Study Committee C6

Active Distribution Systems and Distributed Energy Resources

10206_2022

Directional Power Flow Monitoring in Overhead Line Distribution Networks with High Penetrations of DER

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Motivation

- Difficult to capture data in overhead networks, due to the construction of the system and the availability of equipment throughout the network to gather data.
- As Western Power Distribution (WPD) transitions from a DNO to a DSO, there is an increasing requirement for localised network monitoring to enable and enhance system operation functions.
- Moreover, improved monitoring could unlock latent capacity, hence leading to more efficient and economical utilisation of the assets.
- This project contributed towards the "Network Monitoring and Visibility" challenge within the "Assets" section of WPD's "Distribution System Operability Framework".

Method

- This project has trialled a device that is capable of self-powering operation to provide real-time voltage, current and power flow information, without the requirement for a bonded reference to earth.
- Smart Navigator 2.0 sensors clip onto overhead lines (operating at voltages from 11kV to 132kV) and sample the voltage and current waveforms (multiple times per cycle) to determine the real-time power flow direction at that point in the network.

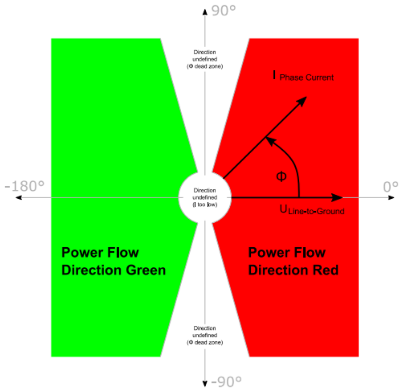

Figure 1: Directional Power Flow Theory

- Using encrypted DNP3 communications over mobile networks, the devices transmit power flow data from remote sites to a central system (for example, Nortech's iHost, or GE's PowerOn).

Objectives

- Carry out assessments of the accuracy and consistency of determining power flow directions within WPD's distribution network.
- Provide recommendations on the number and location of devices needed for full visibility of power flow direction.
- Provide the control room with visibility of directional power flows through overhead circuits.

Field Trials

- 100 sets of Smart Navigators were installed on OHLs across two of WPD's licence areas; West Midlands (11kV, 33kV and 66kV circuits) and South West (132kV circuits).
- Trials were conducted over a period of two years.

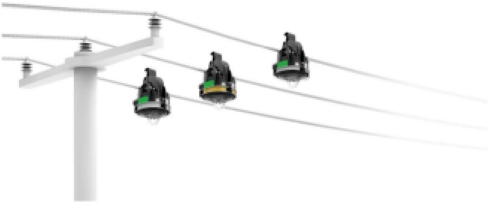

Figure 2: Smart Navigator 2.0 OHL Monitoring Equipment

Discussion

- Changes in power flow direction were observed regularly in circuits throughout the field trial period.
- The accuracy and consistency of the solution has been assessed and quantified in a controlled laboratory environment, and during the live field trials the performance of the solution was successfully tested against SCADA records.

Conclusions

- Visibility of power flow direction through circuits will enable planning engineers to accurately assess the available headroom in the system to inform planning applications for new generation connections.
- Without due consideration a saturation point could be reached prematurely when the limits of reverse power flow capacity of primary and grid transformers are approached.
- This could result in curtailment of distributed generation connections without major network reinforcement.

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Field Trial Test Setup

- The schematic (Figure 3) illustrates a typical 11kV radial feeder, the yellow symbols are indicative of the locations of Smart Navigator 2.0 equipment.
- Similar schemes were established for 11kV, 33kV, 66kV and 132kV overhead line systems.
- The operational running arrangement was monitored to capture the influence of manual switching events on power flows through circuits during the field trials.
- One device was installed on each phase, which also informed the unbalance across the different phases.

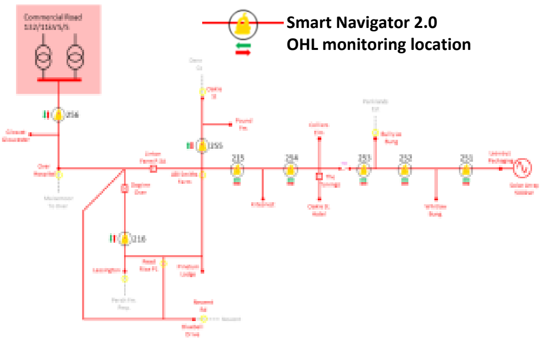

Figure 3: Representative 11kV Feeder

Figure 4: Interactive Dashboard for Real-time Operations View

User Interface

- An interactive dashboard (Figure 4) was developed to display live operational data was made available to WPD's control room.
- A standalone symbol was developed for WPD's Distribution Management System (PowerOn) to alert the control room to the location of fault events on the network, present direction of power flow information and line current magnitude.

Results

- The contour diagram (Figure 5) presents the observed power flow magnitude and direction over the course of a year through a 132kV OHL circuit.
- The reversal of power flow on a typical day was attributable to the influence of utility scale solar PV generation connected cross the region.

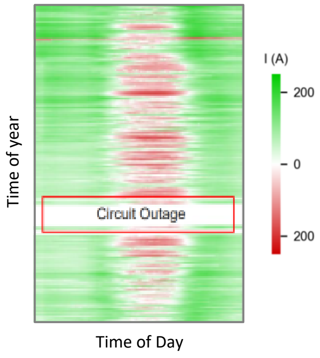

Figure 5: Daily & Seasonal Directional Power Flow Trends

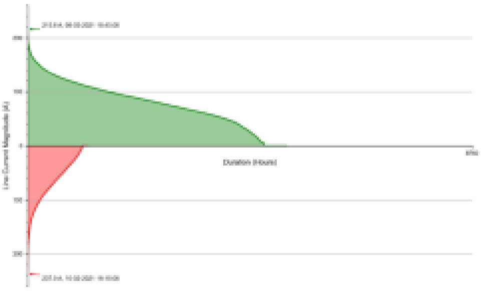

Figure 6: Load Duration Curve

- The dataset has also been presented as a load duration curve (Figure 6).
- A notable observation is that the peak power flow was observed to be in the 'red' direction, i.e. the opposite direction to the conventional flow of power ('green') through direction through this particular system.

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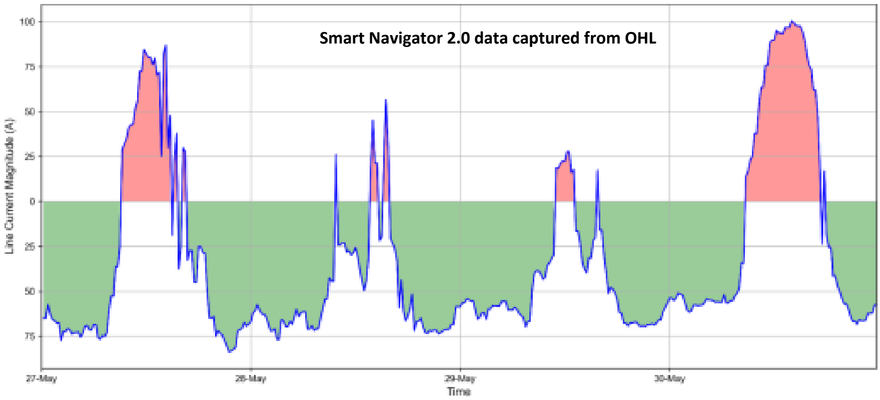
Validation of Field Trial Results

- Below is a comparison of the data captured from the Smart Navigator 2.0 sensors installed on a 33kV OHL, and data recorded by typical transducers installed in a substation.
- The red / green shading indicates power flowing in the forward / reverse directions, respectively.
- The Smart Navigator 2.0 sensors were configured to record routine analogue data every 15 minutes, changes in power flow direction are captured and reported immediately, on change.
- The data indicates that the direction of power flow through the circuit changed several times over successive days.



- Close correlation between the two datasets established.
- The innovative voltage detection mechanism is sufficient to derive the *approximate* phase angle between voltage and current flowing through the conductor.
- The minimum line current required to determine the phase angle is approximately 3A, this was found to result in a lag of approximately 1 minute in reporting a change of power flow direction when comparing the MW signal with the Smart Navigator 2.0 data on a granular level.