Low Cost MPPT Algorithms for PV Application: PV Pumping Case Study

M. A. Elgendy, B. Zahawi and D. J. Atkinson

Presented by:

Bashar Zahawi

E-mail: bashar.zahawi@ncl.ac.uk

Outline

- Maximum power point tracking
- Experimental system description
- Directly Connected PV Pumping Systems
- PV Pumping systems with MPPT
  - Constant Voltage MPPT Algorithm
  - Perturb and Observe (P&O) MPPT Algorithm
  - Incremental Conductance (INC) MPPT Algorithm
- Conclusions

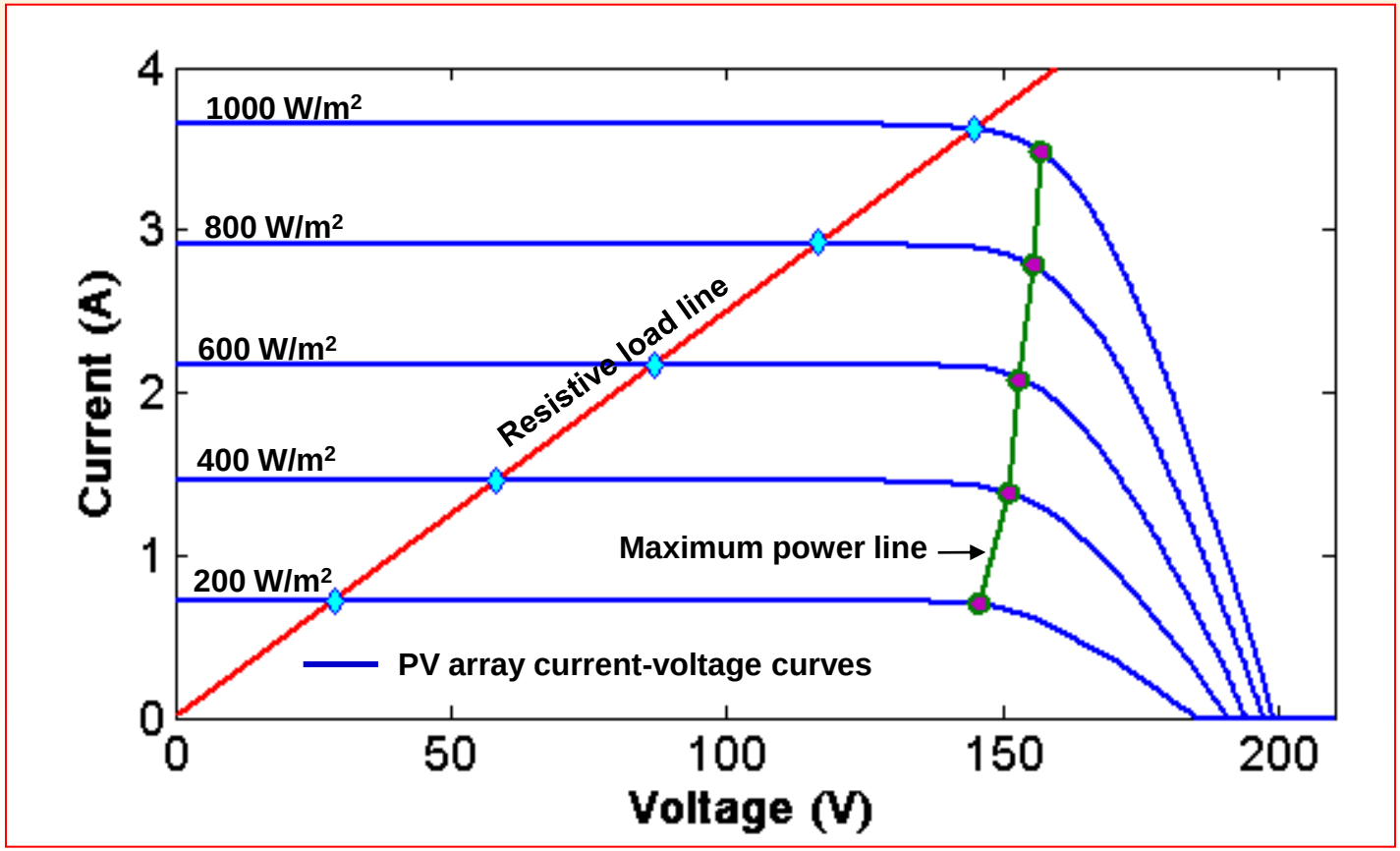
Introduction

- **Water pumping is probably one of the most important applications of PV systems**
  - **Particularly in rural areas with no grid supply**
  - **Low power pumps ranging from 200W to 2kW**
- **Most commonly used motor is the PM brushed dc motor**
  - **Induction motors used for bore-hole and deep-well pumping**
- **The dc motor/pump set is connected directly to the PV array in most commercial systems**

Maximum Power Point Tracking

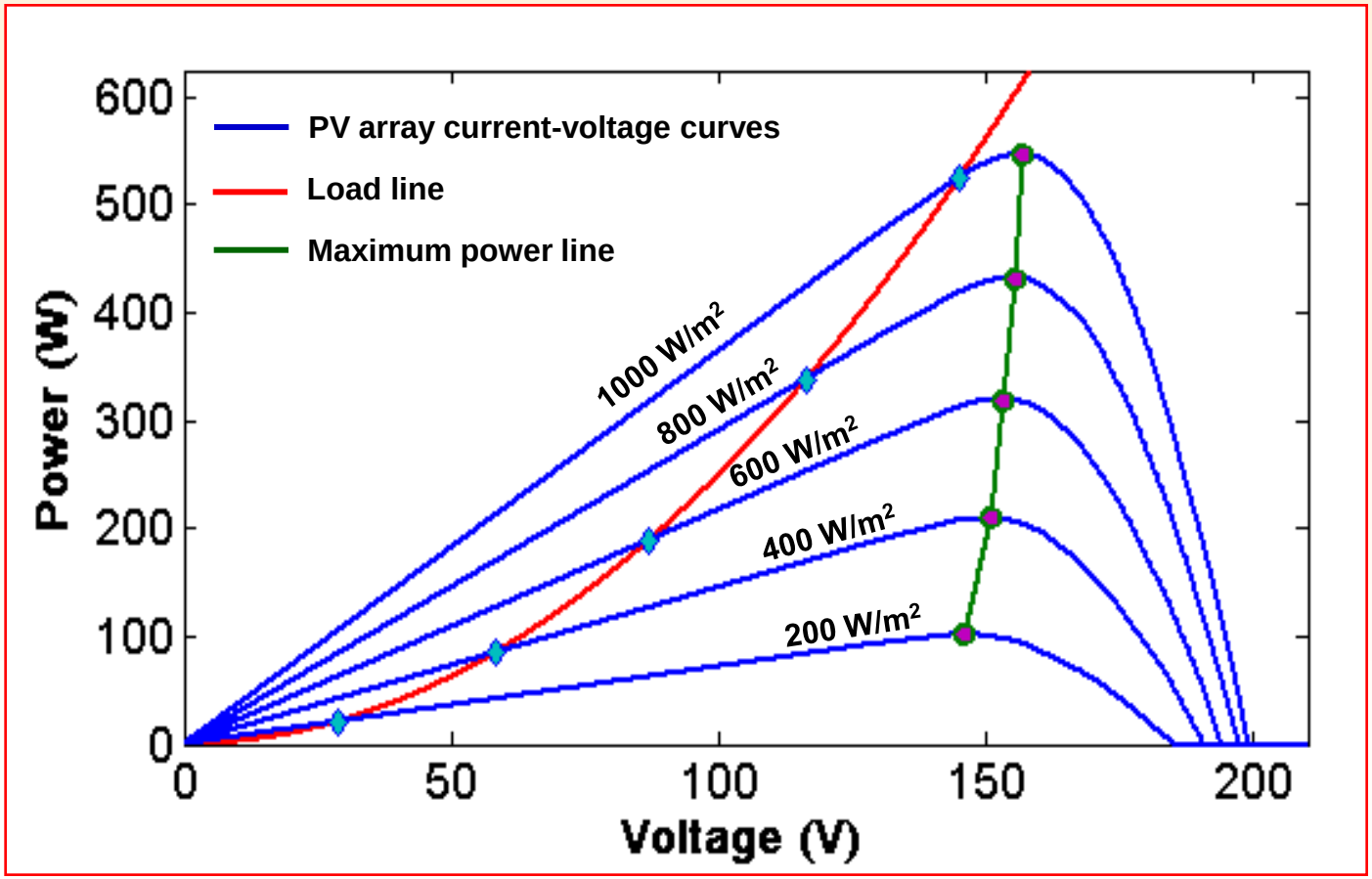
- A PV array or generator will have one point on its current/voltage characteristic that corresponds to maximum power output
  - This is referred to as the maximum power point or MPP
- Directly connected systems do not operate at the MPP
  - Significant amounts of available energy are wasted
- A pump controller (dc-dc converter) is required to better match the PV generator to the motor/pump set
- This is referred to as MPPT

PV Array Current-Voltage Curves



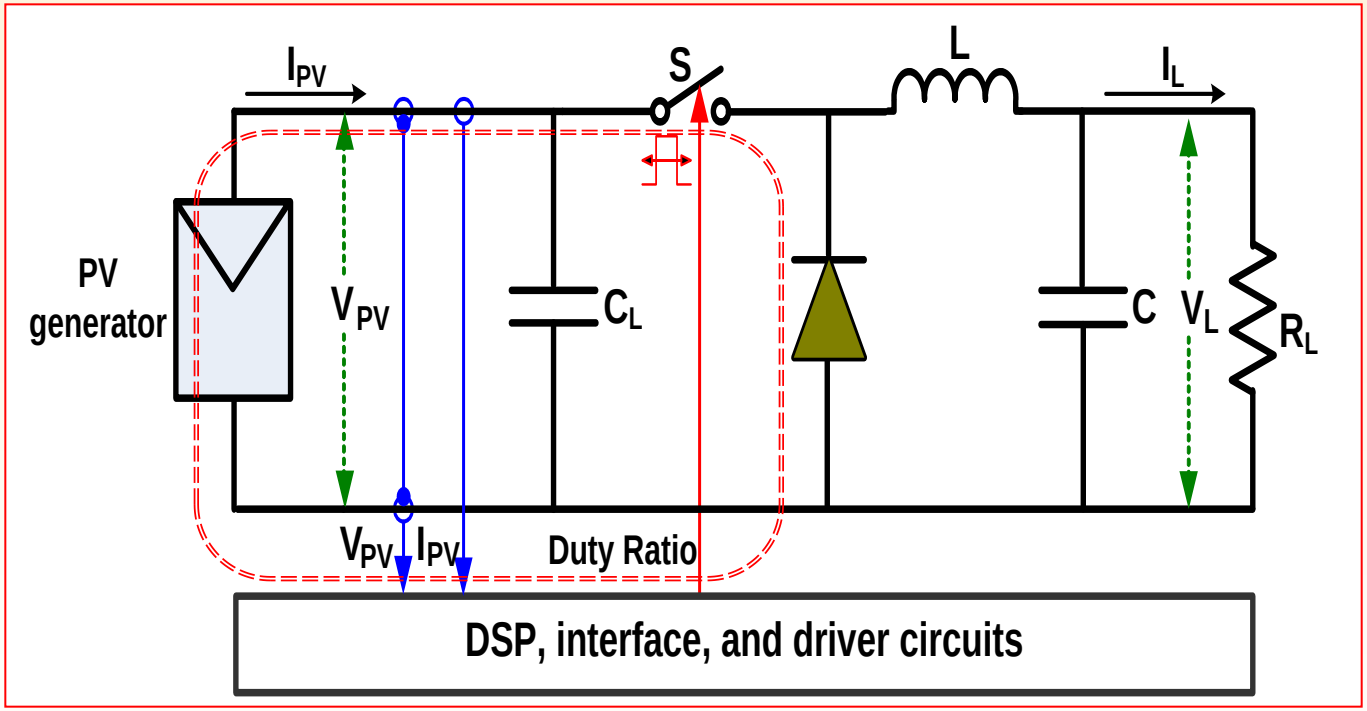
Mismatch between resistive load and PV Source; current–voltage curves

PV Array Power-Voltage Curves



Mismatch between resistive load and PV Source; power–voltage curves

MPPT Circuit

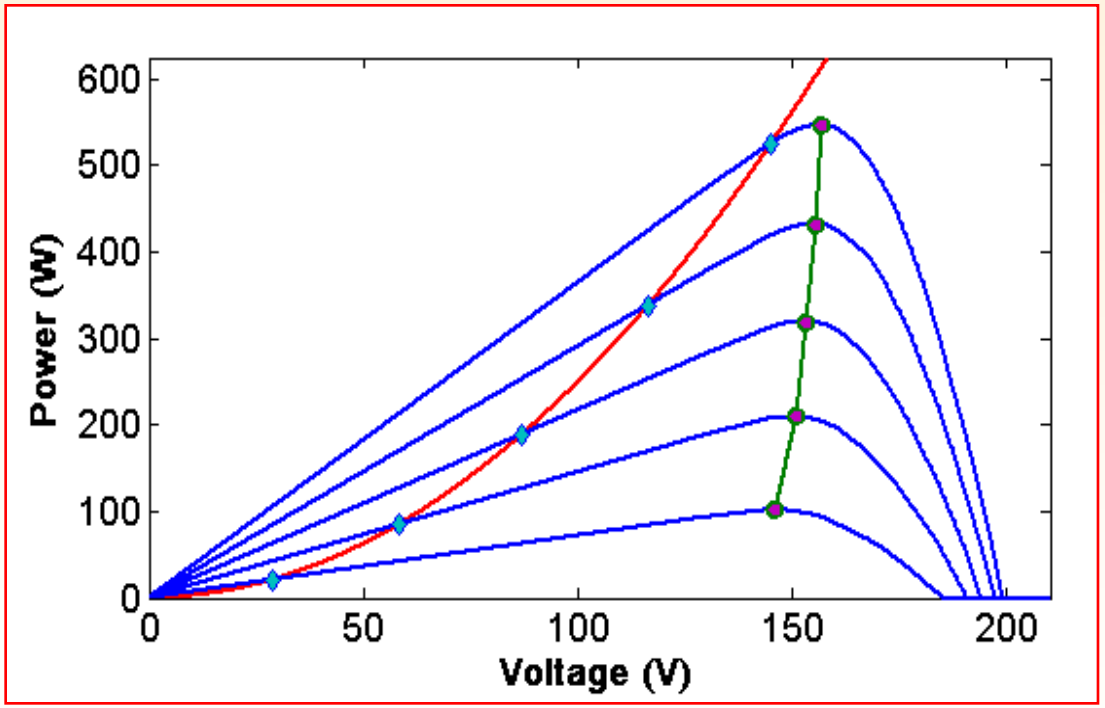


Circuit diagram for PV system with MPPT control

MPPT Algorithms

- **Mapping or Model Based algorithms**
  - **A model of the system is developed to "map" the operating characteristics and identify the MPP**
  - **Simple models are not very effective**
  - **More complex models require significant computational resources and are site specific**
  - **Not suitable for commercial applications**
- **Constant voltage algorithm**
- **Hill climbing algorithms**

Hill Climbing MPPT



Outline of Presentation

- Experimental investigation of the performance of Maximum power point tracking algorithms for pumping applications
- Constant Voltage Algorithm
- Perturb and Observe (P&O) Algorithm
- Incremental Conductance (INC) Algorithm
- In each case, system performance is investigated and the energy utilisation efficiency calculated

Experimental Set Up

- Experimental investigation of the performance of Maximum power point tracking algorithms for pumping applications
- Constant Voltage Algorithm
- Perturb and Observe (P&O) Algorithm
- Incremental Conductance (INC) Algorithm
- In each case, system performance is investigated and the energy utilisation efficiency calculated

Experimental Set Up

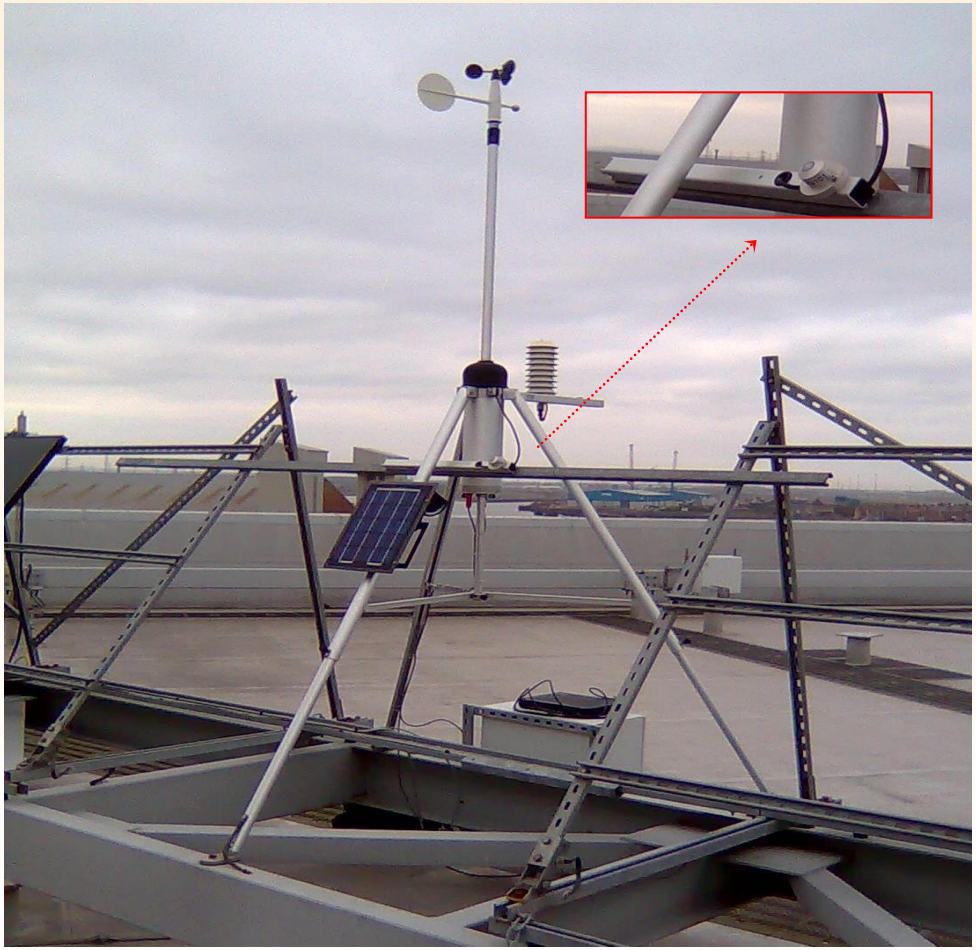
- 1080-Wp PV array facing south at a tilt angle of 54° w.r.t. the horizontal
  - Two parallel branches of 3 series connected 180-Wp solar modules
- Weather station installed at the same roof
  - Weather parameters were recorded at a 1 sec sampling rate
  - Solar irradiance was measured by a radiation sensor fixed on a surface inclined at the same tilt angle
- 10-stage centrifugal surface pump driven by a brushed PM dc motor

Experimental Set Up

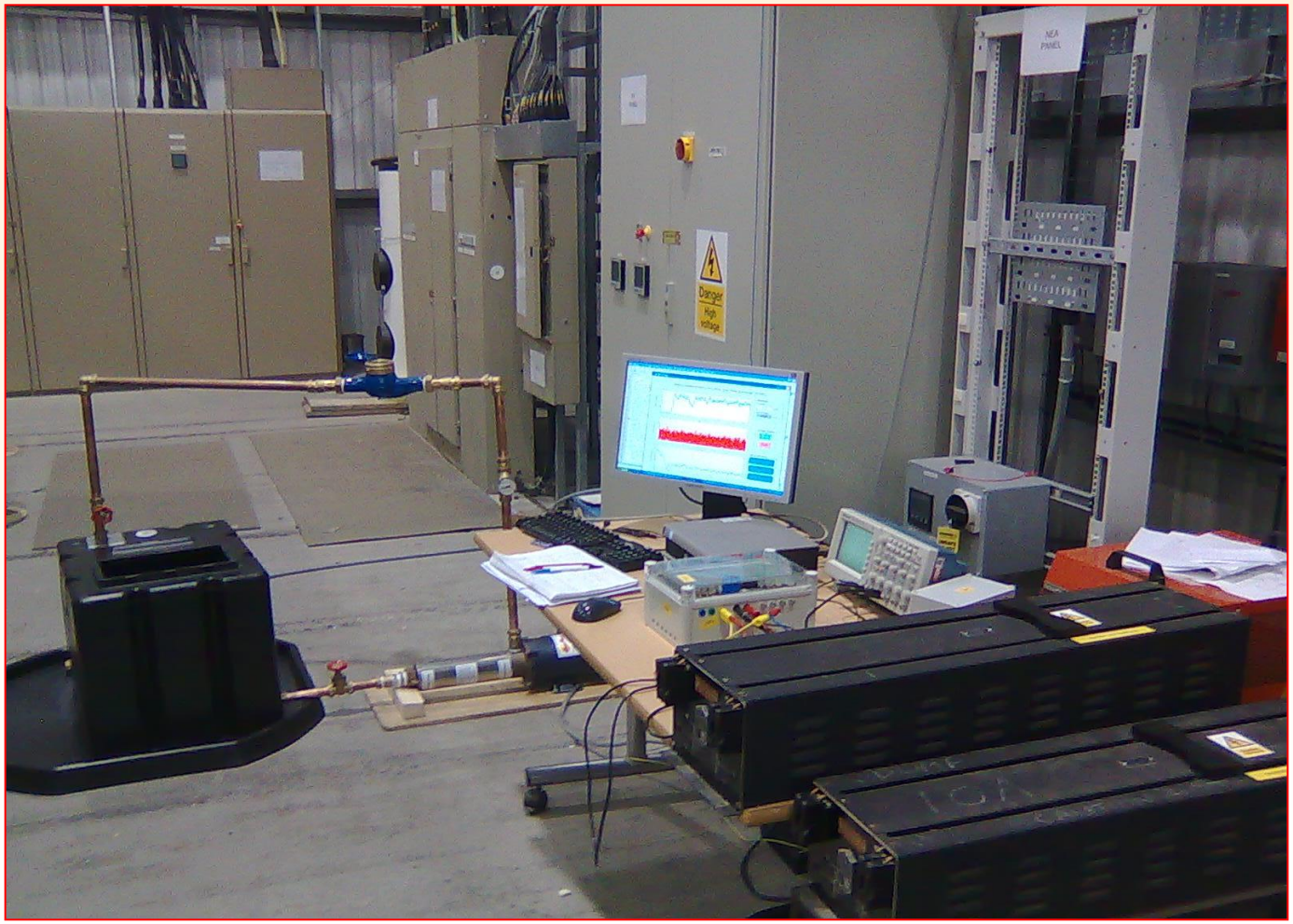
- **Step-down dc-dc converter**
  - **470μF link capacitance and 10kHz PWM frequency**
- **Texas Instruments DSP based eZdsp kit used for control and data acquisition**
  - **DSP used to provide flexibility**
  - **In a commercial product, a low cost microcontroller would be more than adequate**
- **Array installed on the roof of the New and Renewable Energy Centre (NaREC) in Northumberland.**

Experimental System

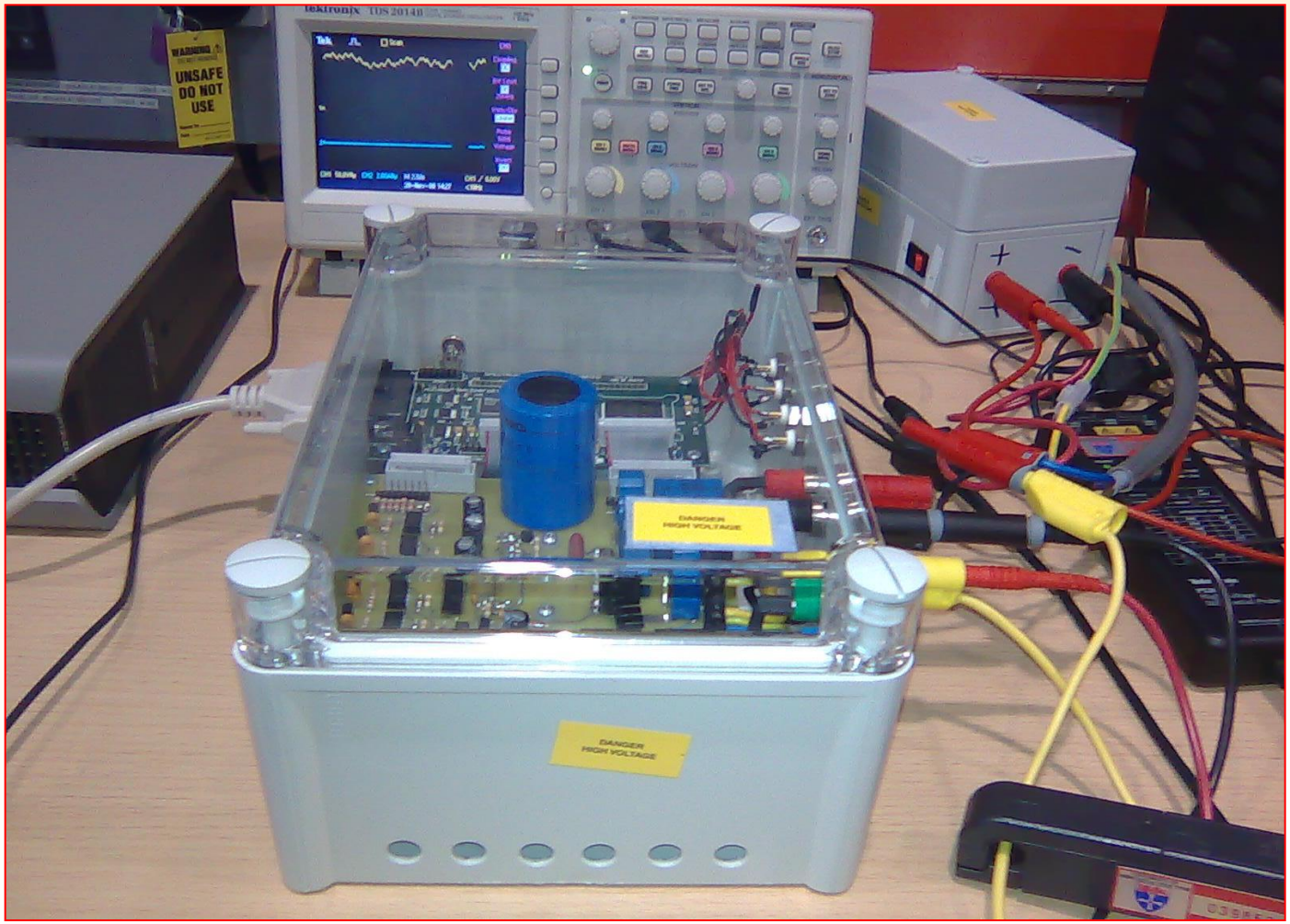
Experimental System



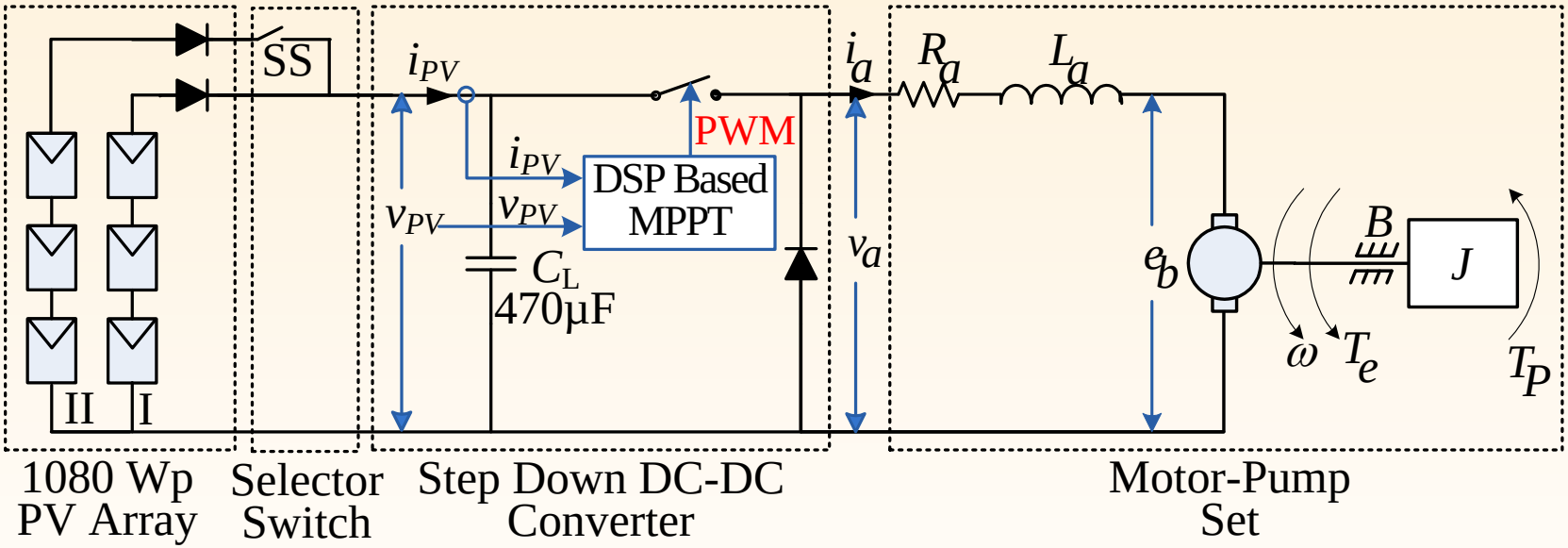
Experimental System



Experimental System

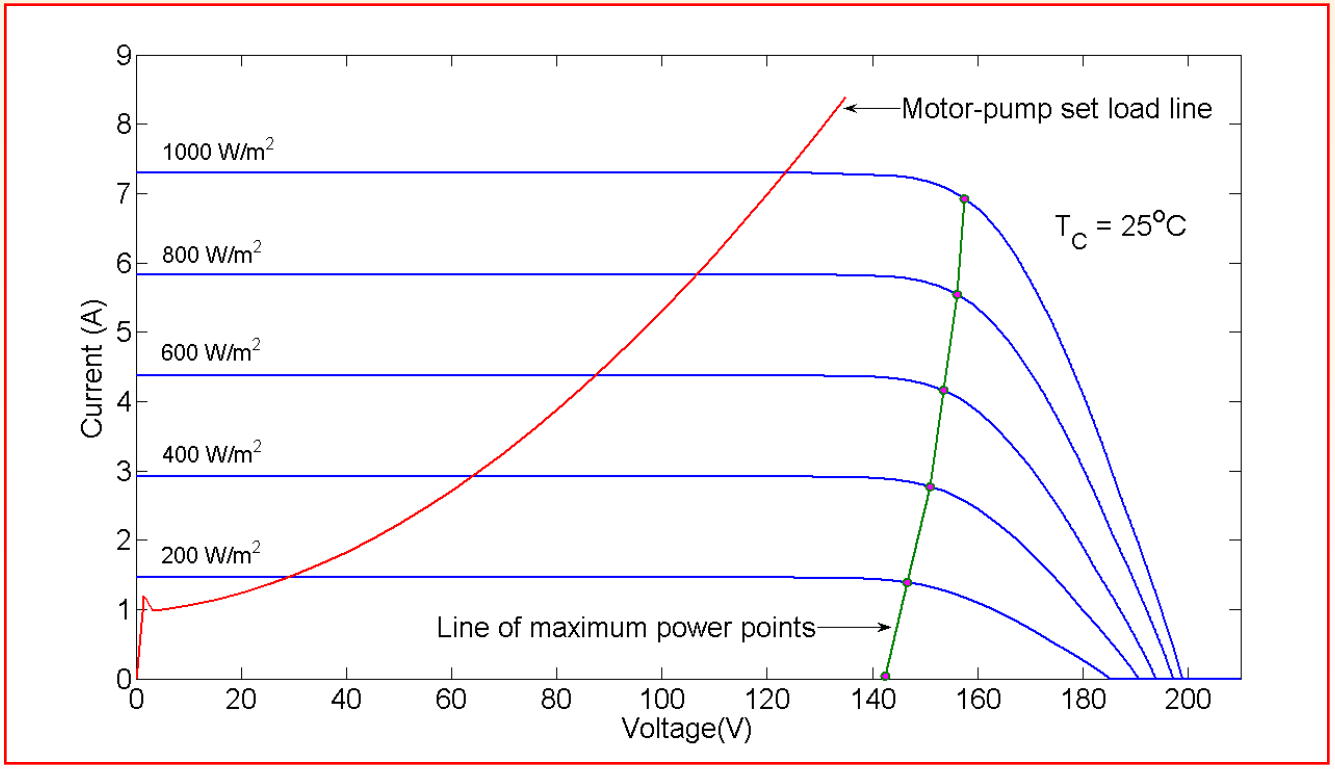


Circuit Diagram



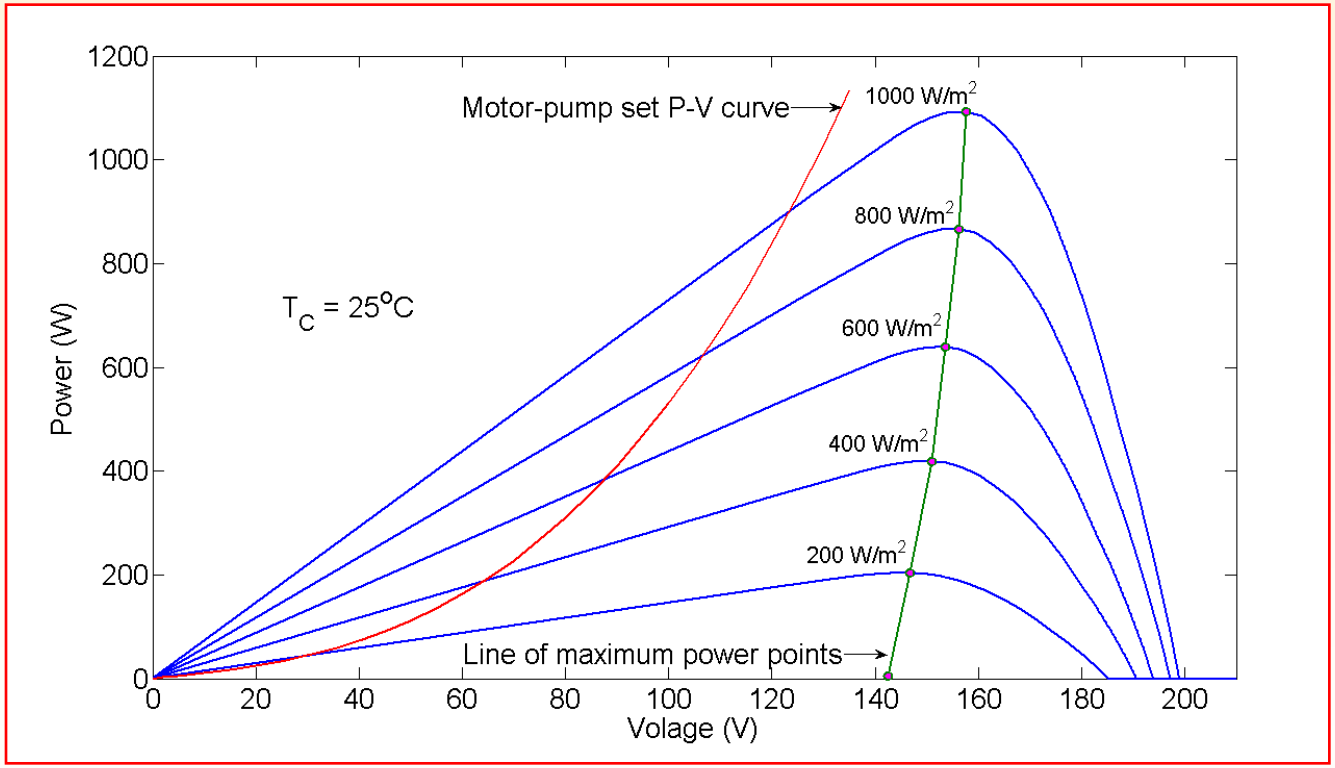
Equivalent circuit of the PV pumping system setup

System Description



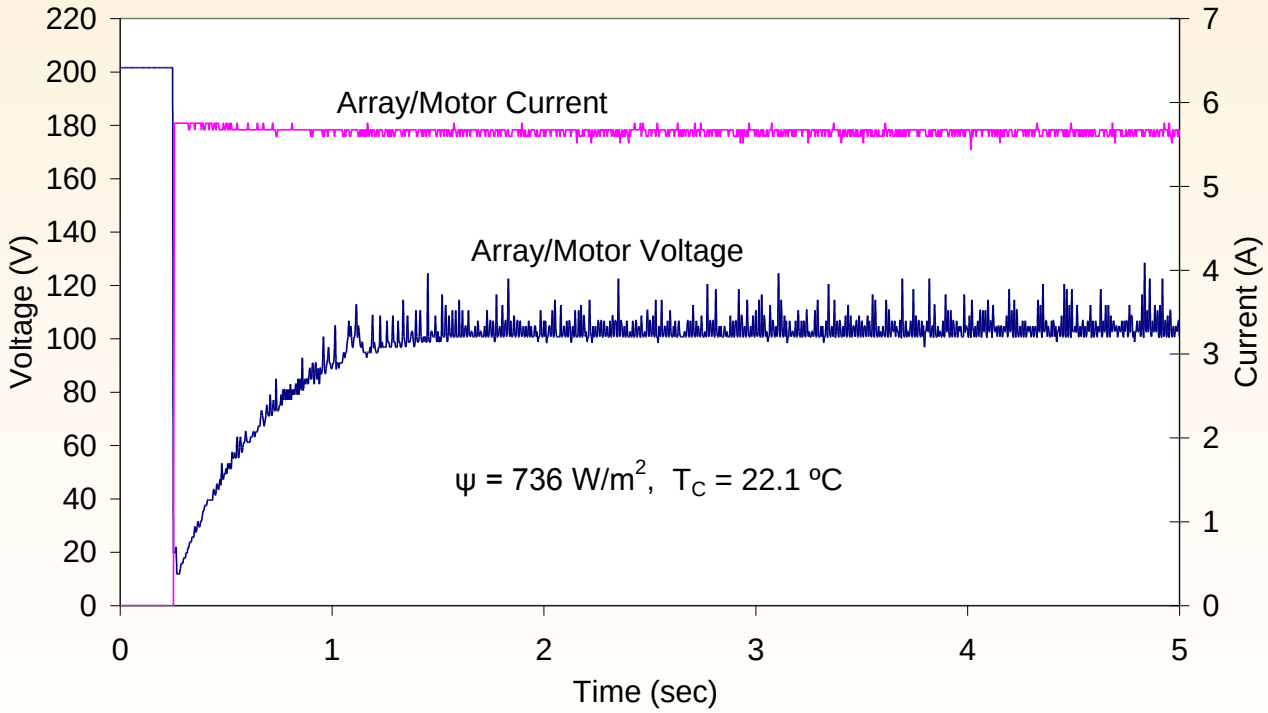
Mismatch between motor-pump load and PV generator when pump is connected directly to PV array; current-voltage curves

System Description



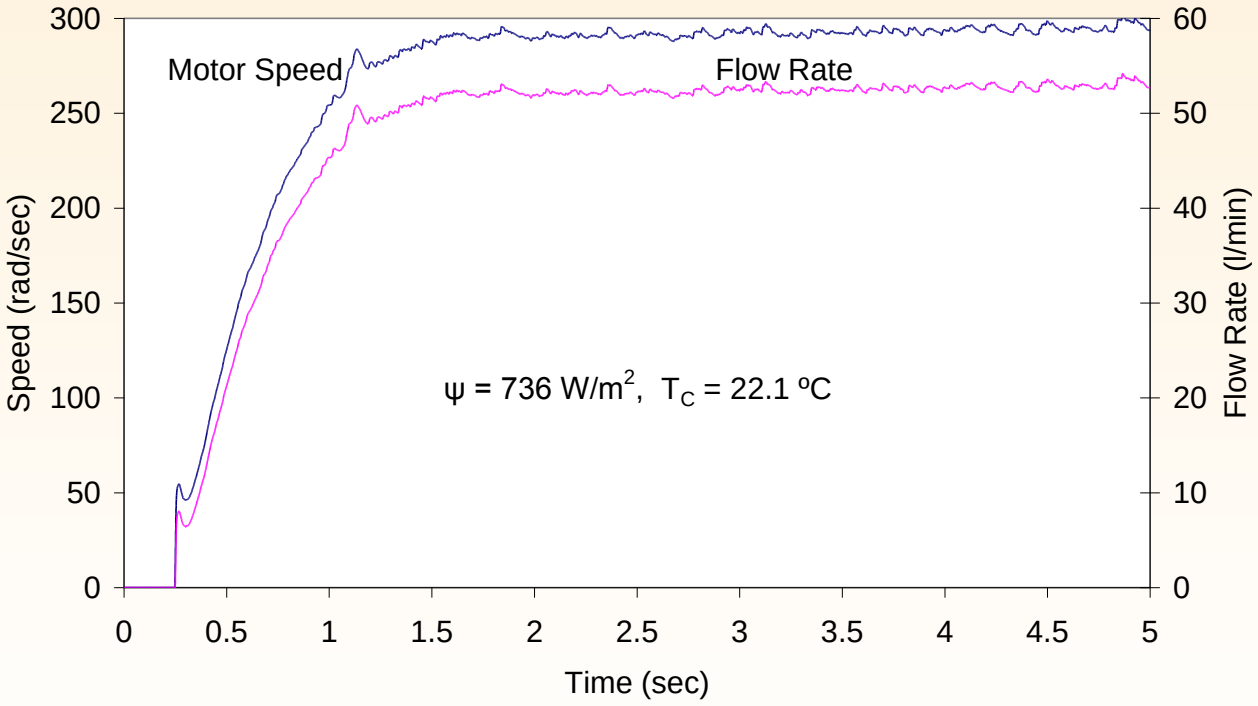
Mismatch between motor-pump load and PV generator when pump is connected directly to PV array; power-voltage curves

Directly Connected DC PV pumping system



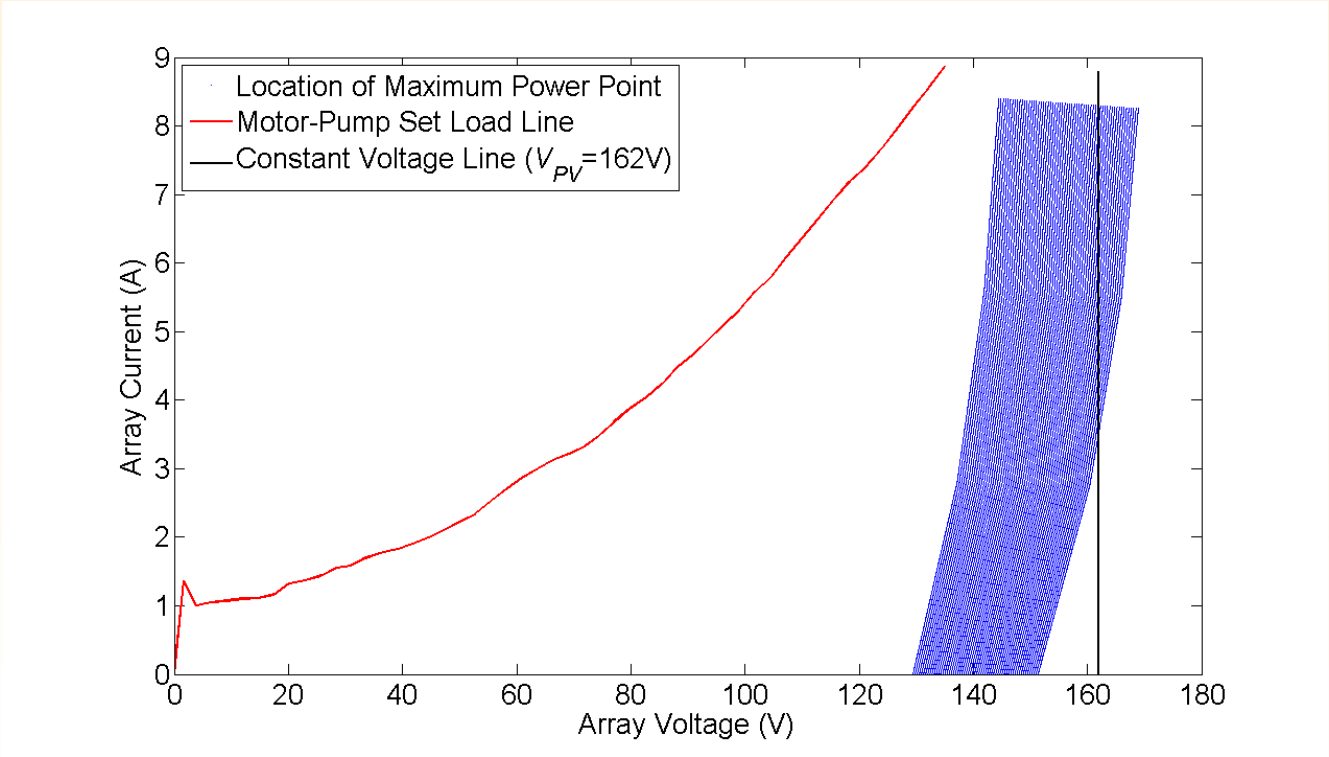
Experimental results showing array/motor voltage and current waveforms

Directly Connected DC PV pumping system



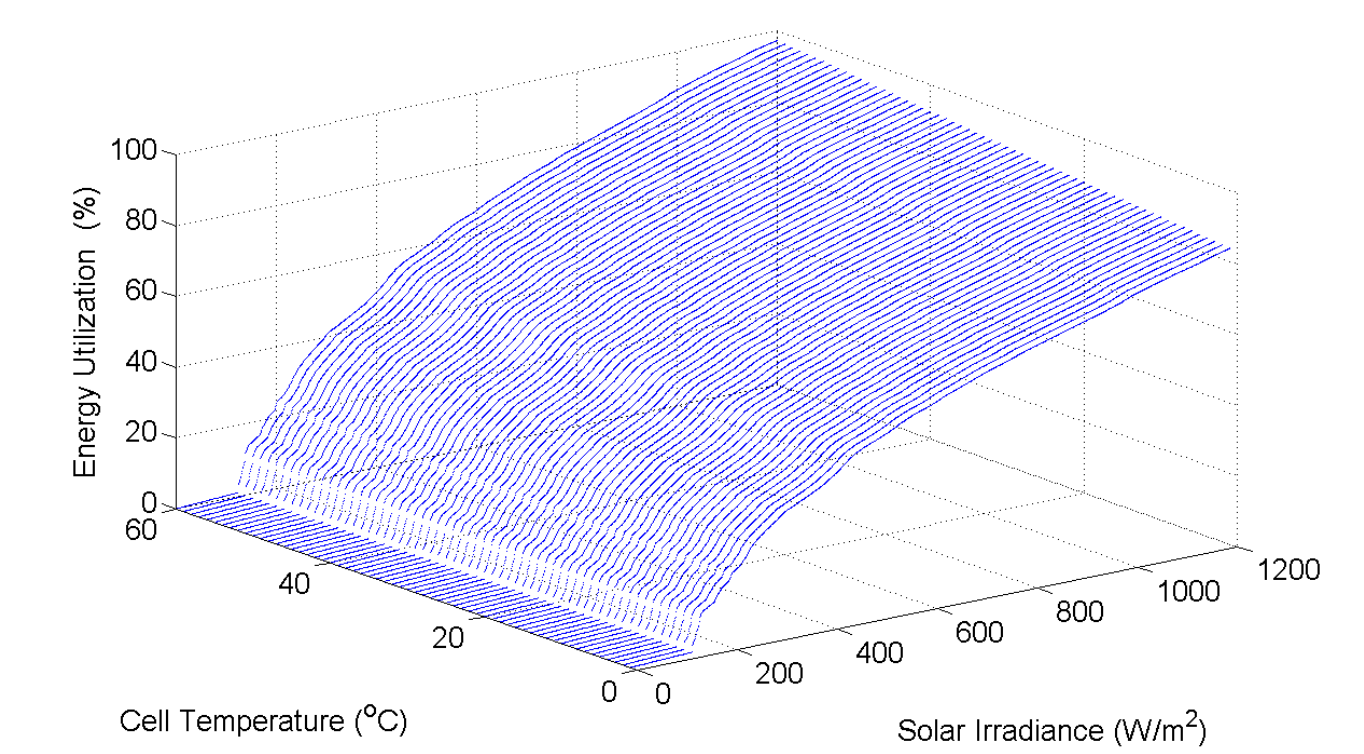
Motor speed and flow rate waveforms

Directly Connected DC PV pumping system



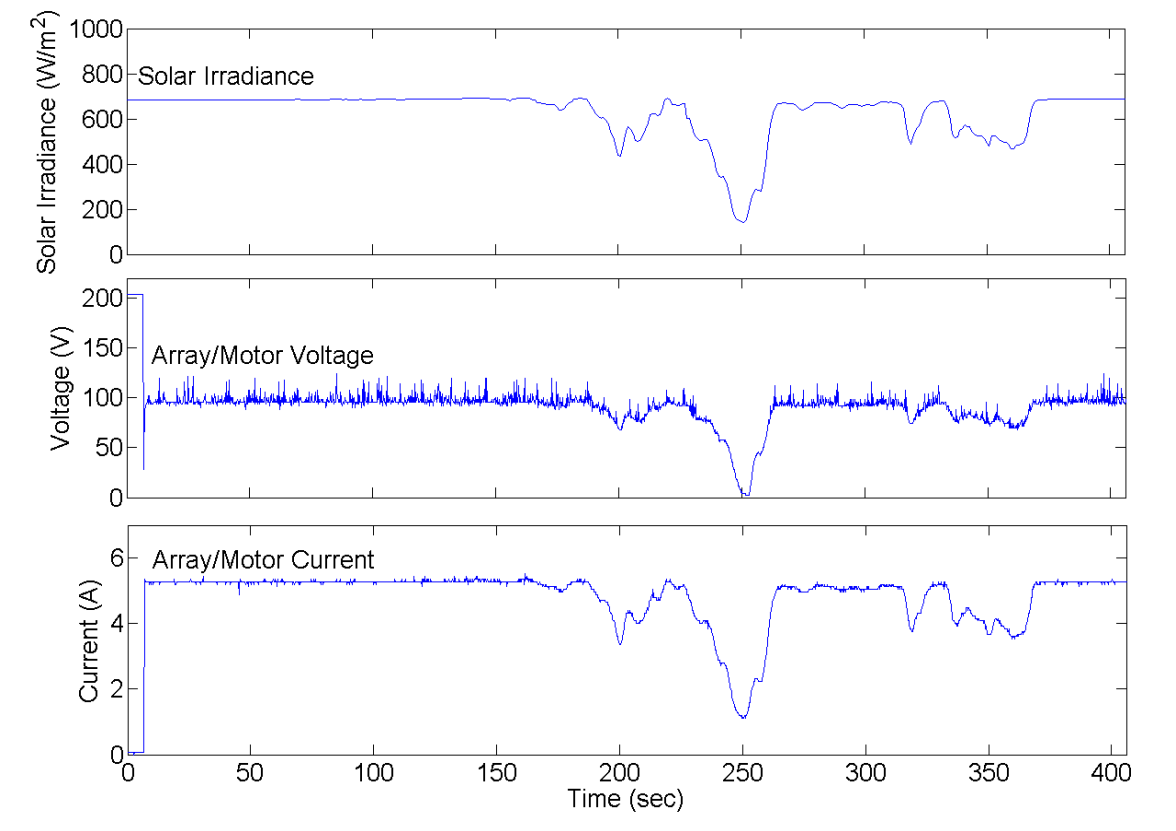
Influence of solar irradiance and cell temperature on MPP location

Directly Connected DC PV pumping system



Influence of solar irradiance and cell temperature on the energy utilization

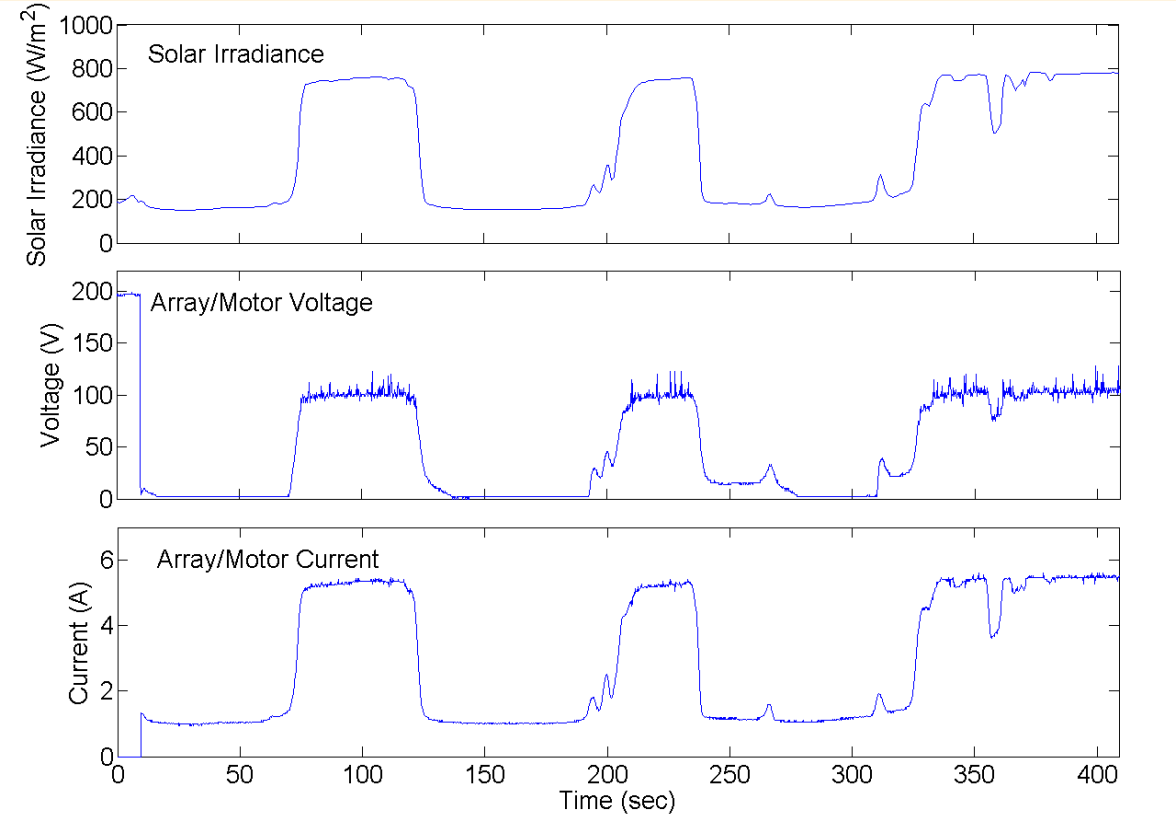
Directly Connected DC PV pumping system



62.7%

Experimental system performance under slow changing irradiance

Directly Connected DC PV pumping system



51.3%

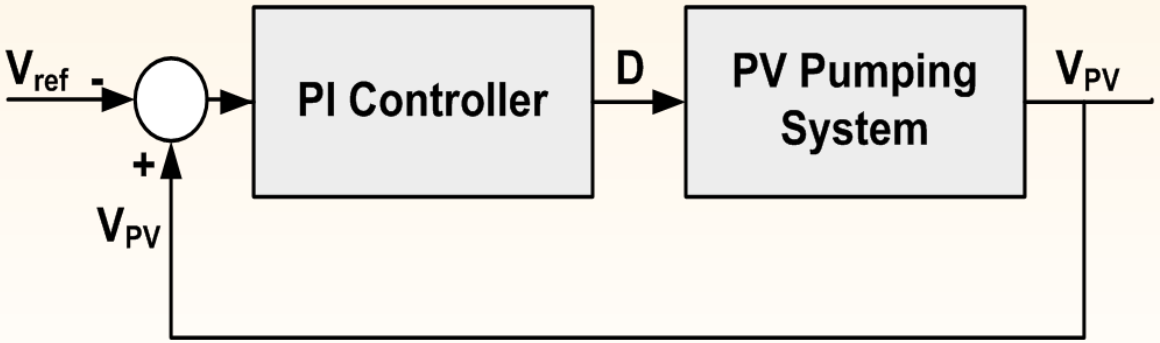
Experimental system performance under rapidly changing irradiance

Outline

- Introduction
- System Description
- Directly Connected PV Pumping Systems
- PV Pumping systems with MPPT
  - Constant Voltage MPPT Algorithm
  - Perturb and Observe (P&O) MPPT Algorithm
  - Incremental Conductance (INC) MPPT Algorithm
- Conclusions

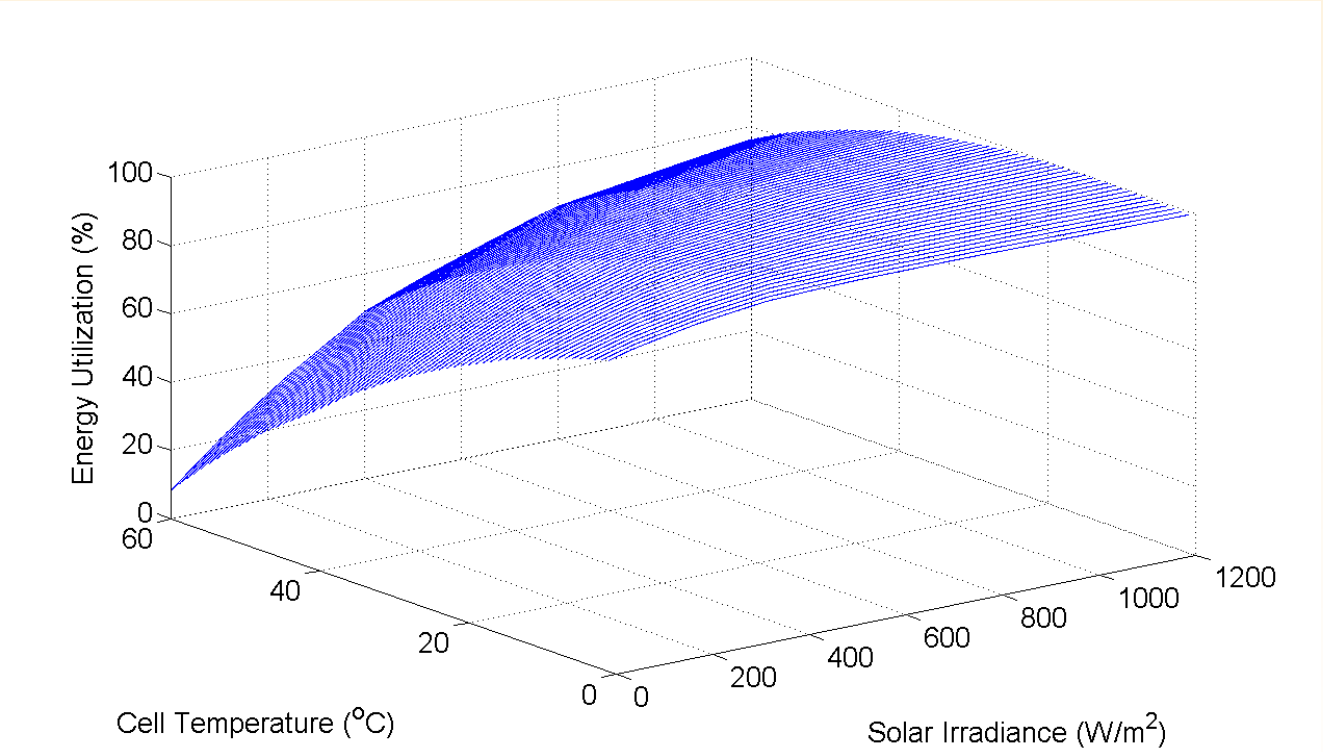
Constant Voltage MPPT Algorithm

- **The system performance is affected by:**
  - **V_{ref}**
  - **K_P and K_I**



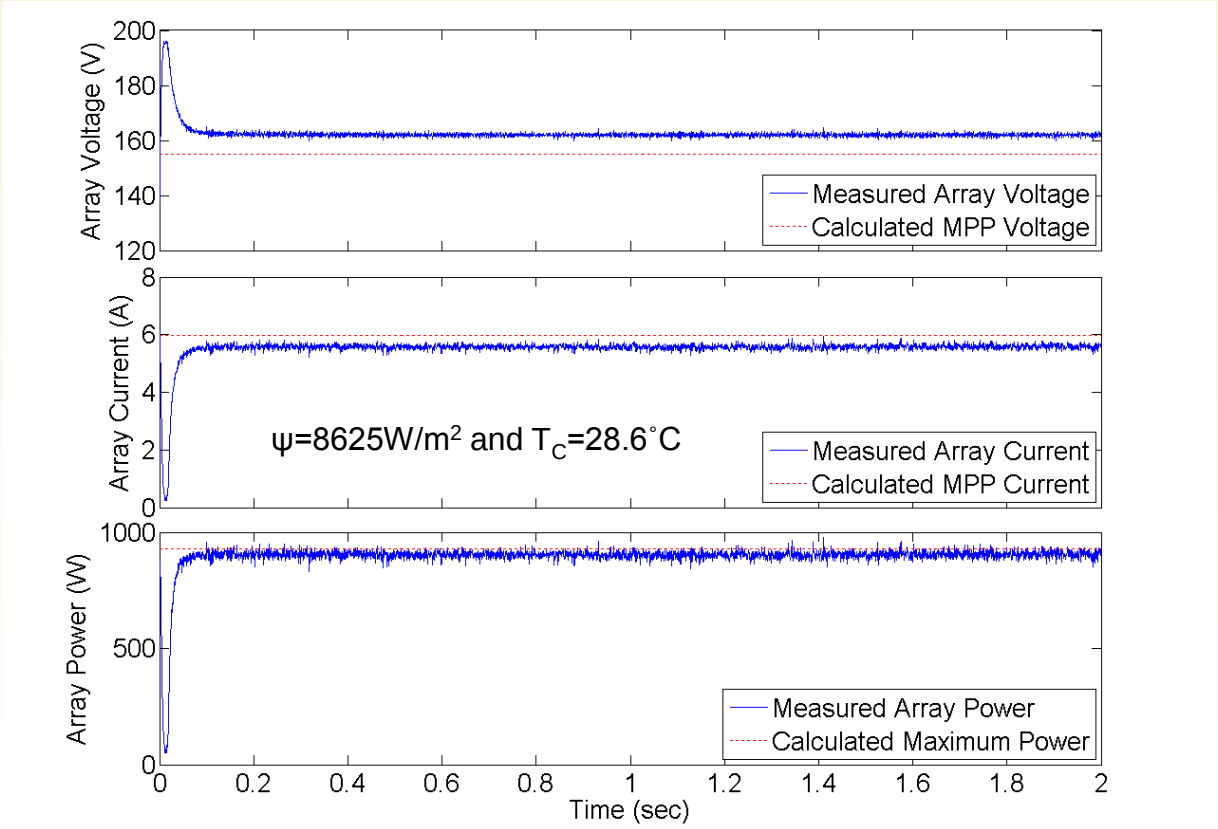
Block Diagram of Constant Voltage MPPT Algorithm

Constant Voltage MPPT Algorithm



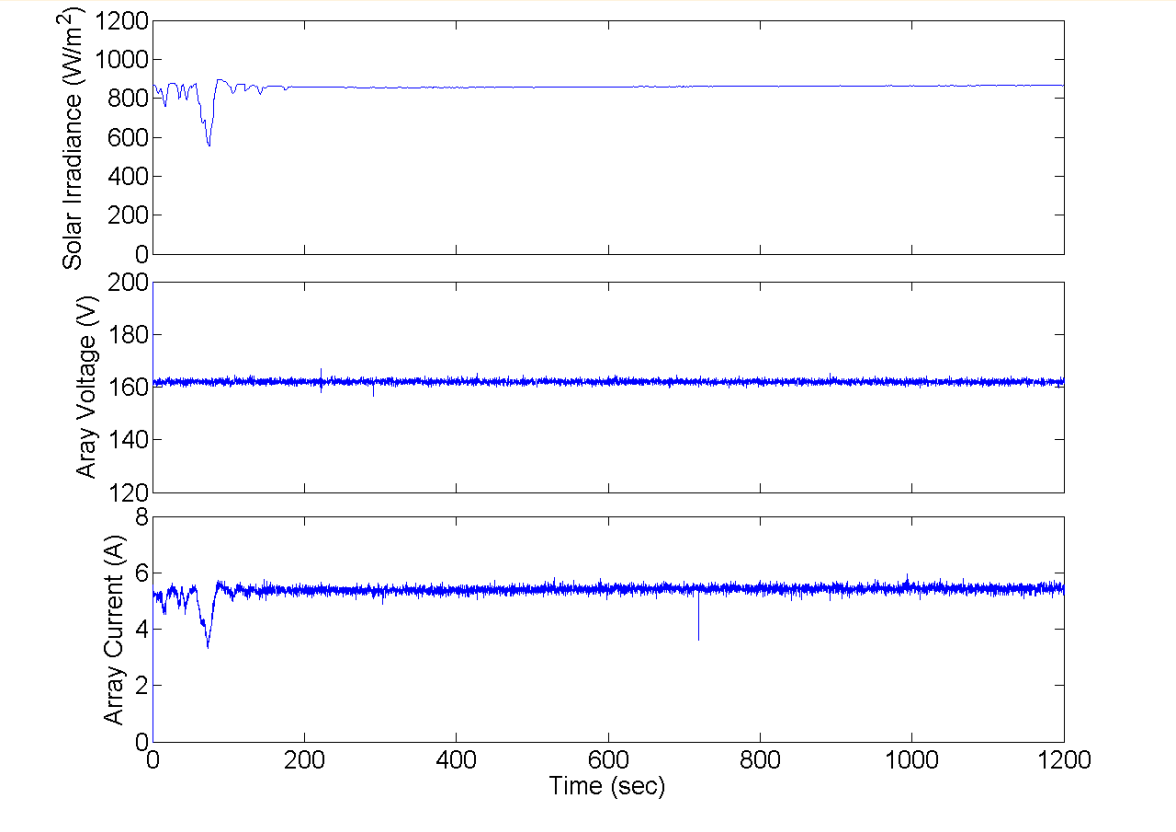
Influence of solar irradiance and cell temperature on the energy utilization

Constant Voltage MPPT Algorithm



Experimental results showing array voltage, current, and power waveforms

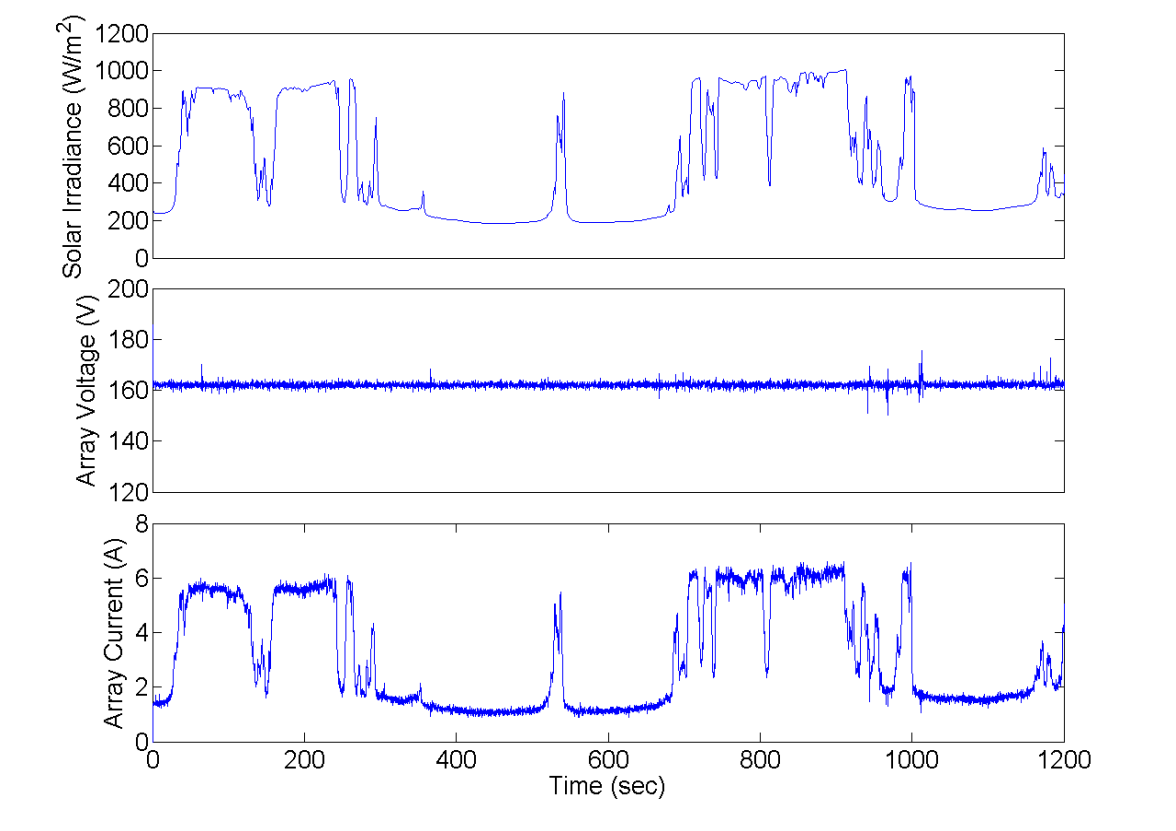
Constant Voltage MPPT Algorithm



91.3%

Experimental performance at nearly constant irradiance

Constant Voltage MPPT Algorithm



91.1%

Experimental performance at rapidly changing irradiance

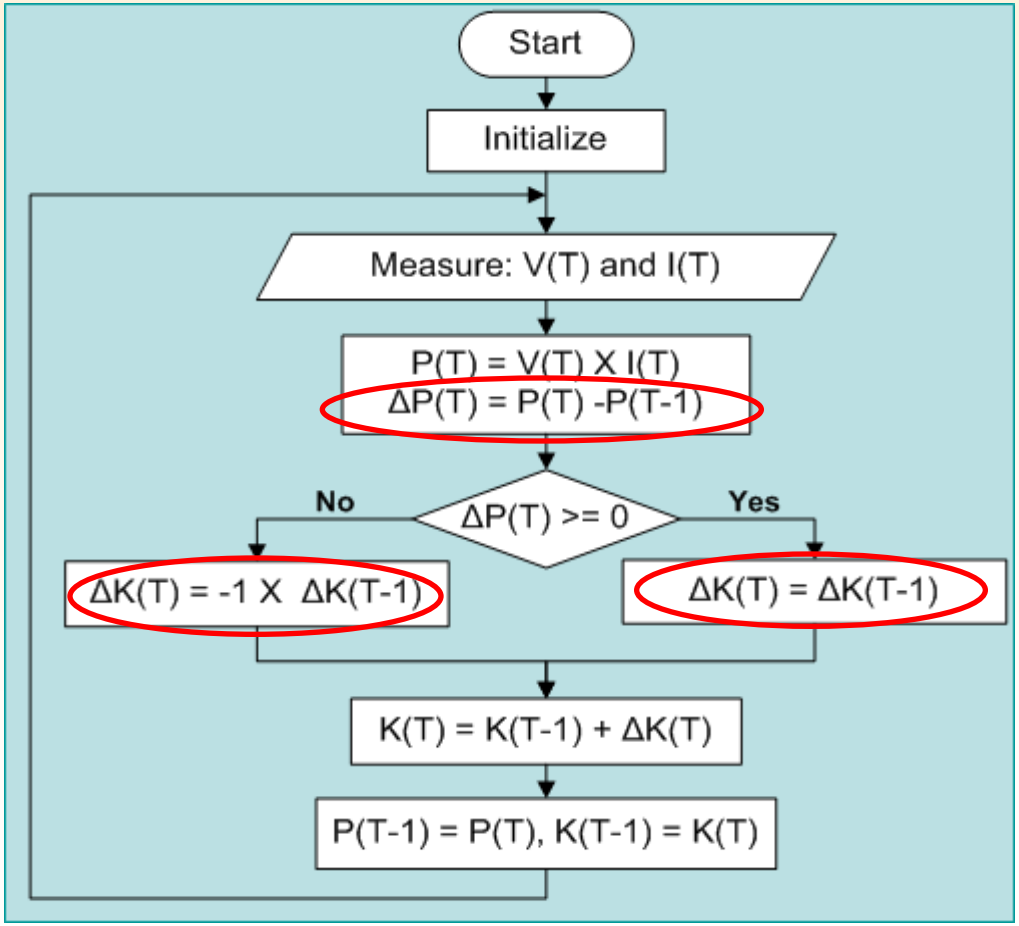
Conclusions I

- **Directly connected PV pumping systems eliminate the use of power electronics converters but suffer from low energy utilization efficiency.**
- **Simple constant voltage MPPT algorithm offers significantly higher energy utilization efficiencies (about 91%).**
- **For more significant improvements in energy utilization, more efficient MPPT control algorithms that take into account the effects of insolation and temperature variations on the MPP voltage would be required.**

Outline

- Introduction
- System Description
- Directly Connected PV Pumping Systems
- PV Pumping systems with MPPT
  - Constant Voltage MPPT Algorithm
  - Perturb and Observe (P&O) MPPT Algorithm
  - Incremental Conductance (INC) MPPT Algorithm
- Conclusions

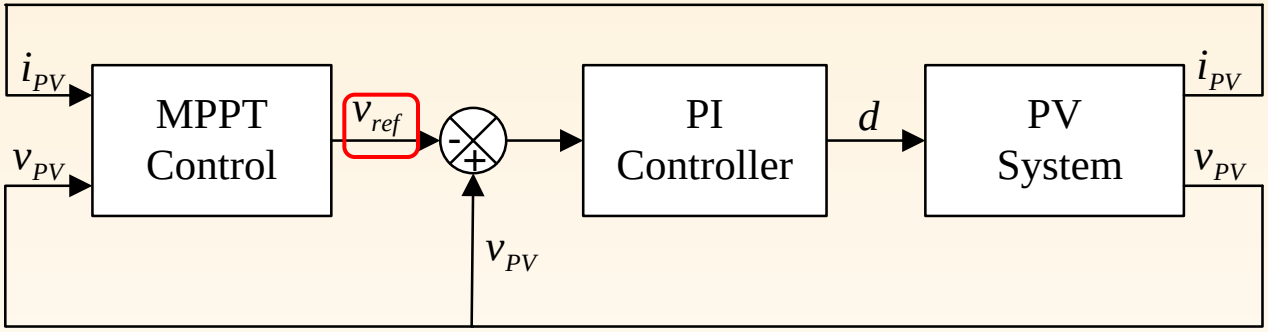
Perturb and Observe MPPT Algorithm



Flowchart of P&O MPPT Algorithm

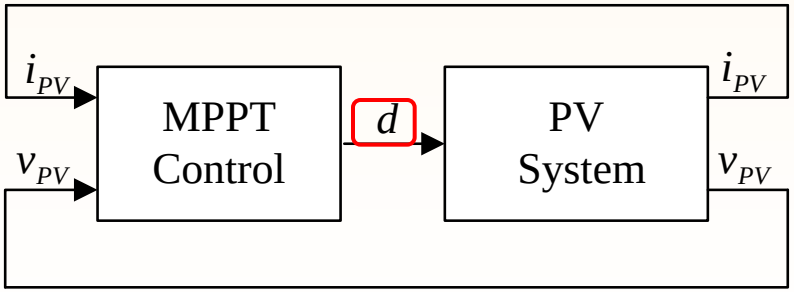
Perturb and Observe MPPT Algorithm

- **Reference voltage control**



Block diagram of MPPT with reference voltage control

- **Direct duty ratio control**

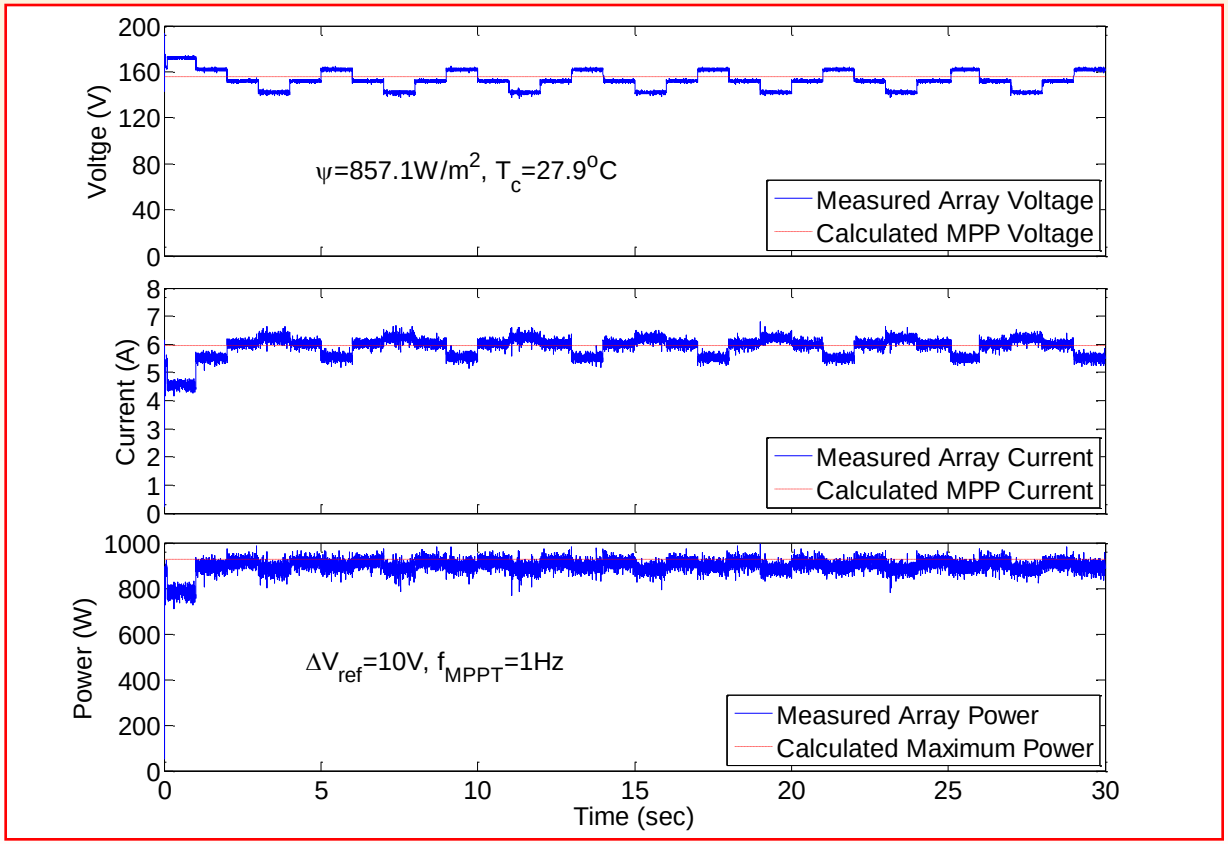


Block diagram of MPPT with direct duty ratio control

Perturb and Observe MPPT Algorithm

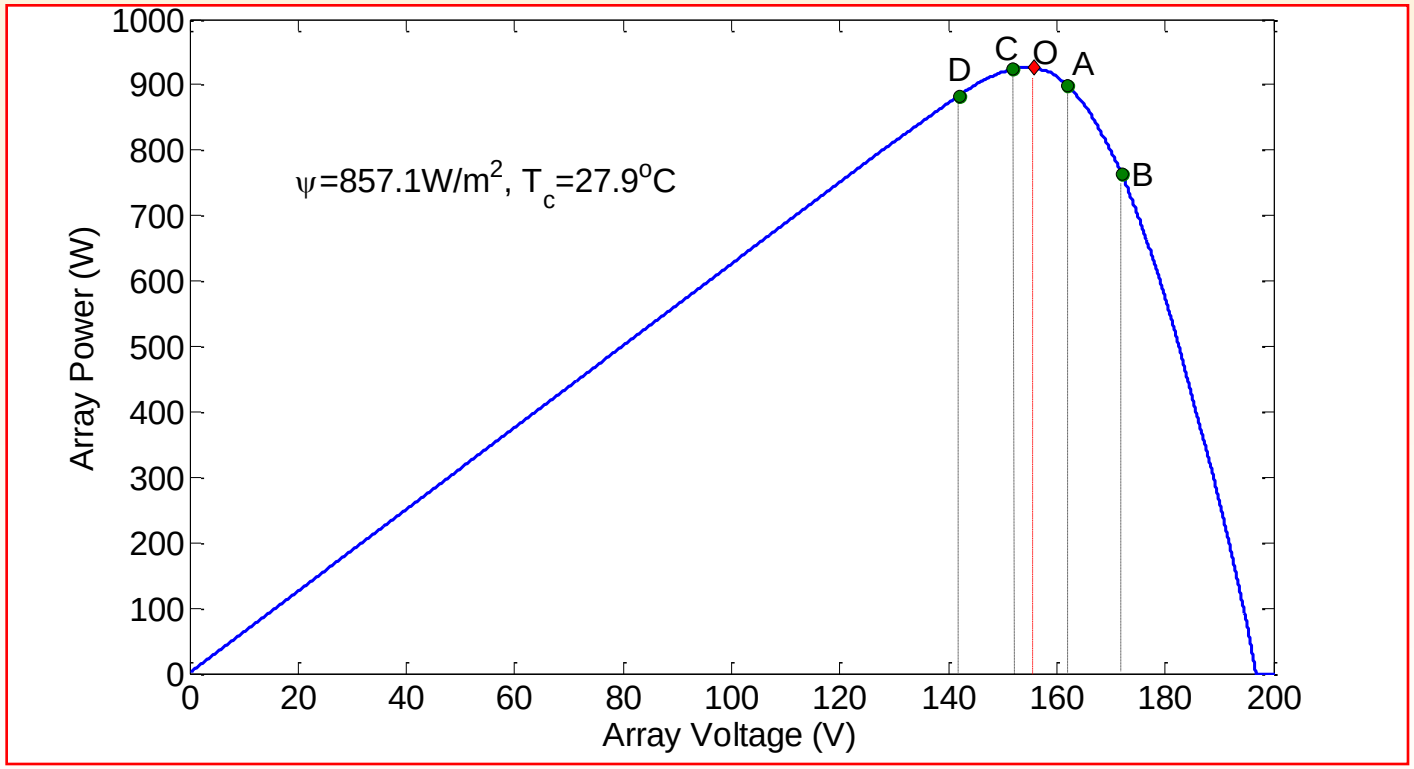
- **System performance is affected by:**
  - **Step Size (Δd or ΔV_{ref})**
  - **Perturbation Frequency (f_{MPPT})**

P&O Algorithm Parameters



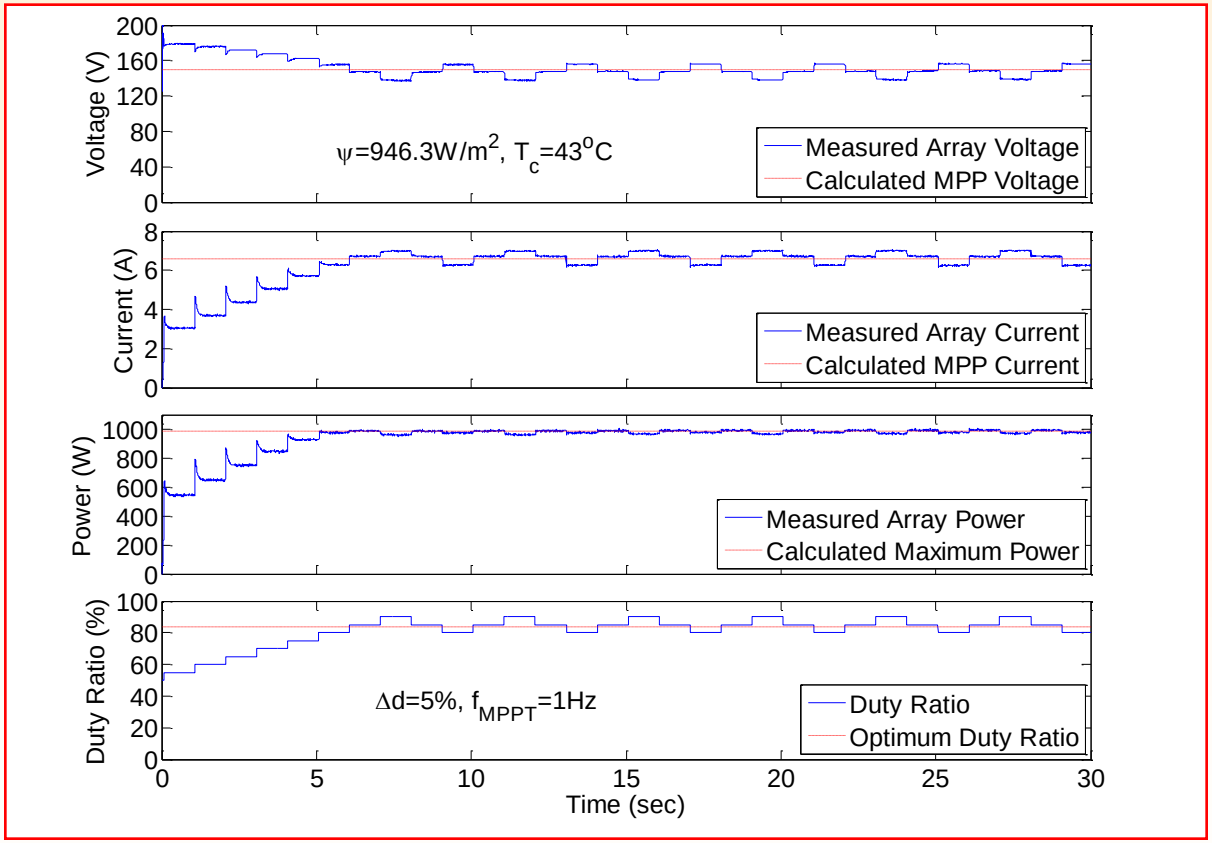
Three-level operation with reference voltage perturbation

P&O Algorithm Parameters



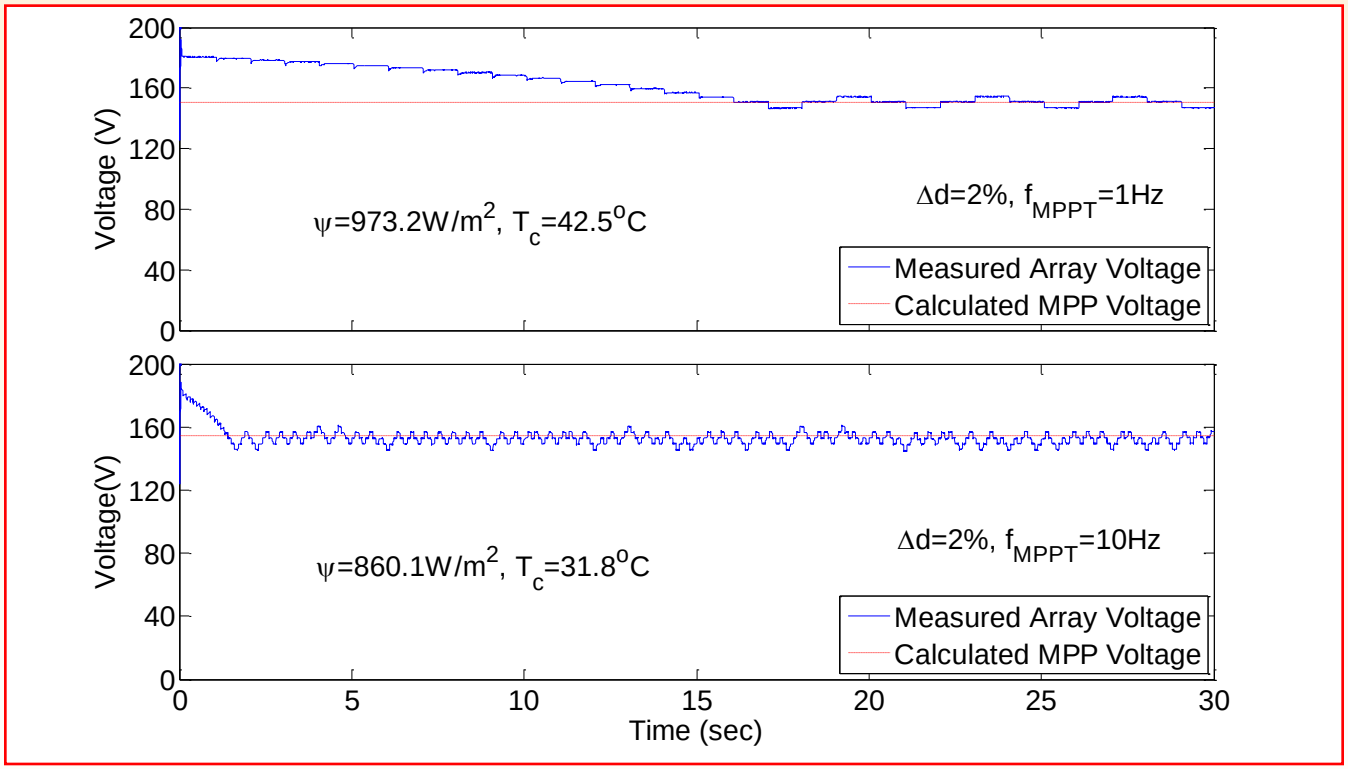
Behavior with reference voltage perturbation in thee-level operation

P&O Algorithm Parameters



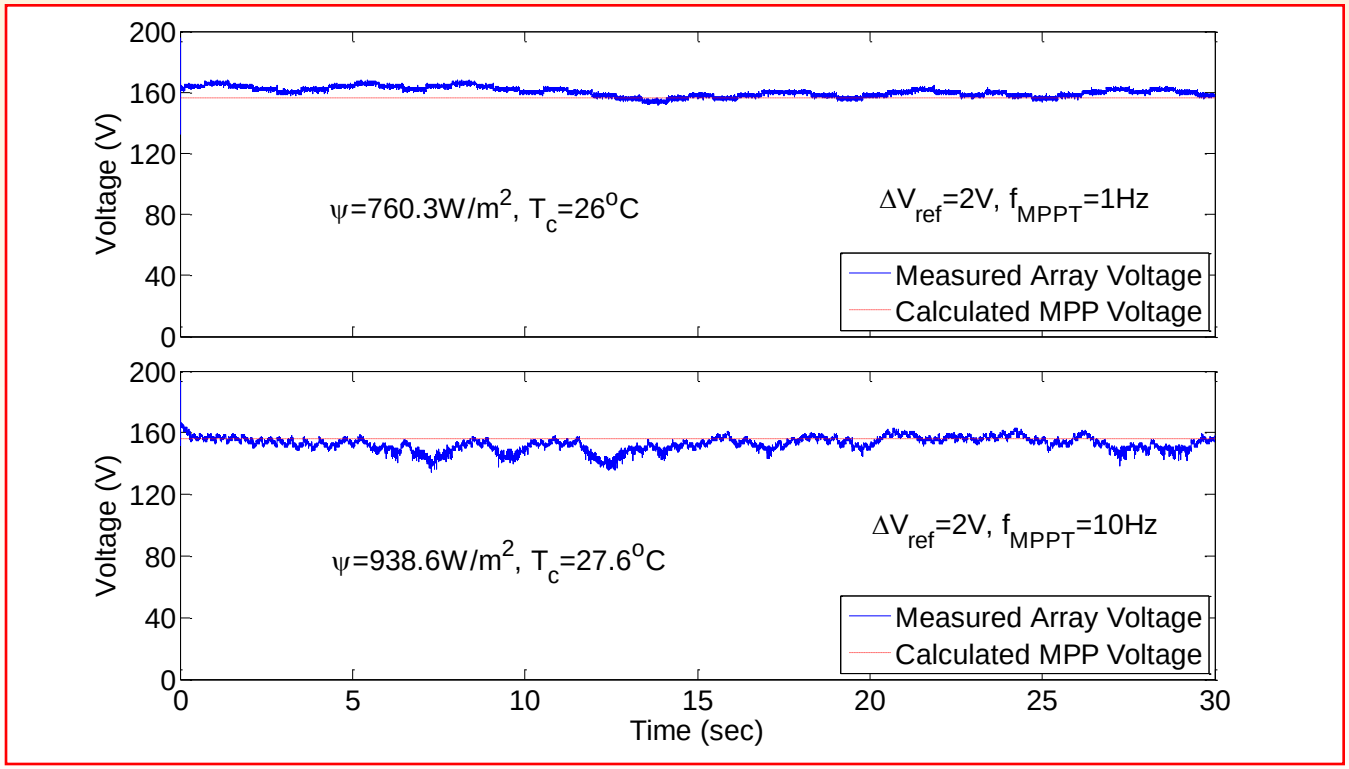
Three-level operation with direct duty ratio perturbation

Effect of P&O Algorithm Parameters



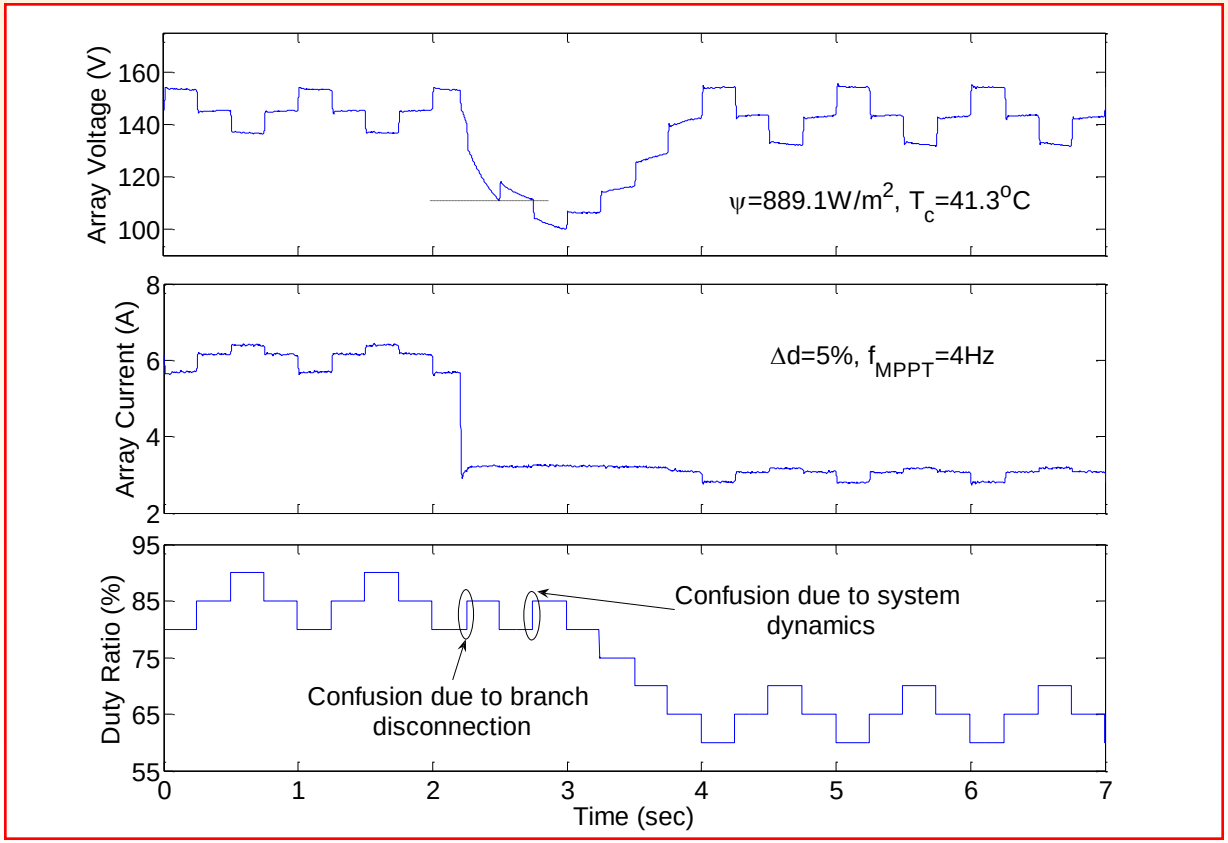
The effect of algorithm parameters on the array voltage; P&O MPPT algorithm with direct duty ratio perturbation

P&O Algorithm Parameters



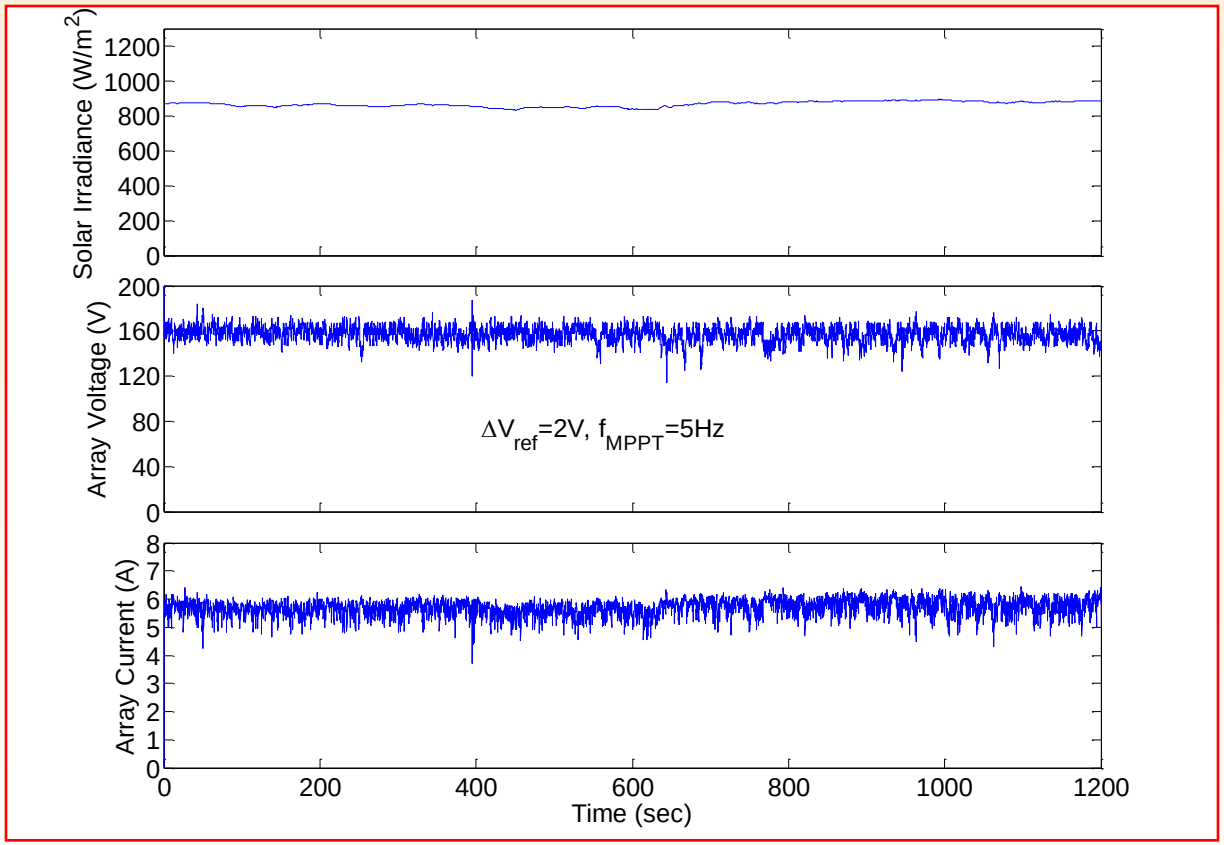
Experimental results showing the effect of algorithm parameters on the array voltage; P&O MPPT algorithm with reference voltage perturbation

P&O Algorithm Parameters



Experimental results showing the system responses to a PV array branch disconnection (Δd=5%, fMPPT=4Hz)

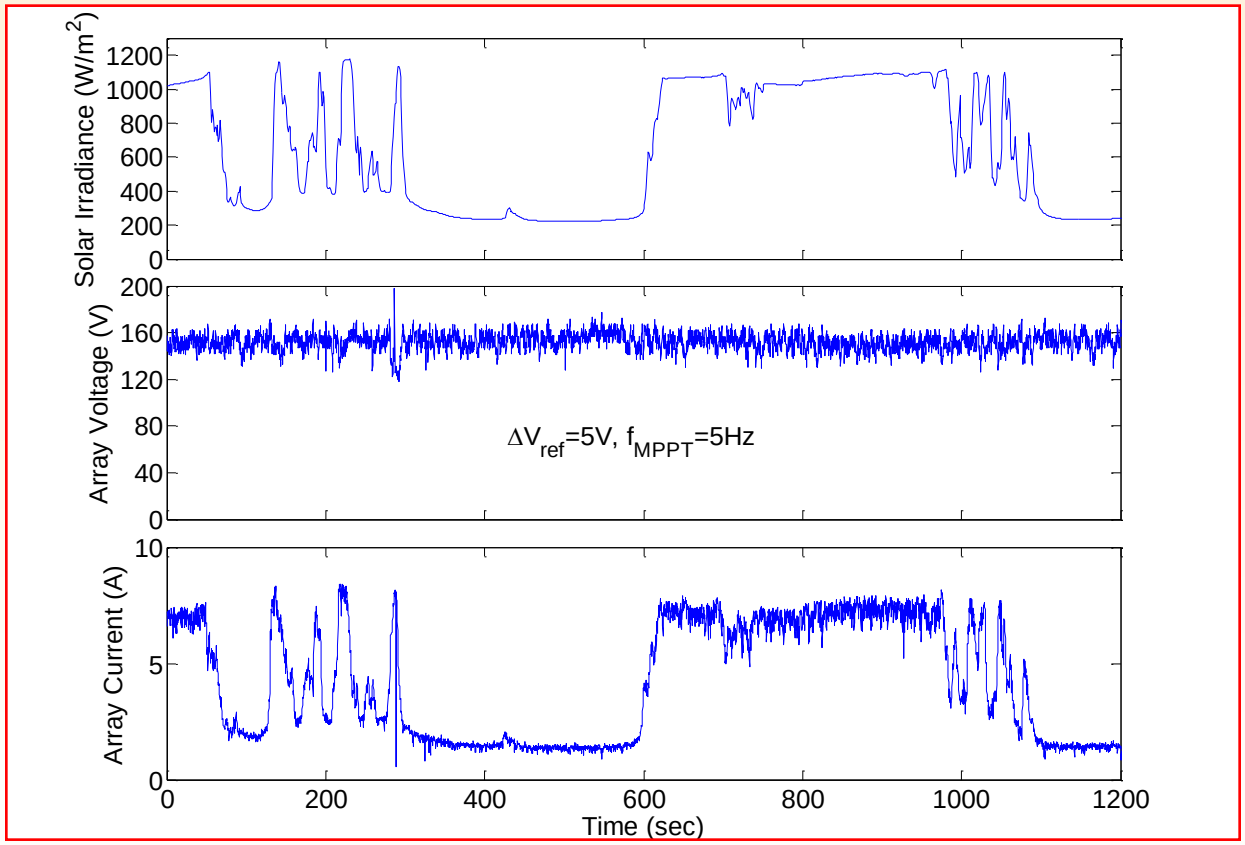
Energy Utilization with P&O Algorithm



97.2%

Experimental system performance under slow changing irradiance; P&O algorithm with reference voltage perturbation (ΔV=2V and f_{MPPT}=5Hz)

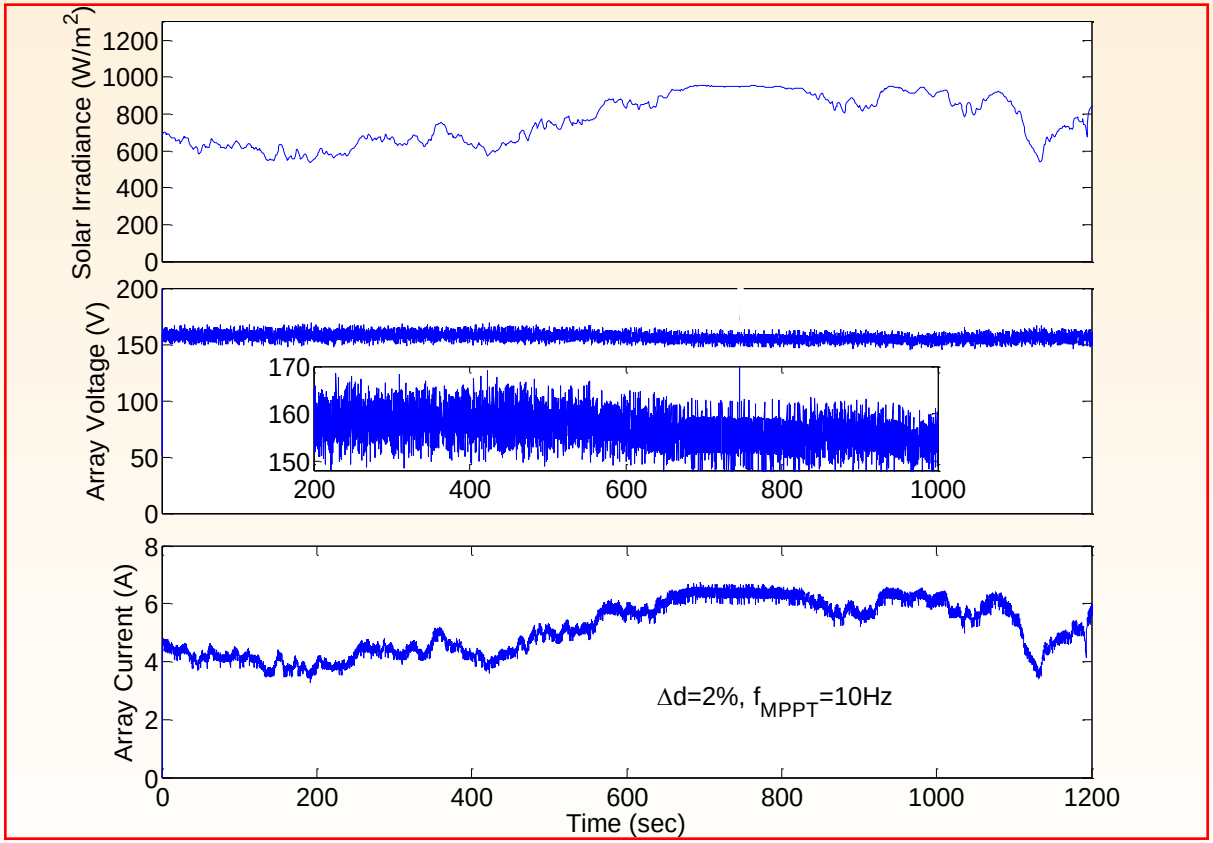
Energy Utilization with P&O Algorithm



97%

Experimental system performance under rapidly changing irradiance; P&O algorithm with reference voltage perturbation

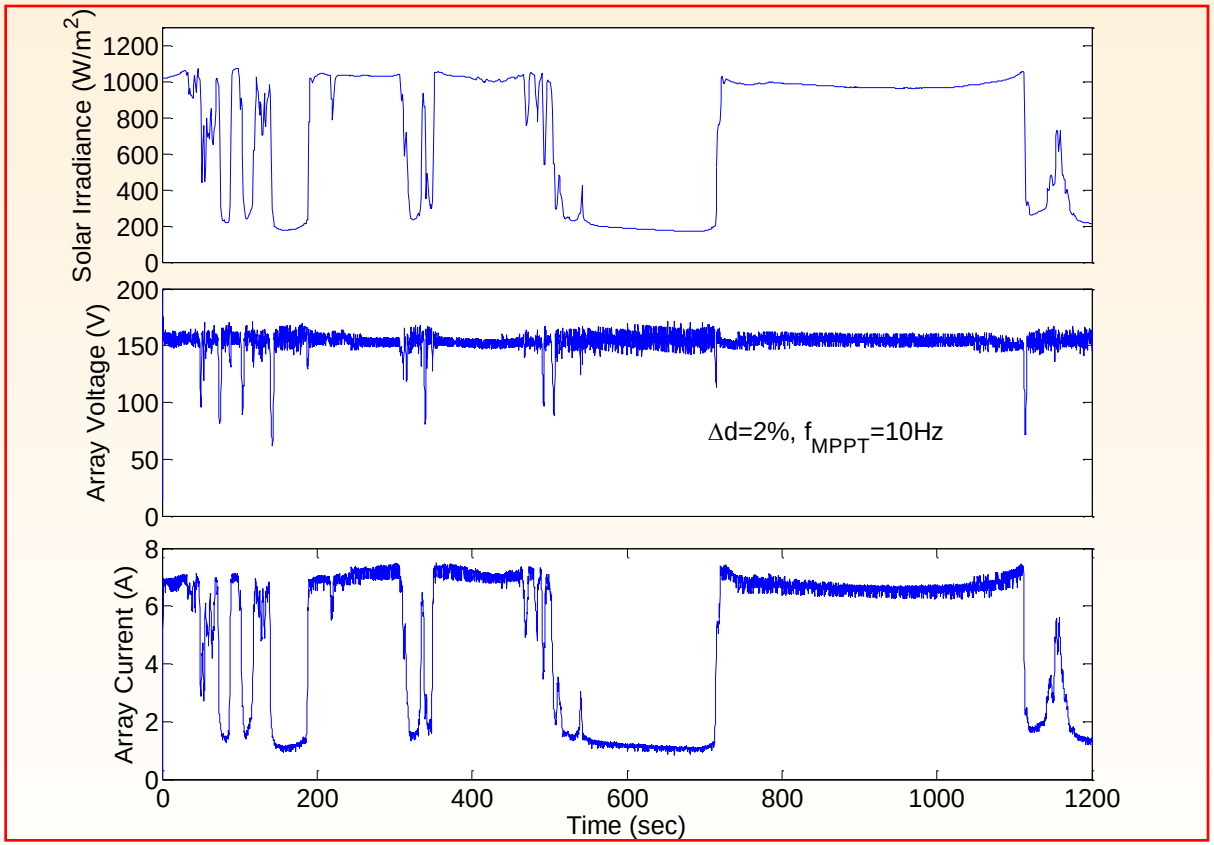
Energy Utilization with P&O Algorithm



99%

Experimental system performance under slow changing irradiance; direct duty ratio perturbation

Energy Utilization with P&O Algorithm



97.9%

Experimental system performance under rapidly changing irradiance; direct duty ratio perturbation

Conclusions II

- **The P&O MPPT algorithm is a simple algorithm that does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature.**

- **Two approaches for implementing the P&O algorithm have been investigated; reference voltage perturbation and direct duty ratio perturbation.**

Conclusions II

- With reference voltage perturbation, the system has a faster transient response **to irradiance and temperature transients.**

- However, stability is lost if the MPPT algorithm is operated at high perturbation rates or if low pass filters are used to reject noise from the array current and voltage feedback signals.

Conclusions II

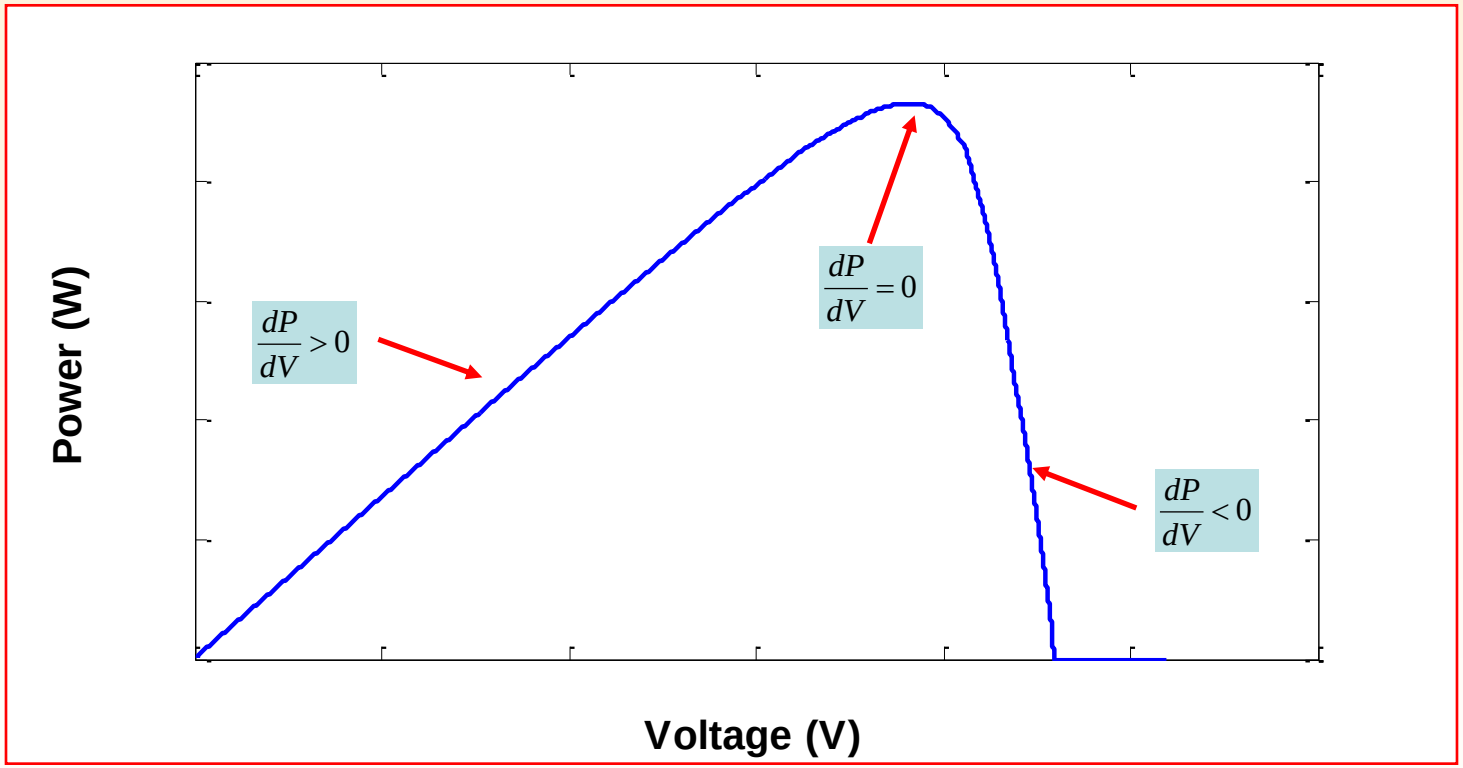
- Direct duty ratio control offers better stability characteristics and higher energy utilization efficiency at a slower transient response and worse performance at rapidly changing irradiance.

- **Noise has significant impact on the algorithm performance, especially with low step sizes where the system response to noise is comparable to that of MPPT perturbations.**

Outline

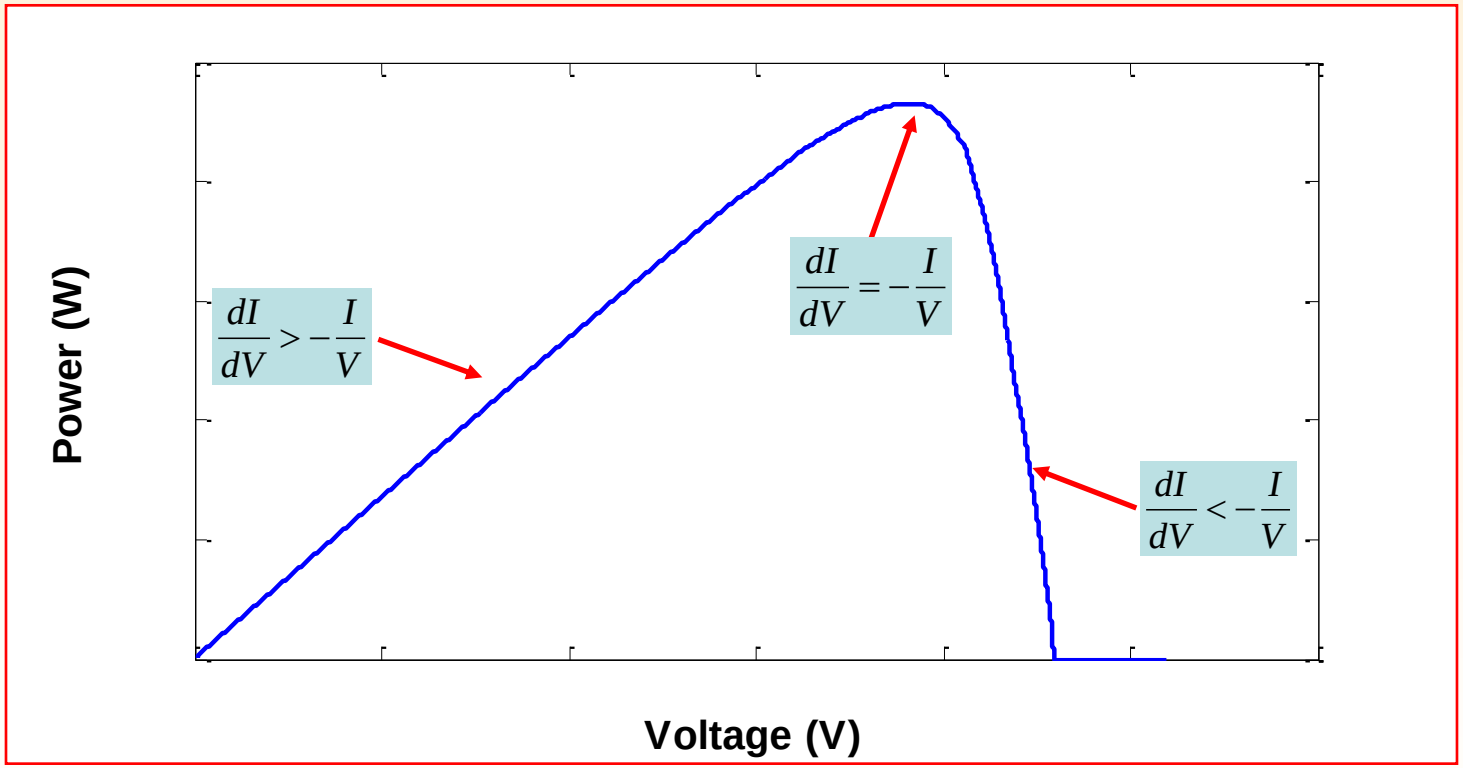
- Introduction
- System Description
- Directly Connected PV Pumping Systems
- PV Pumping systems with MPPT
  - Constant Voltage MPPT Algorithm
  - Perturb and Observe (P&O) MPPT Algorithm
  - Incremental Conductance (INC) MPPT Algorithm
- Conclusions

Incremental Conductance MPPT Algorithm



Power-Voltage Curve of a PV Generator

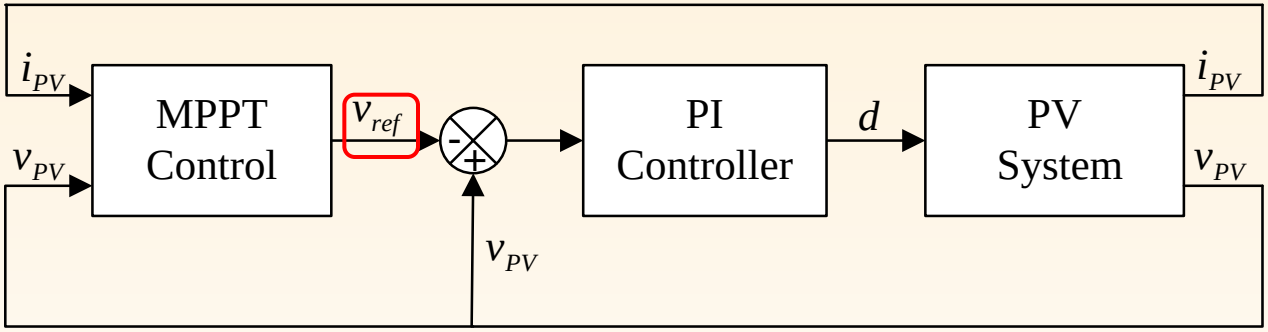
Incremental Conductance MPPT Algorithm



Power-Voltage Curve of a PV Generator

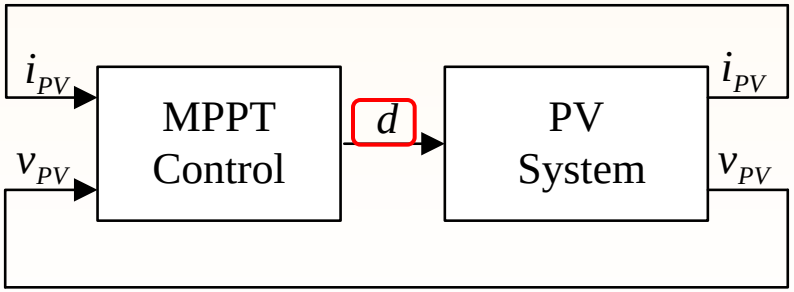
Incremental Conductance MPPT Algorithm

- **Reference voltage for the array output voltage**



Block diagram of MPPT with reference voltage control

- **Converter duty ratio**

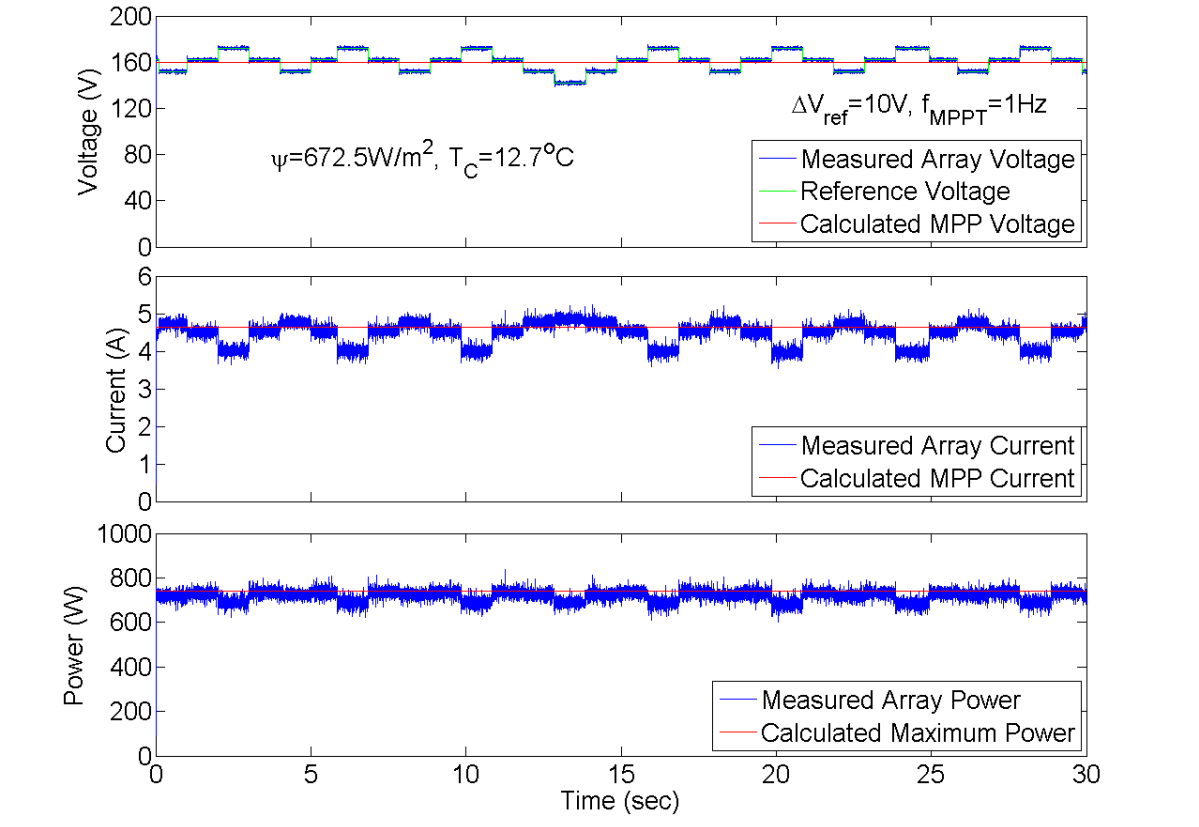


Block diagram of MPPT with direct duty ratio control

Incremental Conductance MPPT Algorithm

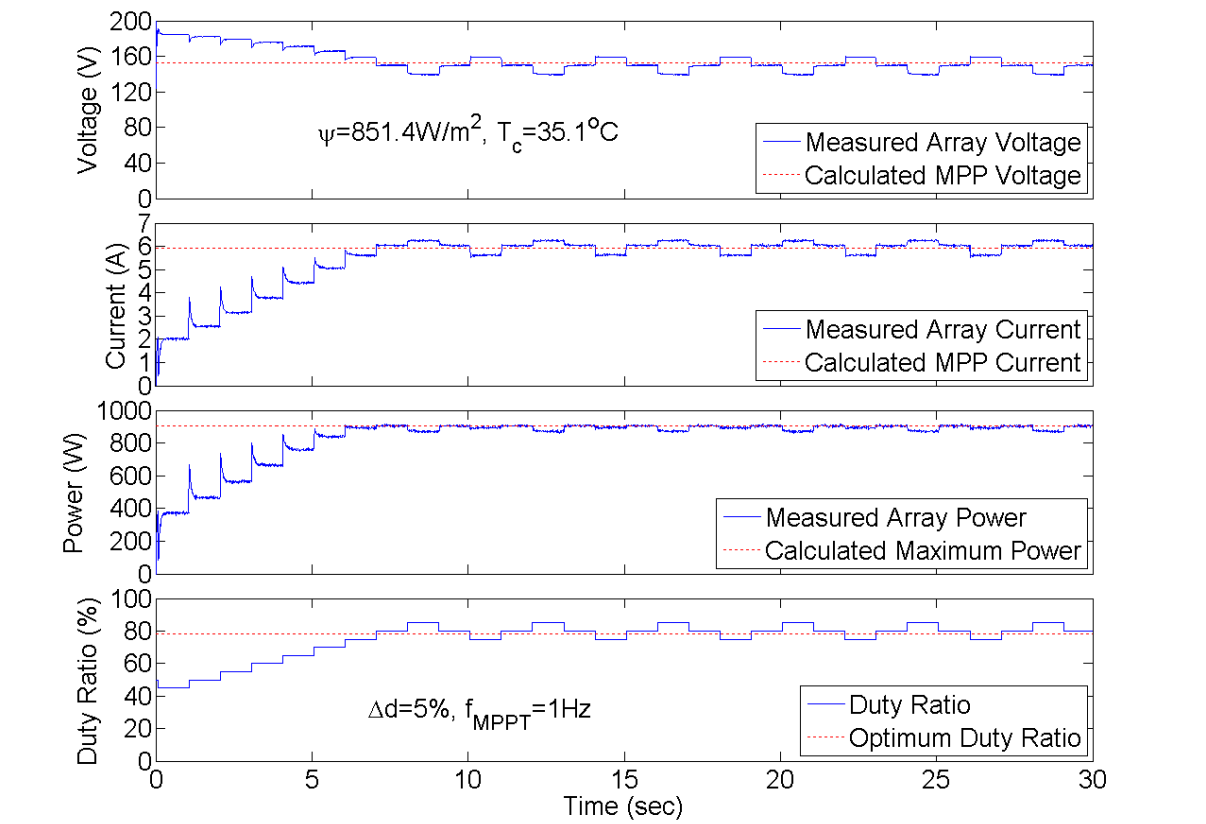
- **The system performance is affected by:**
  - **Step Size (Δd or ΔV_{ref})**
  - **Perturbation Frequency (f_{MPPT})**

INC Algorithm Parameters



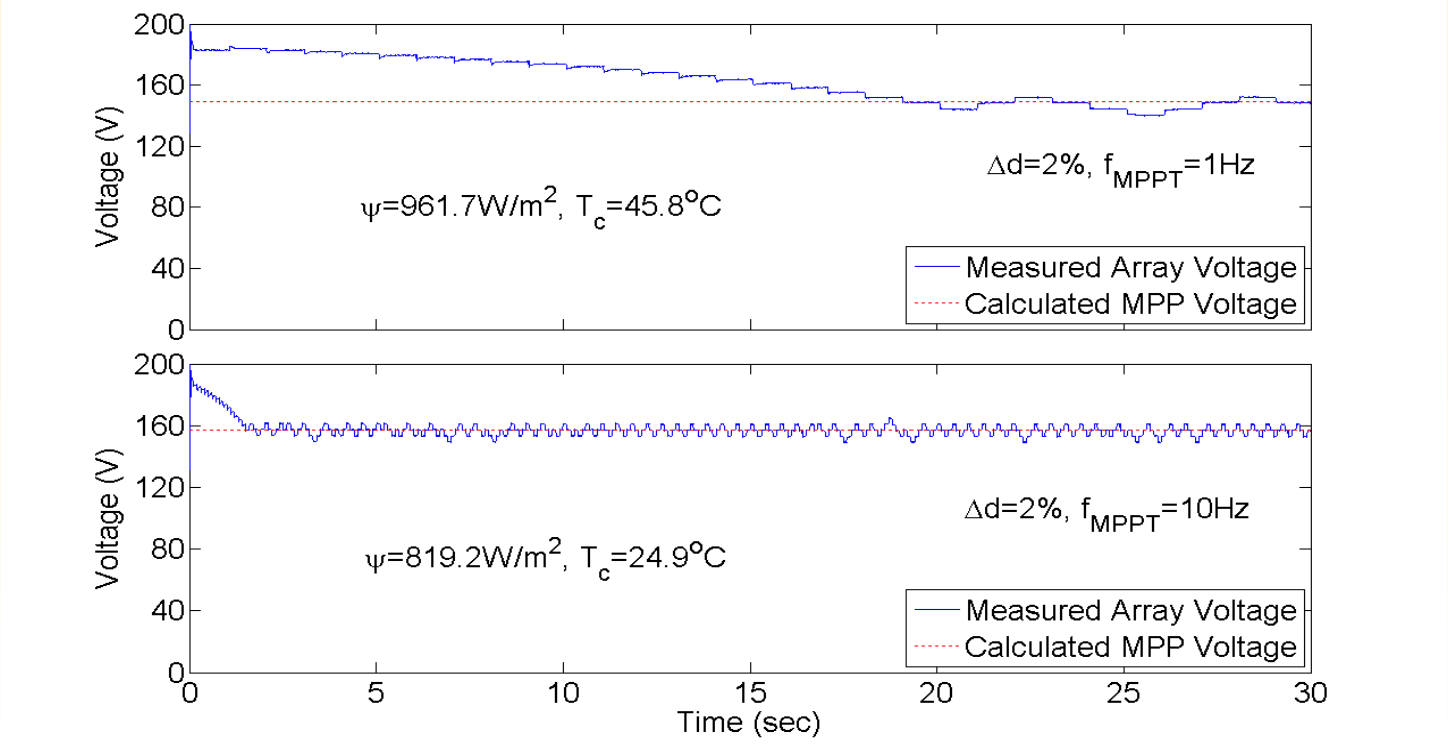
Three-level operation with reference voltage perturbation

INC Algorithm Parameters



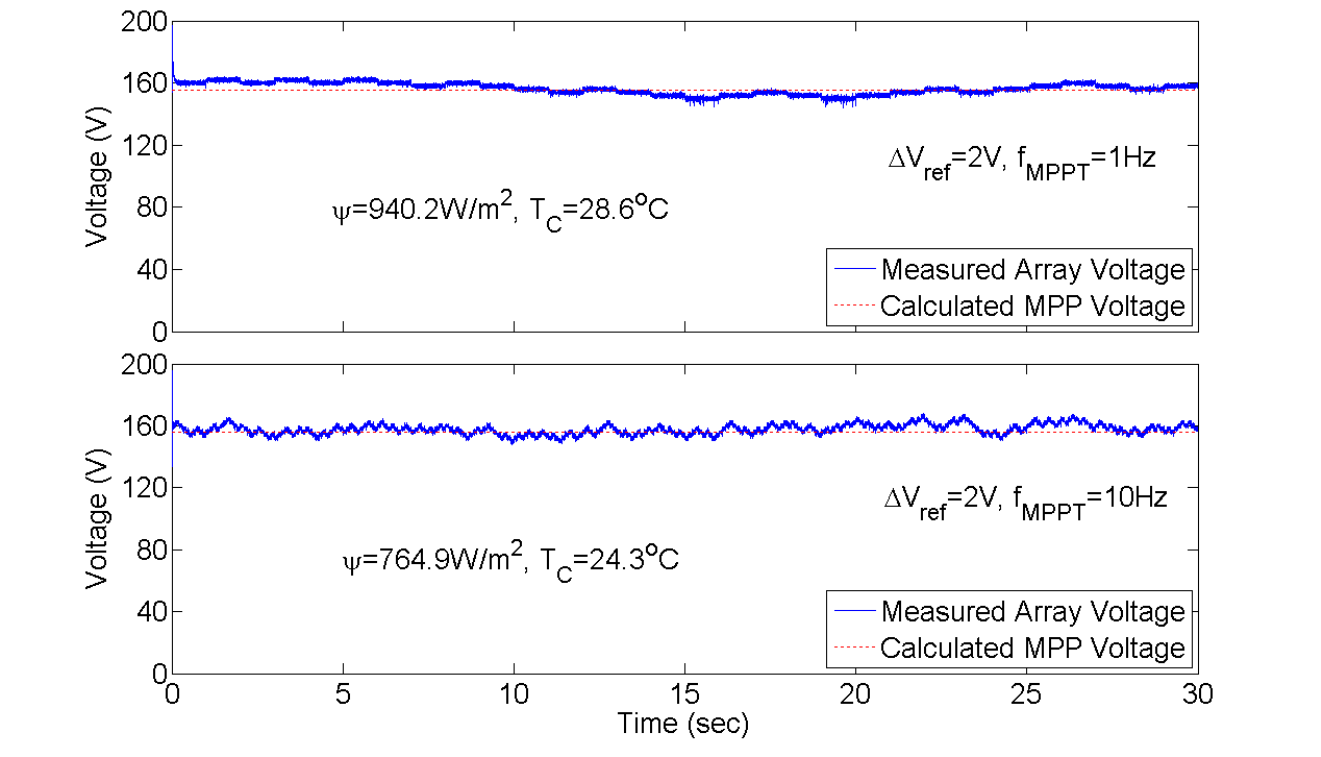
Three-level operation with direct duty ratio perturbation

INC Algorithm Parameters



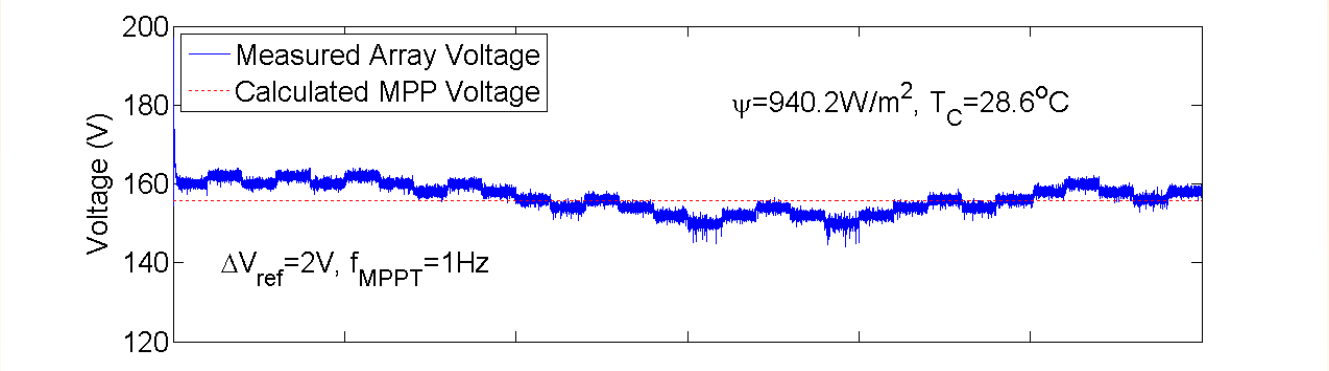
The effect of algorithm parameters on the array voltage; INC MPPT algorithm with direct duty ratio perturbation

INC Algorithm Parameters



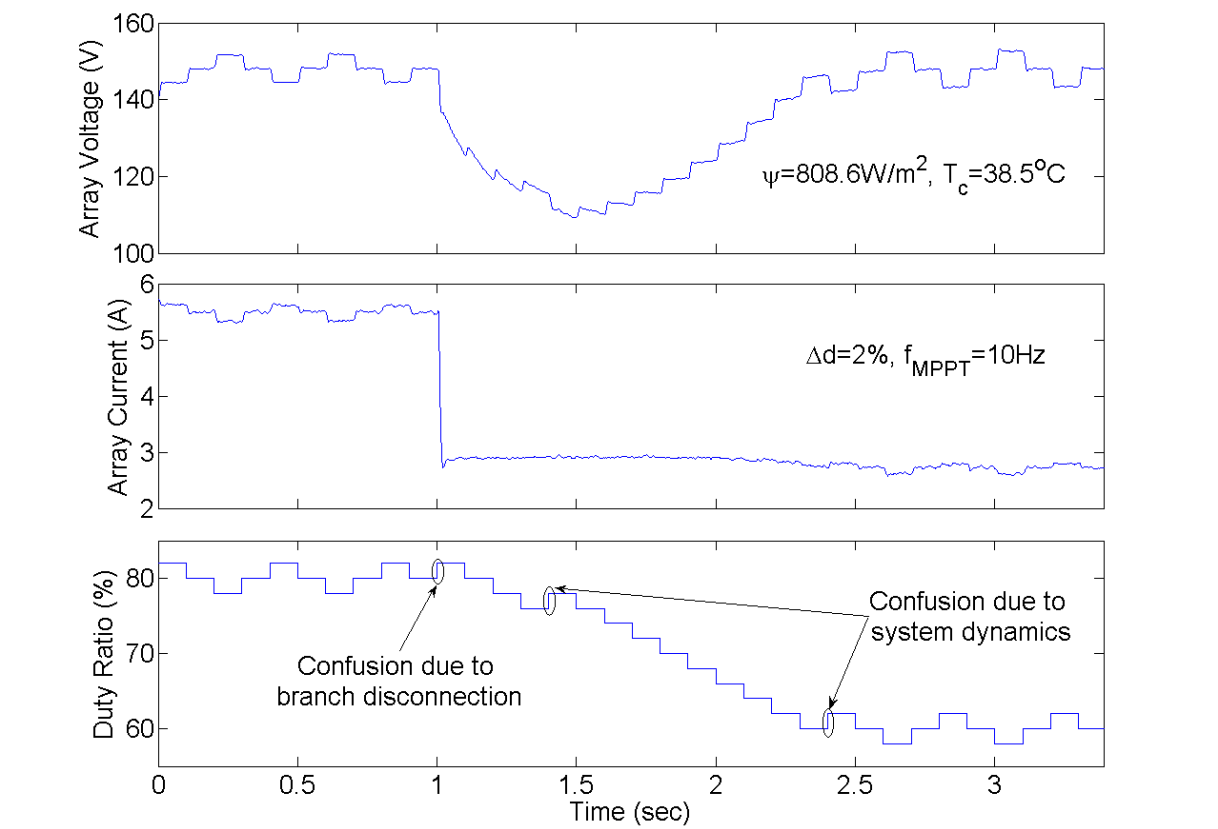
The effect of algorithm parameters on the array voltage; INC MPPT algorithm with reference voltage perturbation

INC Algorithm Parameters



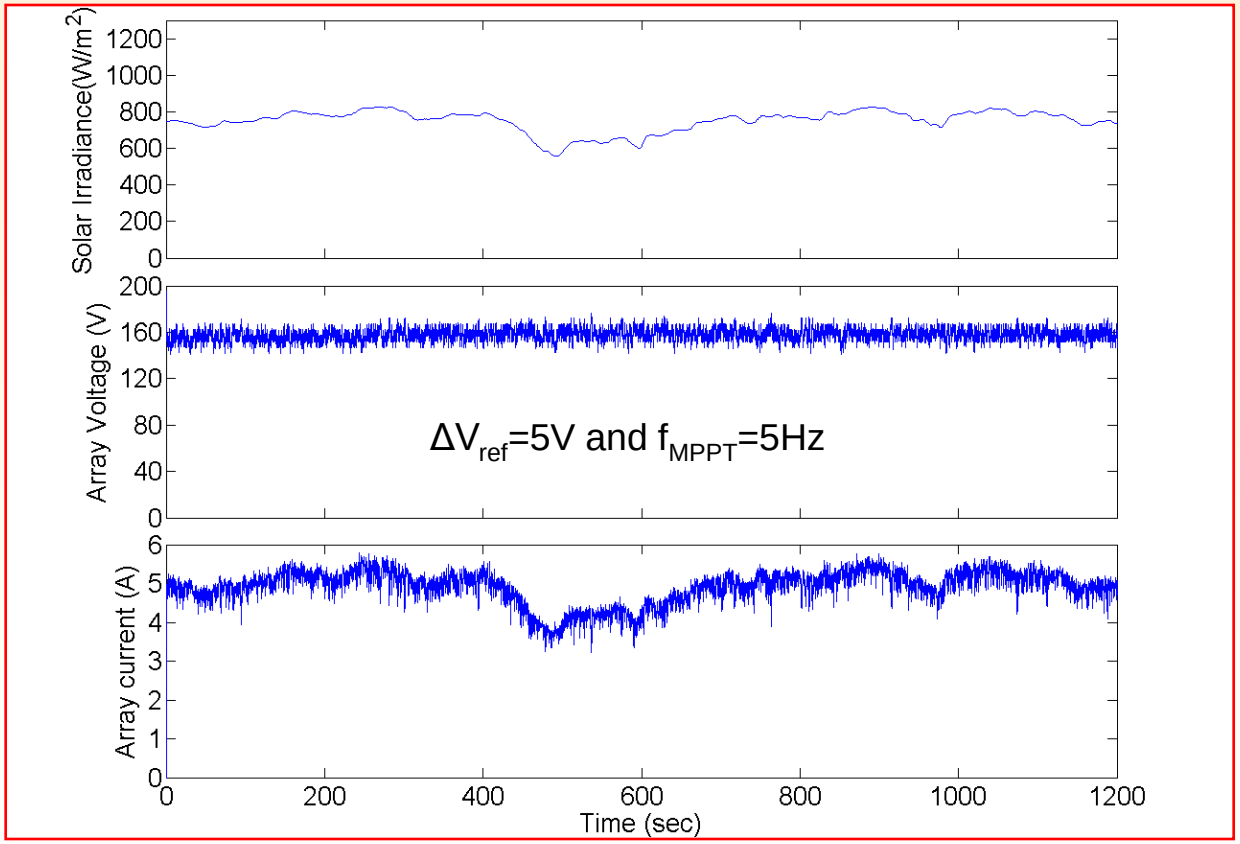
The effect of noise on the decision of the INC algorithm; reference voltage perturbation

INC Algorithm Parameters



Experimental results showing the system responses to a PV array branch disconnection (Δd=2%, f_{MPPT}=10Hz)

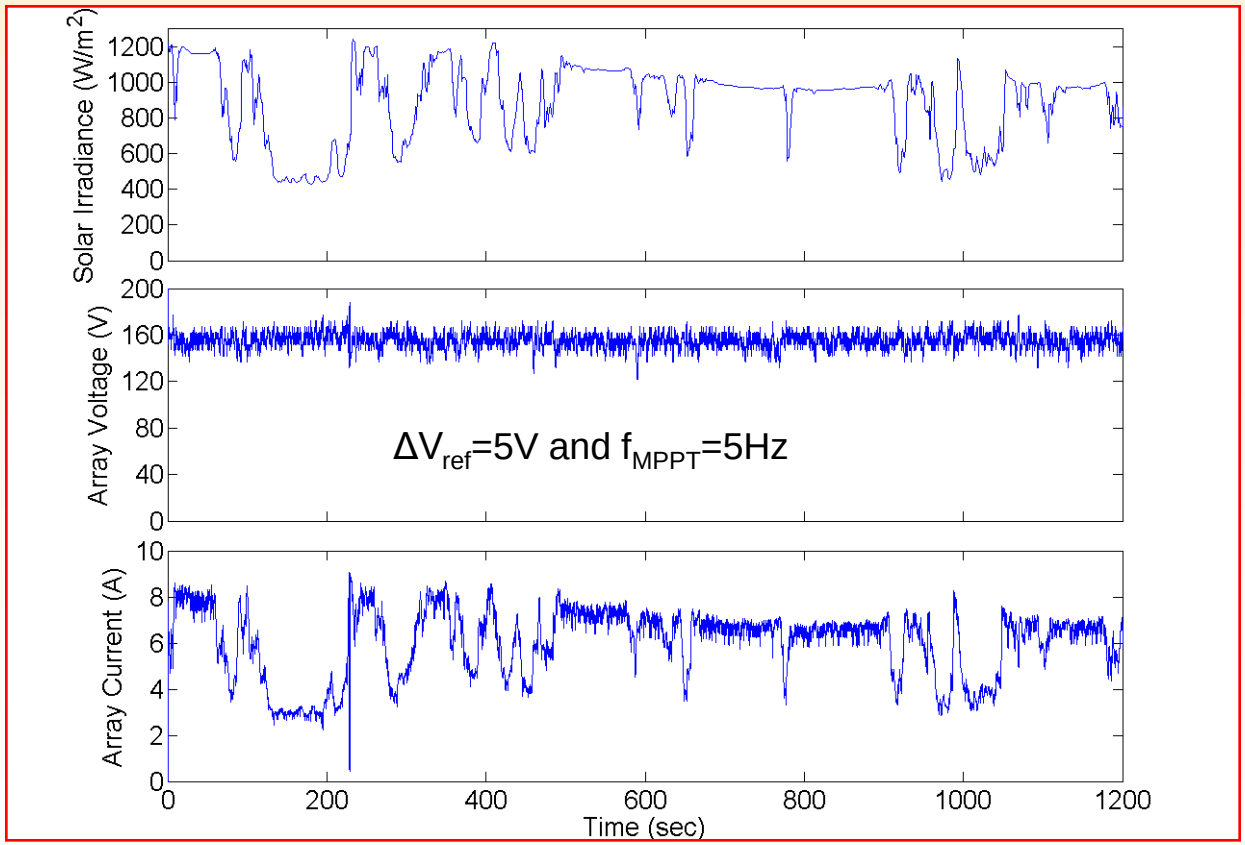
Energy Utilization with INC Algorithm



97.6%

Experimental system performance under slow changing irradiance; reference voltage perturbation (ΔV=2V and f_{MPPT}=5Hz)

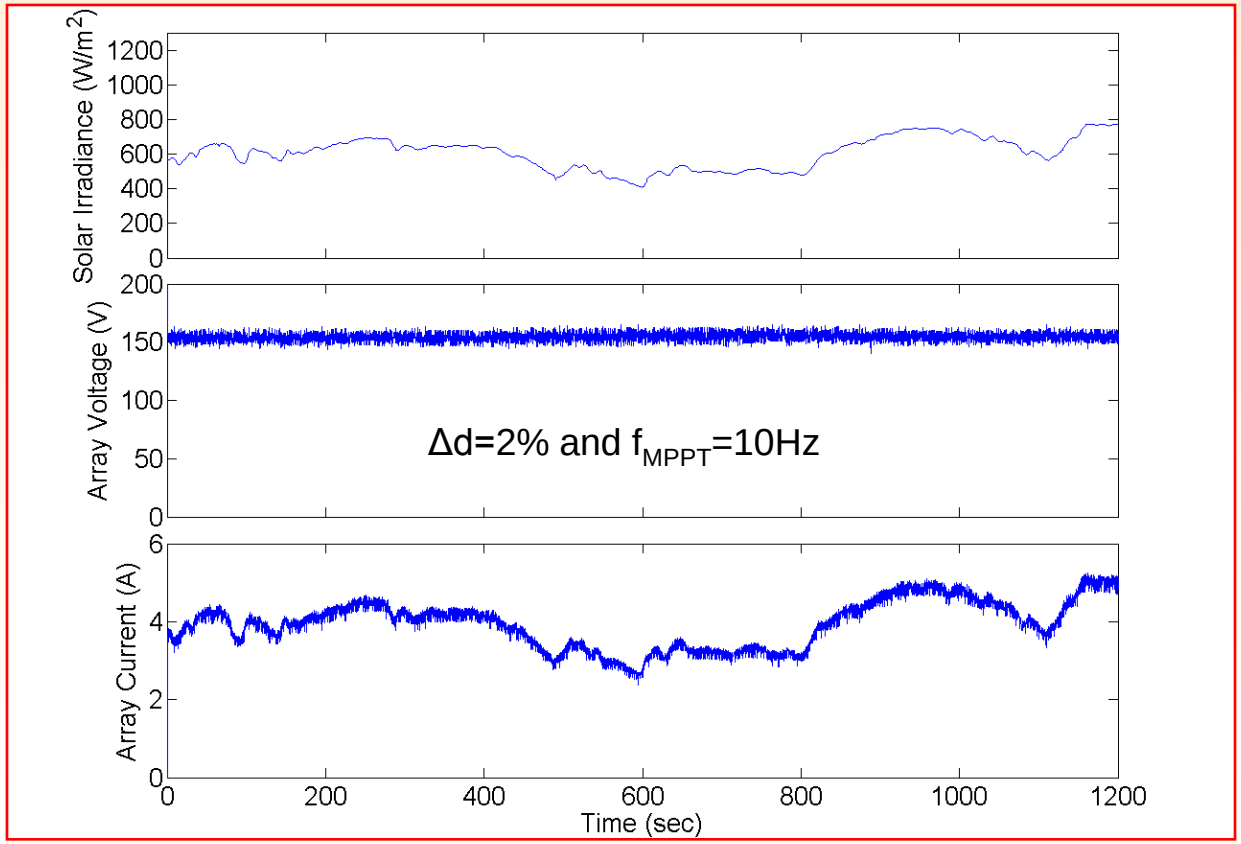
Energy Utilization with INC Algorithm



94.9%

Experimental system performance under rapidly changing irradiance; reference voltage perturbation

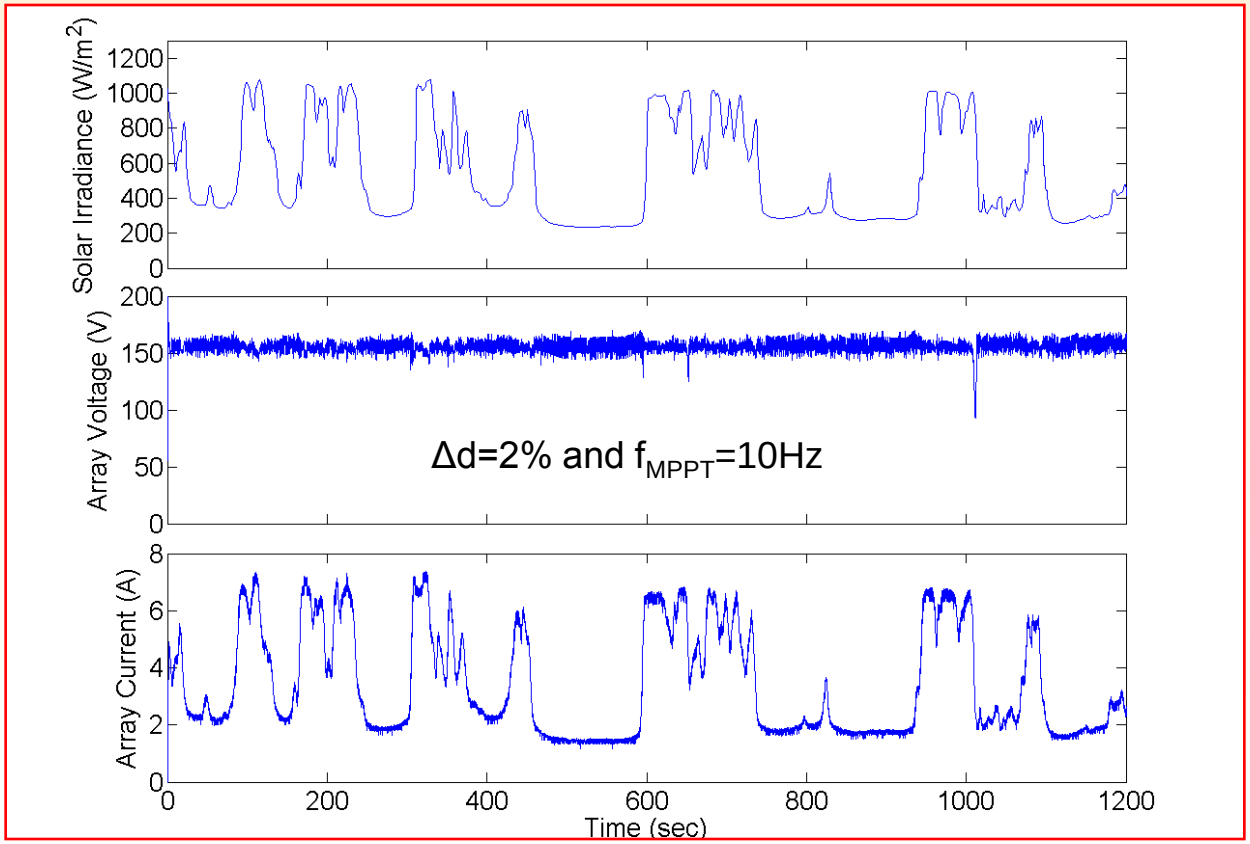
Energy Utilization with INC Algorithm



98.5%

Experimental system performance under slow changing irradiance; direct duty ratio perturbation

Energy Utilization with INC Algorithm



96.8%

Experimental system performance under rapidly changing irradiance; direct duty ratio perturbation

Conclusions III

- The INC algorithm is less confused by noise and system dynamics compared to the P&O algorithm. However, contrary to general perceptions, it was found to exhibit worse confusion than the P&O algorithm in rapidly changing weather conditions.

- **Both algorithms offer high energy utilization efficiencies of up to 99% depending on weather conditions. The efficiency is marginally lower for rapidly changing irradiance due to the energy loss during the confusion and recovery periods.**

More Details

- M. A. Elgendy, B. Zahawi and D. J. Atkinson, "Comparison of Directly Connected and Constant Voltage Controlled Photovoltaic Pumping Systems," IEEE Transactions on Sustainable Energy, Vol. 1, No. 3, pp. 184-192, Oct. 2010
- M. A. Elgendy, B. Zahawi and D. J. Atkinson, "Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications," IEEE Transactions on Sustainable Energy, Vol. 3, No. 1, pp. 21-33, Jan. 2012

Thank you

Bashar Zahawi

E-mail: bashar.zahawi@ncl.ac.uk