Solar Enablement Initiative – Increasing Visibility of Distribution Networks to Maximise PV Penetration Levels
5 December 2019

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Project results and lessons learnt

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Executive Summary

The Solar Enablement Initiative Project (SEI) demonstrates the technical feasibility of achieving full network visibility from incomplete measurement data using an innovative distribution network state estimation algorithm (SEA).

The project was a collaboration between:

- The University of Queensland (UQ)
- Queensland University of Technology (QUT)
- Australian Power Institute (API)
- Energy Networks Australia (ENA)
- Aurecon
- Energex/Energy Queensland
- TasNetworks
- United Energy
- Springfield City Group

The scope of the project was to develop an SEA and additional tools to facilitate the PV integration in the network. A dashboard was developed to be a user-friendly interface to use these tools and to launch real-time and historical estimations.

This algorithm allows monitoring the voltages, currents and power flows within an entire network and has been demonstrated on 20 Australian medium-voltage distribution feeders from the DNSP project partners. The improved visibility of the network state assists network planners to better evaluate the connection of new photovoltaic (PV) systems and has potential to support additional network assessment, planning and operational processes. During the two past years, this $A2.9 million project has demonstrated that the three participating Australian Distribution Network Service Providers (DNSPs) already have collected enough data to run a Distribution System State Estimation Algorithm (SEA) on the majority of their MV feeders.

The response to the project both its goals, technology and execution has been overwhelmingly positive and seen as a great achievement in collaboration between university research and industry partners. The project has been able to extend the knowledge of state estimation in distribution networks and its many important applications in the future of distribution networks where the penetration of PV and particularly controllable PV and other controllable DER sources is rapidly increasing. This enhanced visibility gives the opportunity to develop tools to facilitate the integration for customers.

The need for visibility of the network and a system that can identify the constraints and optimise the dispatch of these devices will be fundamental and the SEA and its associated tools will become a large part of delivering the best outcome for electricity customers.

There are ongoing challenges of integrating new systems into DNSPs, as these are understandably very reliant on formal process as they are large and regulated organisations.

The rights of exploitation of the produced technology belong to the GridQube Company that is in charge of the commercialisation of the network monitoring software. It will also be responsible for the continuous improvement of the SEA and the analysis tools. GridQube will be continuing the development and roll out of the SEA and PV analysis tool with the DNSP partners as well as using it for further research into other applications.

Acknowledgement and Disclaimer

This Activity received funding from ARENA as part of ARENA's Advancing Renewables Program. The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Additional funding was also provided by ENA, API and the Springfield City Group. In-kind support was also generously provided by Energex, United Energy and TasNetworks, as well as QUT and Aurecon.

The University of Queensland and the SEI project team would like to acknowledge the funding that made this project possible and thank all those that contributed.

Any views expressed in this report are those of the authors not necessarily those of the University of Queensland.

Project Overview

Project summary

The Solar Enablement Project (SEI) demonstrates the technical feasibility of achieving full network visibility from incomplete measurement data using an innovative distribution network state estimation algorithm. This algorithm allows monitoring the voltages, currents and power flows within an entire network and has been demonstrated on 20 Australian medium-voltage distribution feeders. The improved visibility of the network state assists network planners to better evaluate the connection of new photovoltaic (PV) systems and has potential to support additional network assessment, planning and operational processes. During the two past years, this $A2.9 million project has demonstrated that the three participating Australian Distribution Network Service Providers (DNSPs) already have collected enough data to run a Distribution System State Estimation Algorithm (SEA) on the majority of their MV feeders.

Project scope

The scope of the project was to develop an SEA and additional tools to facilitate the PV integration in the network. A dashboard was developed to be a user-friendly interface to use these tools.

This interfaces allows the user to upload a new network with its measurements and transformer details, display its specifications and run the estimator. It is also possible to display the estimation results and to analyse them to compare their accuracy with the actual measurements. Among the set of available tools:

- The clustering analysis identifies the critical cases and stores them into clusters according to their topology or their temporal evolution.
- The PV analysis tools assesses the feasibility of adding new PV on a specific node.
- The constraining analysis tool gives the constraints of the network in the form of matrices and displays a graph to visualise the constraint and the conditions in which the customer is in compliance with the network's requirements

The project's key objective was to demonstrate that the semi-automated network analysis tool and the state estimation algorithm (SEA) provide a reliable mechanism to allow more flexibility in a PV system's operation and thereby reduce the protective measures that currently need to be adopted and funded by the customer.

Outcomes

A ‘dashboard’ was produced including a tool to launch real-time and historical estimations. Furthermore, the analysis tools described above (clustering analysis, PV analysis and Constraining analysis) can be used through the dashboard.

The novel SEA and analysis tools produced by the project improves the visibility of the network for the DNSPs. This technological advance optimises the PV connection assessment process and increase the solar PV penetration levels by reducing the solar PV connection costs for the customers.

The achievements of the project align with the expectations since all the outcomes were reached. The SEA and analysis tools are functional and integrated in a dashboard and working on feeders across all the partner DNSPs as well as a real-time implantation functioning autonomously. Extensive knowledge sharing and reporting was conducted through the project to track its progress and inform industry and the public of the developments.

The team had to face a few surprises during the project development:

- On top of the eight feeders initially provided by the DNSPs collaborates (seven for the historical estimation and one for the real-time estimation), 13 additional feeders were provided to the project. They were successfully integrated into the dashboard to perform the estimation and the analyses. This success proved the computation speed and scalability of the software for a further use on a real network.
- The differences in the network configurations and measurement data provided by the DNSPs were a challenge for the feeders’ integration into the dashboard. A work on data standardisation and feeders input flexibility allowed the team to overcome this obstacle.
- One of the partners provided large networks (approximately 1,000 nodes on the feeder’s model) with a low measurement coverage (less than 3%). However, the SEA converged and delivered an accurate estimation, proving the robustness of the system.

Several supporting documents were supplied to the partner DNSPs to explain how to use the dashboard and all the tools it gives access to. These supports include a written user manual and several tutorial videos.

Transferability

The project engaged in an extensive knowledge sharing plan through the two year of it existence. This included:

- Regularly presenting at or hosting industry and academic workshops, summits and conferences.
- Personally visiting each of the Partner DNSPs twice a year to present the project progress and results and discuss the project with the subject matter experts.
- Submitting papers to academic journals and industry magazines.

The key objectives of the knowledge-sharing plan are to present the following outcomes which we believe were achieved:

- increased skills, capacity and knowledge in Distribution State Estimation within Australia and its potential application to improve renewable energy penetration in distribution networks;

- production and dissemination of information that advances Distribution State Estimation through the Technology and Commercial Readiness Levels (as defined by ARENA from time to time) towards commercialisation;
- sharing of high quality research into Distribution State Estimation which enhances Australia's world-class research position and addresses conditions specific to Australia;
- increased public awareness and understanding of the impact of PV systems on the operational state of a Distribution System, and the potential PV hosting capacity of such systems;
- increased understanding of roadblocks to integration of large and medium scale PV systems and solutions to address them;
- increased understanding of the challenges experienced when testing requirements for minimum measurement coverage and static data requirements for MV network State Estimation and approaches trialled to overcome them;
- increase the collaboration between Australian DNSPs and Australian Universities in the field of integrating renewable energy sources into Distribution Systems;
- increased understanding of the performance characteristics of Distribution State Estimation in PV system connection application assessment and Distribution System planning;
- Improved grid constraint information for medium and large-scale PV systems.

It has been identified that the technology developed for this project can be extremely valuable in a number of areas outside of the core scope of this project. Some key examples that are being investigated are:

- LV state estimation (projects underway using the same SEA)
- Network constraint envelopes and optimisation or market dispatch
- Traction (train network) fault detection
- Use of other measurement devices or network information
- Analysis of load profiles to provide higher quality statistical data for unmeasured points

To the best of our knowledge, there are two other projects relative to distribution network visibility enhancement:

- Evolve DER Project: aims to increase the network hosting capacity of distributed energy resources (DER) by maximising their participation in energy, ancillary and network service markets, while ensuring the secure technical limits of the electricity networks are not breached.
- API / ARENA Electrical Vehicle (EV) Charging Project: delivers reports, datasets and models to forecast the impact of EV charging on the electricity network.

Publications

Several publications were produced during the project to advertise for the project and to broadcast its achievements:

- An article was published on the ARENAWIRE website: "Planning for the future with solar forecasting" (https://arena.gov.au/blog/planning-for-the-future-with-solar-forecasting/)
- Written articles were published in specialised magazines such as T&D World and Transmission and Distribution
  - June 2018 in Transmission and Distribution
  - March 2019 in T&D World

  - Article sent to Transmission and Distribution in October 2019

- Infographics were also designed to advertise for the project and to explain the SEA principle during the different conferences attended (see Appendix)
- M. Shafiei, A. L. Liu, G. Ledwich, G. Walker, G.-M. Morosini, and J. Terry, "Solar Enablement Initiative in Australia: Report on Efficiently Identifying Critical Cases for Evaluating Voltage Impact of Large PV Investment," presented at the IEEE Power and Energy Society General Meeting, Atlanta, Georgia, US, 2019.

Awards

The project was nominated at the iAWARDS 2019 and received a Queensland Merit Recipient for Business Service Markets category.

Conclusion and next steps

The SEI project delivered a semi-automated network analysis tool, based on a novel SEA, which can give DNSPs increased visibility of their MV networks and help them improve their PV connection assessment processes.

The response to the project both its goals, technology and execution has been overwhelmingly positive and seen as a great achievement in collaboration between university research and industry partners. The project has been able to extend the knowledge of state estimation in distribution networks and its many important applications in the future of distribution networks where the penetration of PV and particularly controllable PV and other controllable DER sources is rapidly increasing. This enhanced visibility gives the opportunity to develop tools to facilitate the integration for customers.

The need for visibility of the network and a system that can identify the constraints and optimise the dispatch of these devices will be fundamental and the SEA and its associated tools will become a large part of delivering the best outcome for electricity customers.

There are ongoing challenges of integrating new systems into DNSPs, as these are understandably very reliant on formal process as they are large and regulated organisations.

The rights of exploitation of the produced technology belong to the GridQube Company that is in charge of the commercialisation of the network monitoring software. It will also be responsible for the continuous improvement of the SEA and the analysis tools. GridQube will be continuing the development and roll out of the SEA and PV analysis tool with the DNSP partners as well as using it for further research into other applications.

Lessons Learnt

Lessons Learnt Report: Project Team

Project Name: Solar Enablement Initiative

Knowledge Category:	People
Knowledge Type:	**Project Management**
Technology Type:	
State/Territory:	Queensland

Key learning

The makeup of the project team including with people with diverse professional backgrounds tailored to the project deliverables was extremely valuable. Having team members with backgrounds in academia, consultancy, utility companies and software development, meant that a project that had

- High technical requirements,
- Need for knowledge of and integration with DNSPs,
- A tight schedule and delivery milestones, and
- Complex and extensive coding requirements for both backend and user interface

was able to be delivered successfully. In fact, the team that was assembled was fundamental to the project's success.

Implications for future projects

Focus on assembling a team to meet the overall project goals and deliverables. Attempt to have a diverse set of backgrounds with different skill sets. Fit the skill sets to the project requirements (e.g. software developers for projects where the software is a deliverable).

Lessons Learnt Report: DNSP Integration

Project Name: Solar Enablement Initiative

Knowledge Category:	Processes
Knowledge Type:	**Technical**
Technology Type:	Software
State/Territory:	Queensland

Key learning

One of the hopes for the project was that by the end of the project the NSPs would be using the analysis tool and state estimator as a part of business as usual in their day to day work. Using the analysis tool for PV assessments and the estimator for other planning activities.

While the DNSPs have expressed serious interest and begun using the software, they have stated that the time required to get any new process or software into the business as usual in large, highly regulated organisations is very long. This was not possible in the time frame of 2 years which included development time.

Implications for future projects

When targeting the use of a new process or tool in an organisation or multiple organisations, set realistic goals based on the time available. Integration is perhaps a separate project entirely.

Knowledge gap

Experience with integrating new systems in large organisations.

Background

Objectives or project requirements

Have the analysis tool as part of the business as usual at the partner DNSPs

Process undertaken

The partners DNSPs are using the software developed in an experimental way, and real time estimator is being used to set maximum outputs to a PV system. Further roll out of the analysis tool and estimator is ongoing post project in a commercial setting.

Lessons Learnt Report: Data quality

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

Since these partial models and pieces of data have never been combined in this way, many data quality issues have either not been noticed or were manually compensated for or corrected in the past. Not all these corrections and information about bad data has been fed back to the original source of the bad data.

Implications for future projects

The correction feedback should be done to avoid duplication of work.

Knowledge gap

Incomplete feedback.

Background

Objectives or project requirements

Partial feedback about bad data correction to harmonise the dataset to integrate it into the dashboard.

Process undertaken

Partial feedback about bad data correction to harmonise the dataset.

Lessons Learnt Report: Data consistency

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

Pieces of data provided by DNSPs can be inconsistent.

Implications for future projects

Find a way to combine data from different sources.

Knowledge gap

Different sources of data use inconsistent identifiers, which requires manual mapping to combine data from different sources. This remains to be an issue and needs to be addressed by the DNSPs.

Background

Objectives or project requirements

Manual mapping was performed to combine data from different sources and integrate this data into the dashboard.

Process undertaken

Manual mapping was performed to combine data from different sources.

Lessons Learnt Report: Data completeness

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

Despite the estimator being able to handle incomplete measurement data, other auxiliary data (such as load statistics) and data about mutable parameters of the network (transformer tap positions and switching state) need to be available for the entire network for it to function correctly.

Implications for future projects

Mutable network parameters should be stored and associated with the network models by DNSPs.

Knowledge gap

Throughout the project this has remained a manual task, including locating and validating these pieces of data.

Background

Objectives or project requirements

Harmonize the dataset to integrate it into the dashboard.

Process undertaken

Throughout the project this has remained a manual task, including locating and validating these pieces of data.

Lessons Learnt Report: Data transfer

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

With the required data usually being collected for separate purposes and not having been combined in this way before, throughout the project many different IT systems had to be interfaced with or manually interacted with to retrieve the required data.

Implications for future projects

Beyond the previously mentioned need for consistency amongst element identifiers, there would be benefits from establishing a data exchange middle-ware, which would allow some level of abstraction and reduce the complexity to interface with multiple different, often home-grown, IT subsystems. A coordinated approach supported and implemented by all Australian DNSPs, possibly in line with international activities in this space, would make future integration work and the transferability of solutions between DNSPs less time consuming and less error prone.

Background

Objectives or project requirements

Many different IT systems had to be interfaced with or manually interacted with to retrieve the required data to harmonize the dataset and integrate it into the dashboard.

Process undertaken

Many different IT systems had to be interfaced with or manually interacted with to retrieve the required data.

Lessons Learnt Report: Data security and access

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

The participating DNSPs established different security zones within their IT network as part of their Cyber Security strategy. This, in many cases, led to the situation that not all required data sources could be connected to from the same client, leading to additional manual work and increased risk of inconsistencies.

Implications for future projects

Establishing data mirroring schemes, that allow read access to data from other security zones, while still isolating the primary data source, would be beneficial for further integration.

Background

Objectives or project requirements

Additional manual work and increased risk of inconsistencies to retrieve data from the DSNSPs IT systems.

Process undertaken

Additional manual work to retrieve data from the DSNSPs IT systems.

Lessons Learnt Report: Data privacy

Project Name: Solar Enablement Initiative

Knowledge Category:	Technical
Knowledge Type:	Data management
Technology Type:	SQL database
State/Territory:	Queensland

Key learning

Some of the most useful auxiliary data (e.g. customer energy consumption data) can create issues around privacy and existing privacy regulations. While not a major issue in this project, as one aggregate values on transformer level were needed as input data, this can become an issue when expanding the use of state estimation into Low Voltage networks, where data of individual customer might be required, or in sparsely populated areas where distribution transformers might supply single customers.

Implications for future projects

It would be beneficial if DNSPs could develop policies and procedures as to if and how this data can be made available for developing and testing purposes and how access in the course of support and maintenance work carried out by an external service provider, could be managed.

Background

Objectives or project requirements

Data was manually anonymised and analyses were performed on this dataset to test the constraining analysis tool.

Process undertaken

The transformer on which the analysis was performed was renamed “Customer X” to maintain the customer’s privacy.

Lessons Learnt Report: Provide results earlier

Project Name: Solar Enablement Initiative

Knowledge Category:	Planning
Knowledge Type:	Coordination with the DNSPs
Technology Type:	
State/Territory:	Queensland

Key learning

An area that could have been improved is providing results on the feeders chosen for the study a little bit early in the project timeline. Detailed evaluation/discussion of the results from the model would have added further value. The true value will lie in the DNSPs using the tool moving forward.

Implications for future projects

Delivering results early in the project's timeline could allow a more thorough discussion about the model and the estimation.

Background

Objectives or project requirements

Delivering estimation results to the DNSP partners.

Process undertaken

The results were delivered but a bit late in comparison with the partners' expectancy.

Lessons Learnt Report: DNSP Collaboration

Project Name: Solar Enablement Initiative

Knowledge Category:	Planning
Knowledge Type:	Coordination with the DNSPs
Technology Type:	
State/Territory:	Queensland

Key learning

A single primary contact person in each DNSP worked well in terms of keeping track of tasks, the regular DNSP updates were valuable to keep the wider business engaged and interested, and the list of recommendations to kick off state estimation in DNSP is helpful (clear and simple).

However, clarity from DNSPs around the particular experts to engage and seek feedback from at each stage was sometimes lacking (i.e. development of the analysis tool). Furthermore, engaging a customer for the real-time trial was far more time consuming than originally thought.

Implications for future projects

It is important to keep an efficient collaboration between the DNSPs and the project members to have a good exchange of information and feedbacks.

For the real-time trial, it would be better to stick with internal parties/company owned trial sites as much as possible.

Background

Objectives or project requirements

Collaboration with the DNSPs to develop a tool that corresponds to the requirements of the customers.

Process undertaken

Regular meeting with the partners were organised to keep a track of the project advancement and to have feedbacks on the DNSPs' expectations about the estimator and the analysis tools.

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The Evolution of State Estimation

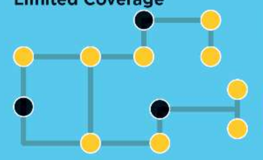
The ARENA-funded Solar Enablement Initiative* is demonstrating how electricity distributors can enable more export of generation from solar PV systems of 30–1500 kW. Application of a State Estimation Algorithm will significantly enhance a distributor's knowledge of the operational conditions of its feeders. This will facilitate more informed technical assessments of PV connection applications as well as dynamic orchestration, and therefore maximisation, of PV export.

Solar Enablement Initiative

Measured node density scenarios

Estimated nodes · Measured nodes

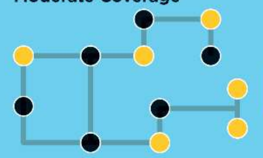
Limited Coverage



- Uncertainty quantified
- Estimations replace worst-case assumptions.

75% nodes on feeder estimated | 25%

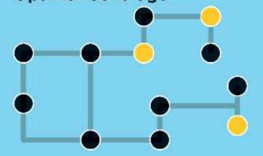
Moderate Coverage



- Uncertainty reduced
- Decision-making confidence increased.

50% nodes estimated | 50% nodes measured

Optimal Coverage



- Uncertainty negligible
- Decision-making confidence optimised.

25% | 75% nodes measured

Note: 100% coverage is not necessary to provide sufficiently accurate estimates of conditions on the entire feeder.

Estimated State vs Measured State

As the number and quality of measurements on a feeder increase, the differences between estimated and measured (actual) values of voltage, current and power reduce.

Estimated State · Measured State

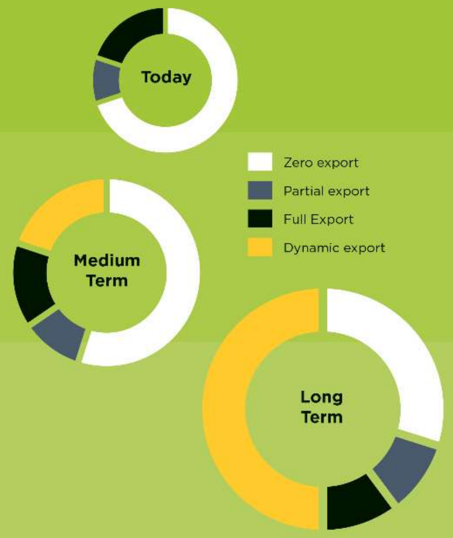
Limited Coverage

Moderate Coverage

Optimal Coverage

Evolving PV export-status mix

The progressive implementation of State Estimation across a distribution network will enable increased connections of, and export from, 30-1500 kW PV systems. State Estimation technology can also be used to dynamically control and maximise export. These benefits will change the PV export-status mix, which will minimise network impacts and enhance customer, market and environmental outcomes.



*The Solar Enablement Initiative is administered by The University of Queensland.
Other Activity Participants include electricity distributors Energex Limited, United Energy and TasNetworks; Energy Networks Australia; Australian Power Institute; Aurecon; Springfield City Group; and Queensland University of Technology.

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Keywords

State Estimation, DER, Distributed Energy Recourses, Network Visibility, Constraint optimisation

Glossary of terms and acronyms

- **PV**: solar photovoltaic panels
- **SEA**: State Estimation Algorithm
- **DNSP**: Distribution Network Operator
- **DNSP**: Distribution Network Service Provider (= DNSP)
- **EV**: Electrical Vehicle
- **DER**: Distributed Energy resources

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