessment of the performance of a grid-assist PV system with battery storage. A data acquisition (DAQ) system was developed to monitor the MPPT performance of a grid-assist PV system. Charging cycles and the MPPT algorithm effects on the PV array efficiency were investigated. Experimental results show that the perturb and observe (P&O) algorithm operates most efficiently under most of the test conditions. However, the open circuit voltage (OV) algorithm has the best efficiency under cloudy conditions and worst case efficiency during high and stable irradiance conditions. Three charging cycles under investigation showed a noticeable reduction in the efficiency of the grid assist PV system. Voltage sweeps with lengthy perturbation times were found to cause inefficient power conversion.

Index Terms- Grid assist, photovoltaic system, performance assessment, balance of system

1 Introduction

Grid reliability issues are not yet fully mitigated by many countries and as a result many electricity users in these countries employ grid-assist systems due to the need for power back-up during load shedding conditions. Due to limited research base on the performance of various types of grid assisted systems in South Africa, there is a need to carry out investigations on the performance, monitoring and degradation of the various grid assist systems. This study will focus on maximum power point tracking (MPPT) on the PV array and its effect on the performance of the whole system. Since PV systems are sensitive to many parameters, good planning, deploying and optimizing a PV system require a thorough understanding of the environmental conditions, PV technology that is used and balance of system (BOS) components.

Due to the nature of the solar resource that is utilized, PV systems do not provide a constant power source. PV generation systems have two major limitations: the conversion efficiency of electric power generation is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously with weather conditions. Moreover, the solar cell and thus current-voltage (I-V) characteristic is non-linear and varies with irradiation and temperature [1].

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In general, there is a unique point on the I-V and power-voltage (P-V) curve, called the Maximum Power Point (MPP), at which the PV module - produces its maximum output power. The current and voltage operating point that yields the maximum power from the PV system continuously changes with changing environmental conditions. The current and voltage of this maximum power point (MPP) is not generally known but can be located, either through direct calculation models or by dynamic search algorithms, known as Maximum Power Point Tracking (MPPT). These techniques are needed to maintain the PV array's operating point at its MPP [2].

The majority of MPPT control strategies depend on characteristics of PV panels in real time, such as the duty cycle ratio control or using a look-up table [3]. In this study, a data acquisition (DAQ) system was developed and used to monitor the MPPT performance of a grid-assist PV system with battery storage. To investigate the performance of the system a separate data logger was used together with the inverter's internal data logger to monitor environmental and electrical data on the system. In this study the charging cycles and the effects of the MPPT algorithm on the PV array efficiency were investigated.

2 Grid Assist PV System Configuration

2.1 System Layout and Load Requirements

When designing a grid assisted system the daily load profile impacts the sizing of the PV array, battery storage and the selection of the inverter. In this study the grid assist PV system consisted of nine 175W mono-crystalline silicon PV modules, twenty four 2V (750 Ah) , flooded, deep cycle lead acid batteries, MPPT charge controller and a single phase 230V, 50Hz, 3kVA inverter. The output load of the system primarily provided energy to personal computers, refrigerator and data logging equipment situated in an outdoor research laboratory. (See Fig.1 for layout)

The daily AC load energy which the grid assist system needs to supply was ~6.2 kWh. Periodic peaks of approximately 280-295W that was observed in the load profile were caused by on/off operations of a fridge which formed part of the load.

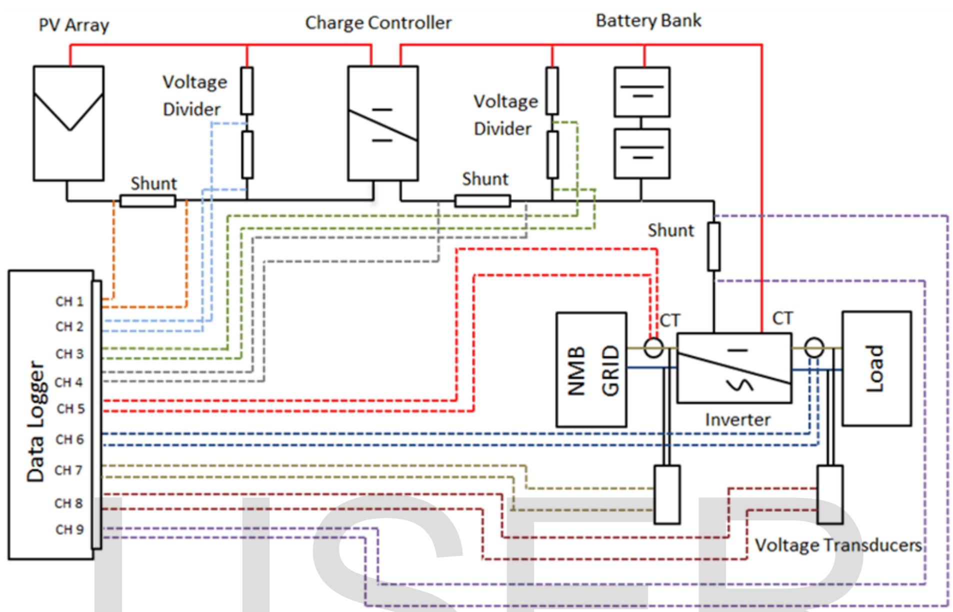

Fig. 1. Layout of 1.6 kWp grid assisted PV system with placement of sensors.

2.2 Data Acquisition and Measurement Technique

In order to record variations in the operating DC current and voltage of the PV system at 1 second intervals, a National Instruments USB 6343 data logger with 16-bit resolution and measurement speed of 900 kS/s was used. Additional slow changing data was recorded with a National Instruments USB 6008 12-bit data logger together with the grid assist system's internal data acquisition system [4]. The data loggers were interfaced to a PC with a LabView programme to acquire and analyse the data.

The I-V curve of the entire PV system was determined from the measured and normalized I-V curves of the individual PV modules. The module string's I-V curve was used as a guide to compare the measured and normalized current- voltage operating points that the MPPT imposed on the system. Fig. 2 shows how the individual measured maximum power operating points track the system's I-V curve.

2.3 Charge Controller

The charge controller (CC) in the system controlled the DC charging current to the batteries using a DC/DC conversion, charging cycles and maximum power point tracking (MPPT) for maximum possible yield from the PV modules. An Outback MX-60A charge controller device which is programmable for different battery configurations, charging cycles and MPPT was used. In this study the influence of the charging cycles and the MPPT algorithm on the PV array efficiency were investigated. The efficiency of the CC was calculated using equation (1).

$$\eta_{CC} = \frac{\text{Energy in kWh delivered by the CC}}{\textit{Energy in } \text{kWh} \textit{ supplied by the PV array}} \quad (1)$$

Routines were set in the charge controller to manage the grid assist system over a 24 hour period. The routines used include [5]:

1. Sleep mode: Sleep mode occurs when there is no voltage from the PV array.
2. Snooze mode: As the voltage increases logarithmically with an increase in irradiance typically during sunrise, the CC will scan the PV system current production. The scanning interval for increasing PV array voltage is 1 minute. As the PV array voltage decreases with decreasing irradiance typically during sunset, the CC will still scan for system current every 5 minutes.
3. Park mode: During the snooze mode once a small

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amount of system current is produced, the CC switches to the park mode. The CC will operate the PV array at 77% of the V_{OC}. This value is programmable and is fairly accurate for Si PV modules [6]. The system continues in this mode until the irradiance level reaches approximately 250 W/m² or while no usable PV system current is being produced.

4. MPPT Mode: When the system current increases with increased irradiance levels of above 250 W/m² the CC will switch to MPPT mode. The device used offers two MPPT algorithms, open voltage (OV) and perturb and observe (P&O).
5. Three charging modes are performed: Bulk, Absorb and Float.

2.4 Maximum Power Point Tracking Algorithms

There are numerous MPPT algorithms deployed in PV systems to maximize the energy yield from the PV system. In this study two of these algorithms, namely, perturb and observe (P & O) and open voltage (OV), sometimes called constant voltage [7], were investigated. The most commonly used MPPT algorithm is the P&O due to its simplicity of implementation. The P&O algorithm finds the MPP of a PV array by periodically perturbing the PV array voltage and comparing the output power to that of the previous perturbation cycle [2], [8], [9].

The OV algorithm uses the principle that the MPP of a PV array occurs approximately at a predetermined percentage of the system V_{OC} [10]. In general this value is approximately 76% but may be adjusted seasonally to increase the yield [1], [11].

3 Results and Discussions

3.1 Current Voltage Characteristics

Fig. 2. shows the partial I-V curve captured under real operating conditions using the DAQ system and the PV array's I-V curve. There were no major differences between the two I-V curves. A slight difference in the fill factor values of 0.73 and 0.70 for the PV systems I-V curve measured by the I-V curve tracer and the partial I-V curve from the MPP data logged was observed.

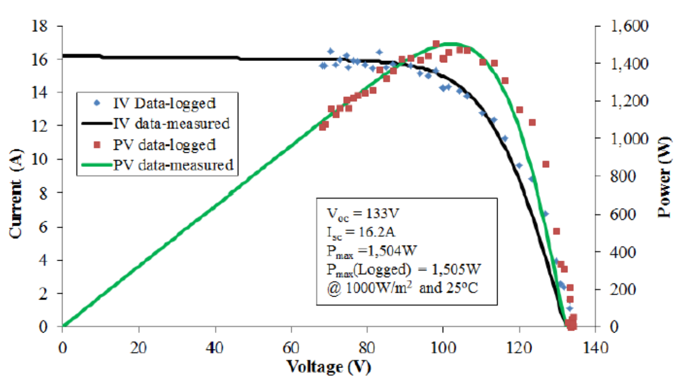

Fig. 2. 1.6 kWp PV system's real operating points and complete array's I-V and P-V curve. The temperature and irradiance corrections were carried out to standard test conditions (STC).

3.2 Charging Cycles

The CC performs three charging cycles on the batteries to extend the life of the battery bank. The charging cycles include; bulk charging, float charging and absorb charging cycles. Bulk charging occurs when the batteries require large amounts of energy to charge. Maximum current available is passed through the battery bank under bulk charge conditions to achieve this. Absorb charging occurs when the batteries reach 100% state of charge (SOC), the voltage across the batteries is increased and current is limited to the amount that the lead acid batteries will absorb at the preset voltage point. Float charging is implemented after absorb charging, the battery voltage is decreased to compensate for self-discharge.

Table 1. Comparison of the efficiency of PV Array during different charging conditions on a clear day.

Operating Condition	PV Efficiency (%)
Bulk Charge	12.0 ± 0.8
Absorb and Float Charge	11.1 ± 0.7

Fig. 3. shows the impact of the three charging cycles during a clear sky day on the PV efficiency. The large efficiency drop seen in the absorb charge region is a result of a large voltage perturbation. PV array efficiency was observed to fall in these 2 regions as compared to the bulk region (see Table 1). The observed drop in PV efficiency was due to battery maintenance routines. The fluctuating regions in Fig. 3. show the switching between the charge routines and during these periods the batteries only absorb current to maintain a 100% SOC. These charging cycles prevent the growth of lead sulphate crystals on the anode and cathode plates of the batteries and prevent electrolyte stratification which prolongs the life of the lead acid batteries.

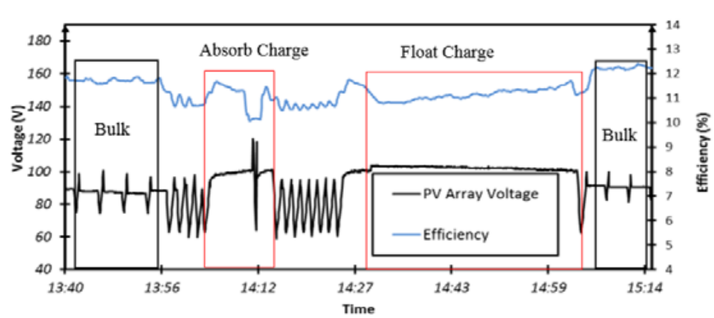

Fig. 3. PV array voltage and PV array efficiency during a float and absorb charge cycle.

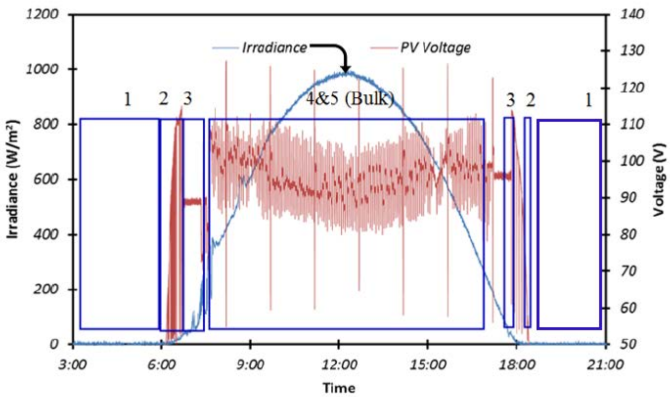

Fig. 4. PV array voltage and irradiance versus time of day (P&O) algorithm active).

3.3 Maximum Power Point Tracking Algorithms

Fig. 4. shows the effects of the P & O MPPT algorithm on the performance of the grid assist PV system. The highlighted regions are numbered according to the order of the listed routines. The region with concentrated pixels indicates the PV array operating voltage. Two types of P&O MPPT algorithm perturbations can be seen on the plot of PV voltage versus time in Fig. 4 as sweeping periodic variations in order to find a new MPP. The less frequent larger amplitude perturbation is needed for the establishment of V_{OC} so that the CC can easily switch to park mode when the current output from the PV array drops below a level that prevents voltage perturbation sweeps to find an effective MPP on the I-V curve with a very low ISC.

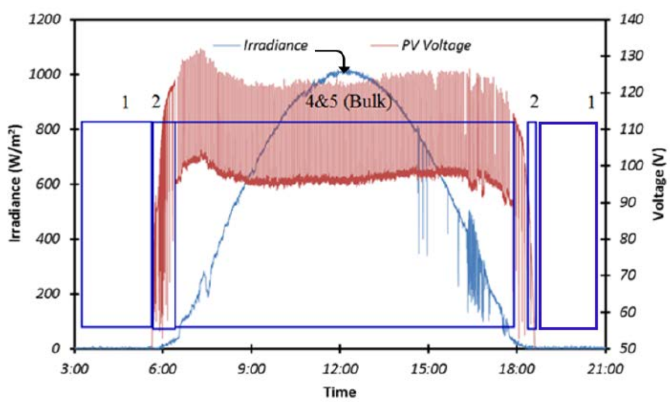

Fig. 5. PV array voltage and irradiance versus time of day (OV algorithm active).

In Fig. 5. the highlighted regions are numbered according to the order of the listed routines. The OV algorithm perturbs the PV array voltage to V_{OC} in order to find a new MPP. The voltage fluctuations in both Fig. 4. and Fig. 5. are a result of the MPP shifting due to changes in temperature and irradiance.

The testing conditions of the two algorithms were split into three categories, high and stable irradiance (clear sky), high and fluctuating irradiance (partly cloudy) and low and fluctuating irradiance (overcast). PV power was corrected for temperature to 25^o C so that the operating temperature does not influence the efficiency results. The study was broken into the experimental conditions presented in Tab. 2.

Table 2. Testing results for the MPPT algorithms

Testing conditions	PV Efficiency, η_{PV} (%)	Charge controller Efficiency, η_{CC}(%)
OV (Sunny)	12.6 ± 0.9	96.7 ± 3.9
OV (Partly Cloudy)	12.7 ± 0.8	96.5 ± 3.8
OV (Cloudy)	13.1 ± 0.6	92.1 ± 3.7
P&O (Sunny)	13.2 ± 0.9	97.2 ± 3.9
P&O (Partly Cloudy)	12.9 ± 0.7	96.3 ± 3.8
P&O (Cloudy)	13.2 ± 0.8	95.8 ± 3.8

The P&O algorithm operates most efficiently under the test conditions with an average PV efficiency of 13.2%. The OV algorithm has the best efficiency of 13.1% under cloudy conditions. The worst case efficiency of the PV array is under the OV algorithm during high and stable irradiance conditions with efficiency of 12.6%.

Although the P&O algorithm is the better algorithm inefficiencies was still observed. Examination of how the voltage perturbations influence the power output of the PV array helped to identify the inefficiencies. Two types of sweeps were identified in the P&O MPPT algorithm, the 'knee' sweep and the 'V_{OC}' sweep. The perturbation time was found to take ~30s for the 'knee' sweep and ~60s for the larger 'V_{OC}' sweep. These lengthy perturbation times cause inefficient power conversion [10], [11]. During these perturbations, partial IV curves of the PV array are captured (see Fig.6).

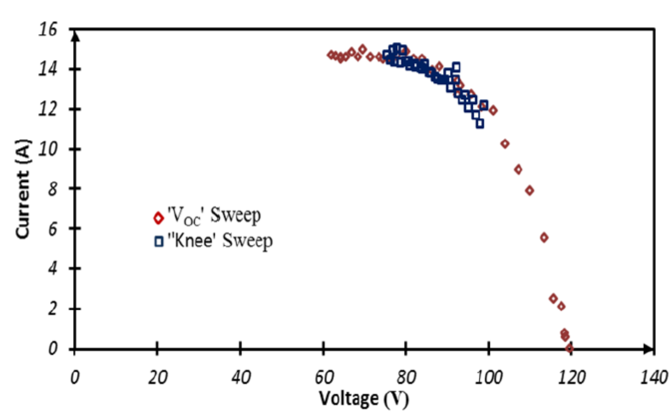

Fig. 6. Partial I-V data for the PV array measured during the

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perturbation cycles of the P&O algorithm.

4 Conclusions

The main aim of this study is to assess the effects of P & O and OV MPPT algorithms on the performance of the Grid Assist PV system. The two MPPT algorithms are chosen due to their simplicity of operation. The effects of the two algorithms were studied under three testing conditions such as clear sky, partly cloudy and overcast. Experimental results show that P&O algorithm operates most efficiently under the test conditions. However, it was noted that the OV algorithm has the best efficiency under cloudy conditions and the worst efficiency during high and stable irradiance conditions.

Additionally, the impact of the three charging cycles during a clear sky day on the grid assist PV system efficiency was investigated. There was a reasonable drop in the efficiency of the PV system during the float and absorb charging cycles. Two types of voltage perturbations known as the 'knee' and the 'V_{OC}' sweeps with perturbation times of about 30s and 60s respectively were identified in the P&O MPPT algorithm. These lengthy perturbation times caused inefficient power conversion.

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