Building a robust Disturbance Analysis Tool for Distributed Energy Resources (DERDAT) in an Electricity System

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Abstract

Australia has one of the world's highest rates of solar photovoltaic (PV) power with more than one third of homes having installed solar. Whilst a significant achievement for the transition towards renewable energy, increasing Distributed Energy Resources (DER) also raises concerns regarding power system security. Project MATCH is a collaborative research project that aims to develop robust tools for understanding the risks and opportunities DER pose for power system security during major grid disturbances. The project is a collaboration between UNSW Sydney, the Australian Energy Market Operator (AEMO) and solar monitoring company Solar Analytics. A key output of the project is an open-source Analysis Tool for DERs (DERDAT). It is used to analyse large real-world operational datasets from distributed PV at high temporal resolution (1s-60s) from 1000's of sites. Key functionalities include data cleaning, analysis of individual PV behaviours, and upscaling. This paper discusses the capabilities of DERDAT and its value in performing disturbance analysis for decision-making.

Overview of DERDAT

AEMO has highlighted the risks DER pose to power system security during major electricity grid disturbances if not coordinated appropriately, as well as the opportunity DER offer to contribute during disturbance events (AEMO, 2023). DERDAT aims to support robust, streamlined, repeatable analysis of DER behaviour during disturbances to provide AEMO and broader industry with an evidence base for decision making. Expected inverters behaviours are defined by inverter connection standards (AS4777.3-2005, AS4777.2-2015 and 2020), however grid disturbance events are complex and rare, and how they permeate the distribution system is largely unknown. In addition, the DER fleet is highly diverse, and there has existed some ambiguity in standards. DERDAT aims to assist answer the question of "how to handle this ambiguity to create a robust electricity system in the future?". At a high level, DERDAT ingests real-world operating data from a sample of DER (n =1000's), cleans the data, analyses individual DER behaviours, groups the DER based on key characteristics and provides initial visualisations of population trends, such as compliance rates. It can then be used to upscale the observed response to estimate overall fleet behaviour and visualize the outcome as in Figure 1.

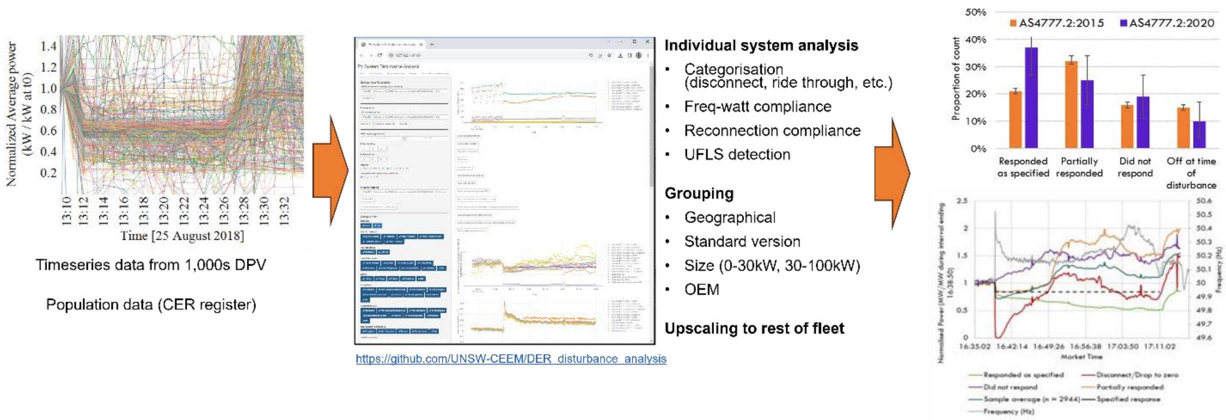

Figure 1. DERDAT ingesting real world data to produce outcomes on DER behaviour.

The analysis framework developed initially prior to, and then extended up through Project MATCH performs analysis of DER power variations during voltage and frequency disturbance events. With DERDAT inverter compliance can be monitored, the effects of key inverters characteristics (e.g. those listed above) can be analysed, and fleet behaviours estimated. This information is then used by AEMO in its incident reporting, and to develop power system models that inform operational decision making such as constraint setting and procurement of Frequency Control and Ancillary Services (FCAS).

Functionality of DERDAT

DERDAT is an open-source tool https://github.com/UNSW-CEEM/DER_disturbance_analysis (available at) and as its name implies, it is designed to perform disturbance analysis of DERs. Details of disturbances such as DER sites, circuits and their respective location, event time and duration are used. It requires voltage, frequency, and power values of DERs. DERDAT performs its analysis with the above information as in Figure 2. Initially, a clean version of data is created from the raw data obtained from energy service providers. Cleaning handles discrepancies with the time intervals of monitored and recorded voltage, power and frequency values, missing information, and duplicates.

Individual DER behaviour is analysed during disturbances where categorization for disturbance responses such as ‘drop to zero’, ‘disconnected’, ‘curtailed’ and etc are observed. Furthermore, frequency-watt compliance, compliance of inverters during reconnection and Under Frequency Load Shedding (UFLS) are detected.

Then, distinct grouping categories are created, and their key characteristics have been determined through prior analysis and may not be exhaustive. DER disturbance response has been observed to vary significantly based on:

- **Standard version:** namely the current AS4777.2-2020, legacy standards published in 2005 and 2015, with 12-month transition periods each time a new standard is published (Standards Australia, 2020).
- **Inverter/system capacity:** smaller (<30kW) systems and larger (30-100kW) system, likely due to additional Distribution Network Service Provider (DNSP) requirements above 30kW.
- **Original Equipment Manufacturer (OEM):** with marked differences observed between certain inverter brands, particularly for different types of disturbance event.
- **Physical location:** proximity to voltage disturbance events also significantly impacts observed DER behaviours.

Statistical methods can then be applied to upscale to represent the entire DER fleet, based on the sample available in the dataset. Upscaled data are fed to DERDAT along with disturbance information such as disturbance occurrence time, duration and location. Then, DERDAT performs eight main visualizations which are the variation of (1) aggregate power (2) frequency, voltage variations (3) fraction of PV systems per each ‘response to disturbances’ category (4) cumulative count of disconnected PV systems vs distance from the disturbance location (5) fraction of PV systems vs zone for various ‘response to disturbance’ (6) voltage visualization: disconnection percentage of PV systems vs zone under different voltage ranges (7) frequency-watt response during over-frequency and (8) identifying UFLS.

Importantly, analysis undertaken using DERDAT requires understanding of the broader event conditions, to draw meaningful conclusions regarding reasons DER deviations from the expected behaviour. This relies upon external datasets from network service providers (NSPs) to understand conditions such as undervoltage, overvoltage, phase angle jump, frequency excursions and Rate of Change of Frequency (ROCOF).

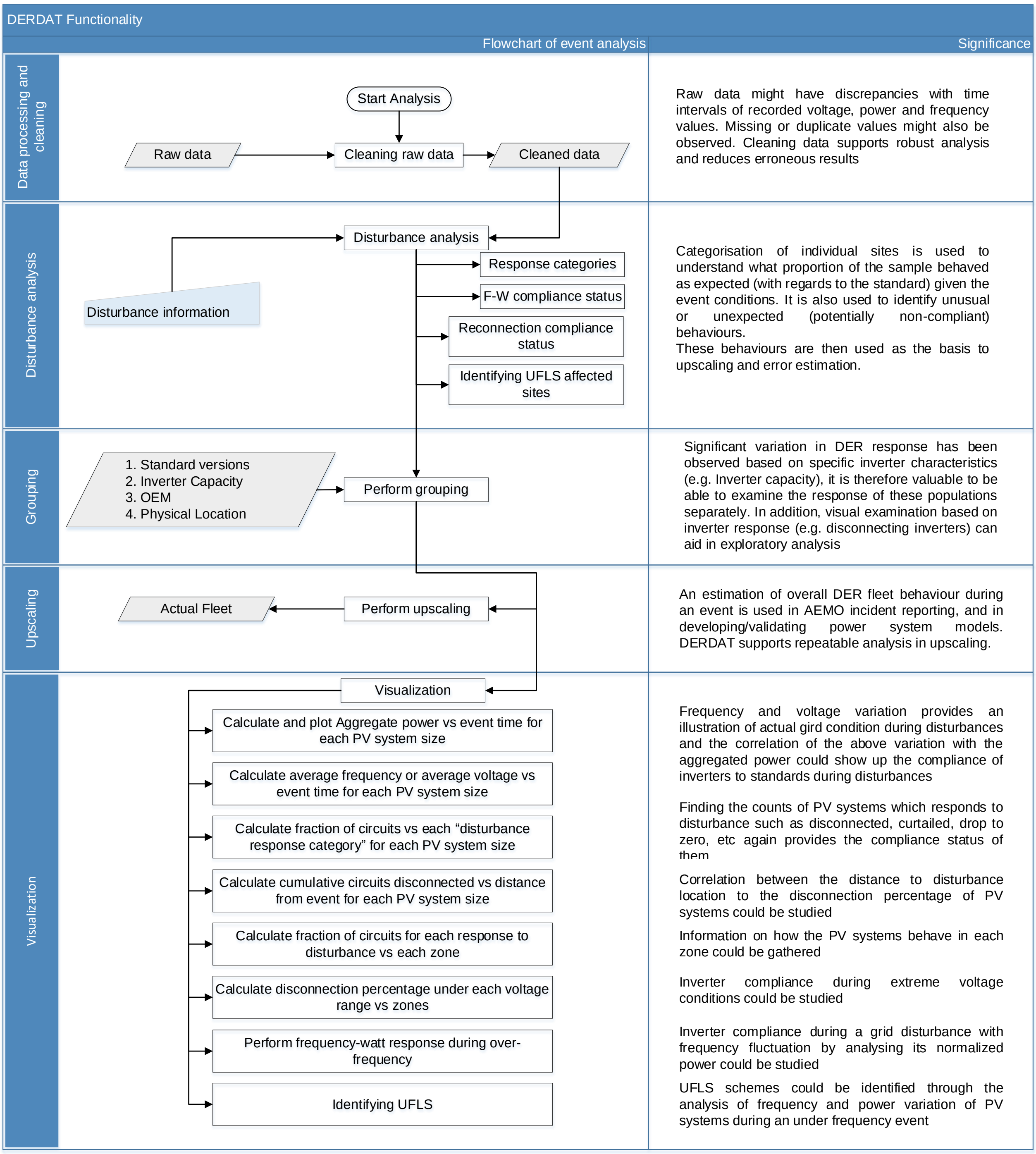

Figure 2. Functionality of DERDAT

Case Study of DERDAT being used for disturbance analysis.

DERDAT is being used as part of ‘business-as-usual’ practises by AEMO to assess DER behaviour during disturbance events. One such analysis was undertaken for an event caused by a bushfire in South Australia on 24th January 2021 (AEMO, 2021) near Cherry Garden substation in between 1630-1700 Hrs, encapsulating the disturbance timeframe.

DERDAT provides visualisation of the above data, including normalized power and average voltage variation with time as in Figure 2 (a) and (b). When the disturbance occurs at 1643 Hrs a reduction in DER can be observed due to curtailment, disconnections and drop to zero responses of inverters. Figure 2 (b) also shown an undervoltage condition which might be the cause for inverter disconnections at that time. Voltage visualization has recently been added to DERDAT and offers a means of quickly checking the data for voltages that would have caused disconnection, noting that there are challenges to capturing voltages dips (that typically last 200ms). Zones are identified at 50km, 150km and 250km radius from the disturbance location. This is as expected, given increased severity of voltage dip is likely to occur in zone 1 as in Figure 4.

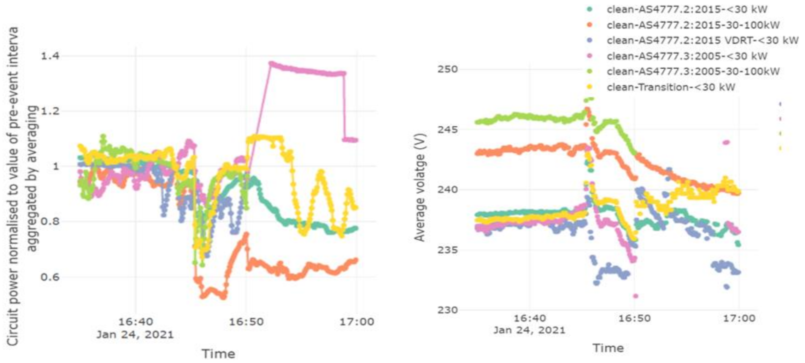

Figure 3 (a) variation of normalized power (b) average voltage vs time

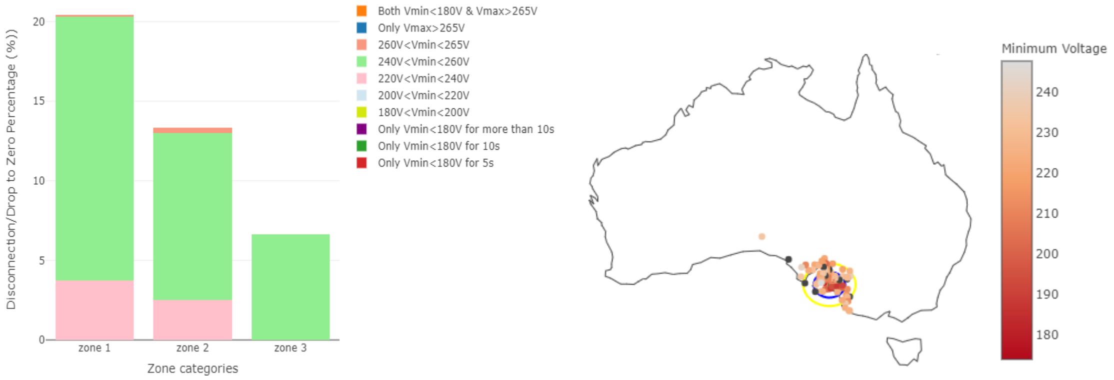

Figure 4 Voltage visualization of DERDAT

Summary

DERDAT is indeed the first ever tool developed to prioritize disturbance analysis for an electricity system with DERs. It provides insight of possible security threats where mitigative measures could be proposed. A disturbance analysis of DERs with their power, frequency and voltage profiles and with appropriate grouping and functions such as visualizing normalized power, frequency, voltage variations, disconnection percentages of PV systems, reconnection statuses, frequency-watt response during over-frequency and identification of UFLS is done. Outcomes aid to find the compliance of inverters to their standards. Possible changes in inverter standards are proposed to improve system security. DERDAT is initially built to analyse data obtained from “Solar Analytics”. However, it is upgraded with the capability of analysing data from other OEMs with high temporal resolution, and with mixed duration for power, voltage and frequency. Every database is cleaned to match “Solar Analytics” format before integrating them into DERDAT.

Acknowledgement

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