TESTING OF A DEPLOYED ACTIVE NETWORK MANAGEMENT SCHEME

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ABSTRACT

Flexible Plug and Play (FPP) is a UK Power Networks innovation project funded by the UK Low Carbon Network Fund (LCNF) scheme. The project has connected Distributed Generation (DG) onto constrained parts of the network in eastern England, avoiding the costs and delays associated with conventional reinforcement. The development and implementation of new technical solutions as well as flexible commercial arrangements makes it a landmark project that will provide the basis for future roll-out of Active Network Management (ANM). This paper describes the key highlights of the rigorous testing of the deployed solution. The ANM scheme was subject to a comprehensive set of tests, including unit testing of different components, IEC 61850 inter-operability testing with different vendors, and full system testing. Testing continues through commissioning, including testing each time a new generator connects. An important stage of testing was conducted in an environment with a combination of real ANM hardware and software with simulated generators and network measurements. This environment, was used to test a set of hypotheses on ANM operation, identified as important learning outcomes for the project.

INTRODUCTION

The testing occurred at the UK Power Networks' test facility and at the trial area of approximately 700 km^2 between Peterborough and Cambridge in the East of England The simulation environment allowed for the testing of specific conditions that occur under normal, real life operation without risking equipment health and creating a controlled environment to understand potential malfunctions. This allowed for confidence to be built over the developed solutions.

These advantages provided an opportunity to test the system behaviour in a controlled environment before proceeding to the operational phase of the project. Performing tests during the operational phase was not possible and may have unforeseen implications for other equipment. It is not possible to test all conditions in simulated environments so some results shown are from the commissioned operational equipment in actual service.

The simulation environment consisted of simulated generators, communications links using an RF mesh network and measurement points. The overall simulation architecture is in Figure 1. All information was stored in UK Power Networks' PI data historian.

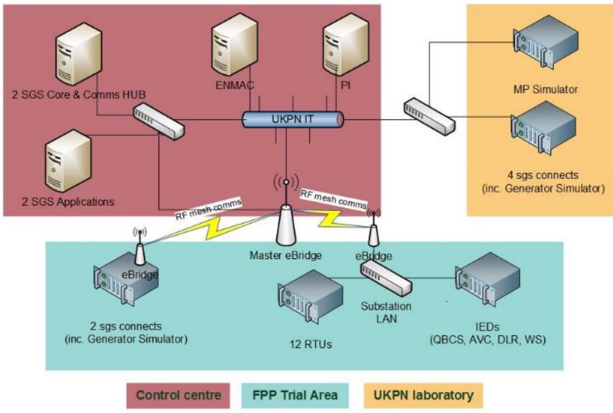

Figure 1: Flexible Plug and Play testing environment

The hypotheses tested using the simulation environment and the real system are the following:

1. Manage DG output against reverse power flow constraints;
2. Manage DG output against thermal constraints;
3. Manage DG output against voltage constraints;
4. Manage DG output with different commercial arrangements;
5. ANM thresholds vary based on dynamic line ratings;
6. ANM coordinates DG real and reactive power control to manage thermal and voltage constraints simultaneously;
7. ANM manages device and communication failures.

This paper is organised as follows: the active network management test section presents some of the formulation used to confirm the results obtained, the results section presents graphical and tabular results, the discussion section comments on the results before presenting the conclusions in the final section.

ACTIVE NETWORK MANAGEMENT TEST

The hypotheses studied simulate real world situations such as violation of thermal, voltage or reverse power flow limits and the ANM system behaviour when they occur. Functionality tested includes issuing correct setpoints according to the commercial principles of access (PoA), response of the ANM internal equipment system failover time and system behaviour under communication loss.

The setpoint calculation is based on thresholds. Each threshold has an associated timer. The timers are used for observation to determine if further actions are required. The higher the threshold importance, the lower its observation time will be. The **sgs power flow** application has a set of four thresholds:

- GLOBAL TRIP
- SEQUENTIAL TRIP
- TRIM
- RESET

The following levels are used to create a target to release or curtail the generation to in order to bring the power flow at the measurement point below the desired threshold.

- TRIM LESS
- RESET LESS

The generator's setpoint calculation is key to an ANM system's successful implementation. The setpoint calculation requires a target value (e.g. RESET LESS), to bring the power flow at the measured point below a specific threshold (e.g. RESET threshold observation time) a set period of time. Thus giving the confidence that the constraint level is below the maximum allowed. When the setpoint is issued and the measured constraint does not fall below the specified level the ANM system recalculates the setpoints to bring the measured constraint below the level desired.

As an example a set of expressions that are used to calculate a generator setpoint, using Shared PoA, are shown below.

The generator setpoint when curtailment is required is determined by the following equation:

$$Setpoint = P_a - \left(\frac{P_a}{P_a + P_b + P_c}\right) * \Delta * SF \qquad (1)$$

P_a – Represents the generator power output

$P_a + P_b + P_c$ – Represents the summation of power output of all generators under the Shared PoA contributing to the constraint

Δ – Represents the existing power flow at the constraint minus the target power flow at the constraint, where the target is the RESET LESS threshold

SF – Represents the sensitivity factor.

The generator setpoint when a release is required is determined by the following equation:

$$Setpoint = (SP_a - \left(\frac{RP_a}{RP_a + RP_b + RP_c}\right) * \Delta) * SF \qquad (2)$$

SP_a – Represents the generator setpoint before releasing

RP_a – Represents the rated power of the generator in question

$RP_a + RP_b + RP_c$ – Represents the summation of the rated power of all generators under the Shared PoA contributing to the constraint

Δ – Represents the existing power flow at the constraint minus the target power flow at the constraint, where the target is the TRIM LESS threshold

SF – Represents the sensitivity factor.

The **sgs voltage** application has a series of thresholds and operation zones. The thresholds and operation zones are defined below:

- **Target Value** : The value that the system will attempt to achieve when a threshold is breached for the defined observation time;
- **Release Zone**: The area between Release Lower and Release Upper defining the limits that the system may release between;
- **Lower Thresholds:** Two thresholds were defined to be of lower voltage than Release Lower. The priority of the threshold is inversely proportional to the value of the threshold;
- **Upper Thresholds:** Two thresholds were defined to be of higher voltage than Release Upper. The priority of the threshold is directly proportional to the value of the threshold.
- **Normal Zone:** The area indicating that no thresholds are being breached, bounded by the lowest Upper Threshold and the highest Lower Threshold. The Release Zone will always be contained wholly within the Normal Zone.

Figure 2 shows the thresholds and zones defined above in a diagram.

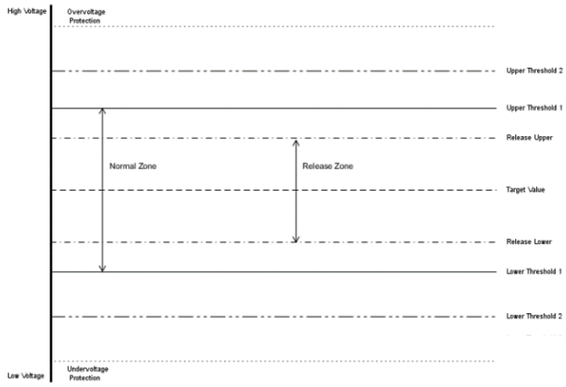

Figure 2: sgs voltage thresholds

The reactive power required to solve the voltage breach can be calculated using the following expression:

$$\Delta Q = \frac{\Delta V}{SF_Q} \qquad (3)$$

$$if\ \Delta Q \geq system\ limits\colon \Delta Q = system\ limits\ and$$

$$\Delta P = \frac{(\Delta V - \Delta Q * SF_Q)}{SF_P} \qquad (4)$$

$$if\ \Delta P \geq system\ limits\colon \Delta P = system\ limits$$

ΔQ – Variation in the reactive power output

ΔP – Variation in the real power output

ΔV – Actual voltage minus the desired value

SF_P, SF_Q – Sensitivity Factors

If ΔQ is greater than the equipment capacity, the system caps the variation to its limit. The remaining required power is curtailed from the generator's real power output. **sgs power flow** and **sgs voltage** applications limit the generator maximum setpoint change. This helps to create a smoother generator release to avoid sudden increases of power flow/voltage at the measurement point that could trigger generation trip.

The maximum duration expected uses the generation ramp rate, the threshold observation time and the number of steps required to achieve the desired level of operation at the measurement point.

RESULTS

Figure 3 to Figure 8 show the evolution of the generator values at the MP and ANM issued setpoints. Relevant events are presented in Table 1 to Table 7 and show the amount of time that the system took to reach the state determined by the ANM system, and the expected time to reach the desired system state. These tests were conducted in the simulation environment created for the FPP trial.

Table 8 to Table 10 show the time that the operational system took to manage communication and equipment failure. These results were obtained from the FPP ANM system installed in eastern England.

Manage DG output against reverse power flow constraints

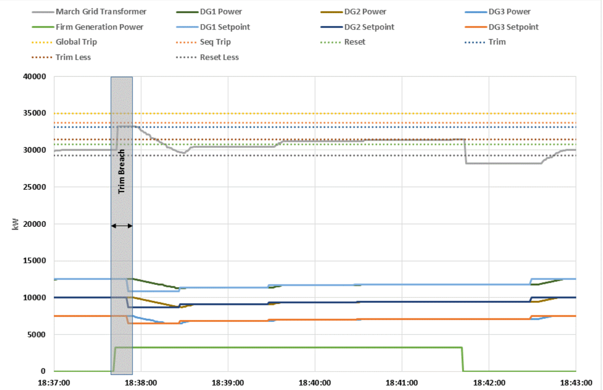

Figure 3: Reverse power flow test result

Table 1: Reverse power flow test relevant events duration

Relevant events	**Duration [s]**	**Maximum Duration [s]**
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	7	<=8
Communications Delay	<=5	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	32	<=68
Generation release duration to reach TRIM LESS	185	<=260

Manage DG output against thermal constraints

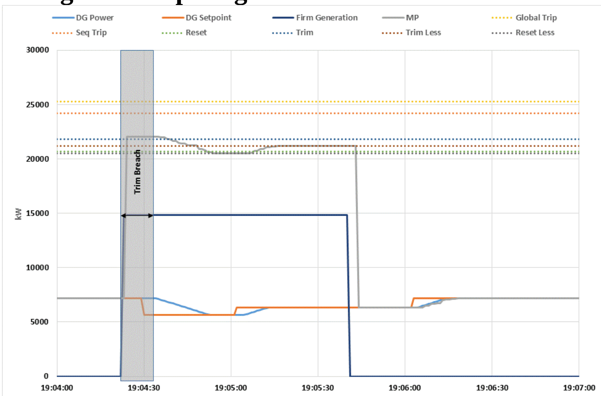

Figure 4: Thermal constraint test result

Table 2: Thermal constraint test relevant events duration

Relevant events	**Duration [s]**	**Maximum Duration [s]**
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	8	<=8
Communications Delay	<5	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	25	<=44
Generation release duration to reach TRIM LESS	12	<=60

Manage DG output against voltage constraints

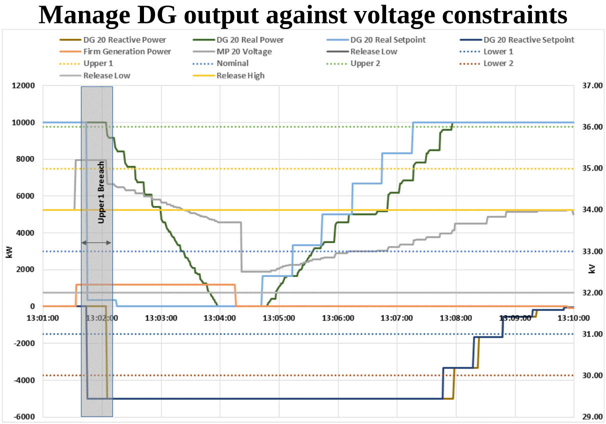

Figure 5: Voltage constraint test result

Table 3: Voltage constraint test relevant events duration

Relevant events	**Duration [s]**	**Maximum Duration [s]**
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	6	<=8
Communications Delay	<=9	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	24	<=43
Generation release duration to reach TRIM LESS	126	<=180

Manage DG output with different commercial arrangements

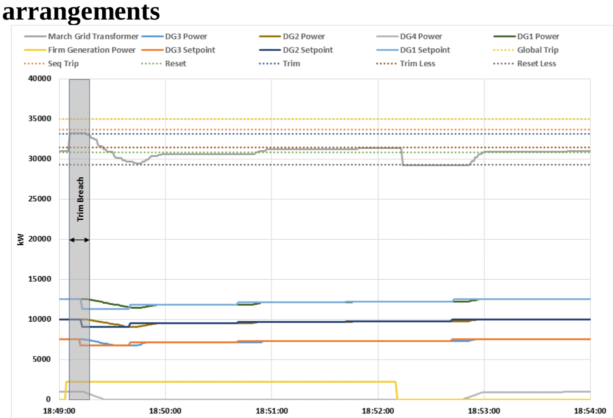

Figure 6: Different PoA application test

Table 4: Different PoA relevant events duration

Relevant events	Duration [s]	Maximum Duration [s]
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	6	<=8
Communications Delay	<=9	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	24	<=43
Generation release duration to reach TRIM LESS	126	<=180

ANM thresholds vary based on dynamic line ratings

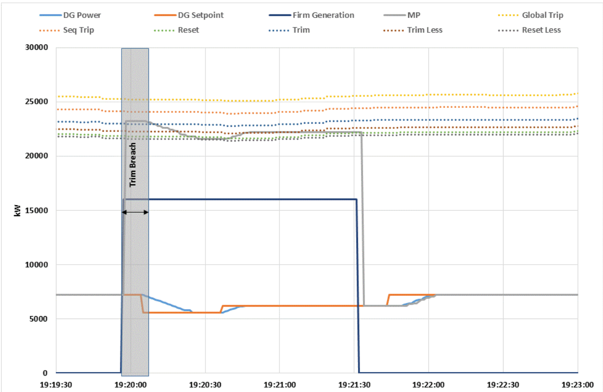

Figure 7: DLR application test

Table 5: DLR application test relevant events duration

Relevant events	Duration [s]	Maximum Duration [s]
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	6	<=8
Communications Delay	<6	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	26	<=48
Generation release duration to reach TRIM LESS	10	<=60

ANM Coordinates DG real and reactive power control to manage thermal and voltage constraints simultaneously

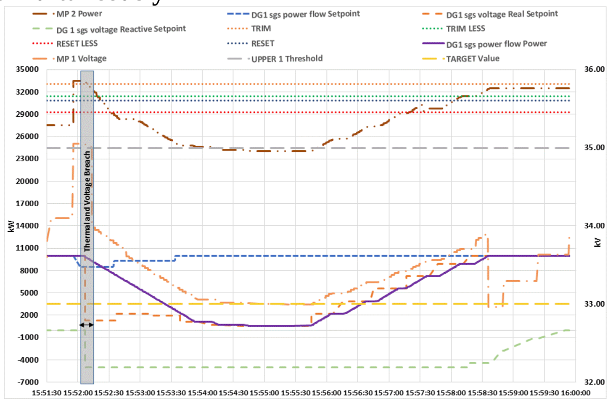

Figure 8: Thermal and voltage constraints simultaneous control test

Table 6: Voltage constraint relevant events

Relevant events	Duration [s]	Maximum Duration [s]
Time that the ANM took to issue a setpoint after the UPPER 1 threshold is breached	11.5	<=12
Communications Delay	<5	<=20
Time duration to reduce the voltage measured from UPPER 1 threshold to below TARGET voltage threshold	200	<=268
Generation release duration to reach RELEASE upper	245	<=300

Table 7: Thermal constraint relevant events

Relevant events	Duration [s]	Maximum Duration [s]
Time that the ANM took to issue a setpoint after the TRIM threshold is breached	6.5	<=8
Communications Delay	<5	<=20
Time duration to reduce the power flow measured from TRIM threshold to below RESET threshold	27.5	<=98
Generation release duration to reach TRIM LESS	158	<=180

ANM manages device and communication failures

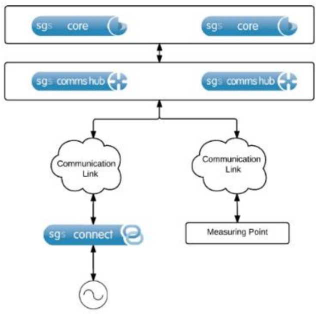

Figure 9: ANM architecture

Table 8: Communication failure between ANM and MP

Timestamp	Communication Link	Setpoint [kW]	Power output [kW]
02:31:09	OK	237	0
02:31:10	Failure	237	0
02:31:15	Failure	0	0
02:59:47	OK	0	0
03:00:25	OK	50	0

Table 9: Communication failure between ANM and sgs connect

Timestamp	Communication Link	Setpoint [kW]	Power output [kW]
16:54:04	OK	237	61
16:54:18	Failure	0	61
18:43:56	OK	0	0
18:44:54	OK	50	0

Table 10: sgs comms hub 1 failover to sgs comms hub 2

Timestamp	sgs comms hub used	Software status
08:46:10	1	Fail
08:46:26	2	OK

DISCUSSION

Figure 3 and Figure 4 show the ANM system behaviour under a TRIM threshold breach. **sgs power flow** calculates and issues an appropriate setpoint for the controlled generator(s) to reduce the real power. Thus the power flow at the measured point is reduced and brought to a level below the RESET threshold.

Figure 5 shows an UPPER 1 threshold breach. The **sgs voltage** application issues appropriate generator setpoints to manage the breach. In order to minimise the impact on the generator real power production, the application first checks if the amount of reactive power control available is sufficient to reduce the voltage and only if further voltage reduction is required then starts to reduce the real power output.

Figure 6 shows the ANM system applying the correct setpoints to generators that belong to different principles of access, Shared and LIFO [2] [3].

Figure 7 shows the impact that time varying thresholds have on the ANM system. The **sgs power flow** application calculated the appropriate setpoints to bring the power flow below the RESET threshold, respecting the observation times.

Figure 8 shows the ANM system handling two different applications, **sgs voltage** and **sgs power flow,** calculating setpoints for the one generator under a simultaneous thermal and voltage breach**.** The ANM system receives information from both applications and applies the most conservative setpoints to the generator. This allows for safer network operation.

Finally, the ANM system fail-over capability is demonstrated. The communications and control hardware fail-over was successfully demonstrated in the field. The results shown are from the implemented system and not from the simulation environment.

In the hypotheses tested the ANM system always brought the system to a safe state of operation within the maximum expected time.

The following tests did not receive an optimal release setpoint:

- Manage DG output against reverse power flow constraints (Figure 3),
- Manage DG output against thermal constraints (Figure 4),
- Manage DG output with different commercial arrangements (Figure 6).

The algorithm calculates the generator release setpoint which takes consideration of all generators instead of taking only the active generators. The tests described included one generator that was not active but that influenced the release setpoints.

This situation can appear in real operation where some generators are assigned to the controlled generator list before they are commissioned, creating a virtual position that the algorithm takes into consideration when releasing the existing generators.

This observation does not detract from the performance observed because the system did not allow any network limit to be breached.

CONCLUSION

The FPP project represents a significant deployment of the ANM in fully commercial conditions. The lessons learned are applicable to DNOs in all countries considering, or already adopting, similar constraint management methods to enable generation connection in distribution networks with limited hosting capacity. The work described in this paper systematically tested the ANM system in order to prove its reliability and correct application of theoretical principles, such as principles of access, curtailment and release setpoints and equipment failover. The successful testing of the ANM system is a significant milestone in the FPP project and also for the further deployment of ANM with security, reliability and performance criteria fully tested.

REFERENCES

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