Irradiance-induced Ramp Rates in the Low Voltage Distribution Grid

QUEEN'S UNIVERSITY BELFAST

Kevin Murray
EPIC Cluster

Supervisors Prof. John Morrow and Dr. Robert Best

Introduction

Increasing penetration of solar photovoltaic (PV) systems into the low voltage distribution grid has created issues for grid operators world-wide, regarding the maintenance of voltage regulation and control of power flows. Cloud-induced variability in irradiance can create undesirably large ramps in PV system output over very short time-scales. The effect is spatiotemporal in nature and may be enhanced or diminished depending on the spatial distribution of solar PV systems within the network area and the penetration levels of solar PV within the network.

Ireland's Atlantic maritime climate and prevailing weather systems create ideal conditions for the passage of irradiance ramps under skies with broken sunshine. This research co-locates measurement equipment alongside 25 PV systems in a rural 11kV network to investigate how distributed plane-of-array irradiance ramps translate into PV system DC and AC power ramps within the local network. This learning seeks to inform the prediction and modelling of PV impacts and assess the potential for their amelioration through the application of energy storage and advanced inverter controls.

An overview of the equipment designed to facilitate the required measurements is given below along with the methodology for its application in a two-stage process, firstly locally within the identified feeder and later in a network-wide application within the grid in Northern Ireland. A summary of the overall objectives guiding this research is provided.

Geo-spatial distribution of the solar PV systems measurement sites

Methodology

The irradiance sensors have been calibrated with regards to five secondary standard pyranometers over several weeks to confirm operation within their +/- 5% specification.

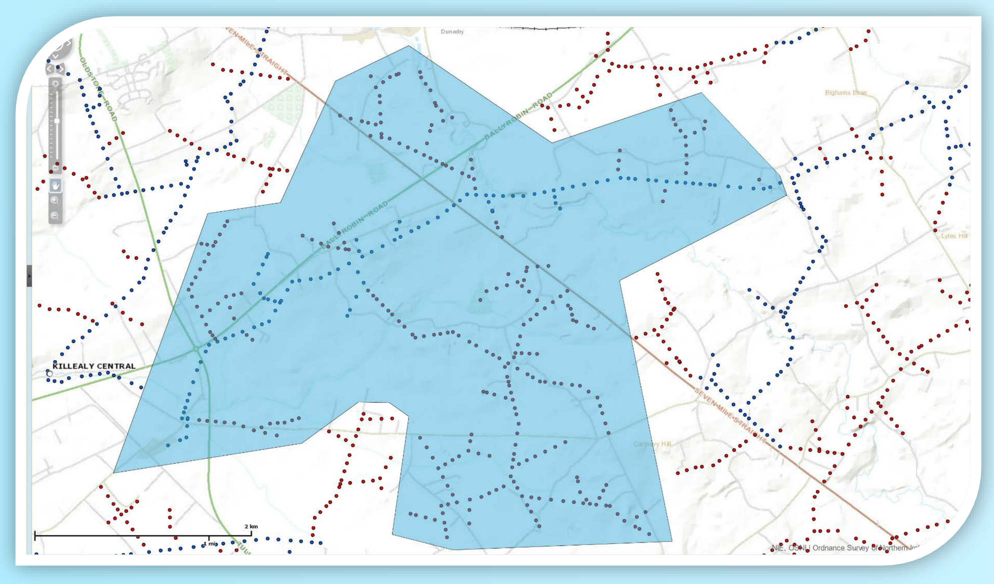
Calibration rig with weather station

The equipment will be installed for a period of six months, with all available PV systems being included to capture the full PV influence on the feeder. Data will be logged at variable sample rates and time-stamped, using phase-locked GPS signals, along with the camera images being recorded every 10 seconds. The low-voltage network at 11kV level and below is being mapped and will be modelled using OpenDSS software. Simulations will be run at high temporal resolution, incorporating the measured irradiance ramps and inverter outputs, as well as additional time-stamped phasor measurements from key network nodes.

The camera network will be used to construct a three-dimensional cloud map, from which will be derived a global horizontal irradiance map. This will be compared with the recorded irradiance values from the horizontal photo-diodes and cross-correlated with the POA irradiance values measured by the PV reference cells.

An artificial neural network will be trained on the images, irradiance and PV systems measurements to provide a short-term forecast capability across the low voltage network. A centrally located weather system within the network will provide additional inputs to the neural network in terms of wind speed and direction, rainfall duration and intensity, humidity and pressure.

11kV rural feeder measurement area and network topology



Hardware

The equipment development has sought to exploit low-cost embedded hardware that is readily available and can be deployed economically in sufficient quantities within the distribution network. The sky camera is based on the new Raspberry Pi Zero W board with its associated 5MP fisheye camera. The camera has a 160° maximum field of view and a resolution of 2952 x 1944 and will be used with bracketed exposure to generate HDR images via post-processing.

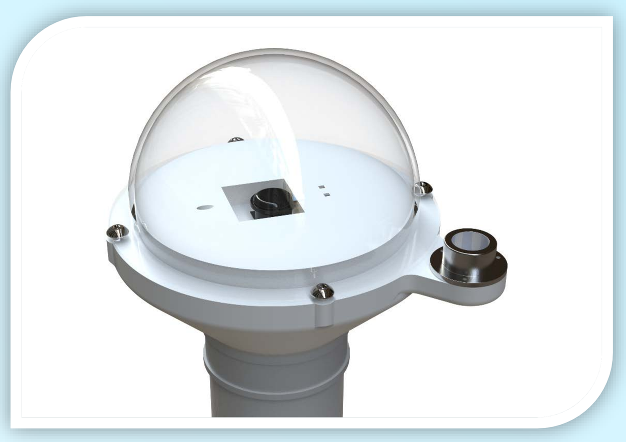
The roof-mounted camera is complemented by irradiance sensors and temperature sensors. The irradiance sensors comprise both a precision PV reference cell (IMT Si-12TC) and two extended response photo-diodes (BPW 34B). The photo-diodes will record Global Horizontal Irradiance (GHI) and plane-of-array (POA) irradiance, while the reference cell will only record POA irradiance. The temperature of the one of the array modules and of the inside of the camera housing will be recorded to compensate for secondary temperature influences.

A roof-mounted U-Blox Neo 7N GPS module, within the housing, facilitates the timing co-ordination between the camera and data-logger at each site, as well as between all the sites across the feeder to a high degree of accuracy.

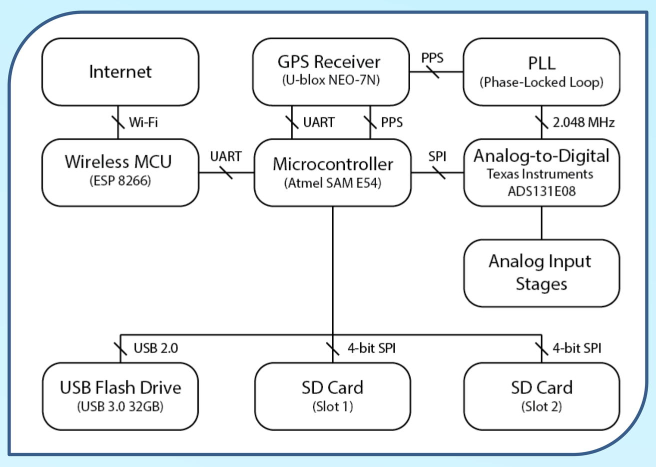
A network of the cameras will be co-located at chosen solar PV system sites distributed across the feeder area and will be complemented by a further four outliers approximately 10km beyond the feeder perimeter.

At each inverter the DC string voltages and currents will be sampled, along with the inverter AC voltage and current using isolated LEM LV and LTS Hall-effect sensors. A Texas Instruments A/D converter that allows simultaneous sampling of 8 inputs at rates up to 1000 samples per second with 24-bit resolution will be employed for all measurements (except temperature, which will be recorded at lower frequency via the Atmel SAM E microprocessor). The microprocessor will co-ordinate the measurements and transfer and store the data locally on USB and Micro-SD storage devices.

The measurement equipment is enclosed in an IP68 box to facilitate outdoor measurements and is powered from the inverter AC supply via an internal DC isolated supply.



Pi Zero-based camera with photo-diodes



Overview of data logger design

Research Objectives

A second-stage of the research, next year, will build on the learning from the first phase to evaluate the utility in improving short-term forecasting of solar PV generation across the whole Northern Ireland grid to optimize grid management and enable the design and control of energy storage facilities. The principal objectives are to:

- Quantify the magnitude and frequency of irradiance ramp rates across a typical feeder area
- Model the irradiance, DC power and AC power transfer characteristic for in-field inverters
- Compare the spatiotemporal variation of irradiance ramps with available models, such as the Wavelet Variability Model (PVPMC)
- Model the feeder in OpenDss and simulate the feeder impact using the measured inputs
- Evaluate the utility of energy storage, both distributed and centrally-located, to ameliorate excessive PV impacts to improve hosting capacity
- Evaluate storage management strategies of some commercial small-scale distributed storage units
- Investigate the effectiveness of energy storage in comparison or in conjunction with other network management techniques, particularly advanced inverter controls
- Employ the Image Processing Toolbox in MATLAB to condition the sky camera images
- Construct an irradiance map from the three-dimensional cloud model derived from the network of low-cost sky cameras
- Investigate any improvement yielded by the irradiance/PV power models over current persistence models for near term forecasting
- Explore the expansion of cloud-based irradiance modelling to a network-wide area across the NI grid
- Investigate the utility of improved near term forecast models to enhance the management of energy storage state-of-charge management and dispatch availability.

DC-coupled distributed energy storage testbed

PVPerformance MODELING COLLABORATIVE

2018 PV Systems Symposium and 10th PVPMC Workshop, Albuquerque, New Mexico USA 1st – 3rd May 2018

This research is funded by the UK Engineering and Physical Sciences Research Council

EPSRC Engineering and Physical Sciences Research Council