MEETING EMERGING AND FUTURE REQUIREMENTS FOR MANAGING DER IN HIGHLY ACTIVE DISTRIBUTION NETWORKS

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ABSTRACT

Active Distribution Networks (ADN) continue to evolve as market requirements follow the changes in regulation. Encouragingly, advanced distribution operational technologies, such as active network management (ANM), have reached a respectable level of maturity, providing a solid foundation for meeting many of the requirements the wider industry is in the process of forging. This paper presents results of testing of ANM at the National Renewable Energy Laboratory (NREL) in Boulder, Colorado. The authors provide an overview of the testing conducted over a period of 18 months and some of the key insights resulting from analysis of results and discussions with the industry advisory committee. We provide our preview of future requirements for managing DER, suggesting the technology will evolve to handle multiple applications, including market signals, leading us to a heightened level of sophistication.

INTRODUCTION

The growth of Distributed Energy Resources (DER) continues in multiple forms and scales across geographical markets. The growth of domestic integrated solar photovoltaic (PV) [1,2] to larger distribution network connected biomass, wind power and PV 'farms', and the growing exploration of responsive demand and energy storage, each at different scales, presents a real diversity of DER for Distribution System Operators (DSOs) to manage.

The innovative technical and commercial solutions to connect, control and manage DER in distribution networks have been addressed in the literature [3-5]. In particular, Active Network Management (ANM) has emerged as a valuable control solution along with supporting techniques to effectively manage DER [3,4]. ANM has recently undergone substantial development and field trial in different power networks and for diverse DER applications and use cases in keeping with the diversity of DER growth.

One specific application for ANM is for flexible, managed Distributed Energy Resource (DER) network integration and management. In the UK, deployments of ANM systems are growing and the portfolio of DER enabled by SGS's technology has reached 250MW. This has led to the recent development and publication of standardised ANM system requirements [6].

In Germany, the recent revision of the EEG Act provides for system and local network constraint management of DER subject to an annual export curtailment cap [7]. In the US the NY REV DSP [8] and California DRP processes [2] are leading the requirements and demonstration of state of the art for full system and market integration of DER.

The NREL Energy Systems Intergration Facility has become a key facility in North America to bring these technologies to bear and the NREL INTEGRATE project is broadening the capabilities of ANM for diverse DER control and management applications [8-10]. The project has already successfully demonstrated three advanced DER control use cases on the Power Hardware in the Loop (PHIL) platform at the NREL Energy Systems Integration Facility (ESIF):

- Smart Home
- Smart Campus
- Smart Distribution.

This paper updates the cross geography requirements and state-of-the-art in ANM, with conclusions for future directions. The paper documents the results of rigorous end-to-end system testing of ANM application in diverse DER control applications in the NREL INTEGRATE project and draws conclusions on the key scale-up and roll-out challenges for this important solution. We conclude with a clear enumeration of system requirements for integration with complementary distribution applications and for the management of DER with ANM, and its integration into emerging power system markets.

INTEGRATE PROJECT

Background

Utilities ultimately hold responsibility for ensuring the grid operates in a safe and reliable way. They must comply with industry regulations and benchmark to ensure power flows and voltages are held within equipment ratings, and its service meets power quality and reliability requirements. As such, without appropriate changes to regulation, utilities are not incentivized to support reliable, predictable and fast interconnection of DER. This philosophy becomes an impediment not only to DER connection but also to the development of mature and open markets.

Mature automation and control based approaches to DER connection and advanced operational technologies can meet reliability requirements while enabling greater access to existing grid capacity and enabling future market concepts. The INTEGRATE project aims to demonstrate the viability of flexible real-time capacity arrangements and the required functionalities to enabling increased hosting capacity.

Shifting from a utility defined hosting capacity perspective, the dynamic hosting capacity becomes market defined, whereby DER developers could provide grid services for the mitigation of curtailment or other DER site solutions (storage; etc.). This could increase further hosting capacity while concurrently enabling market-based solutions, driving innovation and industry change.

Energy Systems Integration Facility

The Energy Systems Integration Facility (ESIF) is an advanced testing facility that goes beyond testing of individual DER. ESIF targets testing that provides understanding of how these technologies scale and interoperate with the larger power system and the architecture variations observed in practice. It consists of numerous commercial DER devices and/or their interfaces, load banks, and real-time simulator (RTS) capabilities. RTS together with bi-directional power converter-based grid emulators allow for integrated testing with larger and larger distribution systems. This enables transposition of actual distribution networks into the testing world.

USE CASE DEMONSTRATIONS

System Configuration

The SGS INTEGRATE project investigated the application of ANM through three representative use cases, attempting to capture how it performs at three scales: Smart Home, Smart Campus, and Smart Distribution. Here, we present the set-up of the ESIF for each of these scenarios.

Smart Home

Three DER were used in the Smart Home use case, presented here and in Figure 1:

1) PowerHub CES – a 30kW, 34kWh battery energy storage system (ESS) de-rated to home scale of 3kW, 3kWh. A simulated CES was used for simulation test runs; only the inverter was employed for testing.
2) Fronius 3kW PV Inverter and TerraSAS PV Simulator – a PV panel Simulator and PV Inverter.
3) Simplex Powerstar 50 Load Bank – A load bank used to represent uncontrolled home load and emulate electric vehicle (EV) charging profiles.

Smart Campus

Smart Campus extended the scale of Smart Home to a campus, employing larger DER devices. Additionally, this use case incorporated the RTS capabilities, modelling the interconnection to the grid in the OPAL-RT platform, linked via a grid emulator. Figure 2 presents the set-up for Smart Campus testing.

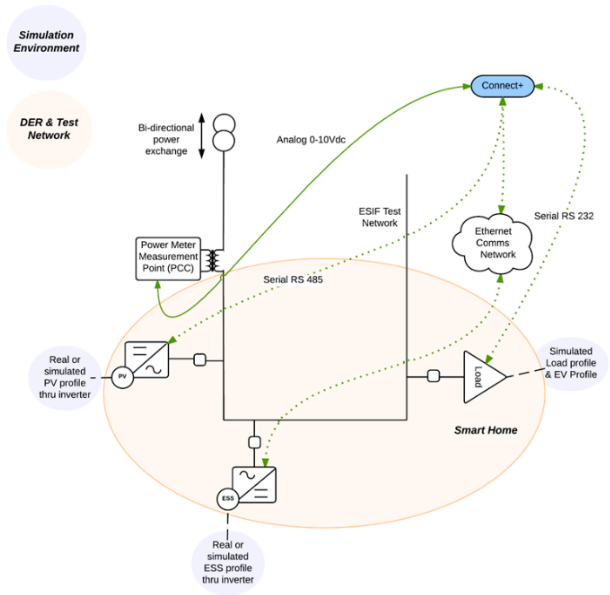

Figure 1. Smart Home Use Case Configuration

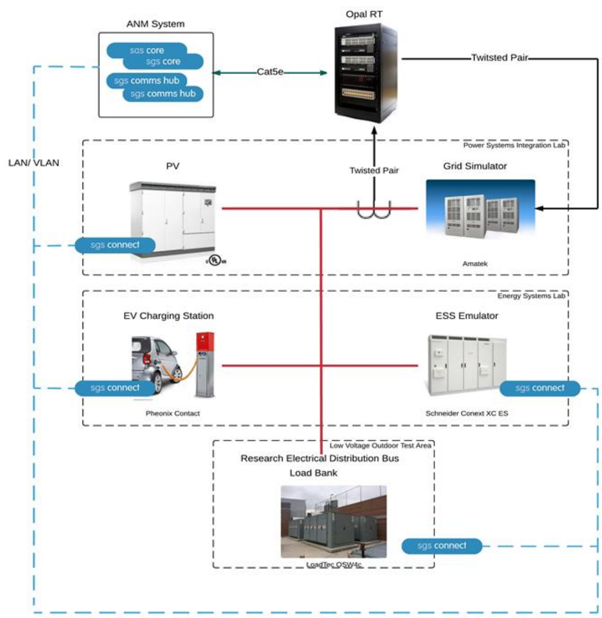

Figure 2. Smart Campus Test Set-up

Smart Distribution

For Smart Distribution the ESIF facility resources and the ANM control system were configured as illustrated in Figure 3. The ANM system comprises of a real-time control and dispatch platform with constraint management and a DER coordination application. The ANM system was deployed across 4 HP DL380 servers split into dual redundant application host (sgs core) and communications gateway (sgs comms hub) systems, each with a centralized and decentralized component (sgs connect).

A modified IEEE 13-Node test feeder, as depicted in

Figure 4 was used as the grid simulation Test Circuit for evaluating SGS' ANM technology at NREL. Adaptations to this circuit were necessary in order to meet the requirements of this study. Also, the two previous use cases were subsumed into the test circuit in the form of controllable active buses, using the profiles captured during previous testing.

In the case of actual DER, two grid emulator enabled connection of the two DER from the ESIF into the RTS, as indicated by PHIL GEN1 and PHIL GEN2 in Figure 4. The DER and the Amatek Grid Simulators were connected to ESIF's Research Electrical Distribution Bus (REDB). The REDB network is a balanced 3 phase network, with a line to line voltage of 480V.

The first ANM managed DG connection was placed within the Smart Campus (second use case of this INTEGRATE project), where a simulated 3 MW PV generator was included. Accompanying this PV generator was a physical inverter with a simulated 600 kWh capacity lithium-ion storage system with a 120 kW power rating and 110 kW of flexible load (aggregated EV's and facility controllable load). These resources together formed the Smart Campus that was actively managed by ANM.

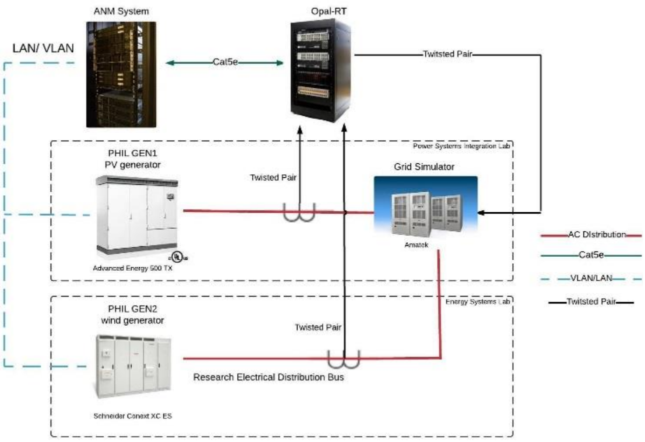

Figure 3. Smart Distribution Use Case Configuration

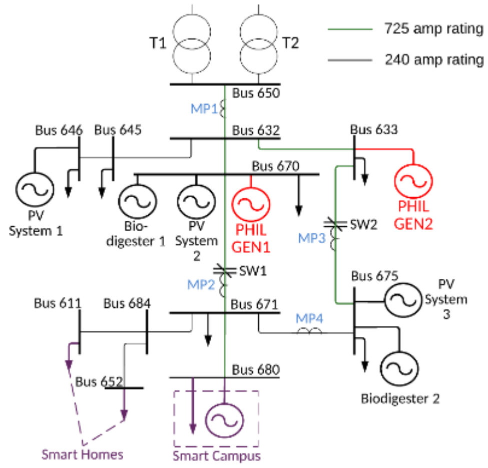

Figure 4. Smart Distribution Test Feeder

Following the connection of the Smart Campus, an additional simulated 500 kW PV generator was interconnected followed by a simulated 500 kW wind generator. These interconnections further exacerbated the thermal export breach as well as the overvoltage.

In addition, the Smart Homes were added as resources controlled by a single ANM sgs connect as the aggregator. Through the aggregator, Smart Home control includes EV charging as well as a combined solar PV + ESS prosumer.

Results

Here we present a subset of the results from Smart Home and Smart Distribution. Each of the three use cases demonstrated constraint management functionality, in addition to functionality related to fail-safes or other advanced operational requirements (dynamic setting changes, topology shift). Constraint management cases included:

1) A reverse power flow or thermal constraint where wider grid constraints mean that the managed bus (DER, Smart Home, Smart Campus) is not permitted to export power to the local grid. ANM coordinates the energy consumption and/or production of the DER to prevent power export across an assets.
2) An overvoltage/voltage rise constraint where power export from the DER can cause the grid voltage to exceed limits. The ANM system coordinates DER to prevent overvoltage on the grid.
3) An import constraint where the actively managed bus participates as part of a wider demand side management system whereby the managed bus is instructed to limit import power when required to resolve grid issues. The ANM system coordinates

the energy consumption or discharge of ESS to maintain demand within limits.

Smart Home

Figure 5 illustrate the net power flow frequently exceeding 0 kW between the time of 13:00:00 and 15:00:00. Figure 6 shows how ANM maintains the net power flow of the home below 0 kW. Short duration excursions above 0 kW in Figure 5 are caused by step increases in the uncontrolled load. These are quickly addressed by the ANM system which reduces power flow to below 0 kW within 2 seconds on each occasion.

Figure 7 shows the uncontrolled PV output versus controlled PV output. Point 1 illustrates a curtailment event where the controlled PV output is reduced by a set amount and then released back up to a value where the net power flow is still below 0 kW. The solar PV output was the only power hardware device subject to the spikes, which took place independent of ANM curtailment control action.

Although not shown, at the start of the test high PV export causes the ANM to instruct the ESS to charge. At 14:49, the ESS becomes fully charged and stops charging. With support from the ESS, the EV is then instructed to charge in order to maintain the power flow below 0 kW and likewise meet the driver's full charge time window.

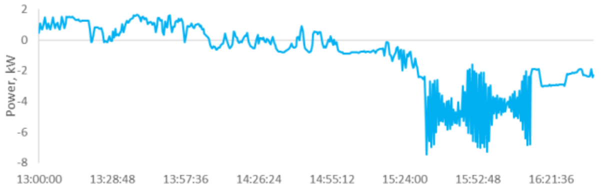

Figure 5: Net power flow at PCC for a home load with uncontrolled 3kW PV system.

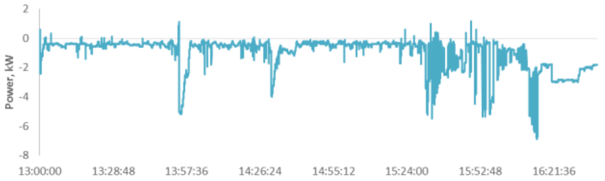

Figure 6: Net power flow at PCC for a home load with controlled DER including EV, ESS and PV.

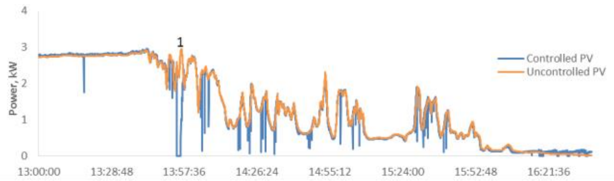

Figure 7: Uncontrolled PV output versus curtailed PV output

Smart Distribution

Figure 8 shows results for a thermal constraint breached at 10:41, followed by a more extreme breach at approximately 10:45. In both instances we see that the current was curtailed almost instantaneously by tripping the Wind Generator as the first line of curtailment in the escalating actions, and then tripping the Smart Campus as the second line of curtailment as was previously defined in the LIFO Principles of Access (POA). This is reflected in Figure 9, where the Wind Generator curtailed at 10:41 and subsequently at 10:45. In Figure 10, the ANM trips the Smart Campus to initially resolve the trim threshold breach and subsequently resolves the sequential trip breach. This test was repeated for the global trip scenario as well.

Figure 11 demonstrated successful on line implementation of new thresholds, motivated either as a switch to new seasonal settings or possibly as part of system maintenance. We can observe this requires no system downtime; the change is undetectable by participating DER, suggesting these solutions are ready to support advanced market concepts as well.

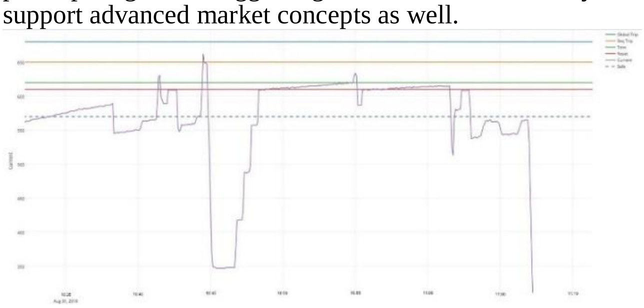

Figure 8: Breach of Sequential Trip Threshold & Resulting Curtailment

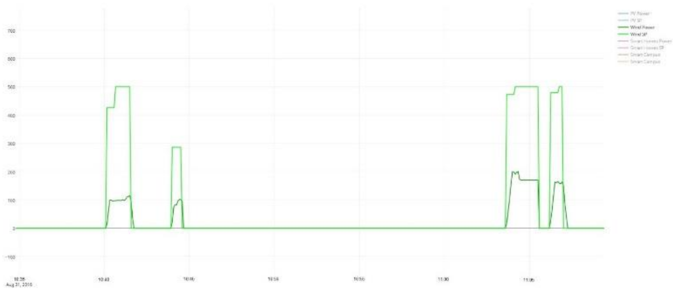

Figure 9: Breach of Sequential Trip Threshold & Resulting Wind Generation Curtailment

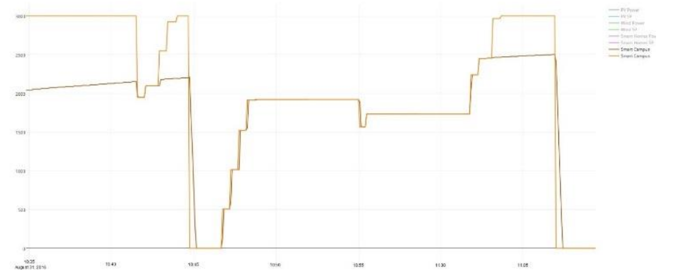

Figure 10: Breach of Sequential Trip Threshold & Resulting Smart Campus Curtailment

Figure 11: Demonstration of New Safe Threshold

FUTURE REQUIREMENTS

Testing within the NREL project demonstrated the application of ANM to manage multiple DER, multiple DER types, and at various scales. The technology has matured to a point at which relatively complicated schemes have proved themselves in the field and also through extensive testing such as at ESIF.

That being said, ANM and advanced distribution operations will continue to evolve as complementary distribution applications and market mechanisms become integrated as new function layers. Supported by discussions with the industry advisory committee, we conjecture future requirements will include:

- Multiple DER providing dynamic volt/VAR in coordination with grid voltage regulation equipment, including Volt-Var Optimization (VVO) or Conservation Voltage Optimization (CVO);
- Possible use of ANM to mitigate voltage flicker on long rural feeder;
- Deploying ANM schemes on underdetermined unbalanced distribution circuits: incorporating, for instance microPMUs with an ANM scheme;
- Role of ANM in multiple points of common coupling (MPCC) utility / community microgrids, with higher level complexity for synchronized macrogrid disconnection (i.e. transitioning) and also island mode operation for weak grids;
- ANM interfacing for adaptive protection and distribution automation schemes;
- Piloting this functionality on secondary mesh grids today aligns with how adaptive projection will be needed in the future for radial grids with very high DER penetrations;
- Application of ANM to manage DER during fault location, isolation and system restoration (FLSIR) schemes.

CONCLUSIONS

The INTEGRATE project successfully demonstrated many of the advanced functionalities currently demanded of ANM, but implemented at various levels of control with distribution networks. Discussion of results and outputs with the industry advisory committee reveal the need for additional technological development to fully address future DER control system requirements. This includes the need for rigorous end-to-end system testing to meet the DER growth, requirements for integration with other distribution applications, and emerging system/market integration requirements.

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