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to the Electricity Industry

Virtual Statcom:
Work Package 1 Report

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List of Revisions

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04	10/04/2019	Grant McCormick	Zia Emin	Zia Emin

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Table of Abbreviations

Abbreviation	Term
DG	Distributed Generator
FPL	Flexible Power link
LTDS	Long Term Development Statement (Nov 2018)
MW	Megawatts, unit for real power
MVAr	Mega Volt-Amps reactive, unit for real power
NIA	Network Innovation Allowance
NOP	Normally open point
OPF	Optimal power flow
ORPD	Optimal reactive power dispatch
p.u	Per unit
pf	Power Factor
PSC	Power Systems Consultants UK Ltd
PSS/E	Power System Simulator for Engineering
Python	A high-level, general-purpose programming language
RPF	Reverse power flow
Statcom	Static Synchronous Compensator
UKPN	United Kingdom Power Networks
VBA	Visual basic for Applications
WP	Work Package
WPD	Western Power Distribution

1 Introduction

Western Power Distribution (WPD) has engaged PSC UK LTD to deliver an innovation project known as the Virtual Statcom project, the project is being run by WPD and funded under the Ofgem Network Innovation Allowance (NIA).

As an increasing number of distributed generators (DGs) connect to distribution networks, technical constraints arise that can limit the total amount of generation a network can host. To overcome the technical constraints associated with distributed generators and continue to operate a safe, secure and reliable network, WPD undertake traditional network reinforcements as well as initiating and leading innovation projects to develop new solutions. A key focus of innovation projects is to increase the utilisation of existing assets to defer network reinforcements, the Virtual Statcom project fits in this category of project.

The objective of the Virtual Statcom project is to determine the technical feasibility of increasing the network hosting capacity, for both generation and load, through implementing an algorithm to control and coordinate the reactive power output of existing generators in the distribution network.

If the project demonstrates benefit it will enable more generation and load to be connected to distribution network without the need for network reinforcement.

The project is structured into the following 5 work packages (WP):

- WP1 - Data gathering/validation and study zone selection.
- WP2 - Power flow simulations & Virtual Statcom algorithm.
- WP3 - Graphical User Interface.
- WP4 - Time series comparison studies.
- WP5 - Virtual Statcom feasibility study reporting.

The work packages are being delivered in order.

This report details the work completed in delivering Work Package 1.

2 Scope of Work – Work Package 1 (WP1)

The scope of WP1 includes all the preparatory work required before commencing the detailed power system studies and the development of the hosting capacity evaluation and optimisation algorithms in Work Package 2. The scope of work for WP1 as set out in the Project Collaboration agreement [1] between PSC and WPD is as follows:

D1-1 Validation of modelling data.
The data that must be validated includes but is not limited to the Power System Simulator for Engineers (PSS/E) power flow models in the selected zones (PSS/E saved cases and single line diagram), time series data, etc.

D1-2 Selection of substation networks to be studied.
Four networks will be selected. The selected networks will cover the substation and all of the feeders it feeds, down to the Normal Open Points (NOPs).

D1-3 Literature review on optimisation algorithms for network capacity optimisation.
This involves researching the already developed optimisation algorithms that optimise the network capacity through reactive power control in the network.

D1-4 Specification of the first version of the methodology that will be implemented to evaluate the network capacity.
The specification will include a flowchart demonstrating the methodology and a written explanation of how the methodology works. This methodology needs to be able to quantify how much is the load capacity and how much is the generation capacity of the network in Megawatts (MWs). It must be able to evaluate the network capacity in any network under any conditions.

D1-5 Specification of the first version of the optimisation algorithm that will be implemented to optimise the network capacity.
The specification will include a flowchart demonstrating the algorithm operation and a written explanation of how the algorithm works. The algorithm must be able to adjust the reactive power output (or other generator parameters if required) of generators in the most optimal way such that the capacity of the network increases compared to the existing network capacity. The algorithm must be able to work on any network and under any operating conditions.

D1-6 Work Package 1 Report.
This report will be documenting all the work completed for all deliverables of Work Package 1.

3 Virtual Statcom project background

3.1 Passive Distribution Networks

The design of traditional distribution networks was based on a top down passive approach. In these traditional distribution systems, the primary function was to transfer power from the transmission system level Grid Supply Points (GSPs) to the Bulk Supply Points (BSPs) and onwards to primary substations and the end consumers of electricity. A key characteristic of passive distribution networks was that power flows were always considered in a single direction, notably from a higher voltage sources towards lower voltage loads.

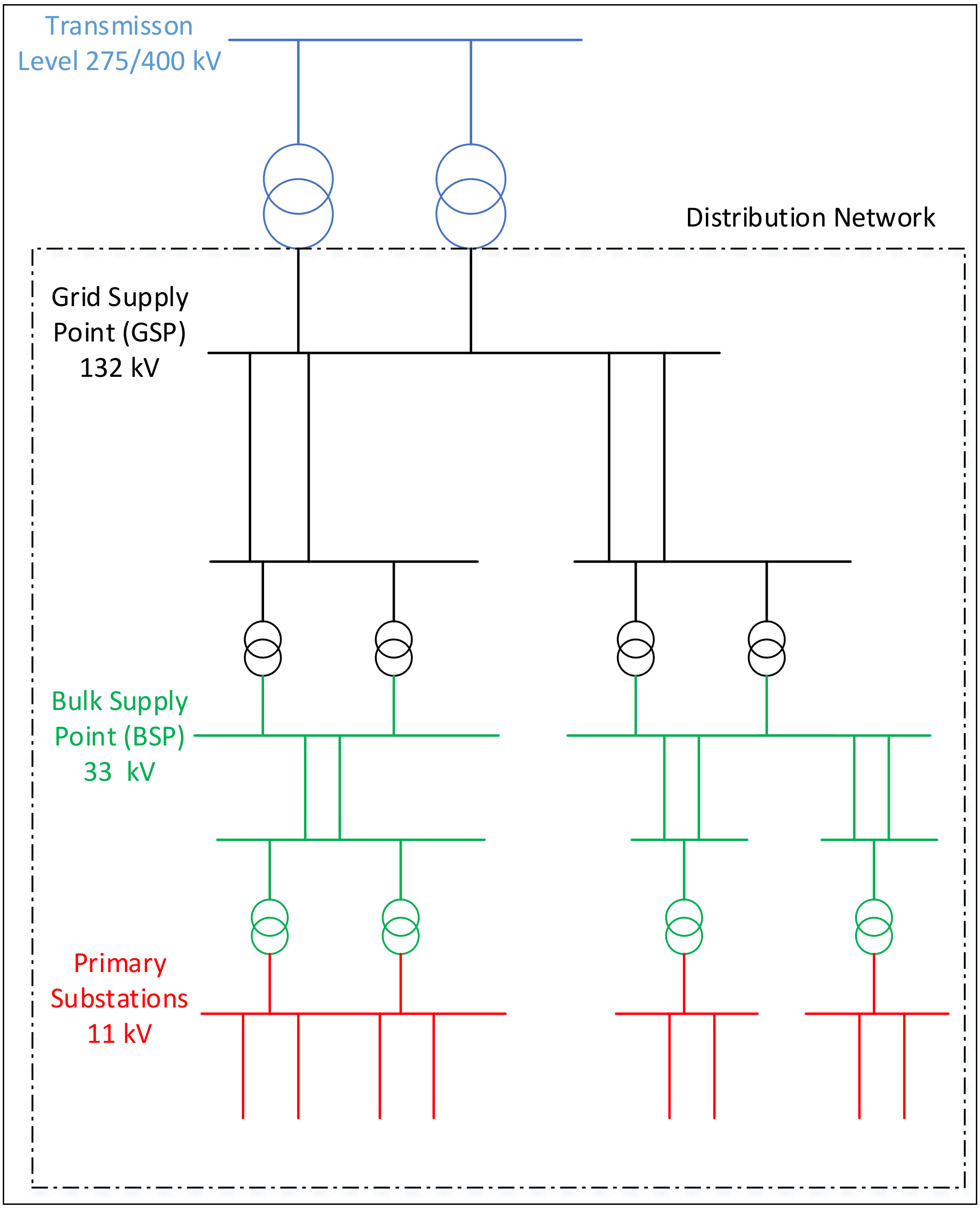

Figure 1 - Distribution Network layout

3.2 Accommodating distribution connected generation

The past 10-20 years has seen an increase in generators connected to distribution networks, known as Distributed Generators (DGs). In WPD's South West network DGs predominantly consist of renewable generation (i.e. wind, solar) connected at 33kV and 11kV voltage levels. The increase of DGs changes the key characteristic of passive distribution networks. Power will now flow in either direction and is dictated by changing loads and generation which can be intermittent in nature.

The uptake of DGs provides benefits of low carbon energy. Initially, it can also help relieve network thermal constraints by supplying power closer to the load centres. This can therefore reduce loadings on upstream lines, cables and transformers. However, distribution networks cannot accommodate ever increasing connections of DGs. Aside from the practical considerations such as land availability and favourable sites for wind or solar irradiance, technical factors will constrain the total amount of DGs that can be connected.

A terminology used to quantify how much generation a network can accommodate is "hosting capacity" [2] [3]. The **Hosting Capacity** of a network is defined as the total amount of distributed generation that the network can accommodate without violating predefined operational, physical and statutory limits.

The technical factors that can constrain the hosting capacity of a network include:

- Voltage regulation
- Voltage step constraints
- Thermal ratings
- Fault levels
- Power quality

The impact of these technical factors on hosting capacity is briefly explained in this section.

3.2.1 Voltage regulation

The statutory voltage limits for distribution networks in the UK are set in the Electricity Safety, Quality and Continuity Regulations 2002 and are +/- 6% of the nominal voltage at 11kV and 33kV. These statutory voltage limits will be incorporated in to the Virtual Statcom project.

The traditional method of voltage regulation in passive distribution networks is to increase the bus voltage at BSPs and primary substations above the 33kV and 11 kV nominal ratings to account for the voltage drop along the distributions feeders and ensure that far end of feeders are within the statutory limits. However, the situation changes if DGs are connected along the feeders or at the end of feeder. The connection of DGs can lead to voltage rise issues. This is due to the voltage at the point of connection of a DG being proportional to the real and reactive power of DG and load [4]. For combinations of load and generation, when load is less than generation a voltage rise takes places at the DGs point of connection. With traditional voltage regulation and DG, bus voltages along the feeder can exceed the +6% statutory voltage limit. It is for this reason that DGs are typically required to operate with a leading power factor (importing reactive power) to counter this voltage rise.

The voltage head room on a feeder limits the size of individual DGs and therefore the hosting capacity for the network. The voltage head room on a feeder is defined as the difference between the upper statutory voltage limit and the bus voltage at a given bus. To illustrate voltage head room, consider the following two bus example where:

- The bus voltage at the BSP is fixed at 1.0 p.u.
- The reactive power of the load and generator are ignored.
- 3 arbitrary scenarios are considered:
  - When the real power of the generator is less than the load. (Pg < Pd)
  - When the real power of the generator is equal to the load. (Pg = Pd)
  - When the real power of the generator is greater than the load. (Pg > Pd)

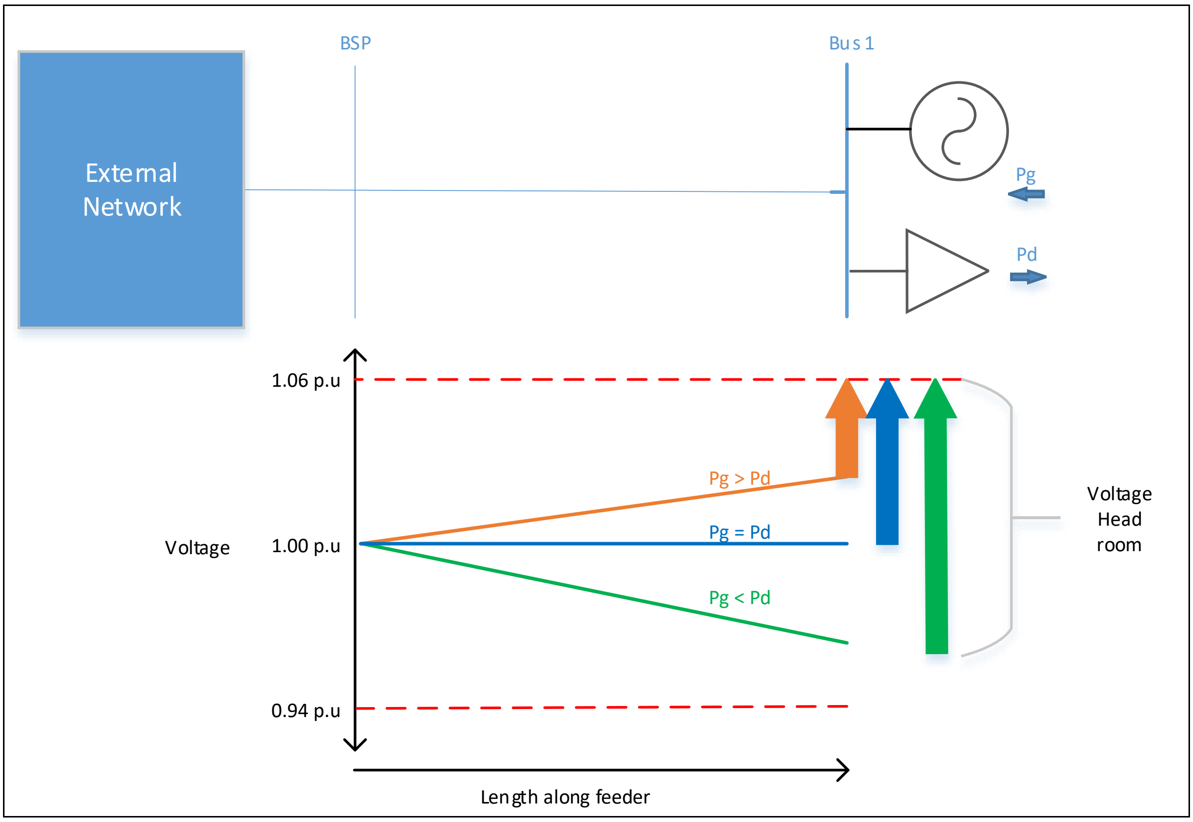

Figure 2 - Voltage head room

Figure 2 demonstrates that as the amount to real power from the generator (Pg) increases the voltage head room decreases.

3.2.2 Voltage step constraints

The hosting capacity may also be constrained by voltage step constraints. The voltage step constraints for distribution networks in the UK are set in the Distribution Planning and Connection Code and Engineering Recommendation P28. The voltage step constraints are +/- 3% for frequently occurring events. The tripping of a DG can cause voltage steps in either direction depending on the size of the DG and system conditions, this can also limit the size of DG on a feeder and hence hosting capacity. These voltage step constraints will be incorporated in to the Virtual Statcom project.

3.2.3 Thermal ratings

The installation of DGs in networks can be beneficial and can reduce the loading of lines, cables and transformers. However, as the total distributed generation installed increases, reverse power flows arise which can exceed the thermal ratings of connected equipment. Therefore, the hosting capacity can be limited by the thermal ratings of equipment. Further to this, some equipment such as transformer tap changers and circuit breakers have lower ratings under reverse power conditions limiting the hosting capacity even further.

3.2.4 Fault levels

A distribution system is designed to safely handle a certain level of short circuit current. In passive distribution networks the short circuit current infeed was assumed to come from the upstream network. However, by adding distributed generation, this condition changes as the distributed generators will also contribute fault current. This can lead to the short circuit capacity of the distribution network being exceeded thus limiting the hosting capacity. Specific issues associated with fault levels are not part of the scope of this project and therefore will not be considered any further in the Virtual Statcom Project.

3.2.5 Power quality

By increasing DG connections, there is the potential to affect voltage and current quality in the grid. The proliferation of power electronic based devices is expected to introduce impacts including: harmonic distortion (both characteristic and low order non-characteristic); rapid voltage changes; unbalance due to single phase connections; and long-term voltage variation and transients due to the connection and disconnection of various DG sources. Specific issues associated with power quality are not part of the scope of this project and therefore will not be considered any further in the Virtual Statcom Project.

3.3 Techniques to increase hosting capacity

The traditional means to increase hosting capacity is to undertake network reinforcements - this can be costly and time consuming. Alternative means to increase hosting capacity include:

- Voltage control schemes to control transformer set points and switched capacitors.
- Reactive power or power factor regulation.

It is worth nothing that non-firm connections that require active power curtailment under certain system conditions which are becoming more prevalent in distribution networks, increase the total installed generation however, do not increase a network's hosting capacity.

3.4 Virtual Statcom concept

The existing DGs connected to WPD's BSPs and primary networks operate with a fixed power factor between unity and 0.95 leading (import reactive power). While this is appropriate for the extreme case of maximum generation and minimum load this fixed power factor may not be appropriate for all network conditions. This is the fundamental concern that the Virtual Statcom project aims to investigate. The concept of the Virtual Statcom is to assume that instead of operating with fixed power factor, the DGs can operate across a power factor range by optimising the reactive power output of DGs in a network for different conditions, the hosting capacity can be increased.

4 Literature review

As part of WP1, PSC undertook a literature review of existing academic journal papers and innovation projects in order to capture the existing academic and industry knowledge on the subject.

The academic journal papers that were reviewed focused on:

- Network hosting capacity evaluation methods.
- Optimisation of network hosting capacity.

The innovation projects that were reviewed were:

- WPD's Network Equilibrium project.
- UKPN/National Grid Power Potential project.

The findings of the literature review are presented in this section.

4.1 Network Hosting Capacity Evaluation

Two approaches for evaluating the network hosting capacity were found from the literature:

- Per node non-concurrent hosting capacity [2] [5]
- Concurrent hosting capacity [6] [3] [7] [8] [9]

4.1.1 Per node non-concurrent hosting capacity evaluation

The per-node non-concurrent approach evaluates the hosting capacity at each node (bus) in the network independent of surrounding nodes. It does this by placing generation (or load) at a node and iteratively increasing the generation (or load), calculating load flows and checking for voltage or thermal excursions. The following flow chart in Figure 3 is of the method presented in [2] and graphical results from [5]:

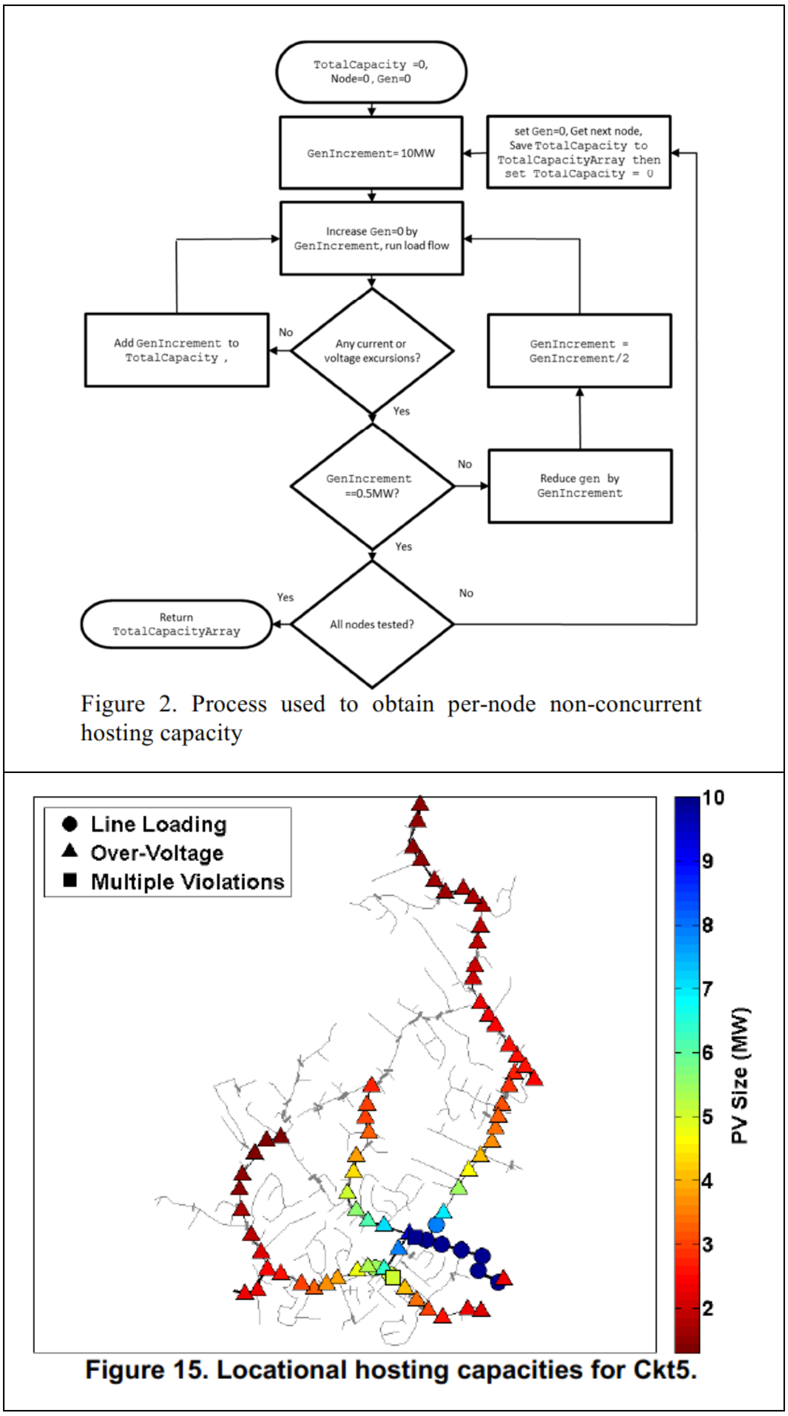

Figure 3 - per-node non-concurrent process and visual results

The metric “mean per-node non-concurrent hosting capacity” is presented in [2] as a method to determine the merit of various techniques to increase network hosting capacity. In [2] it is used to compare back-to-back convertor links in distribution networks for capacity.

The benefits of the per-node non-concurrent method are:

- Computationally simple to implement.
- Effective tool for initial site selection for DG.
- Effective way to visualise capacity.

The per-node non-concurrent approach in the context of the Virtual Statcom project would not be effective as this project is not focused on a per-node analysis at this time.

4.1.2 Concurrent hosting capacity evaluation

Concurrent hosting capacity, unlike per node non-concurrent hosting capacity, is a measure of the total generation (or load) that can be connected to a network without violating operational, physical and statutory limits for a given scenario of load and generation.

Two methods of evaluating concurrent hosting capacity were discovered in the literature review, one method is based on an iterative scaling approach similar to that presented in 4.1.1 [6, 3] and the other method is based on an Optimal Power Flow (OPF) approach [7, 8, 9, 10]

4.1.2.1 Iterative scaling method

The iterative approach for concurrent hosting capacity presented in [6] and [3] differ slightly but both are based on scaling generation until a network limit is violated. The method presented in [6] is calculated by scaling existing DGs in the network whereas the approach presented in [3] places a new generator at every bus to be scaled. The method presented in [6] takes and extra step and performs a per feeder approach to scaling generation, according to the following logic.

1. *Scale all existing generation until a voltage constraint or thermal constraint is found in the network analysed.*
2. *Check if there are any feeders with no constraints.*
3. *Continue scaling the feeders with no constraints.*
4. *Stop scaling once all feeders have constraints.*

The author of [6] states this ensures that the network generation hosting capacity is not underestimated. However, if a feeder doesn't have an existing generator the hosting capacity of the feeder is not included, so in some cases there is the potential to slightly underestimate the hosting capacity.

The benefit of a concurrent iterative method is computational simplicity. This approach also matches the definition of hosting capacity which has been selected for the Virtual Statcom project. Concurrent hosting capacity defines the potential total hosting capacity that can be connected to the network at the same time, so this is a good metric to use to test methods of improving hosting capacity. This method could also easily be extended to evaluate the hosting capacity with fault level and voltage step considerations.

4.1.2.2 Optimal Power flow method

The methods presented in [7, 8] to evaluate the network capacity are based on formulating and solving an Optimal Power Flow problem.

A high-level summary of the method is:

- In a network, identify n candidate buses for new DG.
- Set the objective function to:

$$Maximise \sum_{g=1}^{n} Pg$$

Where $(P_1, P_2, \dots\ P_n,)$ are the control variables i.e. the real power output of each generator.

Subject to (constraints):

- Real and Reactive power balance (i.e. load demand is still met)
- Bus voltage limits
- Branch flow limits (i.e. Thermal limits)
- Voltage step change [9]
- Fault level limits [10]

It is noted that the summation is independent of existing generation, so this must be added

Various solvers were used across the OPF papers. Of interest was that in [8] a method was described that made use of the PSS/E OPF add on module to assess the network capacity.

In the OPF method of evaluating hosting capacity, different outcomes can be achieved depending on the user's manual selection of the candidate bus(es).

- If only one bus is selected the optimisation will return the largest value of generation that can be connected to that bus and in this case is essentially the same as the per-node capacity evaluation method.
- If multiple sites within the network have been identified that are well suited to DG due to land availability and energy source (wind/solar irradiance) the optimisation will provide a comparison of the optimal sizing of DGs across feeders or within the same feeder.
- If the candidate buses are selected at the ends of feeders, as presented in [8], the total potential hosting capacity is returned.

The benefit of the concurrent OPF method for hosting capacity is it may provide a slightly more accurate assessment compared to the iterative method due to using independent continuous control variables for generators rather than iteratively incrementing reactive power contribution from DGs. The downside is computationally it is much more complex to implement and incorporate contingencies and constraints than the concurrent iterative method.

4.1.3 Summary of hosting capacity evaluation and Virtual Statcom approach

The literature review identified the following two approaches in evaluating the hosting capacity of a network.

1. Per-node non-concurrent hosting capacity.
2. Concurrent hosting capacity.

Under the concurrent hosting capacity approach, the hosting capacity can be determined using two methods, an iterative scaling method or an optimal power flow method.

The objective of the Virtual Statcom project is to determine how much extra generation (or load) can be added across a network, rather than maximising the generation or load connected to a single node (bus). The concurrent hosting capacity approach calculates the maximum simultaneous generation (or load) that can be connected to a network. This provides a metric that aligns with the objective of the project and for this reason, the Virtual Statcom project will use the concurrent hosting capacity evaluation approach when calculating network hosting capacity. Of the two methods identified for the concurrent hosting capacity the Virtual Statcom project has opted to use the iterative scaling method over the optimal power flow method as a basis for the development of the hosting capacity algorithm for the following reasons:

- Computational simplicity.
- Ability to easily incorporate contingencies and constraints.
- Applicable to generation and load.

4.2 Optimisation of network hosting capacity

4.2.1 Optimal reactive power dispatch

The literature review identified multiple papers that focused on the Optimal Reactive Power Dispatch (ORPD) problem [11] [12] [13] [14] [15] [16] [17] [18] [19]. The objective function in the papers was set to minimise real power losses in a network using various reactive power devices, including the reactive output of DGs.

The general objective function for ORPD is developed to minimise the active power loss in the network, by summing the real power branch losses.

$$Minimise \sum_{n=1}^{br} Plosses_n$$

Where br = Total number of branches in the network
$Plosses_n$ = Calculated real power losses in branch n

The optimisation can be set up to use control variables that include:

- Reactive power output of generators
- Voltage control setpoints
- Transformer tap positions
- Reactive devices (SVC, Statcoms, Shunts)

Subject to (constraints):

- Limits on control variables
- Real and Reactive power balance (i.e. load demand is still met)
- Bus voltage limits
- Branch flow limits (i.e. thermal limits)

The constrained ORPD problem summarised above ensures that real power losses are minimised. By using exclusively reactive power control variables and the real and reactive power balance constraint, the optimisation corresponds to the maximum thermal headroom of the network. To visualize this, the following two-bus example shown in Figure 4 demonstrates the OPRD method:

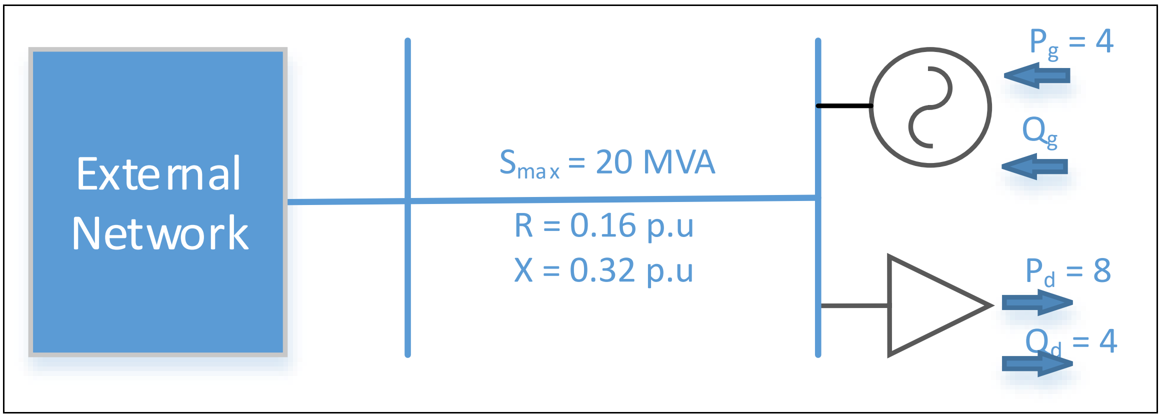

Figure 4 - two bus network

- The objective is to minimise the real power losses of the network using the reactive power of the generator – Q_g is the control variable.
- All other values are fixed i.e. P_g, P_d, Q_d, R, X, S_{max}.
- Only apply the real and reactive power balance and thermal constraints. i.e. ignore the reactive power limits of the generator and the bus voltage limits.

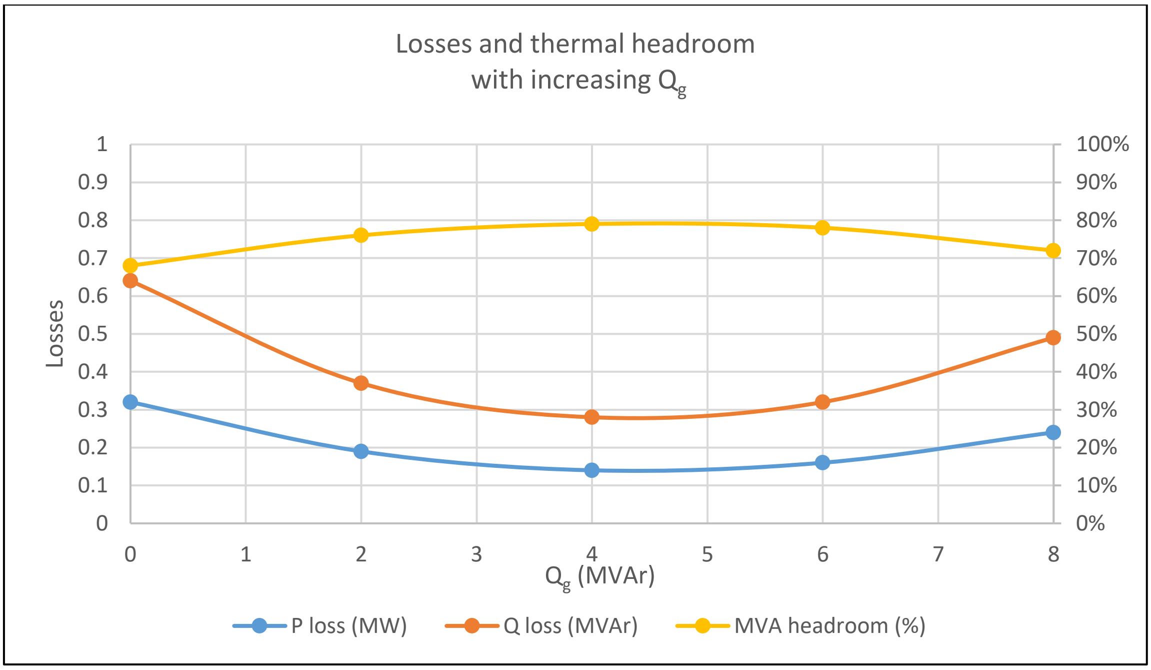

Figure 5 - Losses and thermal head room with increasing Q_g

Figure 5 demonstrates that the locus of the maximum thermal headroom coincides with minimum real power losses and minimum reactive power losses.

4.2.2 Optimisation solvers

For any optimisation problem two main methods exist, gradient based algorithms and gradient-free algorithms. Gradient based algorithms utilise the derivative(s) of the objective function to determine the search direction to locate the optimal solution whereas gradient-free algorithms use stochastic models to determine the search direction to locate the optimal solution.

The preference determined from the literature is to apply gradient-free algorithms to the ORPD problem as opposed to classical gradient based optimisation methods. Gradient-free algorithms are more likely to find the global optimum than gradient based algorithms due to their ability to handle complex objective functions and discrete control variables such as transformer tap position and switchable shunts [12] [14]. Multiple solver algorithms have been applied (academically and professionally) to solve the optimal reactive power dispatch ORPD problem, such as:

- Particle swarm optimisation [12]
- Mean-Variance mapping optimisation [14]
- Flower pollination algorithm [15]
- Artificial bee colony method [16]
- Ant lion optimiser [17]
- Gravitational search algorithm [18]
- Cuckoo search algorithm [19]

The literature reviewed identified Particle Swarm Optimisation as the benchmark to compare new novel solvers to as it is a proven optimisation method. Some of the optimisation methods above are computationally more efficient than Particle Swarm Optimisation but the results converge to very similar values. An overview of particle swarm is presented in Section 9.2.5.

Table 1 presents the open source Python packages for the solvers identified in the literature review.

Table 1 - Python open source solver packages.

Solver from literature review.	Open source Python packages
Particle swarm optimisation [12]	*psopy 0.2.3* *pyswarm 1.0.0.* *NiaPy 1.0.2* *SwarmPackagePy 1.0.0a5*
Mean-Variance mapping optimisation [14]	*None*
Flower pollination algorithm [15]	*NiaPy 1.0.2*
Artificial bee colony method [16]	*honeybee 0.1.0a3* *NiaPy 1.0.2* *SwarmPackagePy 1.0.0a5*
Ant lion optimiser [17]	*None*
Gravitational search algorithm [18]	*optimal 0.2.0* *SwarmPackagePy 1.0.0a5*
Cuckoo search algorithm [19]	*SwarmPackagePy 1.0.0a5*

4.2.3 Summary of network hosting capacity optimisation and Virtual Statcom approach

The objective of the Virtual Statcom project is to determine how much extra generation (or load) can be added across a network by optimising the reactive power output of existing DGs, this is essentially an Optimal Reactive Power Dispatch (ORPD) problem as described in the literature. The literature review demonstrated that gradient-free solvers are best suited to solve ORPD problems and that an array of gradient-free solvers exist.
The Virtual Statcom project will define the optimisation of the network hosting capacity as an ORPD problem and of the many solvers identified, will initially develop the Virtual Statcom algorithm to incorporate a Particle Swarm Optimisation (PSO) solver. A PSO solver was selected for the following reasons:

- PSO is a proven method and often used as a benchmark for ORPD problems.
- Open source Python PSO packages are available.
- For the size of WPD's 33kV & 11kV networks the computational time advantages of other solvers compared to PSO is expected to be minimal.

4.3 WPD's Network Equilibrium project

The Network Equilibrium project was an innovation project undertaken by WPD which investigated and demonstrated that voltage and power flow management can release network capacity, the project's trial locations focused on the 33kV and 11 kV networks in the counties of Somerset and Devon in WPD's South West area. The Network Equilibrium project focused on three technical areas:

- The Enhanced Voltage Assessment (EVA) Method
- The System Voltage Optimisation (SVO) Method
- The Flexible Power Link (FPL) Method

The EVA method involved two parts, 1) the creation of the *advance planning tool* and 2) a Voltage level assessment (VLA) to determine the impact of widening existing statutory voltage limits. The results of the VLA quantify the extra hosting capacity released if the distribution statutory limits mentioned of +/- 6% were relaxed to +/- 8% at 11 kV and +/- 10% at 33kV. No changes to the statutory limits have resulted so far as a result of this work, therefore the Virtual Statcom project will consider bus voltage limits of +/- 6% at 11kV and 33kV.

The SVO method involved assessing and implementing a control system to determine in real time the most optimal Automatic Voltage Control (AVC) setpoint for Bulk Supply Points (BSP) 132/33kV and Primary 33/11 kV transformers. The results in [20] show that for certain BSP and Primary networks significant hosting capacity is released. Some of the BSP networks and Primaries investigated in the Network Equilibrium are also being considered for the Virtual Statcom Project. The Virtual Statcom project is expected to complement the SVO. However, the Virtual Statcom project will consider the AVC setpoints to be static.

The FPL Method involved assessing and implementing a back to back AC–DC-AC converter to control real and reactive power flows between two WPD 33kV networks. The control of a FPL will not be considered in the Virtual Statcom project, however an FPL will be treated as source of controllable reactive power based on a P-Q characteristic if located in a network selected.

4.4 National Grid/UKPN Power Potential project

The Power Potential project is being undertaken by National Grid and UKPN, the aim of the project is to open up new markets for distributed energy resources and generate additional capacity by alleviating transmission and distribution constraints [21]. The project demonstrates that DGs can be used to supply real and reactive power at the Grid Supply Point to manage transmission constraints. The project involves Optimal Power flows (OPF) for a day ahead and real time dispatch of real and reactive power. The project uses an AC heuristic optimisation approach compared to and AC mathematical approach to solve the OPF to ensure solve times are less than 10s for the real time OPF. An AC heuristic optimisation reduces the complexity of the AC mathematical optimisation approach but may only find the local minima not the global minima [21]. PSC contacted National Grid to discuss finer details of the OPF approach but learned this outsourced to a supplier and treated by National Grid/UKPN as a black box. The Virtual Statcom project will implement an AC mathematical approach for optimisation.

5 Validation of Power System models

The objective of validating the power system models in WP1 is to gain insight into WPD's models, modelling assumptions and to ensure that these models can be relied upon for subsequent work packages. This section outlines the steps taken by PSC to validate WPD power system models.

5.1 Models/data provided from WPD

WPD provided PSC with models in PSS/E version 32 and 34 of the WPD South West network area.

The following 400/132/33kV network models were provided:

- *20181219 South West PSSE 20172018 DIV Primary Day MD v32.sav*
- *20181219 South West PSSE 20172018 DIV Primary Day MD v32.raw*
- *20181219 South West PSSE 20172018 DIV Primary Day MD v34.sav*
- *20181219 South West PSSE 20172018 DIV Primary Day MD v34.raw*

A selection of BSP networks PSS/E SLDs were also provided.

The following Primary 11kV network models were provided:

- *310023_TivertonMoorhayes_Final.sav*
- *ColleyLane_20072017_V50.sav*
- *Dunkeswell_310057_FINAL.sav*
- *Lydeard_St_Lawrence - Final v1.0.sav*
- *MarshGreen-Final v2.0.sav*
- *Millfield Final v3.0.sav*
- *Nether Stowey Final v2.0.sav*
- *Waterlake-Final 32 v2.0.sav*

11kV network PSS/E SLDs were provided, one for each of the models above.

5.2 Model validation approach

The following approach was taken by PSC to validate the models provided:

1. Perform initial convergence check in PSS/E.
2. Develop network summaries for the following two cases:
    a. Minimum Generation – Maximum Load
    b. Maximum Generation – Minimum Load
3. Review prepared network summaries with WPD, clarified modelling assumptions, and updated summaries.

The following describes the approach taken and the outcomes of each check.

5.2.1 Convergence Check

The purpose was to check that with the PSS/E models received, a convergent power flow simulation could be performed, and data appeared realistic.

5.2.2 Network summaries

To validate the models received, network summaries were developed for all WPD South West 33kV BSP networks and the 11kV networks received. The network summaries provided power system statistics and analysed the networks under the following two boundary cases:

1. Minimum Generation – Maximum Load
2. Maximum Generation – Minimum Load

The networks summaries and assumptions for the power flow studies were discussed with WPD to ensure that the Min-Gen Max-load and Max-Gen Min-Load used in work package 2 are accurate. The final assumptions and network summary results are detailed below.

33kV networks:

The following assumptions are used when developing the 33kV network summaries:

- The WPD South West region case provided has the correct generation profile for generators connected above 33kV.
- The loads given in the original WPD PSSE models are the maximum load.
- Minimum load is 30% of maximum load – WPD LTDS Nov 2018.
- <u>Min Gen-Max Load case assumptions:</u>
    - All generators that are connected to WPD's network at 33kV and below are out of service.
    - Generators connected above 33kV are in/out of service as provided in original 400/132/33kV model.
    - All battery sites are loads (i.e. not providing power).
    - Loads as provided in original 400/132/33kV model.
- <u>Max Gen-Min Load case assumptions:</u>
    - All generators are in service, regardless of voltage level.
    - All battery sites providing power (i.e. not loads)
    - Scale all loads regardless of voltage level to 30% of max load case provided.

Power flow studies were run for the two cases, the results for the 33kV networks that have been selected for inclusion in the Virtual Statcom project are presented in 6.2.1. The full 33kV networks summary in included in Appendix A – BSP and Primary network summaries

11kV networks:

The following assumptions are used when developing the 11kV network summaries:

- <u>Min Gen-Max Load case assumptions</u>
    - All generators that are connected to WPD's network at 11kV and below are out of service.
    - All battery sites are loads (i.e. not providing power).
    - Loads values as provided in original 11kV model.
- <u>Max Gen-Min Load case assumptions</u>
    - All generators are in service, regardless of voltage level
    - All battery sites in model providing power (i.e. not loads)
    - Scale all loads regardless of voltage level to 30% of max load 11kV case provided.

Power flow studies were run for the two cases. The results for the 11kV networks that have been selected for inclusion in the Virtual Statcom project are presented in 6.2.2. The full 11kV networks summary in included in Appendix A – BSP and Primary network summaries.

5.2.3 Review Discussion

All the models received converged and from discussion with WPD it was determined that the results were reasonable and representative of the WPD system. Thereafter, the models were considered validated and processed through the network selection criteria outlined in Section 6.1.

6 Network selection methodology

The models received contained 42 BSPs in WPD's Southwest region and eight primary substations that had been modelled as part of the WPD's Network Equilibrium project. Out of the models provided, three BSPs and one primary were to be included as study zones in the Virtual Statcom project. The main aim was to select networks with different characteristics to test the applicability of the Virtual Statcom method across a range of network scenarios.

6.1 Study Zone selection criteria

The following describes the criteria that were used to select the networks for study.

1. **Amount of DGs installed** – The Virtual Statcom method seeks to utilise reactive power from existing DGs to increase network hosting capacity. Therefore, it is fundamental to have at least one DG. By choosing networks with larger numbers of generators, the Virtual Statcom method will be given more control points to demonstrate effectiveness. Preference is also given to networks with disperse DGs, rather than networks with all generation at one bus.

2. **Historical data granularity**– To determine the benefit of the Virtual Statcom method, studies will be performed using timeseries data to compare hosting capacity before and after the Virtual Statcom algorithm is run. Therefore, it is essential to have timeseries data with high data granularity to enable this comparison, sites that took part in the Network Equilibrium Project have high data granularity and are preferred for this study.

3. **Networks with historical voltage regulation and thermal constraints** – As discussed in Section 3.2, voltage regulation and thermal issues can limit the hosting capacity of a network. The Virtual Statcom algorithm will seek to mitigate these issues to increase hosting capacity.

4. **No existing reverse power limitations -** The reverse power N-1 limit of the 132/33 kV Grid Transformers must not be exceeded in the Maximum generation, minimum load case as this suggests the transformer reverse power limit is the limiting factor for hosting capacity.

5. **WPD network owner experience –** To select suitable networks it is also essential for PSC to utilise WPD's network experience. PSC assessed the results and learnings from WPD's Network Equilibrium SVO project and consulted with WPD Primary System Design engineers regarding network challenges and historical constraint conditions.

6.2 Networks selected

6.2.1 33kV Networks

After applying the criteria from Section 6.1, the 33kV networks selected for inclusion in the Virtual Statcom project are:

- Barnstaple 33kV BSP
- Pyworthy and North Tawton 33kV BSP
- Tiverton 33kV BSP

Barnstaple 132/33kV BSP

The following tables present the network summary for Barnstaple 33kV BSP. Barnstaple was selected due to having a high number of voltage violations and two branches with high loadings for the Maximum Generation – Minimum load case.

Table 2 - Barnstaple Network summary

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr
BARNSTAPL 33	Max Gen Min Load	8	48.25	-8.45	48.25	-8.45	0.98	12.77	3.65
BARNSTAPL 33	Min Gen Max Load	8	48.25	-8.45	0.00	0.00	0.00	42.58	12.15

Table 3 - Barnstaple Network Violations

BSP	Case	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTx Reverse Power Loading
BARNSTAPL 33	Max Gen Min Load	3 violations	2	2	2	GT1 @ 48.61% GT2 @ 32.54%
BARNSTAPL 33	Min Gen Max Load	0	0	0	0	n/a

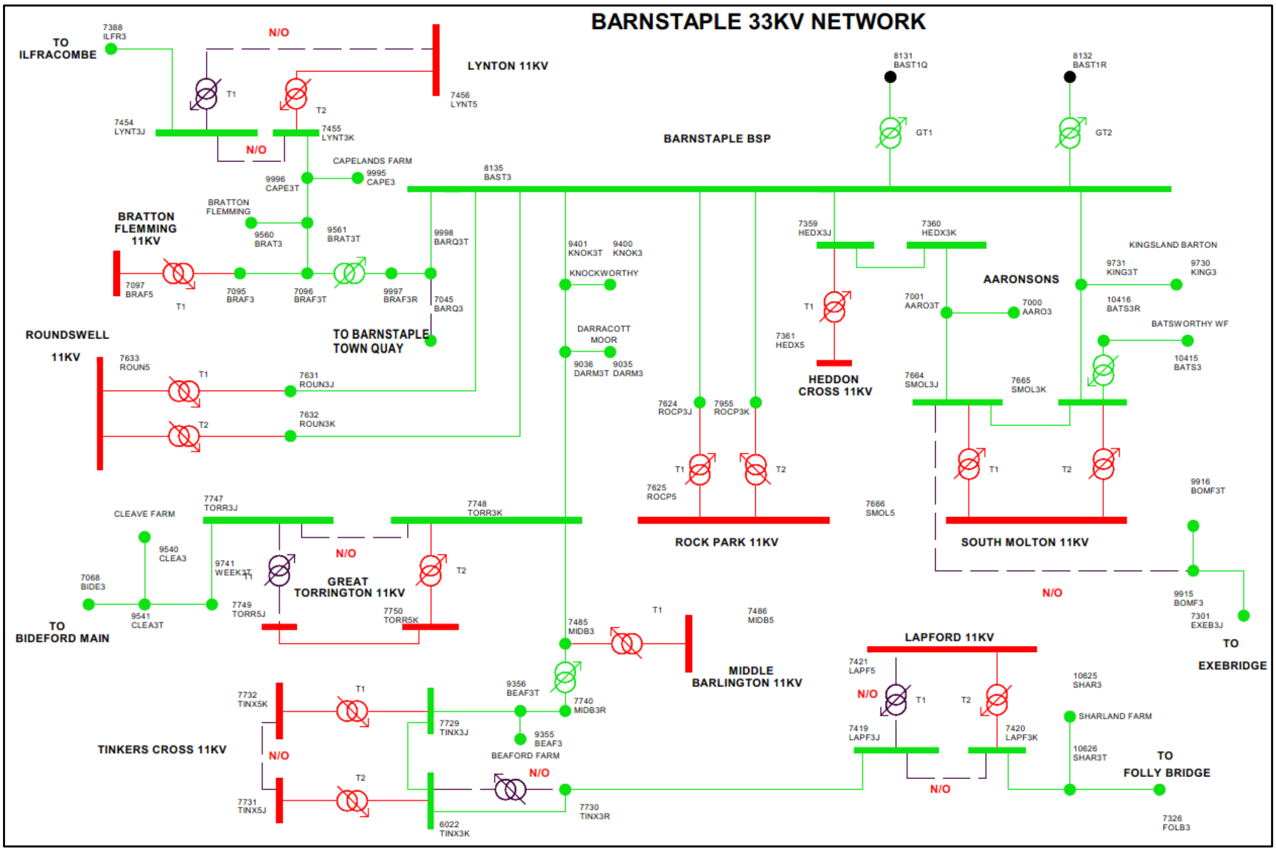

Figure 6 - Barnstaple BSP SLD

Pyworthy and North Tawton 132/33kV BSPs

The following tables present the network summary for Pyworthy and North Tawton 132/33kV BSPs. Pyworthy and North Tawton 33kV BSPs are normally operated in parallel. Pyworthy and North Tawton was selected due to having high number of generators and three/four branches with high loadings for the Maximum Generation – Minimum load case.

Table 4 - Pyworthy and North Tawton network summary

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr
PYWORTHY 33 & N/TAWTON 33	Max Gen Min Load	16	98.172	-8.17	98.172	-8.17	0.985	21.009	4.3029
PYWORTHY 33 & N/TAWTON 33	Min Gen Max Load	16	98.172	-8.17	0	0	0	70.029	14.343

Table 5 - Pyworthy and North Tawton Violations

BSP	Case	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTx Reverse Power Loading
PYWORTHY 33 & N/TAWTON 33	Max Gen Min Load	0	3	3	4	GT1 @ 43.65% GT2 @ 36.52% GT3 @ 37.04% GT4 @ 36.52%
PYWORTHY 33 & N/TAWTON 33	Min Gen Max Load	0	0	0	0	n/a

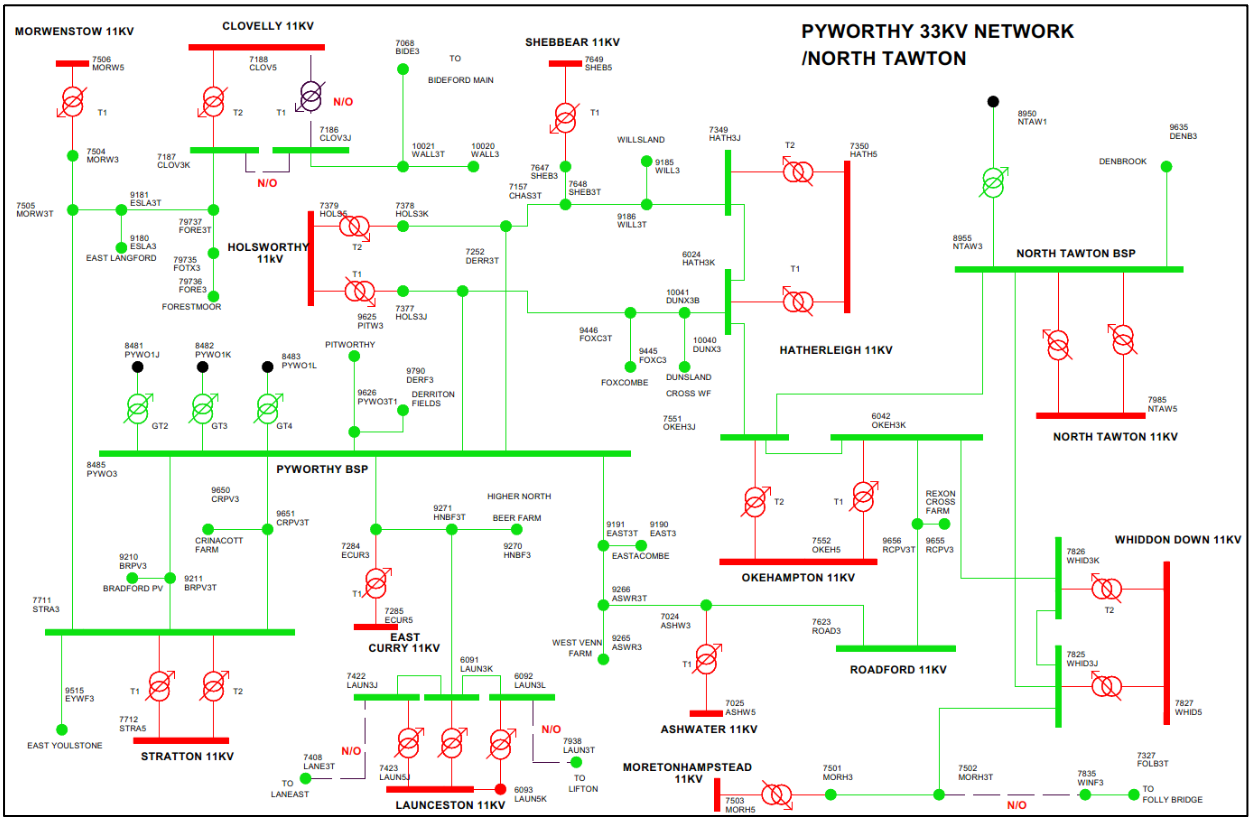

Figure 7 - Pyworthy and North Tawton BSPs SLD

Tiverton 132/33kV BSP

The following tables present the network summary for Tiverton 33kV BSPs. Tiverton was selected from discussion with WPD and it is a smaller and simpler network compared with Barnstaple and Pyworthy/North Tawton. In the Network Equilibrium SVO project Tiverton BSP did not show a large capacity increase – this will test the Virtual Statcom method.

Table 6 - Tiverton Network Summary

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr
TIVERTON 33	Max Gen Min Load	5	18.55	-2.84	18.55	-2.84	0.99	14.78	2.35
TIVERTON 33	Min Gen Max Load	5	18.55	-2.84	-0.65	0.00	1.00	49.27	7.84

Table 7 - Tiverton Violations Summary

BSP	Case	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTx Reverse Power Loading
TIVERTON 33	Max Gen Min Load	0	0	0	0	GT1 @ 27.25% GT2 @ 36.01%
TIVERTON 33	Min Gen Max Load	0	0	0	0	n/a

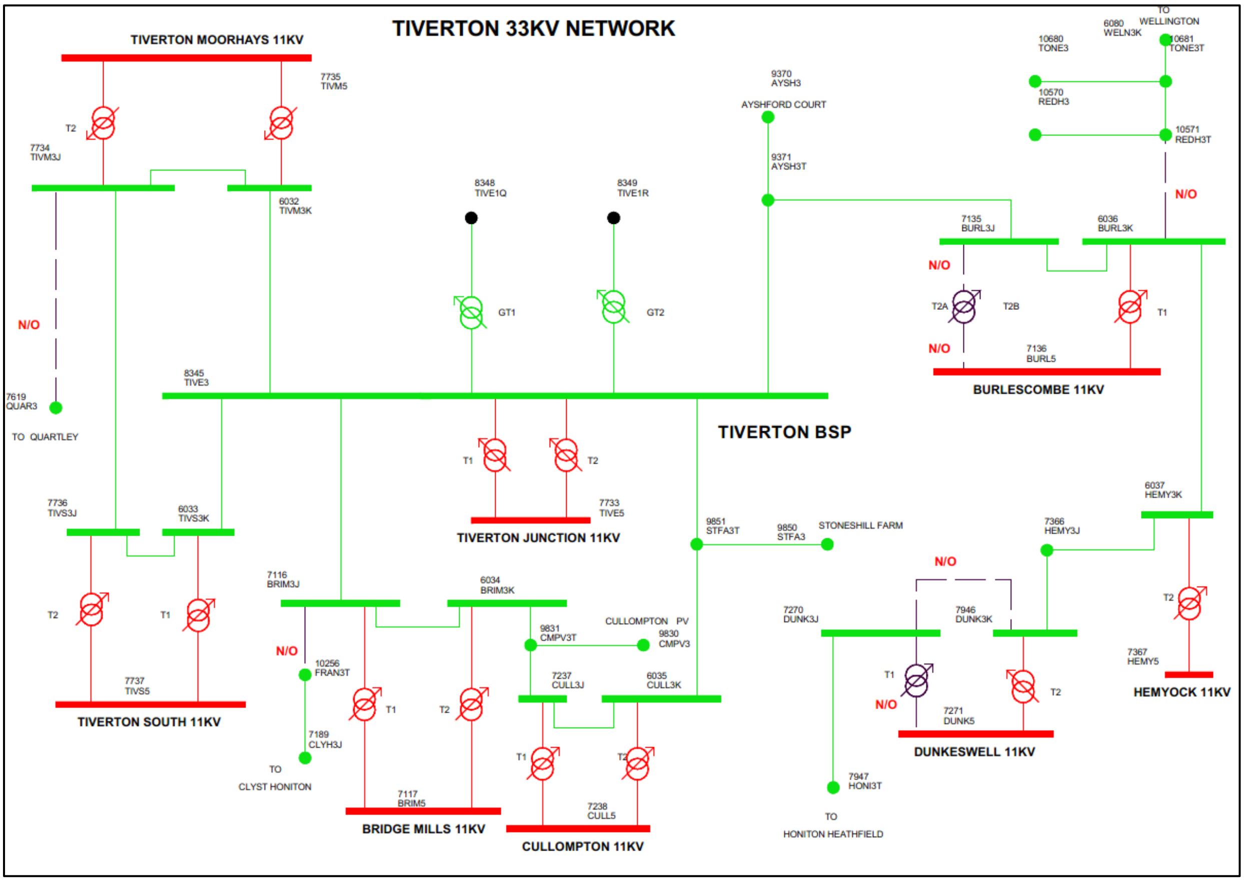

Figure 8 - Tiverton BSP SLD

6.2.2 11kV Networks

After applying the criteria from Section 6.1the 11kV network selected for inclusion in the Virtual Statcom project is Tiverton Moorhayes 11kV Primary substation. Tiverton Moorhayes only has two generators but was selected over Millfield primary with 3 generators as the generator in the Tiverton Moorhayes network are geographical dispersed in the 11kV network. Also, Tiverton Moorhayes has one branch with high loading for the Minimum Generation – Maximum Demand case.

Table 8 - Tiverton Moorhayes network summary

Primary substation	Case	Total Gens @ 11.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr
Tiverton Moorhayes	Max Gen Min Load	2	1.95	-0.64	1.95	-0.64	0.95	1.91	0.39
Tiverton Moorhayes	Min Gen Max Load	2	1.95	-0.64	0.00	0.00	0.00	6.37	1.29

Table 9 - Tiverton Moorhayes violations summary

Primary substation	Case	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	Tx Reverse Power Loading
Tiverton Moorhayes	Max Gen Min Load	0	0	0	0	T1 @ 5.06% T2 @ 5.03%
Tiverton Moorhayes	Min Gen Max Load	0	1	1	1	n/a

The Tiverton Moorhayes primary SLD has not been included here as it is rather large and does not scale well to fit. The Tiverton Moorhayes PSS/E SLD diagram is included in Appendix E – Tiverton Moorhayes 11kV PSS/E SLD.

7 Validation of time series data

The objective of validating the timeseries data in WP1 is to ensure that the Virtual Statcom project has credible and consistent load and generation data for Work Package 4. This section outlines the steps taken by PSC to validate WPD's timeseries data.

7.1 Timeseries data validation approach

Timeseries data for the networks selected in Section 6.2 was provided by WPD. The timeseries data received was for 1 year (2018), with 365 day files per network that include every SCADA tag from that network. The approach taken by PSC to validate the time series data involved:

1. Transforming the data into a standard timeseries format.
2. Defining tag rules to extract or calculate real and reactive power in a format useable by PSS/E.
3. Validating timeseries data against load and generation values from the Long Term Development Statement November 2018 (LTDS).
4. Discussion of timeseries data with WPD Primary System Design and updating tag rules and calculation assumptions.

7.1.1 Standard timeseries format

The initial data received was not in a standard timeseries format. PSC used an Excel VBA script to transform the data received into a standard timeseries format for each site to aid the validation. Individual site comma separated variable (csv) files were saved for each load and generation site. The following tables show the format of the data before transformation and the outputted timeseries data after the transformation. HH stands for a half hour period.

Example File 1 – 1/1/18

Site	Device	Code	Type	Date	SCADA Tag Ref	HH 1	HH 2	…	HH 47	HH 48
HEDDON CROSS	CB 51	6	Yellow current	01/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > 11kV Current	77	78	…	51	53
HEDDON CROSS	VT 1	2	kV	01/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > VT 1 & Isolator > VT 1	11	12	…	12	12
HEDDON CROSS	CB 51	10	Power MVAr	01/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MVAr Analogue	0.1	0.1	…	0.1	0.1
HEDDON CROSS	CB 51	9	Power MW	01/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MW Analogue	1.5	1.6	…	1.0	1.1

Example File 2 – 2/1/18

Site	Device	Code	Type	Date	SCADA Tag Ref	HH 1	HH 2	…	HH 47	HH 48
HEDDON CROSS	CB 51	6	Yellow current	02/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > 11kV Current	69	70	…	46	48
HEDDON CROSS	VT 1	2	kV	02/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > VT 1 & Isolator > VT 1	10	10	…	10	10
HEDDON CROSS	CB 51	10	Power MVAr	02/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MVAr Analogue	0.1	0.1	…	0.1	0.1
HEDDON CROSS	CB 51	9	Power MW	02/01/2018	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MW Analogue	1.4	1.4	…	0.9	1.0

Example output timeseries data for all SCADA tags

Date-Time	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > 11kV Current	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > VT 1 & Isolator > VT 1	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MVAr Analogue	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MW Analogue
01/01/2018 00:30	77	11	0.1	1.5
01/01/2018 01:00	78	12	0.1	1.6
…	…	…	…	…
01/01/2018 23:30	51	12	0.1	1.0
02/01/2018 00:00	53	12	0.1	1.1
02/01/2018 00:30	69	10	0.1	1.4
02/01/2018 01:00	70	10	0.1	1.4
…	…	…	…	…
02/01/2018 23:30	46	10	0.1	0.9
03/01/2018 00:00	48	10	0.1	1.0

7.1.2 Tag rules and calculations

To select the correct SCADA tags for each site, tag rules were developed using detailed SLDs provided by WPD to identify the correct power system devices (circuit breakers, voltage transformers, current transformers). The sign convention used by WPD for SCADA tags is positive flows away from a bus and negative flows into a bus. It is worth noting that program of metering direction consistency is being rolled out progressively at WPD. This has affected some of the sites in the study networks selected.

PSS/E requires that loads have positive real power and positive reactive power (if inductive) and requires that generator have positive real power and positive reactive power (if exporting reactive power). This results in some SCADA values requiring direction changes to be in the correct format for PSS/E.

A different number of SCADA tags were available for each site and some new tags were introduced during 2018 for certain sites. The following list presents a summary of rules in descending preference order to obtain real and reactive power.

1. **Direct method (DM)**: Use real power (MW) and reactive power (MVAr) SCADA values (if available)
2. **Voltage & Current Method (VIM)**: Use Voltage (V) and Current (I) SCADA values and the power factor from the LTDS to calculate real power (MW) and reactive power (MVAr).
3. **Combination Method (CM)**: Use a combination for V&I method and direct method depending on availability and quality of real power (MW) and reactive power (MVAr) SCADA.

A Python script was used for the Direct Methods and Voltage & Current Method but calculations for the combination method were done manually.

After initial tag rules were developed, PSC compared the timeseries data to the LTDS load and generation values. These comparisons results were discussed with WPD Primary System Design engineers. The discussion determined that some sites tag values required scaling and some sites had to revert to the Voltage & Current Method even when real and reactive power tags were available for that site. The tag rules were updated based on the initial LTDS comparisons and discussion with WPD, the final SCADA tag rules are set out in Appendix B – Tag rules for timeseries data.

7.1.3 Validation of timeseries data with LTDS

To validate the timeseries data, PSC compared the SCADA values with values from the LTDS. For load sites the Maximum Demand MVA 2017/18 and power factor from the LTDS was used to calculate the maximum real and reactive power. For generation sites the size of the generator was used to determine the maximum real and reactive power. The timeseries data was plotted over a year to check that expected seasonal variations are present in the data. For example, higher load demand over winter, larger solar generation output over summer.

Figure 9 and Figure 10, show the timeseries data validation plots for a load site and a solar generation site respectively. All site timeseries data validation plots are available in Appendix C.

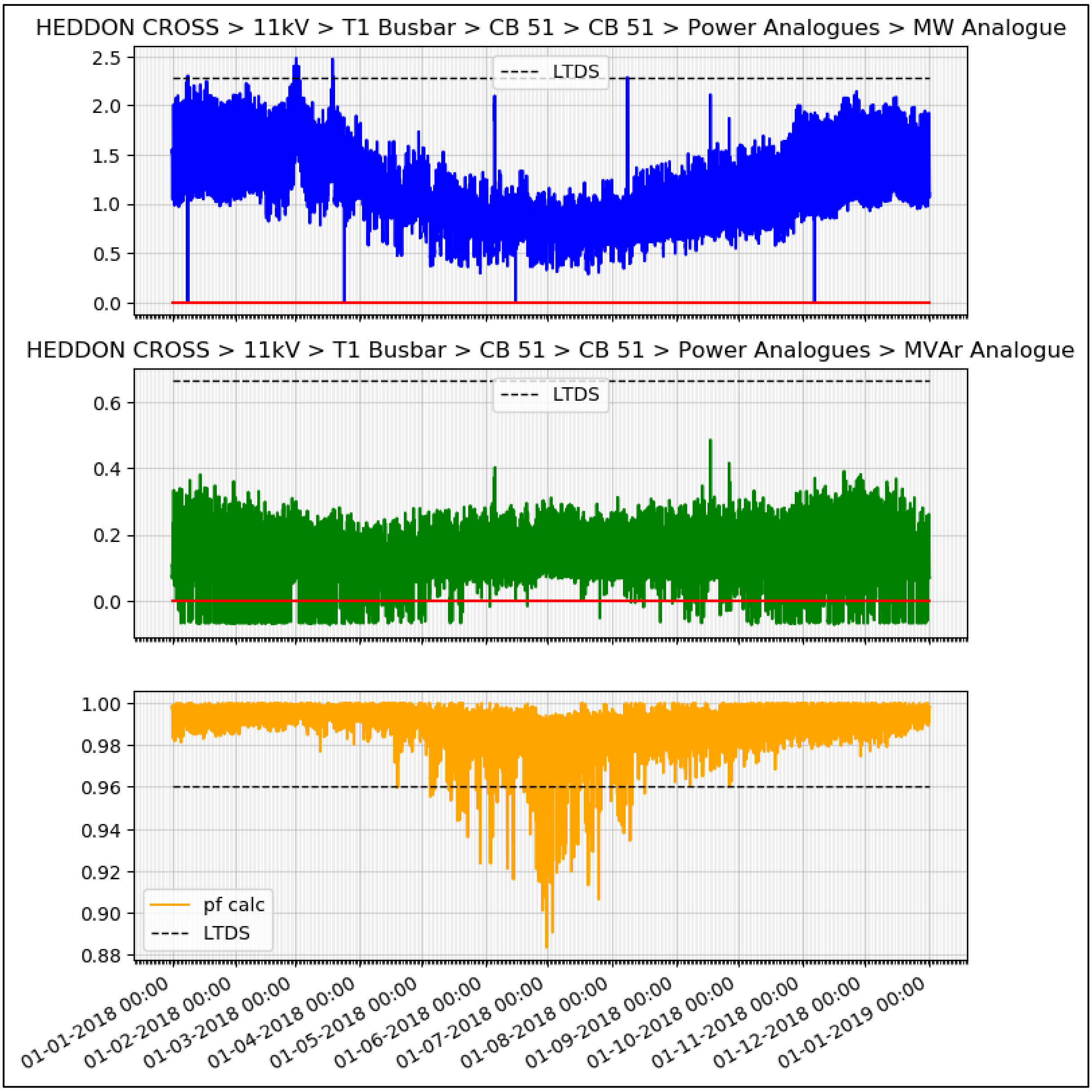

Figure 9 - Heddon Cross Load timeseries data 2018

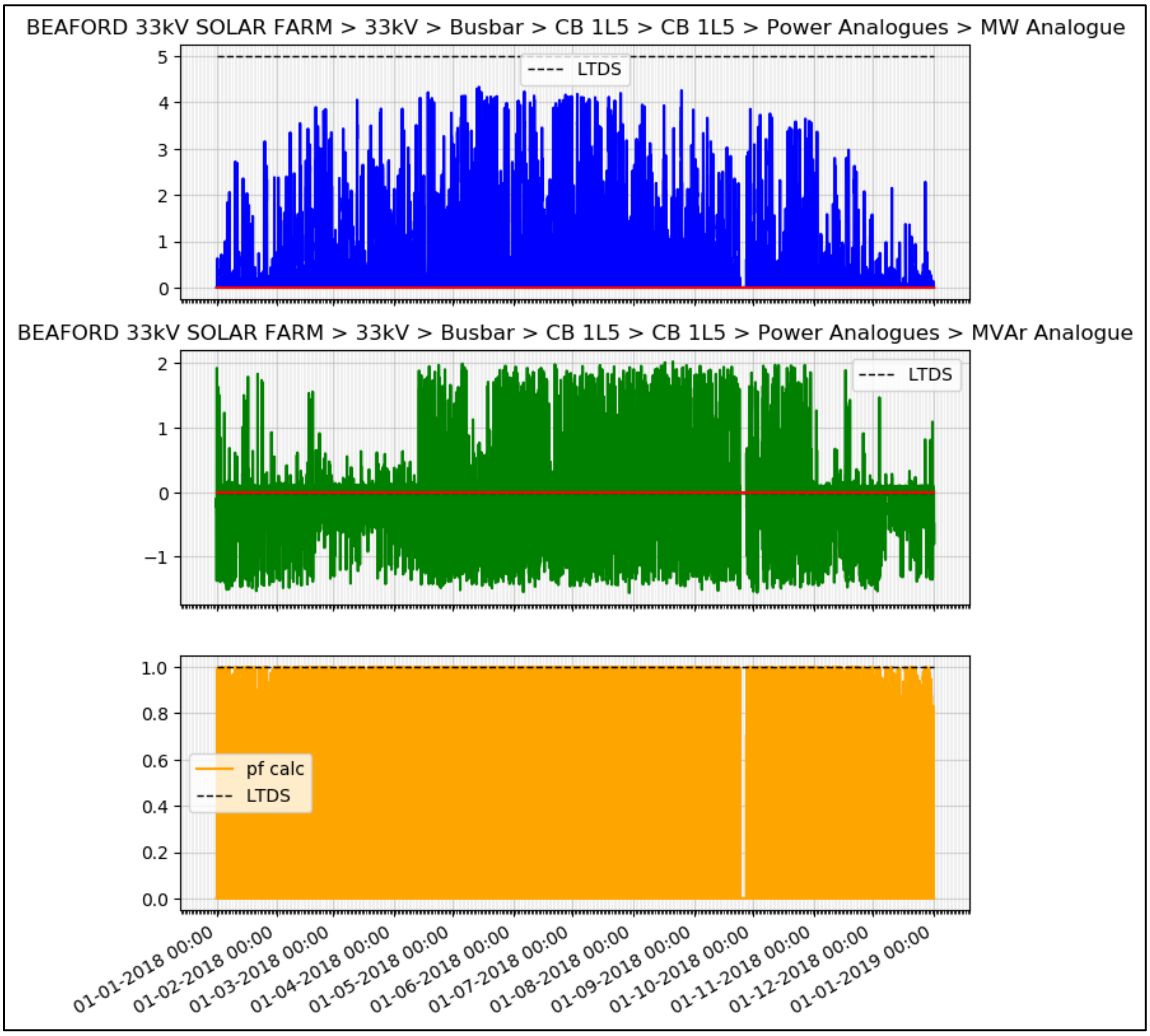

Figure 10 - Beaford 33 kV Solar farm timeseries data 2018

Note: It is expected that the power factor for solar and wind farms will deteriorate when not generating due to zero real power output, Figure 11 shows a zoomed in view of the plot in Figure 10 to demonstrate this.

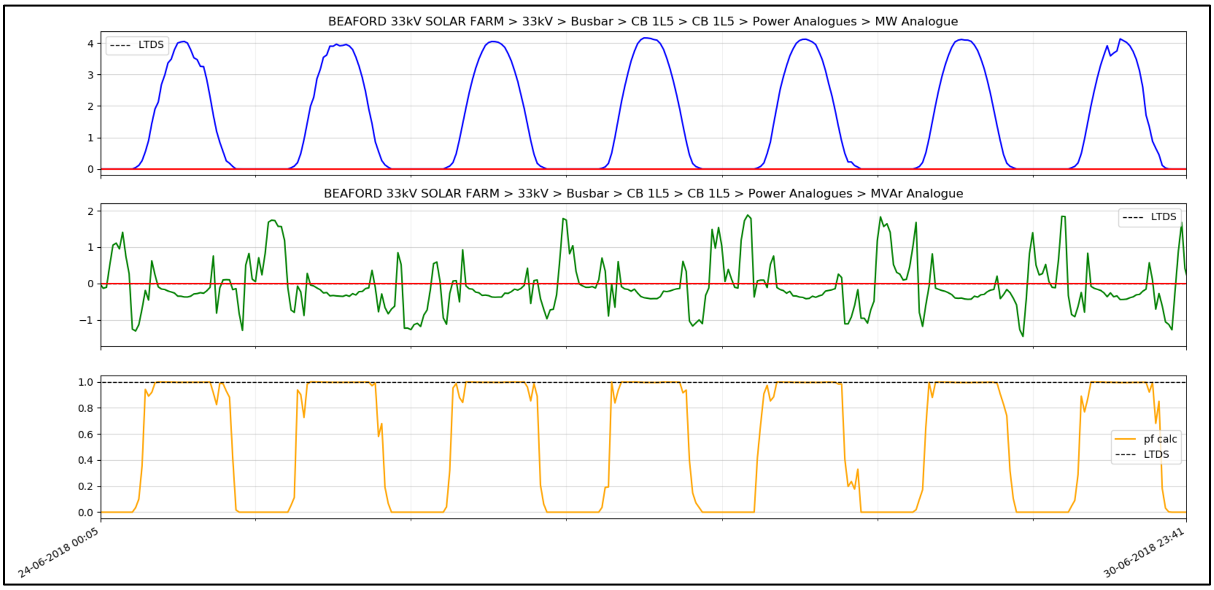

Figure 11 - Beaford 33kV solar farm timeseries data (zoomed in)

7.1.4 Timeseries data mapping to PSS/E

To be able to use the timeseries data in PSS/E the real and relative power extracted/calculated from the SCADA values need to be mapped to the correct PSS/E load and generation. The mapping rules that the timeseries studies will use are set out in Appendix D – Timeseries data mapping to PSS/E.

8 Network hosting capacity algorithms

To determine the benefit of a Virtual Statcom it is necessary to compare the existing network capacity before and after the Virtual Statcom algorithm optimises the reactive power output of generators.

8.1 Generation hosting capacity

8.1.1 Overview

This section presents the concurrent iterative scaling approach that the Virtual Statcom project will adopt, it is based on the literature review section 4.1. The concurrent iterative scaling methodology has been chosen as it provides a whole network metric for comparison, it is computationally simple and can incorporate contingencies and constraints.

The following provides the high-level methodology to determine the generation hosting capability of the network:

1. Place a ‘dummy’ generator at the end of each feeder
2. Scale the ‘dummy’ generators until there are network issues
3. Sum the ‘dummy’ generators and the existing generation. This is the network generation hosting capacity.

This is detailed in the flow chart (Figure 12) and sections 8.1.2 to 8.1.5 below:

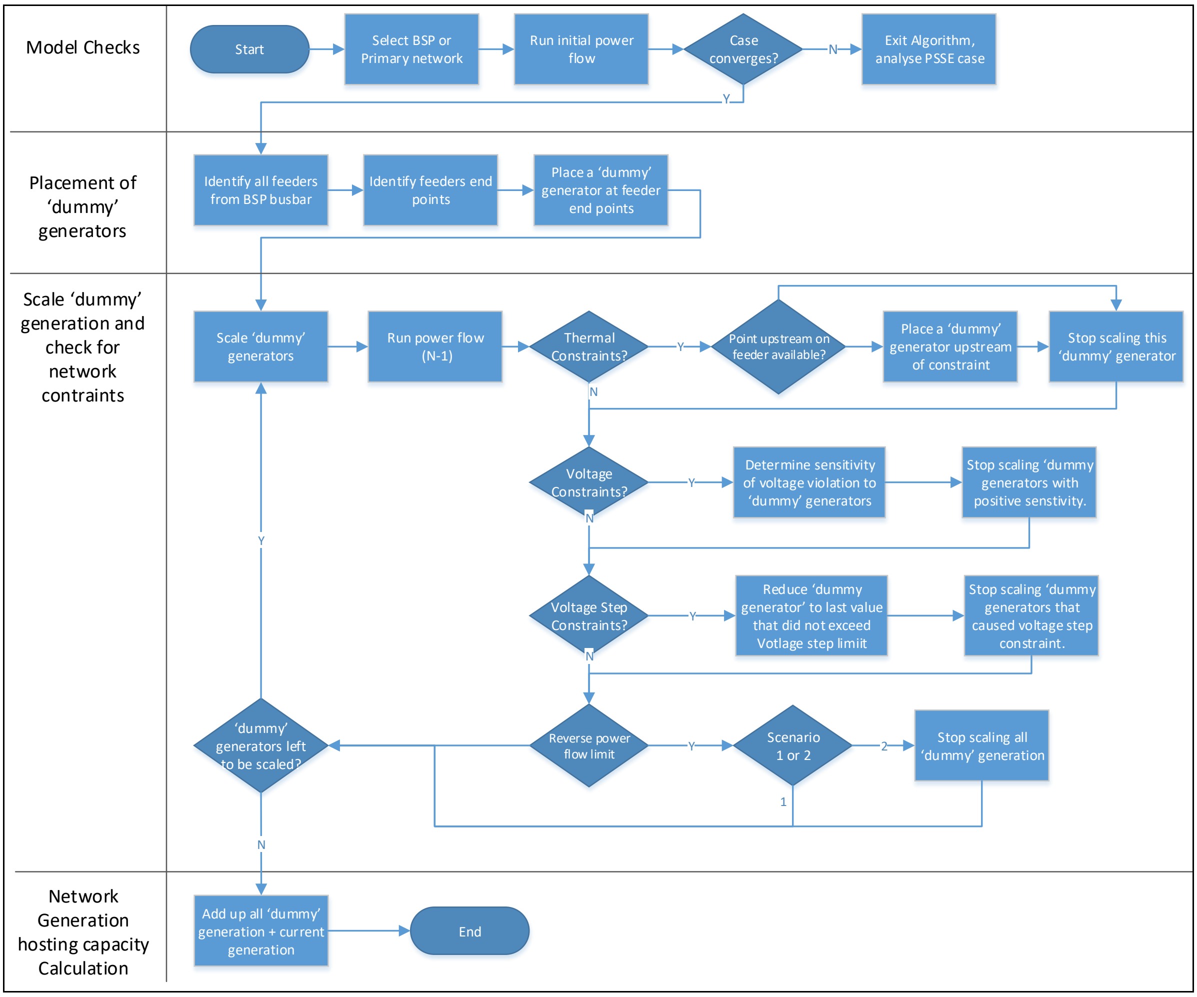

Figure 12 - Generation hosting capacity algorithm logic

8.1.2 Model Checks

The hosting capacity algorithm to be developed in WP2 needs to be generic so that it can work on any of WPD's BSPs or Primary networks. Before entering the algorithm, checks will be performed to ensure that the network model selected results in a convergent power flow.

8.1.3 Placement of 'dummy' generators

The hosting capacity algorithm will be required to identify all feeders from a BSP or Primary busbar and identify the downstream 'end points'. It is anticipated that this will be done by summing the feeder impedance path from the BSP busbar, with particular attention being needed in the algorithm for parallel feeders. Once the end points have been identified the algorithm will add a 'dummy' generator. The initial PQ characteristic of the 'dummy generator' will be a generator with zero real and reactive power and unity power factor. The end of the feeder has been selected to give the largest value of generation that can be located anywhere along the feeder. The existing generators will not be scaled as they will be used to set up the operating conditions, initially this will be a minimum generation maximum load case and a maximum generation minimum load case.

8.1.4 Scale 'dummy' generation and check for network constraints

With the 'dummy' generators placed the algorithm will then scale the set of 'dummy' generators. The initial increment of generation will be 1 MW. The algorithm will use PSS/E to run a power flow after each increment of generation and assess the network constraints described in Section 3.2(including N-1 in networks with parallel feeders).

The algorithm will check for different network constraints after each power flow and perform different adjustments based on the network.

<u>Thermal constraints:</u>

After the power flow is run, if thermal constraints are present the algorithm will determine if there is a location upstream of the constraint where a new 'dummy' generator can be placed. If there is no upstream point available, the 'dummy' generator causing the constraint will not be scaled on the next iteration of the algorithm.

The following example shown in Figure 13 demonstrates the algorithm for a thermal constraint where an upstream unconstrained location exists on the feeder.

- A 'dummy' generator called 'Feeder 1' is placed at Bus 2.
- The algorithm scales generator 'Feeder 1' until the line between Bus 1 and Bus 2 overloads.
- The algorithm then determines that the line from the BSP to Bus 1 still has capacity and places a new 'dummy' generator 'Feeder 1-1' at Bus 1.
- The algorithm stops scaling generator 'Feeder 1' and starts scaling 'Feeder 1-1' until the line between Bus 1 and Bus 2 overloads.
- The hosting capacity will be the summation of the dummy generators. i.e. 'Feeder 1' + 'Fedder 1-1'

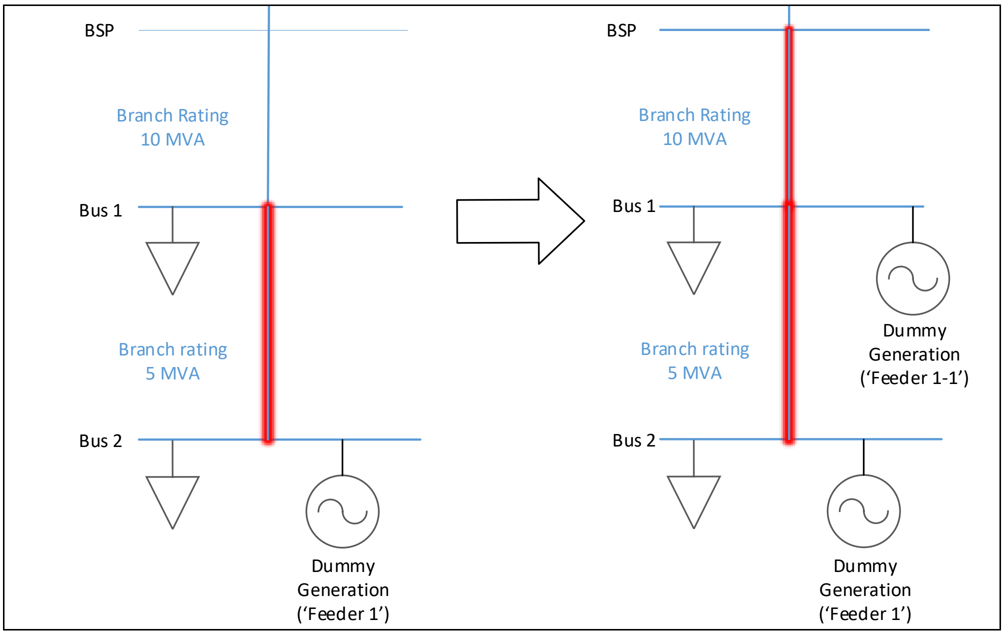

Figure 13 - Thermal constraint example

<u>Voltage constraints:</u>

After the power flow is run, if voltage constraints are present the algorithm will perform sensitivity analysis on the 'dummy' generators. The 'dummy' generators that have a negative effect on the voltage constraint will not be scaled on the next iterations.

<u>Voltage step constraints:</u>

After the power flow is run, the algorithm will determine if any voltage steps greater that +/-3% exist by tripping each 'dummy' generator in turn and running a power flow. If the voltage step limit of +/- 3% is exceeded the 'dummy' generator the causes the voltage step will be reduced to the last value that did not cause a voltage step.

<u>Reverse Power flow (RPF) constraints:</u>

After the power flow simulation is run, if the reverse power flow on a network connection transformer (132/33kV for BSP networks or 33/11kV for primary networks) exceeds its reverse power flow rating the algorithm will check which of the below scenarios is being run and if:

- Scenario 1, will stop scaling all 'dummy' generators.
- Scenario 2, will ignore the reverse power flow constraints and continue to scale the 'dummy' generators.

Scenario 2 is included to test the hosting capacity of the network excluding the upstream transformers' constraints. This provides comparison between results and demonstrates what the hosting capacity could be if the reverse power flow ratings of the transformers are increased.

8.1.5 Calculate network generation hosting capacity

Once the algorithm has stopped scaling all 'dummy' generators in the 'dummy' generator set, the generation hosting capacity is calculated as the sum of the apparent power output of the 'dummy' generators and the apparent power output of existing generation for the given generation scenario being considered.

8.2 Load hosting capacity

The algorithm used to determine the load hosting capacity is similar to the generation hosting capacity algorithm but scales existing load rather than 'dummy' generators. As loads are at the ends of a feeder there is no need to place 'dummy' loads for the algorithm. The following provides the high-level methodology to determine the load hosting capability of the network.

1. Identify existing network loads.
2. Scale the network loads until there are network issues.
3. Sum the new value of existing loads. This is the network load hosting capacity.

This is detailed in the flow chart (Figure 14):

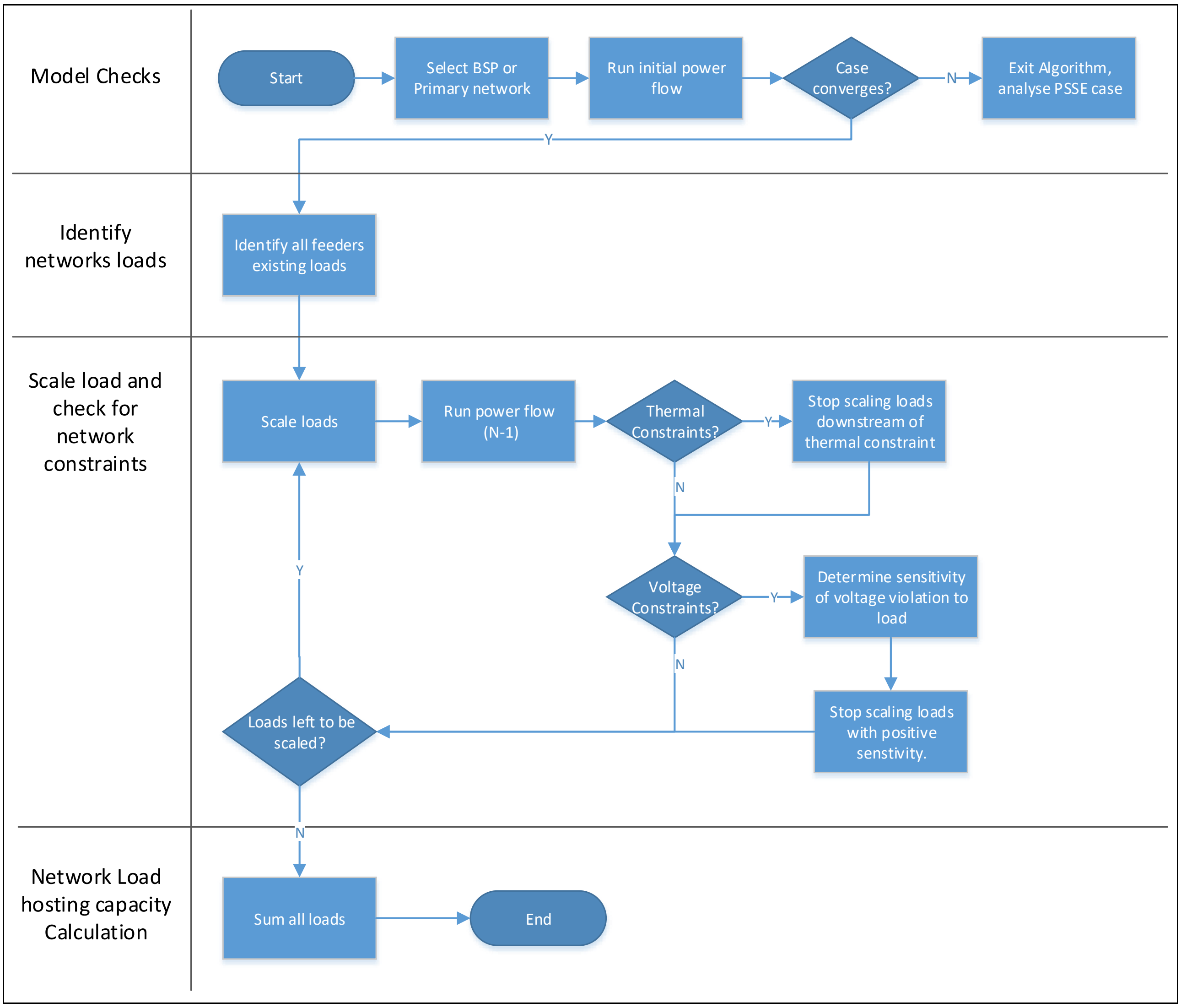

Figure 14 - Load hosting capacity algorithm logic

8.3 Implementing hosting capacity algorithms

The hosting capacity algorithms will be implemented in a Python 2.7 script to automate PSS/E. Automation will follow the algorithms described in Sections 8.1 and 8.2. For each scenario the algorithm will output:

- An excel spreadsheet with the algorithm summary results including:
  - The load and generation summary for the network.
  - The overall hosting capacity (generation and load), with and without RPF constraints.
  - The limiting constraint type and location.
  - The number of power flows run.
  - The time taken to calculate the hosting capacity.
- A .sav file with the scaled model
- A .log file with the details of the automation actions

9 Virtual Statcom optimisation

9.1 P-Q capability of DGs

The DGs modelled in WPD's PSS/E network models are currently modelled with a fixed power factor. The fundamental assumption of the Virtual Statcom algorithm is the ability to control the reactive power output of existing generators.

Detailed modelling of the PQ capabilities of the DGs in the study network selected proved not practical due to the limited information available. For this reason, the initial algorithm developed will assume that every DG can operate in the power factor range from 0.95 leading to 0.95 lagging across the active power range of the DG, this is shown by the blue shaded area in Figure 6 below. This is more conservative than assuming that each DG has a full converter connection.

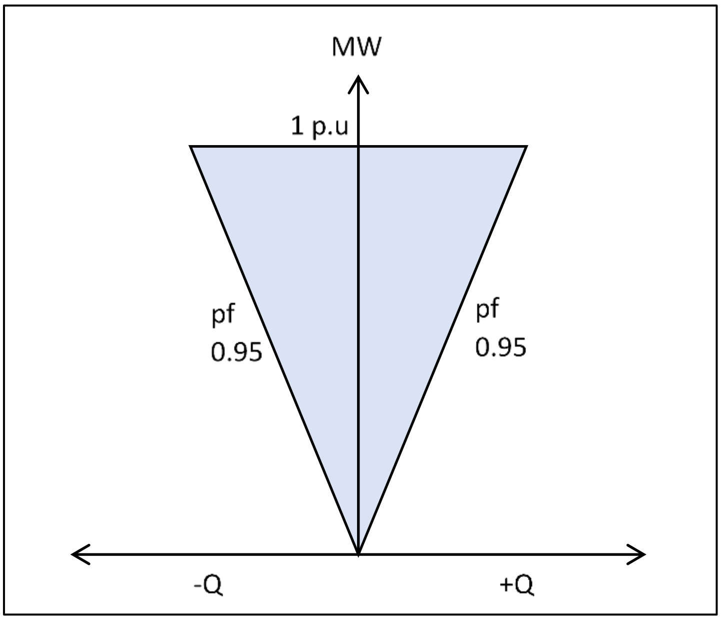

Figure 15 - PQ capability of DGs

9.2 Optimisation strategy

The objective of the Virtual Statcom algorithm is to maximise the hosting capacity using the reactive power output of generators. The literature review in Section 4.2 identified that the objective of Virtual Statcom algorithm can be defined as an ORPD problem, therefore the Virtual Statcom project will take this approach to the optimisation strategy. This section sets out the formulation of the ORPD problem for the Virtual Statcom algorithm.

9.2.1 Objective function

The objective of the Virtual Statcom algorithm is to maximise the hosting capacity using the reactive power output of generators. This suggests that the objective function could be defined to maximise the hosting capacity calculated from the algorithm in Section 8.1 and this is possible. However, hosting capacity is calculated iteratively and during the optimisation process the objective function needs to be evaluated multiple times, this could place a high burden on computation resources and result in slow solving times.

As shown in the literature review Section 4.2.1 the minimisation of real power losses in the branches corresponds to minimised reactive power branch flow and the greatest thermal headroom on branches which can be used as a proxy for maximum hosting capacity. From PSS/E, the branch real or reactive power and losses can be extracted. As both are computationally similar in complexity, either can be used as the objective function. Therefore, the objective function will be set as:

$$Minimise \sum_{n=1}^{br} Plosses_n$$

or

$$Minimise \sum_{n=1}^{br} Qflow_n$$

Where:
br = the total branches in the network
$Plosses_n$ = The real power losses in branch n
$Qflow_n$ = Reactive power flowing on the branch n

Note: When developing the optimisation algorithm, these objective functions will be compared to ensure consistency and if any speed advantages exist between the two.

9.2.2 Control variables

The control variables for the optimisation are the set of power factors for each generator.

$$\theta = (\theta_1, \theta_2, \dots, \theta_n)$$

Where
θ_1 = the power factor for generator 1
n = the total number of DGs in the network

9.2.3 Optimisation constraints

The optimisation will be subject to the following constraints:

- The power factor of each generator is within operating range set out in Section 9.1 or by voltage step considerations.
- Real and Reactive power balance (i.e. load real and reactive power is met).
- Bus voltages are within +/- 6 %.
- Branch flow is less than the branch ratings.

Note: Voltage step constraints will be incorporated by limiting the power factor range of generators initially to reduce computational burden, see Section 9.3.2 for more detail.

9.2.4 Optimisation solver

The initial optimisation algorithm will be developed using a Particle Swarms Optimisation approach as it provides the following advantages:

- From the literature review it is tried and proven and used as a benchmark for optimal reactive power dispatch problems.

- Computational time - with the size of the WPD's BSP and primary networks, it is not anticipated that the computational time associated with particle swarm will be burdensome.
- Availability of open source Python packages – *psopy 0.2.3* and *pyswarm 1.0.0.*

9.2.5 Particle Swarm Optimisation (PSO) overview

The basis of Particle Swarm Optimisation is to define a set of particles (swarm), these particles then search the objective function space following certain rules to find the global solution. It is an iterative approach and the swarm 'communicates' at the end of each iteration to modify the swarm's best solution and particle's best solution. The swarm's and particle's best values are used to update particle search parameters for the next iteration. A particle in the Virtual Statcom algorithm is the vector of generator power factors.

$$\theta_{p1} = (\theta_{pf1}, \theta_{pf2}, \dots, \theta_{pfn})$$

Where
θ_{p1} = is particle 1
θ_{pf1} = the power factor for generator 1
n = the total number of DGs in the network

9.3 Virtual Statcom algorithm overview

The high-level overview of the algorithm is presented in the flowchart in Figure 16. The algorithm is split into the following areas:

1. Model Checks.
2. Pre-optimisation network capacity (using algorithm in Section 8.1).
3. Allocate PQ capabilities.
4. Initialise optimisation.
5. Perform optimisation.
6. Post-optimisation network capacity.

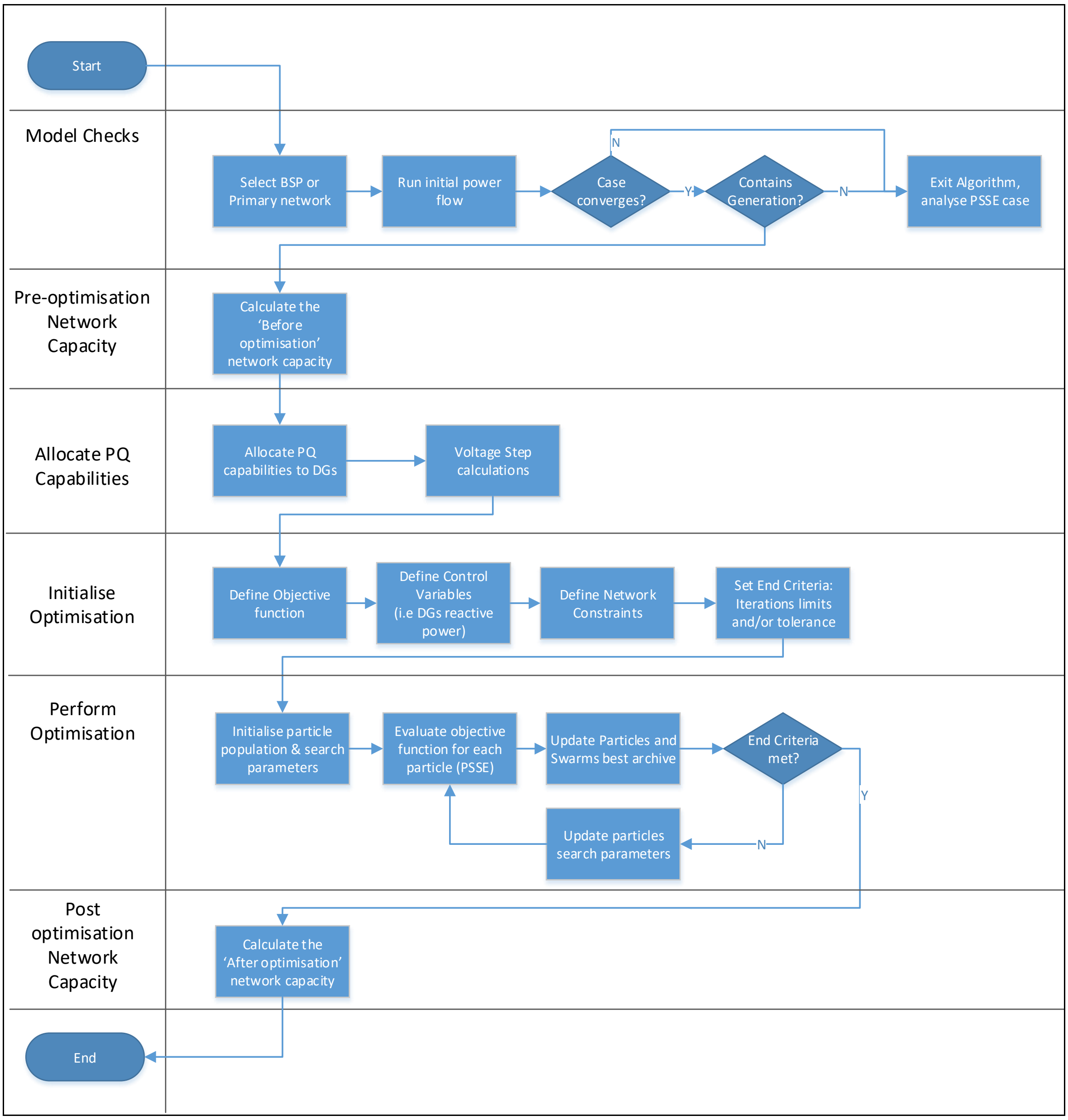

Figure 16 - Virtual Statcom optimisation algorithm

9.3.1 Model Checks & Pre-optimisation network capacity

The Virtual Statcom to be developed in WP2 needs to be generic so that it can work on any of WPD's BSPs or Primary networks. Before entering the algorithm, checks will be performed to ensure that the network model selected results in a convergent power flow and includes generation.

After the model passes the model checks the network hosting capacity algorithms described in Section 8.1 will determine the base case hosting capacity for load and generation for the given generation and load scenario in the model. The base case hosting capacities will be saved to compare with the after-optimisation hosting capacities.

9.3.2 Allocate PQ capabilities

The majority of DGs modelled in WPD's PSS/E network models are currently modelled at a fixed power factor. However, the algorithm will first assess if any of the DGs have PQ capability modelled, indicated in PSS/E by Qmax ≠ Qmin. These DGs will be excluded from being allocated PQ capabilities. For the DGs that have a fixed power, the algorithm will update the DGs reactive power parameters in the PSS/E model to reflect the PQ capability range described in Section 9.1.

After PQ capability have been assigned the algorithm will perform voltage step calculations for each generator at both maximum power factor leading and lagging. If a voltage step change is greater than +/3 % the algorithm will scale back the power factor until there is no violation. The generator PQ capability will then be updated. For example, a certain generator may be updated to a power factor range of 0.96 leading to 0.96 lagging due to voltage step limits, as shown in Figure 17.

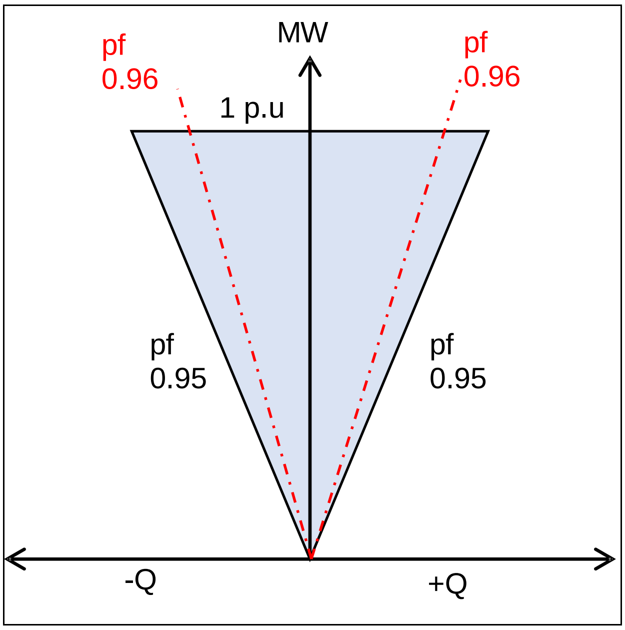

Figure 17 - P-Q characteristic with voltage step limit

9.3.3 Initialise Optimisation

<u>Objective function</u> - For the selected network the algorithm will determine the network branches to include in the objective function summation.

<u>Define Control variables</u> **-** For the selected network the algorithm will determine the generators to control reactive power output through pf control.

<u>Define Network constraints</u> **-** For the selected network the algorithm will determine the network bus and branches to act as constraints. Bus voltage limits will be hardcoded at +/-6%, branch thermal limits will be extracted from the network model. The load balance constraints will be met when the load flow is run in PSS/E.

<u>Set End Criteria</u> **–** Particle Swarm Optimisation is an iterative based optimisation. The end criteria can be a tolerance between successive iterations and/or iterations limit. Based on literature the iterations limit will be initially set at 1000. The effect of the end criteria tolerance and iteration limit will be assessed when developing the Virtual Statcom algorithm and changes may be introduced and best approach will be suggested dependent on the observations and experience gathered.

9.3.4 Perform Optimisation

The algorithm will utilise an open source python PSO package to minimise the objective function. The flow chart in provides a high-level summary of PSO. The number of particles will be initially set at 100. The effect of the number of particles on the performance of the algorithm will be will be assessed when developing the Virtual Statcom algorithm and changes may be introduced.

9.3.5 Post-optimisation network capacity

Once the reactive power has been optimised, the algorithm will evaluate the network capacity using the network capacity algorithms of Section 8 and compare to the un-optimised case.

9.4 Implementation of the Virtual Statcom algorithm

The optimisation algorithm will be implemented in a Python 2.7 script to automate PSS/E. Automation will follow the algorithm described in Section 9.3 and use a PSO python package to optimise the objective function. The output of the algorithm will be:

- An excel spreadsheet with the algorithm summary results including:
    - The load and generation summary for the network.
    - The power factor for each DG in the network.
    - The before and after generation and load hosting capacity.
    - The number of power flows run.
    - The time taken to calculate the capacity.
- A .sav file with the optimised model.
- A .log file with the details of the automation actions.

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Appendix A – BSP and Primary network summaries

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
AVONMOUTH 33	**Max Gen Min Load**	8	77.60	-23.74	77.60	-23.74	0.96	39	6	22.20	11.19	0	2	2	2	8861 GT1 @ 58.56% 8862 - 8865 GT2 @ 39.60%
AVONMOUTH 33	**Min Gen Max Load**	8	77.60	-23.74	0.00	0.00	1.00	39	6	73.99	37.29	0	0	0	0	
BARNSTAPL 33	**Max Gen Min Load**	8	48.25	-8.45	48.25	-8.45	0.98	61	11	12.77	3.65	3 violations	2	2	2	8131 - 8135 GT1 @ 48.61% 8132 - 8135 GT2 @ 32.54%
BARNSTAPL 33	**Min Gen Max Load**	8	48.25	-8.45	0.00	0.00	0.00	61	11	42.58	12.15	0	0	0	0	
BATH 33	**Max Gen Min Load**	0	0.00	0.00	0.00	0.00	0.00	40	9	23.52	1.85	0	0	0	0	8931 - 8935 GT1 @ 18.70% 8932 - 8935 GT2 @ 18.70%
BATH 33	**Min Gen Max Load**	0	0.00	0.00	0.00	0.00	0.00	40	9	78.41	6.15	0	0	0	0	
BOWHAYS X 33	**Max Gen Min Load**	2	30.82	-5.08	30.82	-5.08	0.99	27	7	6.37	0.76	0	1	1	1	8621 - 8625 GT1 @ 43.05% 8622 - 8625 GT2 @ 43.16%
BOWHAYS X 33	**Min Gen Max Load**	2	30.82	-5.08	0.00	0.00	0.00	27	7	21.22	2.54	0	0	0	0	
BRADLY ST 33	**Max Gen Min Load**	5	62.88	-0.79	62.88	-0.79	1.00	55	13	39.94	9.06	0	0	0	0	8871 - 8875 GT1 @ 6.40% 8873 - 8875 GT2 @ 11.31%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
BRADLY ST 33	Min Gen Max Load	5	62.88	-0.79	0.00	0.00	0.00	55	13	110.65	27.39	2 violations	0	1	0	
BRIDGWATR 33	Max Gen Min Load	14	125.05	-24.12	125.05	-24.12	0.98	85	12	33.59	6.49	3 violations	1	2	3	10846 - 10848 GT1 @ 30.03% 10847 - 10849 GT2 @ 30.03%
BRIDGWATR 33	Min Gen Max Load	14	125.05	-24.12	0.00	0.00	1.00	85	12	111.95	21.62	0	0	1	0	
CAMBORNE 33	Max Gen Min Load	4	27.50	-4.70	27.50	-4.70	0.99	28	4	12.38	1.62	0	0	0	1	8461 - 8465 GT1 @ 26.52% 8462 - 8465 GT2 @ 22.47%
CAMBORNE 33	Min Gen Max Load	4	27.50	-4.70	0.00	0.00	0.00	28	4	41.27	5.39	0	0	1	0	
CHURCHILL 33	Max Gen Min Load	5	30.39	-0.85	30.39	-0.85	1.00	72	12	17.71	4.39	0	0	0	0	8731 - 8735 GT1 @ 16.88% 8732 - 8735 GT2 @ 17.85%
CHURCHILL 33	Min Gen Max Load	5	30.39	-0.85	0.00	0.00	0.00	72	12	59.02	14.62	0	0	1	0	
EAST YELL 33	Max Gen Min Load	7	49.53	-8.45	49.53	-8.45	0.99	46	8	16.57	2.15	0	0	1	1	8121 - 8125 GT1 @ 40.47% 8122 - 8125 GT2 @ 50.20%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
EAST YELL 33	Min Gen Max Load	7	49.53	-8.45	0.00	0.00	0.00	46	8	55.23	7.16	0	0	0	0	
ERNESETTL 33	Max Gen Min Load	4	47.00	-6.57	47.00	-6.57	0.99	33	7	14.96	3.67	0	1	1	2	8531 - 8535 GT1 @ 26.94% 8532 - 8535 GT2 @ 26.59%
ERNESETTL 33	Min Gen Max Load	4	47.00	-6.57	0.00	0.00	1.00	33	7	49.88	12.23	0	0	0	0	
EXETER CI 33	Max Gen Min Load	3	42.07	-11.03	42.07	-11.03	0.97	55	11	26.91	5.36	0	3	3	3	8332 - 8335 GT2 @ 53.54% 8333 - 8335 GT3 @ 37.28%
EXETER CI 33	Min Gen Max Load	3	42.07	-11.03	0.00	0.00	0.00	55	11	89.69	17.85	0	0	0	0	
EXETER MA 33	Max Gen Min Load	3	22.90	-0.80	22.90	-0.80	1.00	30	6	8.69	2.35	0	0	0	0	8312 - 8314 GT1 @ 16.92% 8313 - 8315 GT2 @ 16.29%
EXETER MA 33	Min Gen Max Load	3	22.90	-0.80	0.00	0.00	0.00	30	6	28.95	7.84	0	0	0	0	
EXMOUTH 33	Max Gen Min Load	3	13.38	0.00	13.38	0.00	1.00	27	6	8.94	1.65	0	0	0	0	8321 - 8325 GT1 @ 31.33% 8322 - 8325 GT2 @ 5.51%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
EXMOUTH 33	Min Gen Max Load	3	13.38	0.00	0.00	0.00	0.00	27	6	29.79	5.49	0	0	1	0	
FEEDER RD 33	Max Gen Min Load	3	27.50	-9.04	27.50	-9.04	0.95	65	10	54.37	6.64	0	0	0	0	8831 - 8835 GT1 @ 22.14% 8832 - 8836 GT2 @ 11.02% 8833 - 8835 GT3 @ 17.38% 8834 - 8836 GT4 @ 13.05%
FEEDER RD 33	Min Gen Max Load	3	27.50	-9.04	0.00	0.00	1.00	65	10	181.23	22.14	0	0	0	0	
FRADDON 33	Max Gen Min Load	16	133.83	-9.68	133.83	-9.68	1.00	83	12	23.74	2.72	0	0	0	3	8449 - 8457 GT3 @ 36.61% 8450 - 8458 GT4 @ 34.04% 8453 - 8456 GT1 @ 45.60% 8454 - 8455 GT2 @ 55.42%
FRADDON 33	Min Gen Max Load	16	133.83	-9.68	0.00	0.00	0.00	83	12	79.15	9.06	0	0	0	0	
HAYLE 33	Max Gen Min Load	2	33.00	0.00	33.00	0.00	1.00	57	10	18.14	1.13	1 violation	0	1	2	8431 - 8435 GT2 @ 23.51% 8432 - 8435 GT1 @ 23.51%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
HAYLE 33	Min Gen Max Load	2	33.00	0.00	0.00	0.00	0.00	57	10	60.46	3.78	1 violation	0	0	0	
LANDULPH 33	Max Gen Min Load	5	38.42	0.00	38.42	0.00	1.00	36	8	11.43	3.26	0	1	1	1	8512 - 8515 GT2 @ 93.10%
LANDULPH 33	Min Gen Max Load	5	38.42	0.00	0.00	0.00	0.00	36	8	38.09	10.87	0	0	0	0	
LOCKLEAZE 33	Max Gen Min Load	5	47.16	-9.86	47.16	-9.86	0.98	61	11	37.40	2.77	0	0	0	2	8851 - 8856 GT1 @ 15.20% 8852 - 8855 GT2 @ 45.66% 8853 - 8855 GT3 @ 46.39% 8854 - 8856 GT4 @ 16.44%
LOCKLEAZE 33	Min Gen Max Load	5	47.16	-9.86	0.00	0.00	1.00	61	11	124.66	9.23	0	1	1	1	
MILEHOUSE 33	Max Gen Min Load	1	23.90	0.00	23.90	0.00	1.00	19	6	17.94	2.70	0	0	0	0	8061 - 8065 GT1 @ 3.63% 8063 - 8065 GT2 @ 3.60%
MILEHOUSE 33	Min Gen Max Load	1	23.90	0.00	0.00	0.00	0.00	19	6	59.80	8.99	0	0	0	0	
N/TAWTON 33	Max Gen Min Load	3	22.70	-5.90	22.70	-5.90	0.97	20	5	5.69	1.16	0	1	1	1	8950 - 8955 GT1 @ 43.65%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
N/TAWTON 33	Min Gen Max Load	3	22.70	-5.90	0.00	0.00	0.00	20	5	18.96	3.88	0	0	0	0	
NEWTON AB 33	Max Gen Min Load	5	33.62	-3.25	33.62	-3.25	1.00	42	7	22.86	2.72	0	0	0	0	8351 - 8355 GT2 @ 23.82% 8352 - 8355 GT1 @ 23.88%
NEWTON AB 33	Min Gen Max Load	5	33.62	-3.25	0.00	0.00	0.00	42	7	76.20	9.06	0	0	1	0	
PAIGNTON 33	Max Gen Min Load	4	30.58	-8.56	30.58	-8.56	0.96	38	8	18.95	1.99	0	0	0	0	8361 - 8365 GT1 @ 24.10% 8362 - 8365 GT2 @ 26.04%
PAIGNTON 33	Min Gen Max Load	4	30.58	-8.56	0.00	0.00	0.00	38	8	63.18	6.62	0	0	0	0	
PLYMOUTH 33	Max Gen Min Load	3	41.95	-4.96	41.95	-4.96	0.99	53	10	23.92	0.82	0	0	1	1	8051 - 8055 GT1 @ 13.42% 8051 - 8055 GT2 @ 13.44% 8052 - 8055 GT3 @ 12.43%
PLYMOUTH 33	Min Gen Max Load	3	41.95	-4.96	0.00	0.00	0.00	53	10	79.74	2.75	0	0	0	0	
PLYMPTON 33	Max Gen Min Load	5	39.82	-0.81	39.82	-0.81	1.00	41	9	12.10	2.31	0	0	0	0	8041 - 8045 GT1 @ 42.16% 8042 - 8045 GT2 @ 42.13%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
PLYMPTON 33	Min Gen Max Load	5	39.82	-0.81	0.00	0.00	0.00	41	9	40.34	7.69	0	0	0	0	
PORTISHED 33	Max Gen Min Load	0	0.00	0.00	0.00	0.00	0.00	34	7	12.63	2.87	0	0	0	0	8980 - 8985 GT1 @ 12.65% 8981 - 8985 GT2 @ 12.55%
PORTISHED 33	Min Gen Max Load	0	0.00	0.00	0.00	0.00	0.00	34	7	42.10	9.57	0	0	0	1	
PYWORTHY 33	Max Gen Min Load	13	75.47	-2.27	75.47	-2.27	1.00	69	10	15.32	3.14	0	2	2	3	8481 - 8485 GT2 @ 36.52% 8482 - 8485 GT3 @ 37.04% 8483 - 8485 GT4 @ 36.52%
PYWORTHY 33	Min Gen Max Load	13	75.47	-2.27	0.00	0.00	0.00	69	10	51.07	10.46	0	0	0	0	
RADSTOCK 33	Max Gen Min Load	12	68.79	-12.21	68.79	-12.21	0.98	84	12	22.15	4.38	0	1	1	2	8921 - 8925 GT1 @ 38.83% 8922 - 8925 GT2 @ 38.33%
RADSTOCK 33	Min Gen Max Load	12	68.79	-12.21	0.00	0.00	0.00	84	12	73.85	14.60	0	0	1	0	
RAME 33	Max Gen Min Load	8	49.33	-1.56	49.33	-1.56	1.00	54	10	21.32	3.93	0	0	0	0	8471 - 8475 GT1 @ 30.07% 8472 - 8475 GT2 @ 30.07% 8473 - 8475 GT3 @ 32.58%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
RAME 33	Min Gen Max Load	8	49.33	-1.56	0.00	0.00	0.00	54	10	71.06	13.11	0	0	1	0	
SEABANK 33	Max Gen Min Load	4	76.00	-20.37	76.00	-20.37	0.97	14	2	2.51	1.27	0	1	1	1	8085 - 80967 GT1 @ 44.36% 8085 - 80968 GT2 @ 44.37%
SEABANK 33	Min Gen Max Load	4	76.00	-20.37	0.00	0.00	1.00	14	2	8.38	4.22	0	0	1	1	
SOWTON 33	Max Gen Min Load	1	3.40	-0.69	3.40	-0.69	0.98	46	12	18.55	0.00	0	1	1	1	8371 - 8375 GT1 @ 10.08% 8372 - 8375 GT3 @ 0.95%
SOWTON 33	Min Gen Max Load	1	3.40	-0.69	0.00	0.00	0.00	46	12	61.82	0.00	0	0	0	0	
ST AUSTEL 33	Max Gen Min Load	7	44.03	-5.60	44.03	-5.60	0.99	59	10	17.37	0.54	0	0	0	0	8421 - 8425 GT1 @ 48.45% 8422 - 8425 GT2 @ 41.54%
ST AUSTEL 33	Min Gen Max Load	7	44.03	-5.60	0.00	0.00	0.00	59	10	57.91	1.80	0	0	0	0	
ST GERMAN 33	Max Gen Min Load	10	59.38	-1.48	59.38	-1.48	1.00	43	5	8.47	2.42	0	0	0	0	8521 - 8525 GT1 @ 20.13% 8522 - 8525 GT2 @ 75.25%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
ST GERMAN 33	Min Gen Max Load	10	59.38	-1.48	0.00	0.00	0.00	43	5	28.23	8.05	0	0	0	0	
ST TUDY 33	Max Gen Min Load	8	51.96	0.00	51.96	0.00	1.00	56	9	14.38	2.01	0	1	2	2	8441 - 8445 GT1 @ 50.11% 8442 - 8445 GT2 @ 50.32%
ST TUDY 33	Min Gen Max Load	8	51.96	0.00	0.00	0.00	0.00	56	9	47.94	6.71	0	0	0	0	
STREET 33	Max Gen Min Load	4	28.49	-4.45	28.49	-4.45	0.99	34	6	12.04	2.33	0	0	0	0	8741 - 8745 GT1 @ 49.71%
STREET 33	Min Gen Max Load	4	28.49	-4.45	0.00	0.00	0.00	34	6	40.15	7.75	0	0	0	0	
TAUNTON 33	Max Gen Min Load	12	94.55	-20.66	94.55	-20.66	0.98	59	10	23.26	3.63	0	2	3	3	8611 - 8615 GT1 @ 32.29% 8611 - 8615 GT2 @ 32.39% 8611 - 8616 GT3 @ 88.48%
TAUNTON 33	Min Gen Max Load	12	94.55	-20.66	0.00	0.00	1.00	59	10	77.52	12.11	0	1	4	1	
TIVERTON 33	Max Gen Min Load	5	18.55	-2.84	18.55	-2.84	0.99	41	8	14.78	2.35	0	0	0	0	8345 - 8348 G1 @ 27.25% 8345 - 8349 G2 @ 36.01%

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
TIVERTON 33	Min Gen Max Load	5	18.55	-2.84	0.00	0.00	1.00	41	8	49.27	7.84	0	0	0	0	
TORQUAY 33	Max Gen Min Load	1	19.84	-6.52	19.84	-6.52	0.95	25	4	13.45	4.01	0	1	1	1	8032 - 8035 GT2 @ 12.15%
TORQUAY 33	Min Gen Max Load	1	19.84	-6.52	0.00	0.00	0.00	25	4	44.82	13.35	0	0	0	0	
TOTNES 33	Max Gen Min Load	7	40.17	-0.81	40.17	-0.81	1.00	46	7	13.39	1.49	0	0	0	0	8021 - 8025 GT1 @ 34.23% 8022 - 8025 GT2 @ 32.08%
TOTNES 33	Min Gen Max Load	7	40.17	-0.81	0.00	0.00	0.00	46	7	44.63	4.95	0	0	0	0	
TRURO 33	Max Gen Min Load	7	43.86	-4.40	43.86	-4.40	1.00	35	5	10.23	1.50	0	0	0	1	8491 - 8495 GT2 @ 45.26% 8492 - 8495 GT1 @ 43.13%
TRURO 33	Min Gen Max Load	7	43.86	-4.40	0.00	0.00	0.00	35	5	34.09	5.01	0	0	0	2	
WESTON 33	Max Gen Min Load	5	36.38	-10.53	36.38	-10.53	0.96	27	5	16.32	3.35	0	0	0	0	8721 - 8725 GT1 @ 35.82% 8722 - 8725 GT2 @ 46.66%
WESTON 33	Min Gen Max Load	5	36.38	-10.53	0.00	0.00	1.00	27	5	54.39	11.17	0	0	0	0	

BSP	Case	Total Gens @ 33.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Bus Count	Load Count	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch Loadings >80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch Loadings > 80%	GTX Reverse Power Loading
WOODCOTE 33	Max Gen Min Load	10	51.81	-5.36	51.81	-5.36	0.99	69	10	23.08	4.07	0	1	1	3	8221 - 8225 GT1 @ 26.01% 8222 - 8225 GT2 @ 26.19% 8223 - 8225 GT3 @ 24.87%
WOODCOTE 33	Min Gen Max Load	10	51.81	-5.36	0.00	0.00	0.00	69	10	76.93	13.56	0	0	0	0	
YEOVIL 33	Max Gen Min Load	1	20.00	-6.57	20.00	-6.57	0.95	19	5	30.01	5.96	0	1	1	1	8171 - 8175 GT1 @ 9.18% 8171 - 8175 GT2 @ 8.45% 8171 - 8175 GT3 @ 7.73%
YEOVIL 33	Min Gen Max Load	1	20.00	-6.57	0.00	0.00	0.00	19	5	100.04	19.87	0	0	0	0	

11kV Networks

Primary substation	Case	Total Gens @ 11.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch loading > 80%	Tx Reverse Power Loading
Tiverton Moorhayes	Max Gen Min Load	2	1.95	-0.64	1.95	-0.64	0.95	1.91	0.39	0	0	0	0	6032 - 7735 T1 @ 5.06% 7734 - 7735 T2 @ 5.03%
Tiverton Moorhayes	Min Gen Max Load	2	1.95	-0.64	0.00	0.00	0.00	6.37	1.29	0	1	1	1	
Colley Lane	Max Gen Min Load	1	0.75	-0.25	0.75	-0.25	0.95	7.47	1.52	0	0	0	0	7199 - 10925 T2 @ 23.61% 7200 - 7202 T1 @ 24.34% 7201 - 7202 T3 @ 28.53%
Colley Lane	Min Gen Max Load	1	0.75	-0.25	0.00	0.00	0.00	24.60	4.99	0	0	0	0	
Dunkeswell	Max Gen Min Load	1	2.80	0.00	2.80	0.00	1.00	1.32	0.27	0	0	0	0	7271 - 7946 T2 @ 24.92%
Dunkeswell	Min Gen Max Load	1	2.80	0.00	0.00	0.00	0.00	4.41	0.90	0	0	0	0	
Marsh Green	Max Gen Min Load	2	5.50	-1.90	5.50	-1.90	0.95	1.35	0.28	0	0	1	1	7470 - 9011 T1 @ 80.83% 7471 - 7472 T2 @ 3.65%
Marsh Green	Min Gen Max Load	2	5.50	-1.90	0.00	0.00	0.00	4.49	0.92	0	0	0	0	

Primary substation	Case	Total Gens @ 11.0kV	Total MW (Pmax)	Total MVAR (Qmax)	Total MW (Pgen)	Total MVAr (Qgen)	PF (calc)	Load MW	Load MVAr	Voltage Violations	Winter Day / Cyclic (Tx) Branch loadings > 80%	Shoulder/ Nameplate (Tx) Branch Loadings > 80%	Summer/ Reverse Power (Tx) Branch loading > 80%	GTx Reverse Power Loading
Millfield	**Max Gen Min Load**	3	11.03	-3.63	11.03	-3.63	0.95	5.30	1.08	0	0	0	0	7490 - 96602 T2 @ 36.86% 7491 - 7492 T1 @ 37.23%
Millfield	**Min Gen Max Load**	3	11.03	-3.63	0.00	0.00	0.00	17.6	3.59	0	2	2	2	
Waterlake	**Max Gen Min Load**	0	0.00	0.00	0.00	0.00	0.00	1.42	0.28	0	0	0	0	7789 - 7791 T2 @ 7.74% 7790 - 7792 T1 @ 6.15%
Waterlake	**Min Gen Max Load**	0	0.00	0.00	0.00	0.00	0.00	4.74	0.93	0	0	0	0	

Appendix B – Tag rules for timeseries data

Barnstaple Loads

Site	Tags used	Method	Scaling
AARONSONS	AARONSONS > 33kV > CB 1H0 > Current Analogue AARONSONS > 33kV > CB 1H0 > AARONSONS VT AARONSONS > 33kV > CB 1H0 > 1H0 > Power Analogues > MW Analogue AARONSONS > 33kV > CB 1H0 > 1H0 > Power Analogues > MVAr Analogue	CM	-1
BRATTON FLEMING	BRATTON FLEMING > 11kv > CB 121 > 11kV Current BRATTON FLEMING > 11kv > CB 121 > 11kV VT	VIM	1
GREAT TORRINGTON	GREAT TORRINGTON > 33kV > T2 Busbar > CB 2L5 > Current Analogue GREAT TORRINGTON > 33kV > T2 Busbar > VT2	VIM	0.4
HEDDON CROSS	HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MVAr Analogue HEDDON CROSS > 11kV > T1 Busbar > CB 51 > CB 51 > Power Analogues > MW Analogue	DM	1
LYNTON	LYNTON > 11kV > T2 Busbar > CB 72 > 11kV Current LYNTON > 11kV > T2 Busbar > CB 72 > VT 2 & Isolator > VT 2	VIM	1
MIDDLE BARLINGTON	MIDDLE BARLINGTON > 11kV > CB 111 > CB 111 > Power Analogues > MVAr Analogue MIDDLE BARLINGTON > 11kV > CB 111 > CB 111 > Power Analogues > MW Analogue	DM	-1
ROCK PARK	ROCK PARK > 11kV > T1 Busbar > CB 151 > 11kV Current ROCK PARK > 11kV > T1 Busbar > CB 151 > 11kV VT ROCK PARK > 11kV > T2 Busbar > CB 152 > 152 > Power Analogs > MW Analogue ROCK PARK > 11kV > T2 Busbar > CB 152 > 152 > Power Analogs > MVAr Analogue	CM	-1
ROUNDSWELL	ROUNDSWELL > 11kV > T1 Busbar > CB 0081 > 11kV Current ROUNDSWELL > 11kV > T2 Busbar > CB 0082 > 11kV Current ROUNDSWELL > 11kV > T1 Busbar > CB 0081 > 11kV VT ROUNDSWELL > 11kV > T2 Busbar > CB 0082 > 11kV VT	VIM	1
SOUTH MOLTON	SOUTH MOLTON > 11kV > T1 Busbar > CB 0091 > 11kV Current SOUTH MOLTON > 11kV > T2 Busbar > CB 0092 > 11kV Current SOUTH MOLTON > 11kV > T2 Busbar > CB 0092 > 11kV VT SOUTH MOLTON > 11kV > T1 Busbar > CB 0091 > 11kV VT	VIM	1
TINKERS CROSS J	TINKERS CROSS > 11kV > T2 Busbar > CB 0102 > 11kV Current TINKERS CROSS > 11kV > T2 Busbar > CB 0102 > 11kV VT	VIM	1
TINKERS CROSS K	TINKERS CROSS > 11kV > T1 Busbar > CB 0101 > 11kV Current TINKERS CROSS > 11kV > T1 Busbar > CB 0101 > 11kV VT	VIM	1

Barnstaple Generation

Site	Tags used	Method	Scaling
BATSWORTHY CROSS 33kV WIND FARM	BATSWORTHY CROSS 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue BATSWORTHY CROSS 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	1

BEAFORD 33kV SOLAR FARM	BEAFORD 33kV SOLAR FARM > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue BEAFORD 33kV SOLAR FARM > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1
BRATTON FLEMING 33kV SOLAR PARK	BRATTON FLEMING 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue BRATTON FLEMING 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	-1
CAPELANDS FARM 33kV SOLAR PARK	CAPELANDS FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue CAPELANDS FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	-1
DARRACOTT MOOR WINDFARM	DARRACOTT MOOR WINDFARM > 33kV > Busbar > CB 1M0 > Current Analogue DARRACOTT MOOR WINDFARM > 33kV > Busbar > VT 1 DARRACOTT MOOR WINDFARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue	CM	1
KINGSLAND BARTON 33kV SOLAR PARK	KINGSLAND BARTON 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue KINGSLAND BARTON 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1
KNOCKWORTHY 33kV SOLAR PARK	KNOCKWORTHY 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue KNOCKWORTHY 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	1

Pyworthy Loads

Site	Tags used	Method	Scaling
ASHWATER	ASHWATER > 11kV > CB 4081 > CB 4081 > Power Analogs > MVAr Analogue ASHWATER > 11kV > CB 4081 > CB 4081 > Power Analogs > MW Analogue	DM	1
CLOVELLY	CLOVELLY > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MW Analogue CLOVELLY > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MVAr Analogue	DM	1
EAST CURRY	EAST CURRY > 11kV > CB 4061 > 11kV Current EAST CURRY > 11kV > CB 4061 > 11kV VT	VIM	4
HATHERLEIGH	HATHERLEIGH > 11kV > T2 Busbar > CB 192 > CB 192 > Power Analogues > MW Analogue HATHERLEIGH > 11kV > T2 Busbar > CB 192 > CB 192 > Power Analogues > MVAr Analogue HATHERLEIGH > 11kV > T1 Busbar > CB 191 > CB 191 > Power Analogues > MW Analogue HATHERLEIGH > 11kV > T1 Busbar > CB 191 > CB 191 > Power Analogues > MVAr Analogue	DM	-1
HOLSWORTHY	HOLSWORTHY > 11kV > T1 Busbar > CB 4051 > 11kV Current HOLSWORTHY > 11kV > T2 Busbar > CB 4052 > 11kV Current HOLSWORTHY > 11kV > T1 Busbar > CB 4051 > 11kV VT HOLSWORTHY > 11kV > T2 Busbar > CB 4052 > 11kV VT	VIM	1
LAUNCESTON	LAUNCESTON > 11kV > T1 Busbar > CB 25/51 > CB 51 > Power Analogs > MW Analogue LAUNCESTON > 11kV > T1 Busbar > CB 25/51 > CB 51 > Power Analogs > MVAr Analogue LAUNCESTON > 11kV > T2 Busbar > CB 25/52 > CB 52 > Power Analogs > MW Analogue LAUNCESTON > 11kV > T2 Busbar > CB 25/52 > CB 52 > Power Analogs > MVAr Analogue LAUNCESTON > 11kV > T3 Busbar > CB 25/53 > CB 53 > Power Analogs > MW Analogue LAUNCESTON > 11kV > T3 Busbar > CB 25/53 > CB 53 > Power Analogs > MVAr Analogue	DM	-1
MORETONHAMPSTEAD	MORETONHAMPSTEAD > 11kV > T1 Busbar > CB 12/19 > 11kV Current MORETONHAMPSTEAD > 11kV > T1 Busbar > CB 12/19 > 11kV VT	VIM	1
MORWENSTOW	MORWENSTOW > 11kV > CB 4031 > CB 4031 > Power Analogs > MW Analogue MORWENSTOW > 11kV > CB 4031 > CB 4031 > Power Analogs > MVAr Analogue	DM	1

NORTH TAWTON	NORTH TAWTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MW Analogue NORTH TAWTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MVAr Analogue NORTH TAWTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MW Analogue NORTH TAWTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MVAr Analogue	DM	1
OKEHAMPTON	OKEHAMPTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MVAr Analogue OKEHAMPTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MW Analogue OKEHAMPTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MVAr Analogue OKEHAMPTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MW Analogue	DM	1
ROADFORD	ROADFORD > 33kV > Busbar 1 > CB 1H0 > CB 1H0 > Power Analogs > MW Analogue ROADFORD > 33kV > Busbar 1 > CB 1H0 > CB 1H0 > Power Analogs > MVAr Analogue ROADFORD > 33kV > Busbar 2 > CB 2H0 > CB 2H0 > Power Analogs > MW Analogue ROADFORD > 33kV > Busbar 2 > CB 2H0 > CB 2H0 > Power Analogs > MVAr Analogue	DM	1
SHEBBEAR	SHEBBEAR > 11kV > T1 Busbar > CB 13/19 > 11kV ACB > Power Analogs > MW Analogue SHEBBEAR > 11kV > T1 Busbar > CB 13/19 > 11kV ACB > Power Analogs > MVAr Analogue	DM	-1
STRATTON	STRATTON > 11kV > T1 Busbar > CB 4041 > CB 4041 > Power Analogues > MVAr Analogue STRATTON > 11kV > T1 Busbar > CB 4041 > CB 4041 > Power Analogues > MW Analogue STRATTON > 11kV > T2 Busbar > CB 4042 > CB 4042 > Power Analogues > MVAr Analogue STRATTON > 11kV > T2 Busbar > CB 4042 > CB 4042 > Power Analogues > MW Analogue	DM	1
WHIDDON DOWN	WHIDDON DOWN > 11kV > T1 Busbar > CB 21/19 > 11kV Current WHIDDON DOWN > 11kV > T2 Busbar > CB 21/21 > 11kV Current WHIDDON DOWN > 11kV > T1 Busbar > CB 21/19 > 11kV VT WHIDDON DOWN > 11kV > T2 Busbar > CB 21/21 > 11kV VT	VIM	1

Pyworthy Generation

Site	Tags used	Method	Scaling
ASHWATER 33kV SOLAR PARK	ASHWATER > 11kV > CB 4081 > CB 4081 > Power Analogs > MVAr Analogue ASHWATER > 11kV > CB 4081 > CB 4081 > Power Analogs > MW Analogue	DM	1
BRADFORD MANOR 33kV SOLAR PARK	BRADFORD MANOR 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue BRADFORD MANOR 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	-1
CRINACOTT FARM 33kV SOLAR PARK	CRINACOTT FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue CRINACOTT FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	1
DENBROOK 33kV WIND FARM	DENBROOK 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue DENBROOK 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	1
DERRITON FIELDS 33kV SOLAR PARK	DERRITON FIELDS 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > Current Analogue DERRITON FIELDS 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > VT1 DERRITON FIELDS 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > Current Analogue > Power Analogues > MVAr Analogue	CM	1
DUNSLAND CROSS 33kV WIND FARM	DUNSLAND CROSS 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue DUNSLAND CROSS 33kV WIND FARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	-1
EAST LANGFORD 33kV SOLAR PARK	EAST LANGFORD 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue EAST LANGFORD 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1

EAST YOULSTONE 33kV WINDFARM	EAST YOULSTONE 33kV WINDFARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue EAST YOULSTONE 33kV WINDFARM > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	-1
EASTACOMBE FM 33kV SOLAR PARK	EASTACOMBE FM 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue EASTACOMBE FM 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1
FORESTMOOR WINDFARM	FORESTMOOR WINDFARM > 33kV > Busbar > CB 1L5 > Current Analogue FORESTMOOR WINDFARM > 33kV > Busbar > CB 1L5 > VT	VIM	1
FOXCOMBE 33kV SOLAR PARK	FOXCOMBE 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue FOXCOMBE 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1
HIGHER NORTH BEER FARM SOLAR PARK	HIGHER NORTH BEER FARM SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue HIGHER NORTH BEER FARM SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	5 (MW) 1 (MVAr)
PITWORTHY 33kV SOLAR PARK	PITWORTHY 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > Current Analogue > Power Analogues > MW Analogue PITWORTHY 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > Current Analogue > Power Analogues > MVAr Analogue	DM	1
REXON CROSS FARM 33kV SOLAR PARK	REXON CROSS FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue REXON CROSS FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	-1
WILLSLAND 33kV SOLAR PARK	WILLSLAND 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue WILLSLAND 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue	DM	-1

Tiverton Loads

Site	Tags used	Method	Scaling
BRIDGE MILLS	BRIDGE MILLS > 11kV > T1 Busbar > CB 18/19 > 11kV Current BRIDGE MILLS > 11kV > T2 Busbar > CB 18/21 > 11kV Current BRIDGE MILLS > 11kV > T1 Busbar > CB 18/19 > 1819 > Power Analogs > MW Analogue BRIDGE MILLS > 11kV > T1 Busbar > CB 18/19 > 1819 > Power Analogs > MVAr Analogue	CM	1
BURLESCOMBE	BURLESCOMBE > 11kV > T1 Busbar > CB 33/19 > 11kV Current BURLESCOMBE > 11kV > T2 Busbar > CB 33/22 > 11kV Current BURLESCOMBE > 11kV > T1 Busbar > CB 33/19 > 11kV VT BURLESCOMBE > 11kV > T2 Busbar > CB 33/22 > 11kV VT	VIM	1
CULLOMPTON	CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MW Analogue CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MVAr Analogue CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MW Analogue CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MVAr Analogue	DM	Abs(P) Abs (Q)
DUNKESWELL	DUNKESWELL > 11kV > T2 Busbar > CB 57/21 > 11kV Current DUNKESWELL > 11kV > T2 Busbar > CB 57/21 > 11kV VT	VIM	1
HEMYOCK	HEMYOCK > 11kV > T2 Busbar > CB 56/21 > 11kV Current HEMYOCK > 11kV > T2 Busbar > CB 56/21 > 11kV VT	VIM	1
TIVERTON JUNCTION	TIVERTON JUNCTION > 11kV > BUSBAR T1 > CB 32/19 > 11kV Current TIVERTON JUNCTION > 11kV > BUSBAR T2 > CB 32/21 > 11kV Current TIVERTON JUNCTION > 11kV > BUSBAR T1 > CB 32/19 > 11kV VT TIVERTON JUNCTION > 11kV > BUSBAR T2 > CB 32/21 > 11kV VT	VIM	1
TIVERTON MOORHAYES	TIVERTON MOORHAYES > 11kV > T1 Busbar > CB 23/19 > CB 19 > Power Analogues > MW Analogue	DM	Abs(P)

	TIVERTON MOORHAYES > 11kV > T1 Busbar > CB 23/19 > CB 19 > Power Analogues > MVAr Analogue TIVERTON MOORHAYES > 11kV > T2 Busbar > CB 23/21 > CB 21 > Power Analogues > MW Analogue TIVERTON MOORHAYES > 11kV > T2 Busbar > CB 23/21 > CB 21 > Power Analogues > MVAr Analogue		Abs (Q)
TIVERTON SOUTH	TIVERTON SOUTH > 11kV > T1 Busbar > CB 25/19 > 11kV Current TIVERTON SOUTH > 11kV > T2 Busbar > CB 25/21 > 11kV Current TIVERTON SOUTH > 11kV > T1 Busbar > CB 25/19 > 11kV VT TIVERTON SOUTH > 11kV > T2 Busbar > CB 25/21 > 11kV VT TIVERTON SOUTH > 11kV > T1 Busbar > CB 25/19 > 2519 > Power Analogues > MVAr Analogue TIVERTON SOUTH > 11kV > T1 Busbar > CB 25/19 > 2519 > Power Analogues > MW Analogue TIVERTON SOUTH > 11kV > T2 Busbar > CB 25/21 > CB 21 > Power Analogues > MVAr Analogue TIVERTON SOUTH > 11kV > T2 Busbar > CB 25/21 > CB 21 > Power Analogues > MW Analogue	CM	1

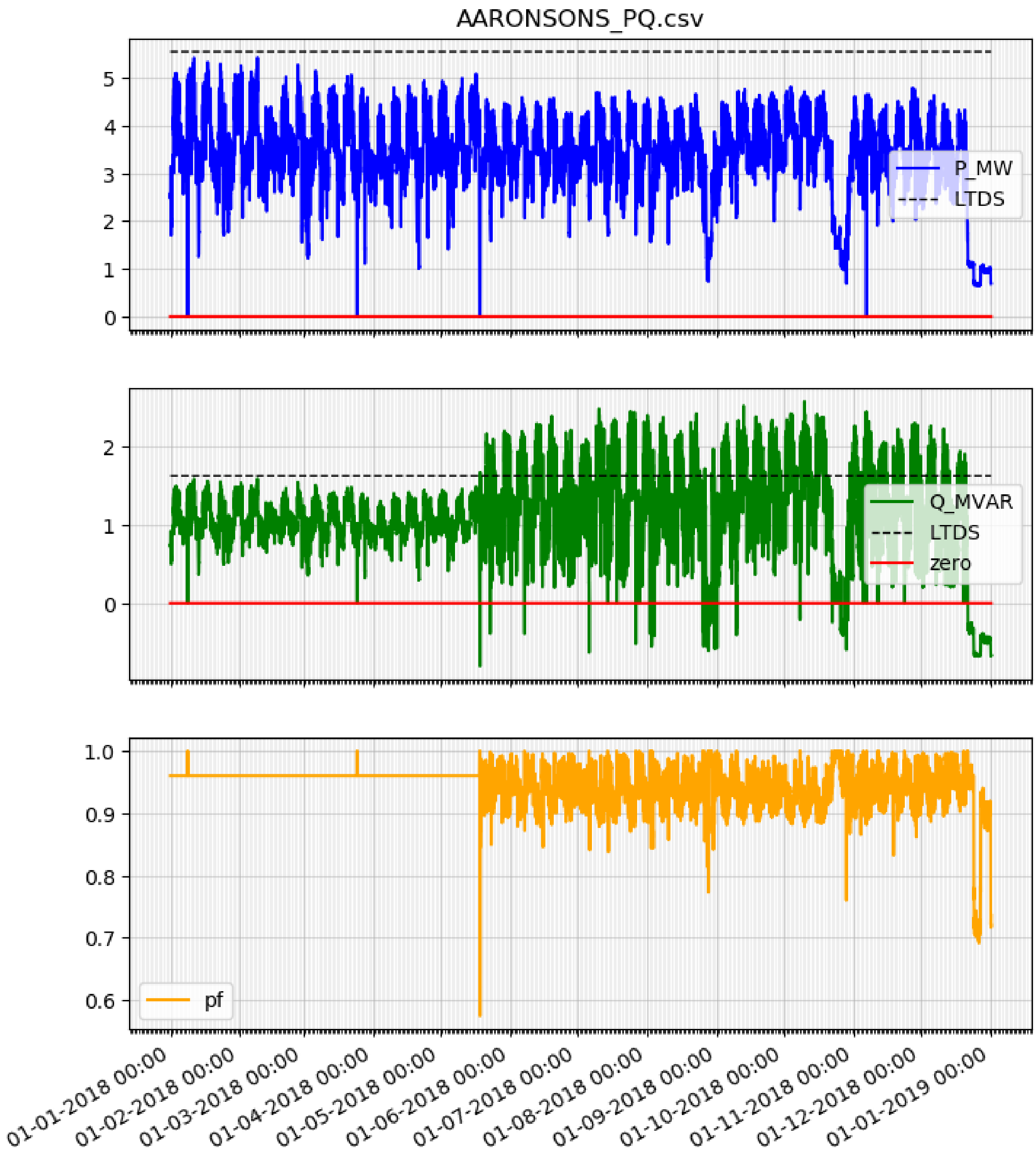
Tiverton Generation

Site	Tags used	Method	Scaling
AYSHFORD COURT FARM 33kV SOLAR PARK	AYSHFORD COURT FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MW Analogue AYSHFORD COURT FARM 33kV SOLAR PARK > 33kV > Busbar > CB 1M0 > CB 1M0 > Power Analogues > MVAr Analogue	DM	1
CULLOMPTON 33kV SOLAR PARK	CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MW Analogue CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MVAr Analogue CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MW Analogue CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MVAr Analogue	DM	1
STONESHILL 33kV SOLAR PARK	STONESHILL 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MW Analogue STONESHILL 33kV SOLAR PARK > 33kV > Busbar > CB 1L5 > CB 1L5 > Power Analogues > MVAr Analogue	DM	1

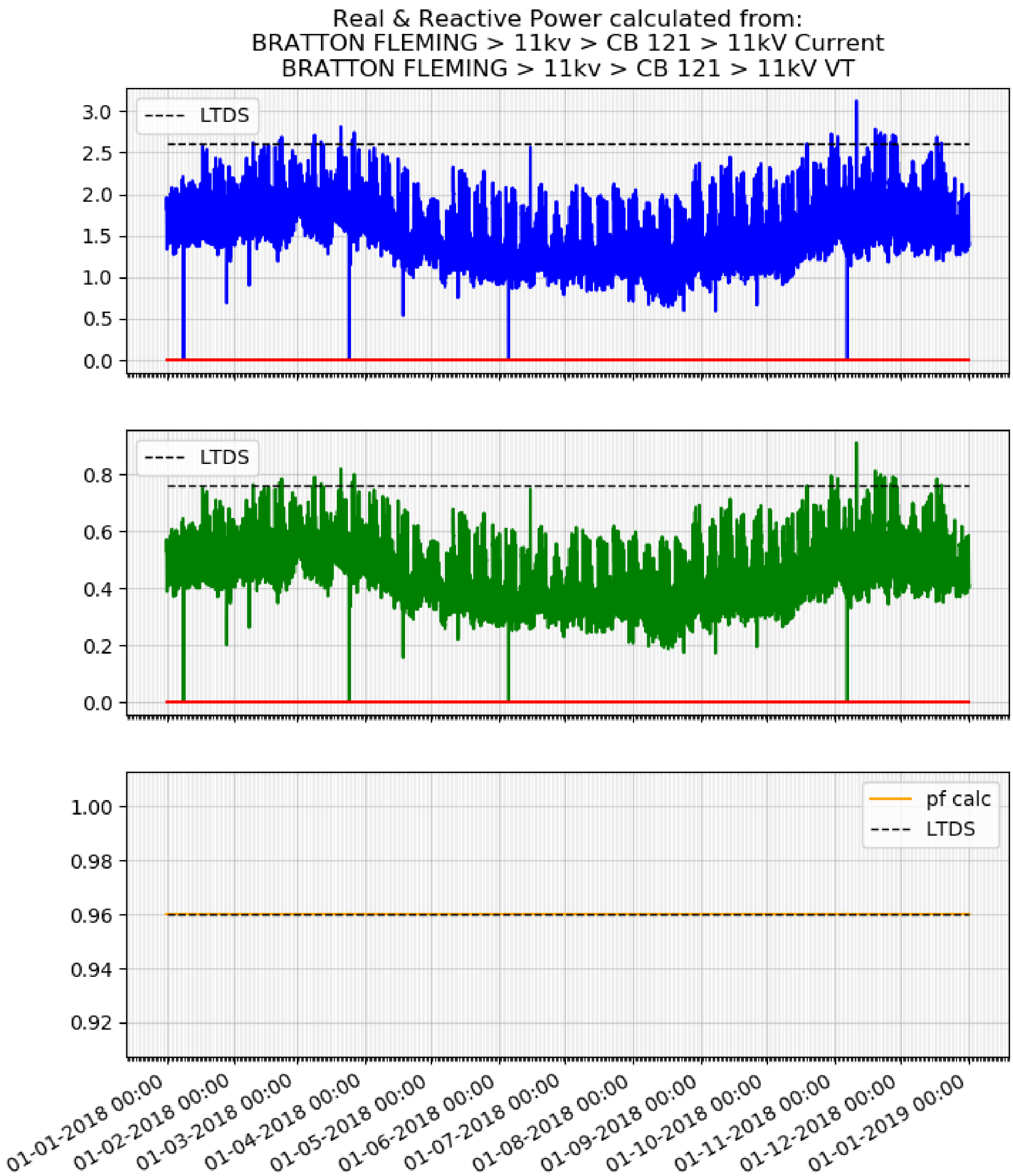
Appendix C – Timeseries data validation plots

<u>Barnstaple Load:</u>

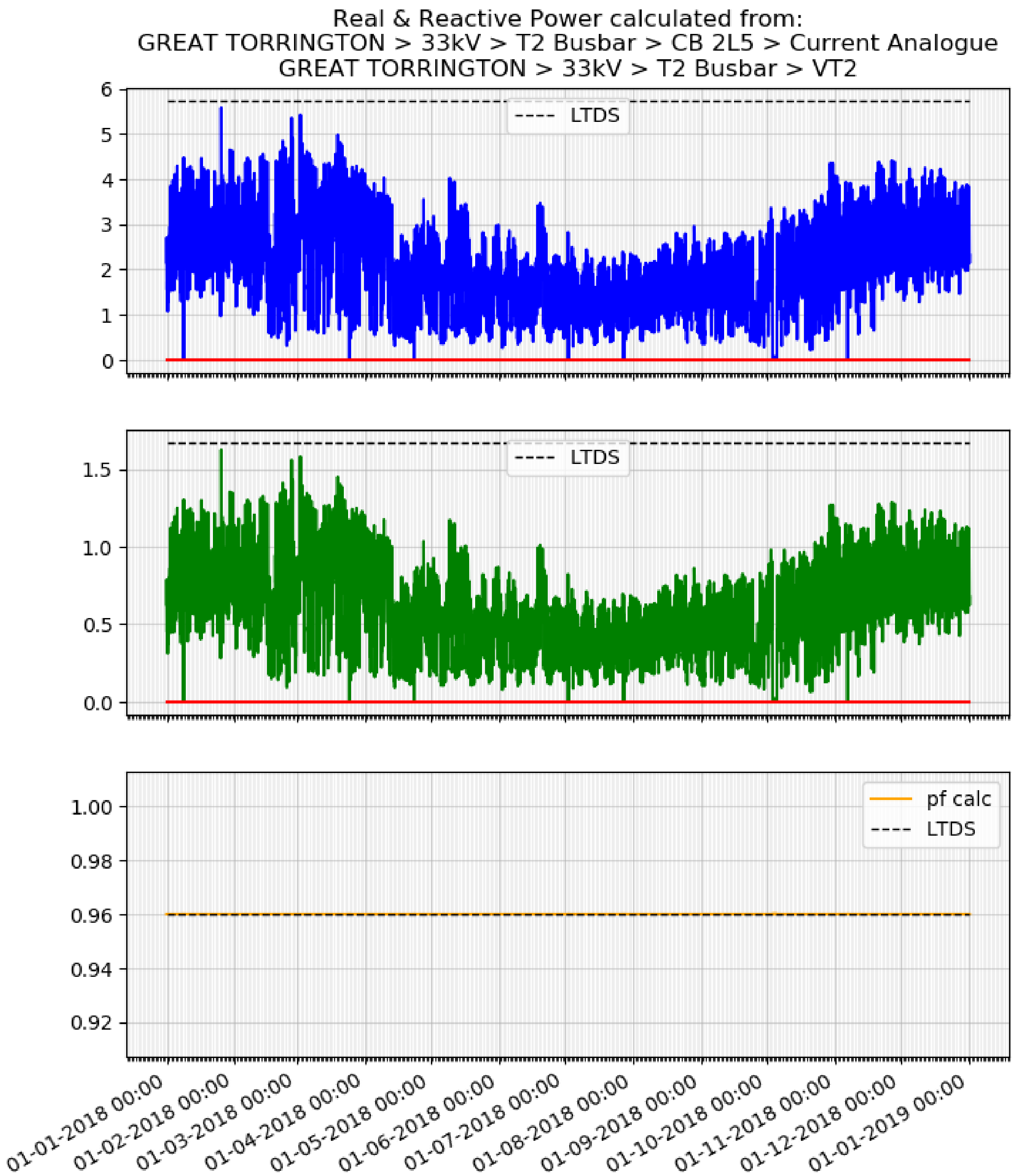
AARONSONS



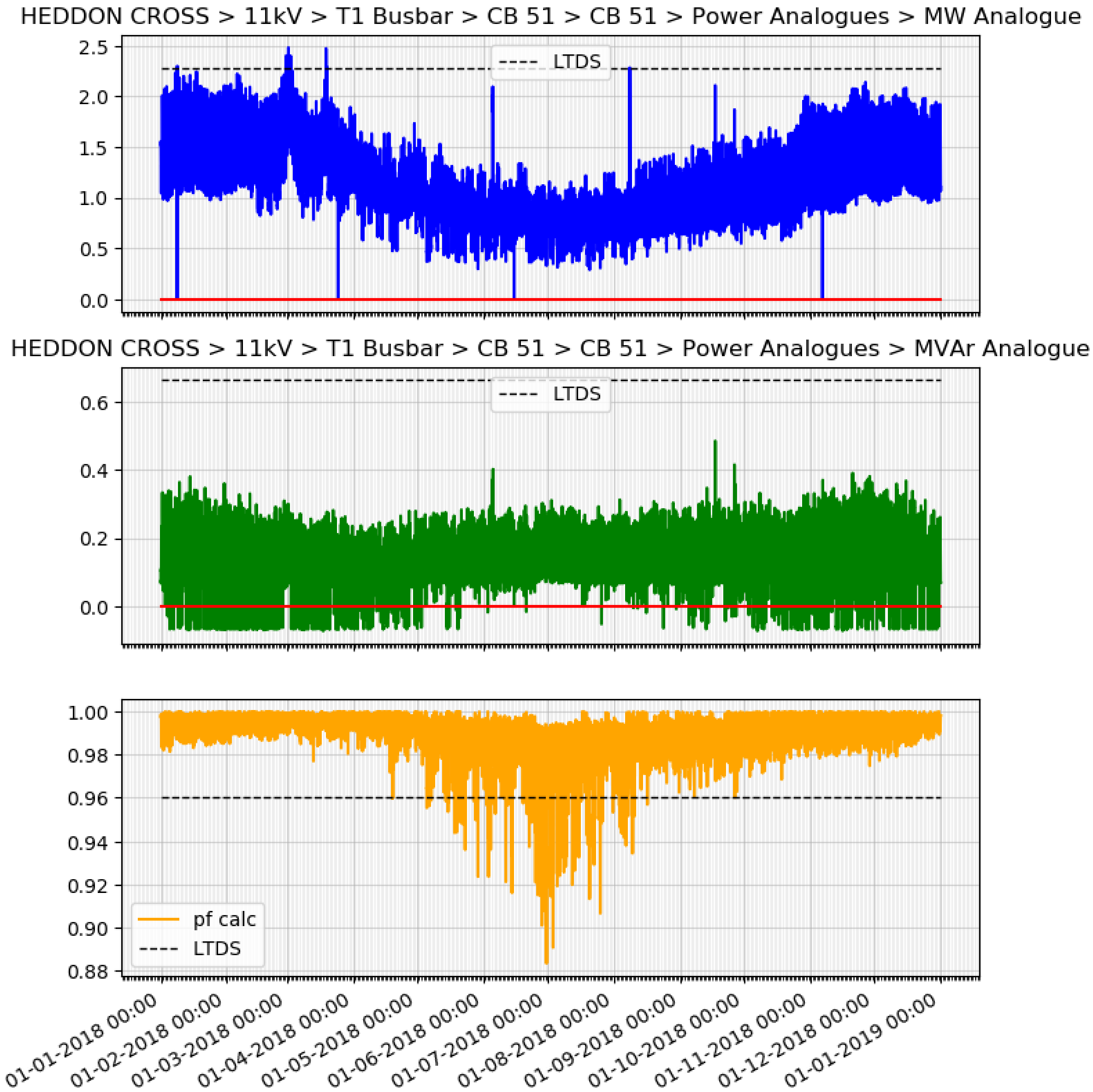
BRATTON FLEMING



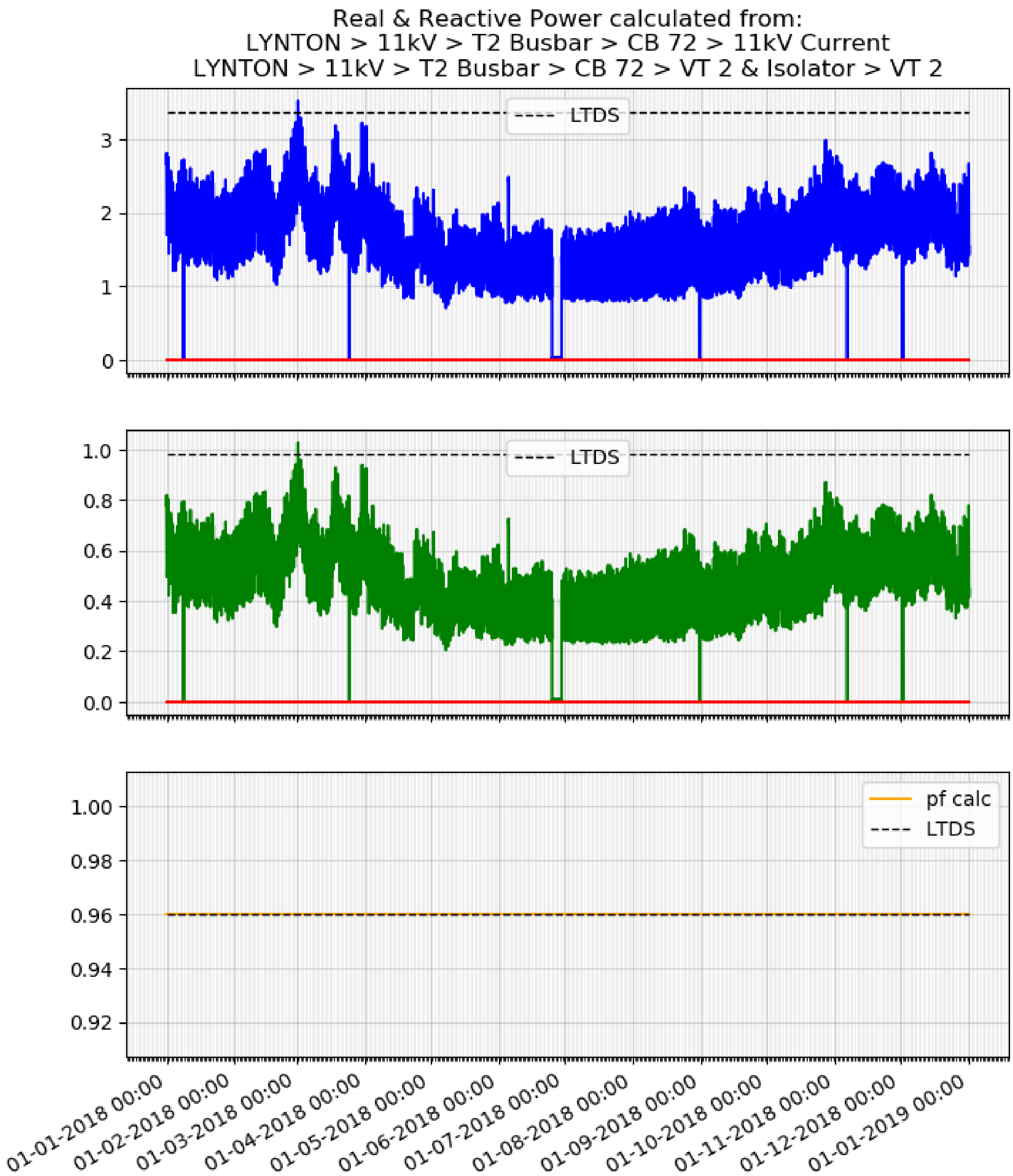
GREAT TORRINGTON



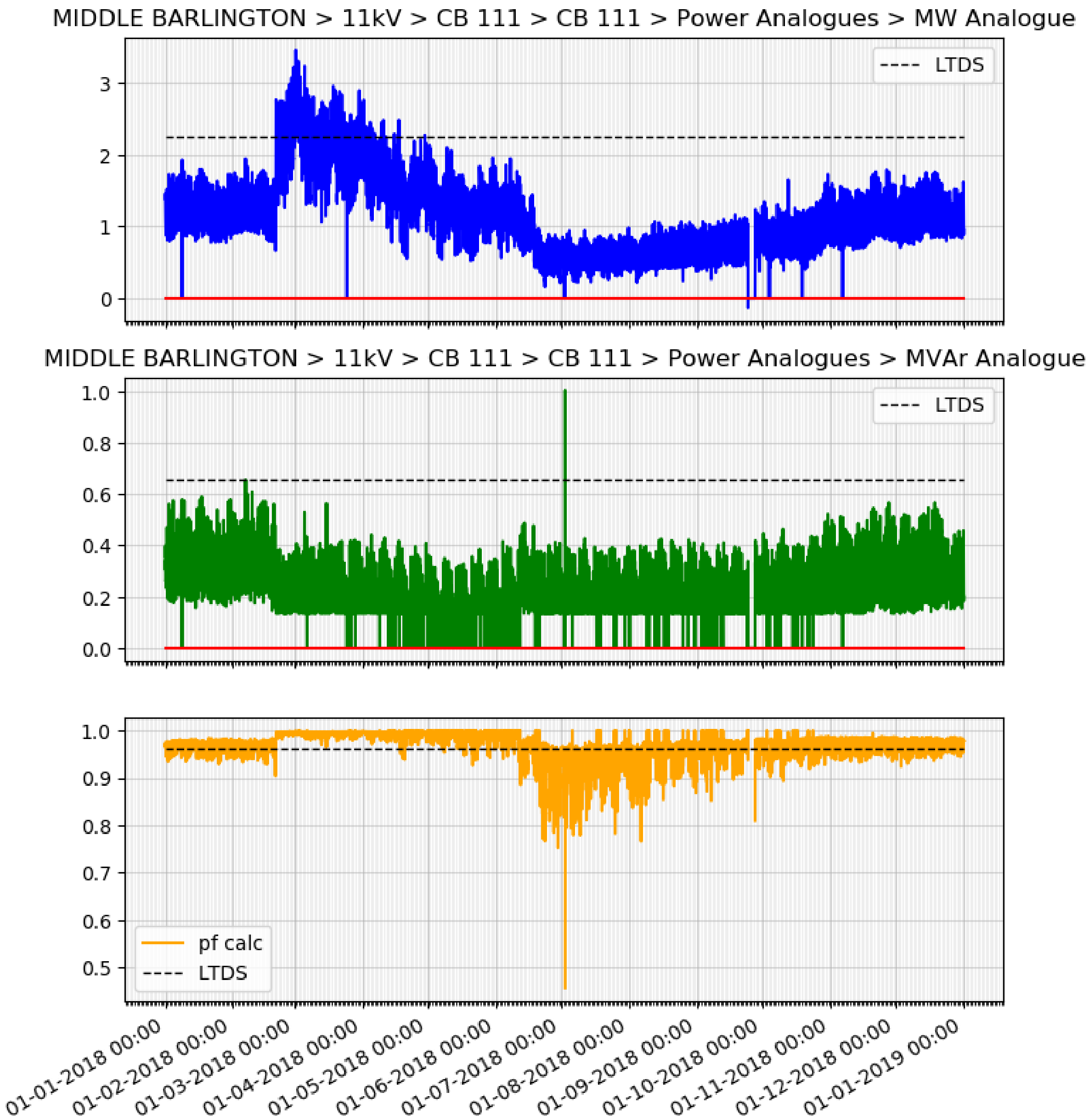
HEDDON CROSS



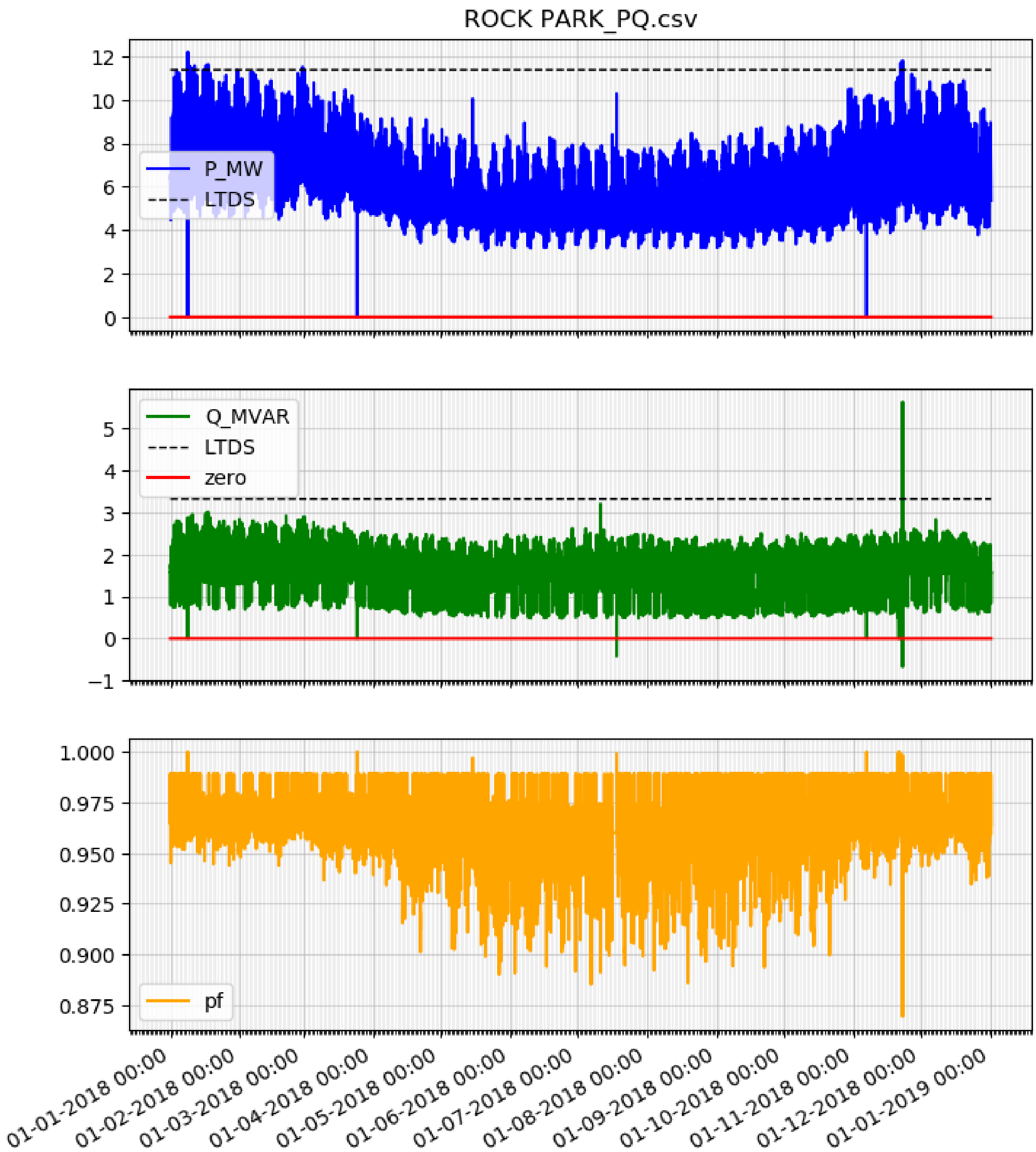
LYNTON


Real & Reactive Power calculated from:
LYNTON > 11kV > T2 Busbar > CB 72 > 11kV Current
LYNTON > 11kV > T2 Busbar > CB 72 > VT 2 & Isolator > VT 2
LTDS
0
1
2
3
LTDS
0.0
0.2
0.4
0.6
0.8
1.0
pf calc
LTDS
0.92
0.94
0.96
0.98
1.00
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

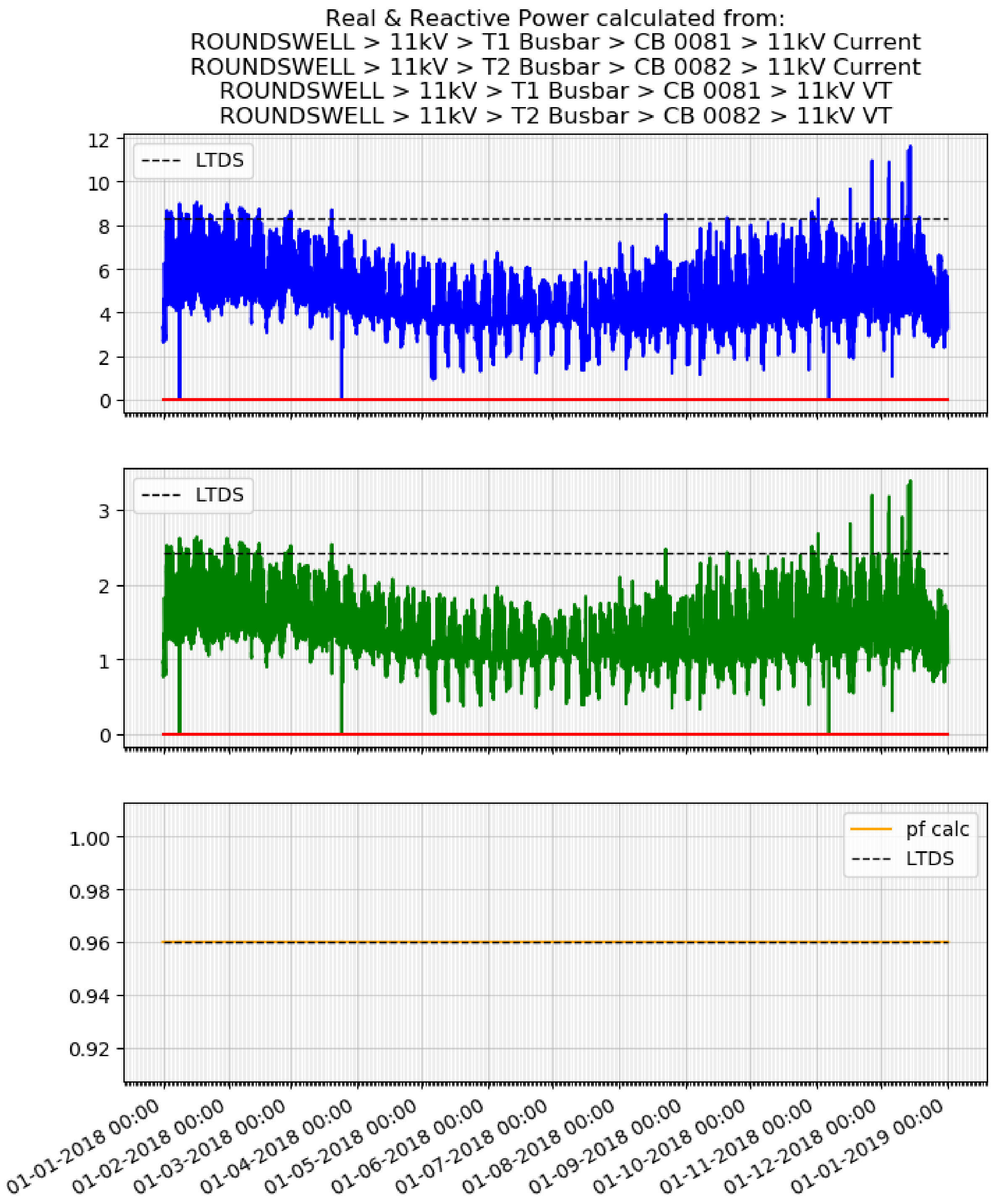
MIDDLE BARLINGTON



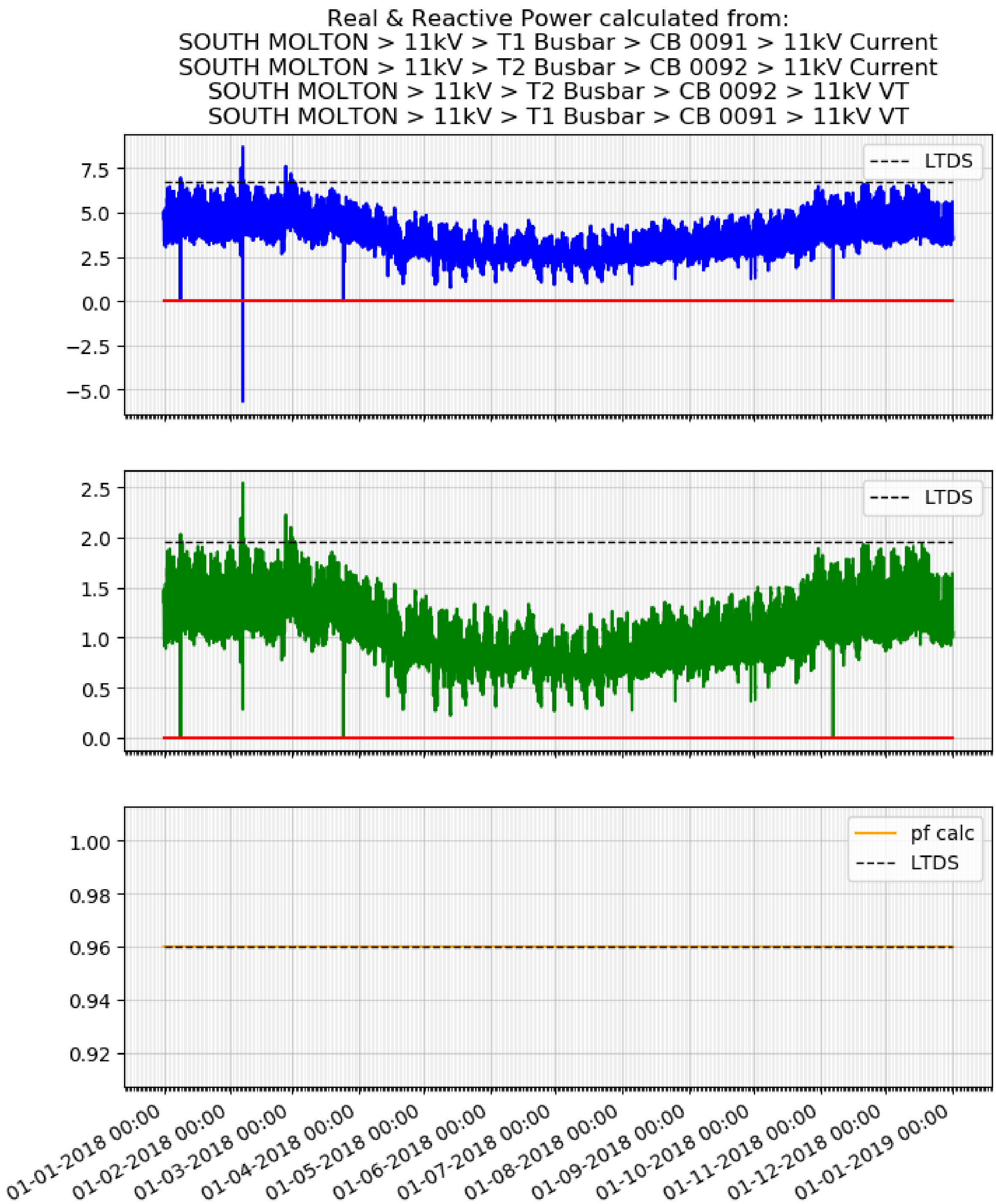
ROCK PARK


ROCK PARK_PQ.csv
12
10
8
6
4
2
0
P_MW
LTDS
5
4
3
2
1
0
−1
Q_MVAR
LTDS
zero
1.000
0.975
0.950
0.925
0.900
0.875
pf
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

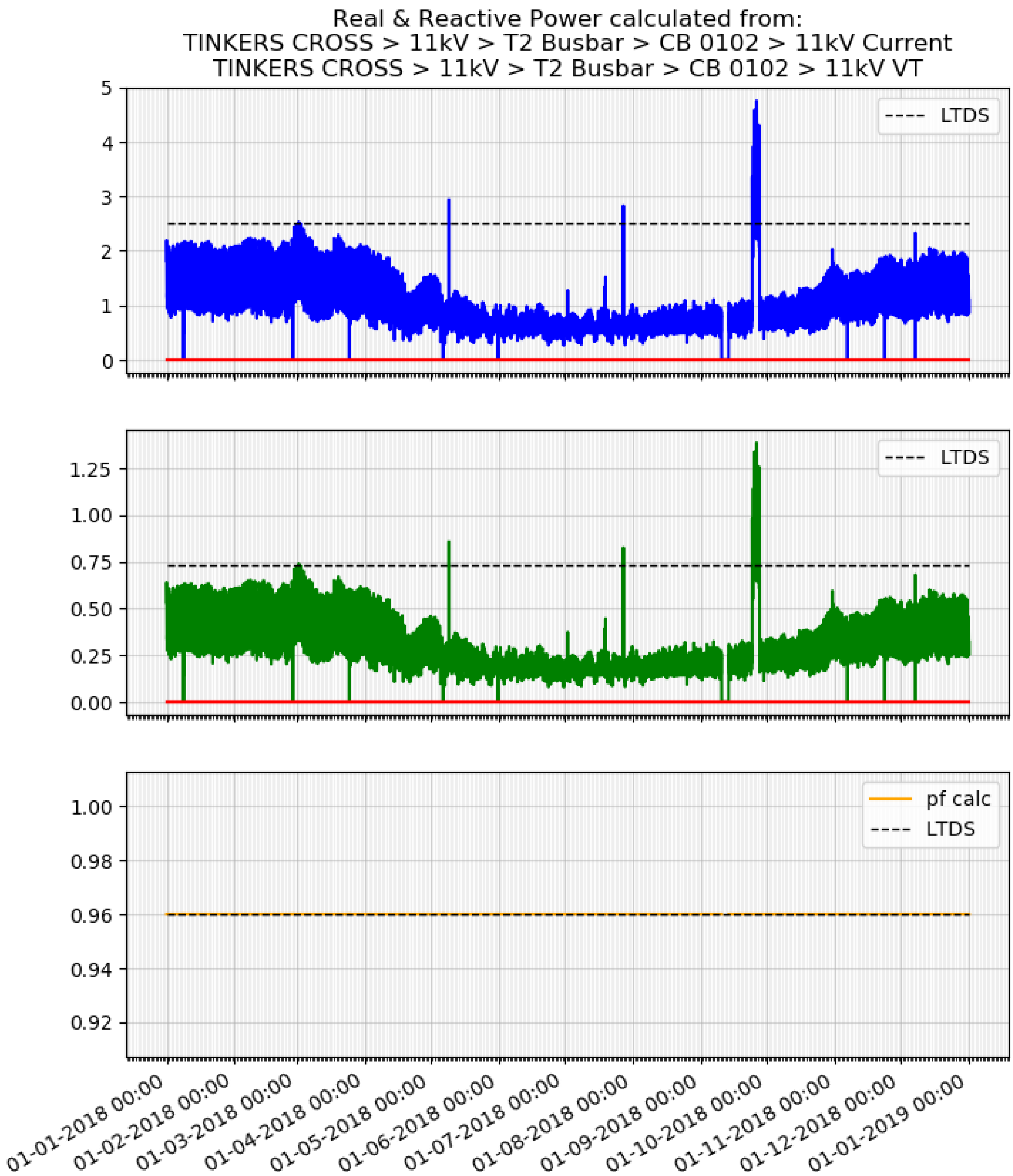
ROUNDSWELL


Real & Reactive Power calculated from:
ROUNDSWELL > 11kV > T1 Busbar > CB 0081 > 11kV Current
ROUNDSWELL > 11kV > T2 Busbar > CB 0082 > 11kV Current
ROUNDSWELL > 11kV > T1 Busbar > CB 0081 > 11kV VT
ROUNDSWELL > 11kV > T2 Busbar > CB 0082 > 11kV VT
LTDS
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

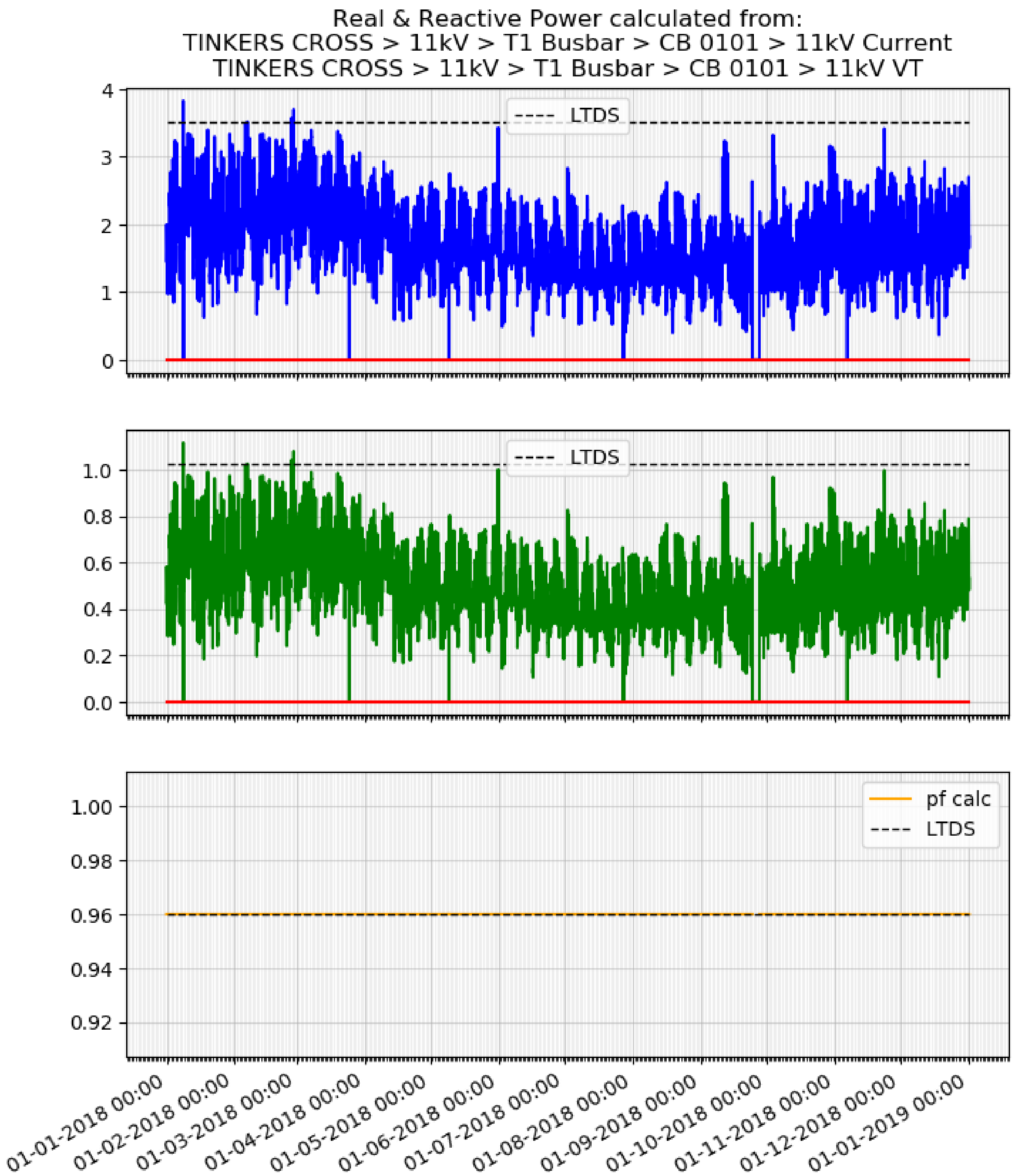
SOUTH MOLTON



TINKERS CROSS

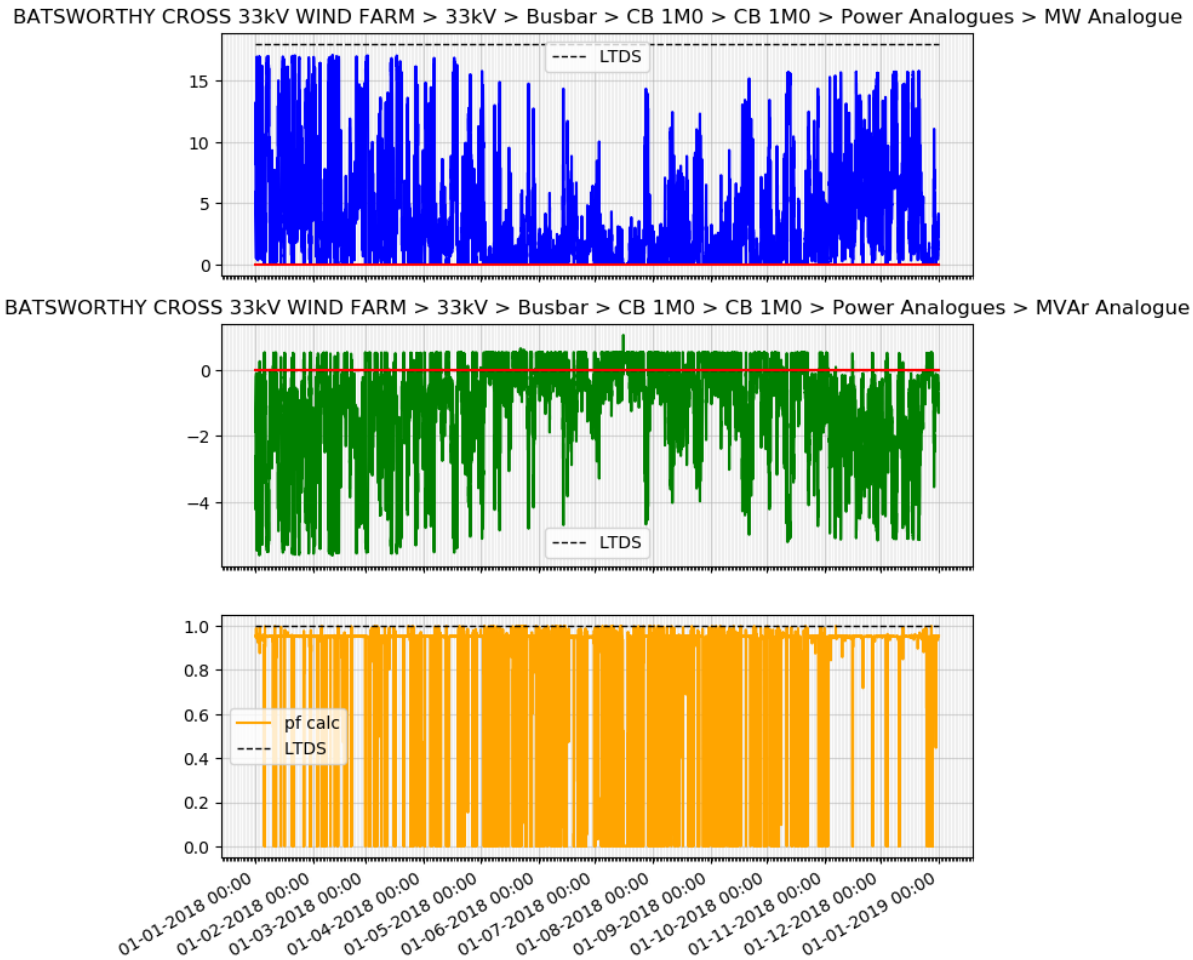


TINKERS CROSSK

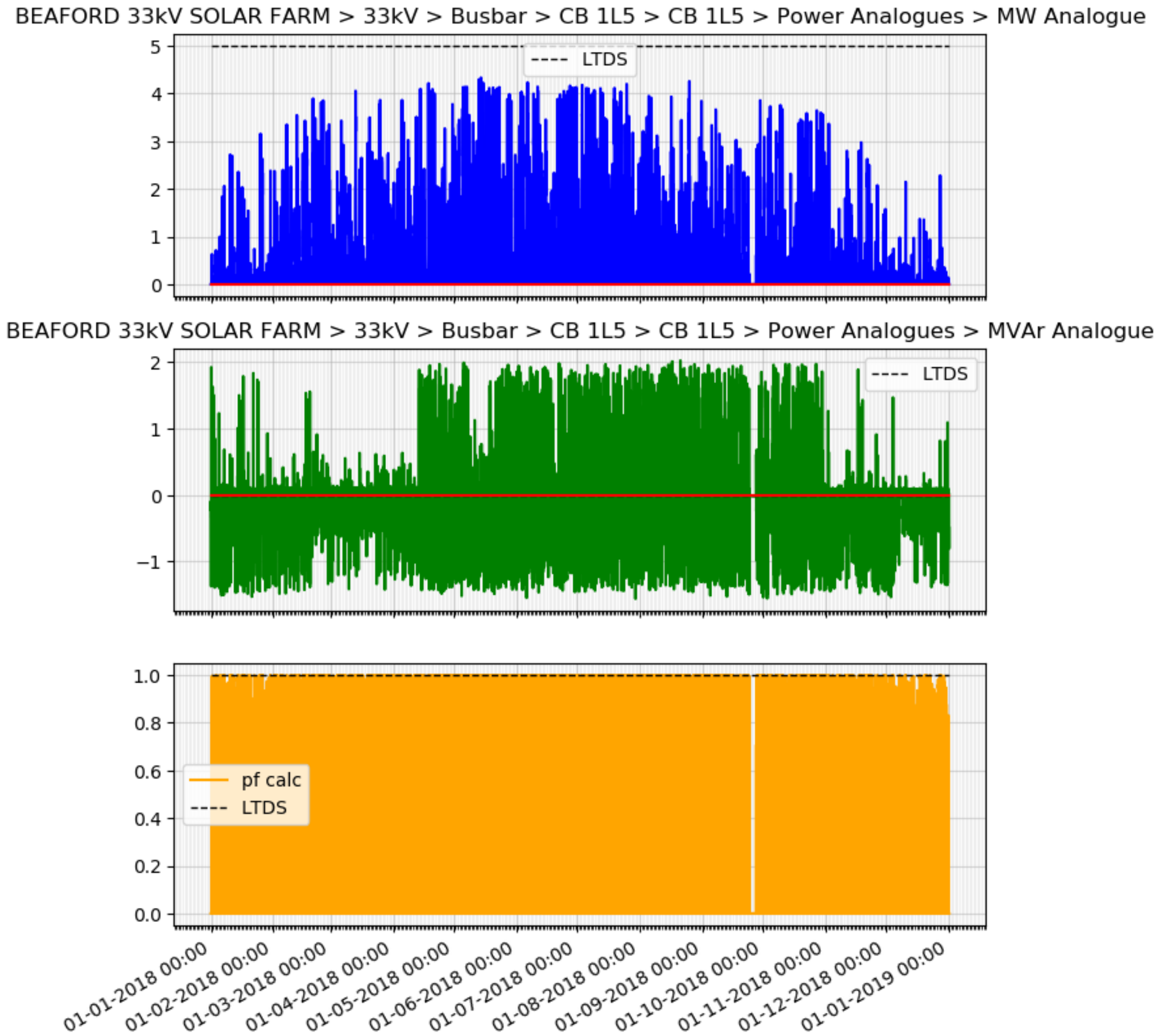


Barnstaple Generation

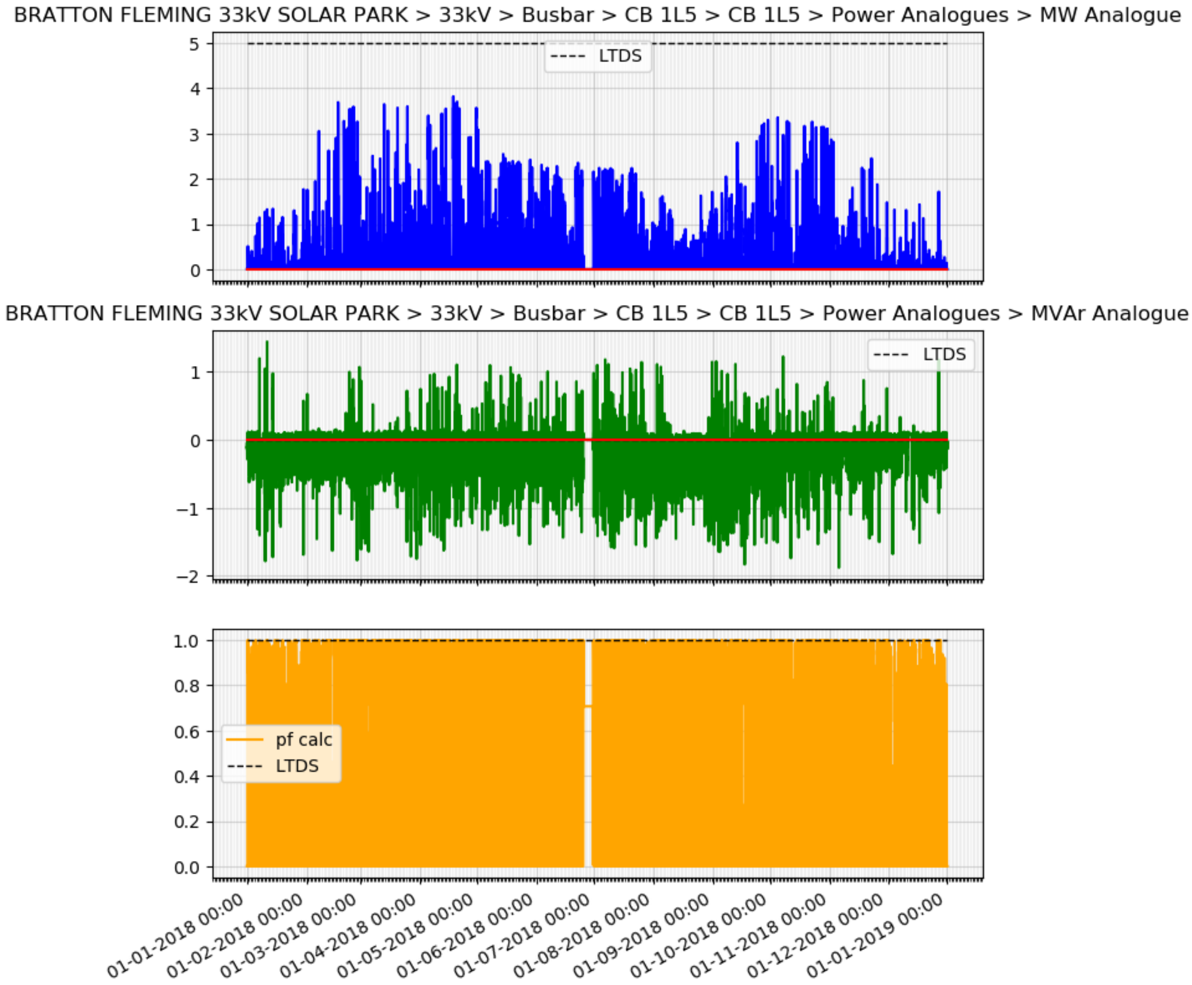
BATSWORTHY CROSS 33kV WIND FARM



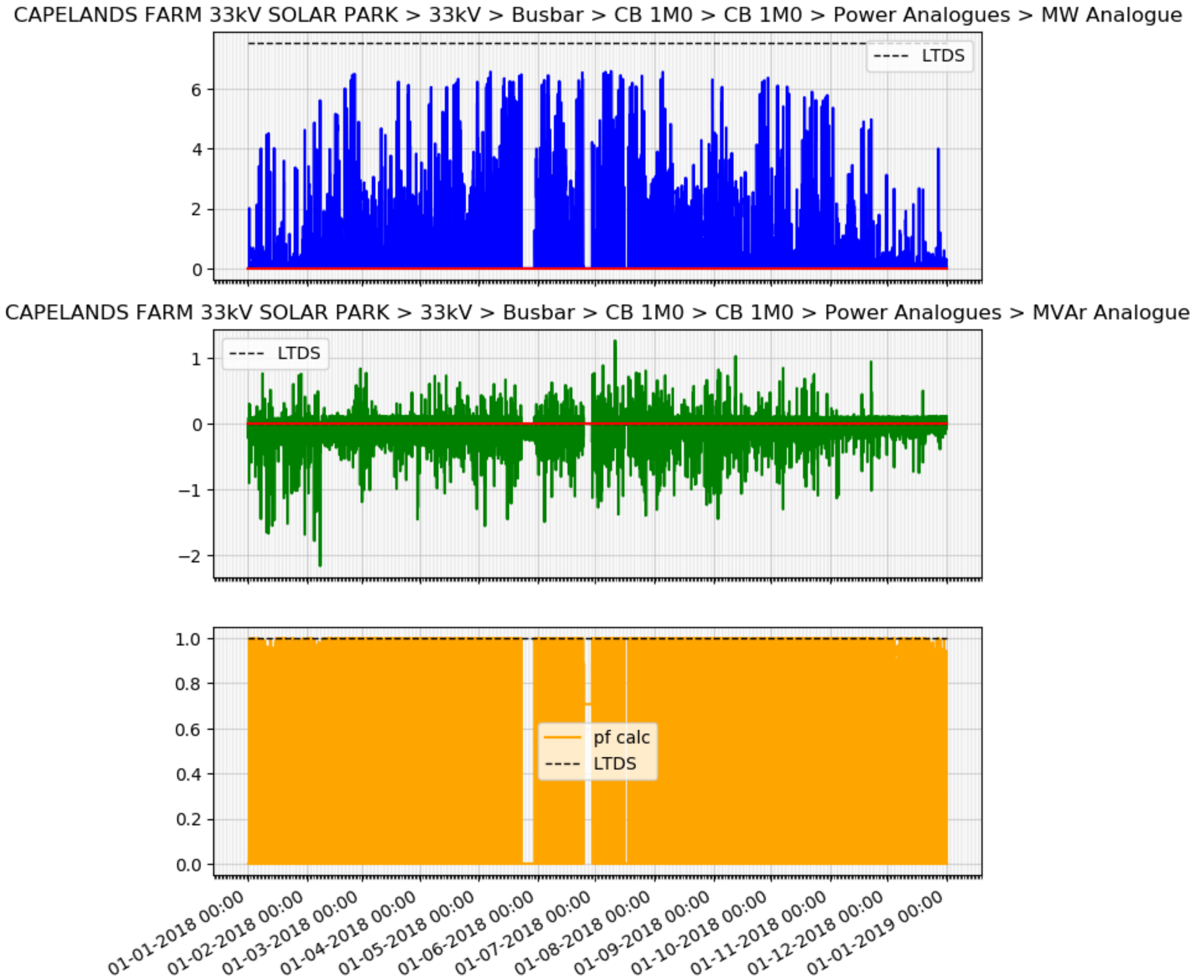
BEAFORD 33kV SOLAR FARM



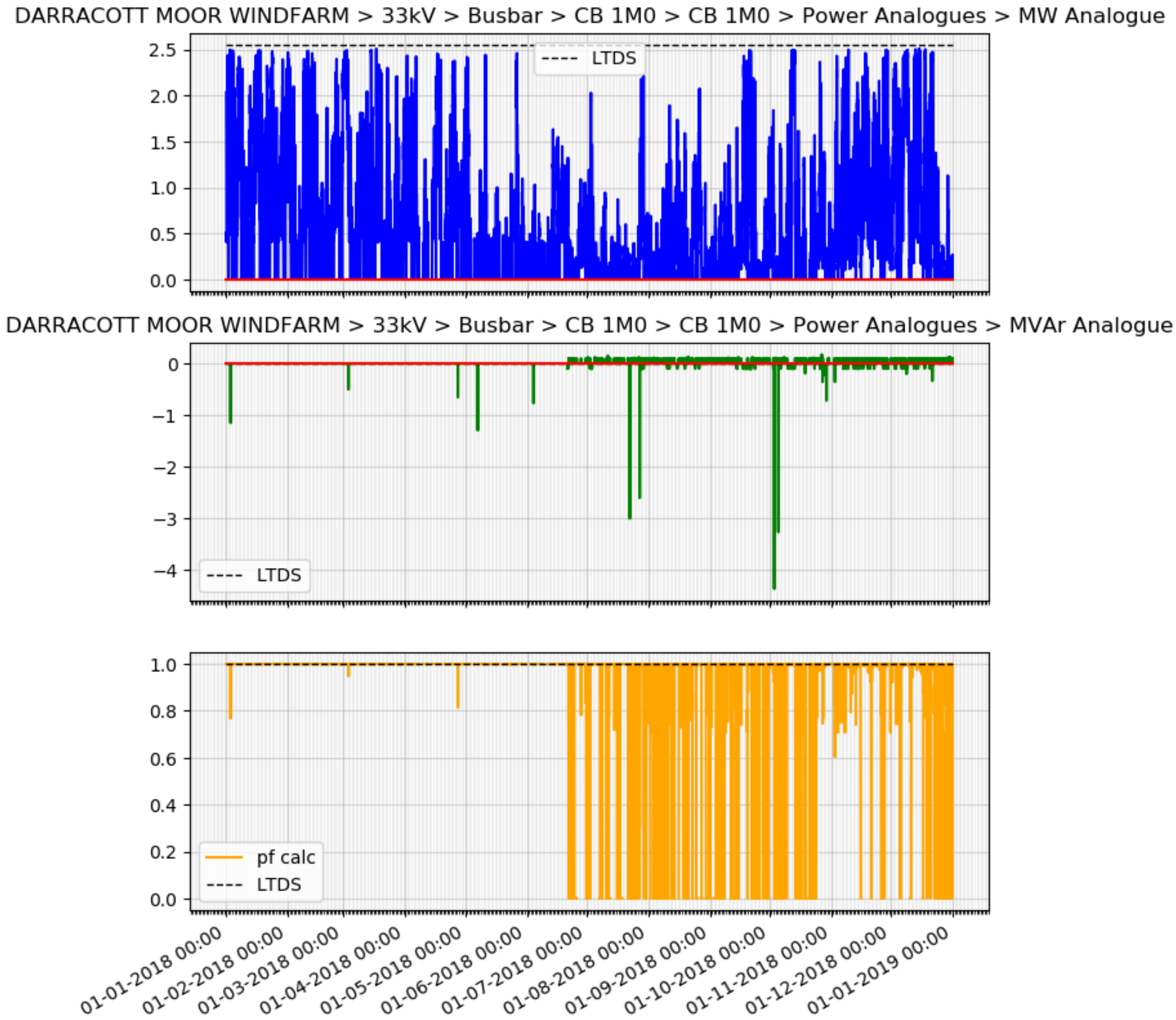
BRATTON FLEMING 33kV SOLAR PARK



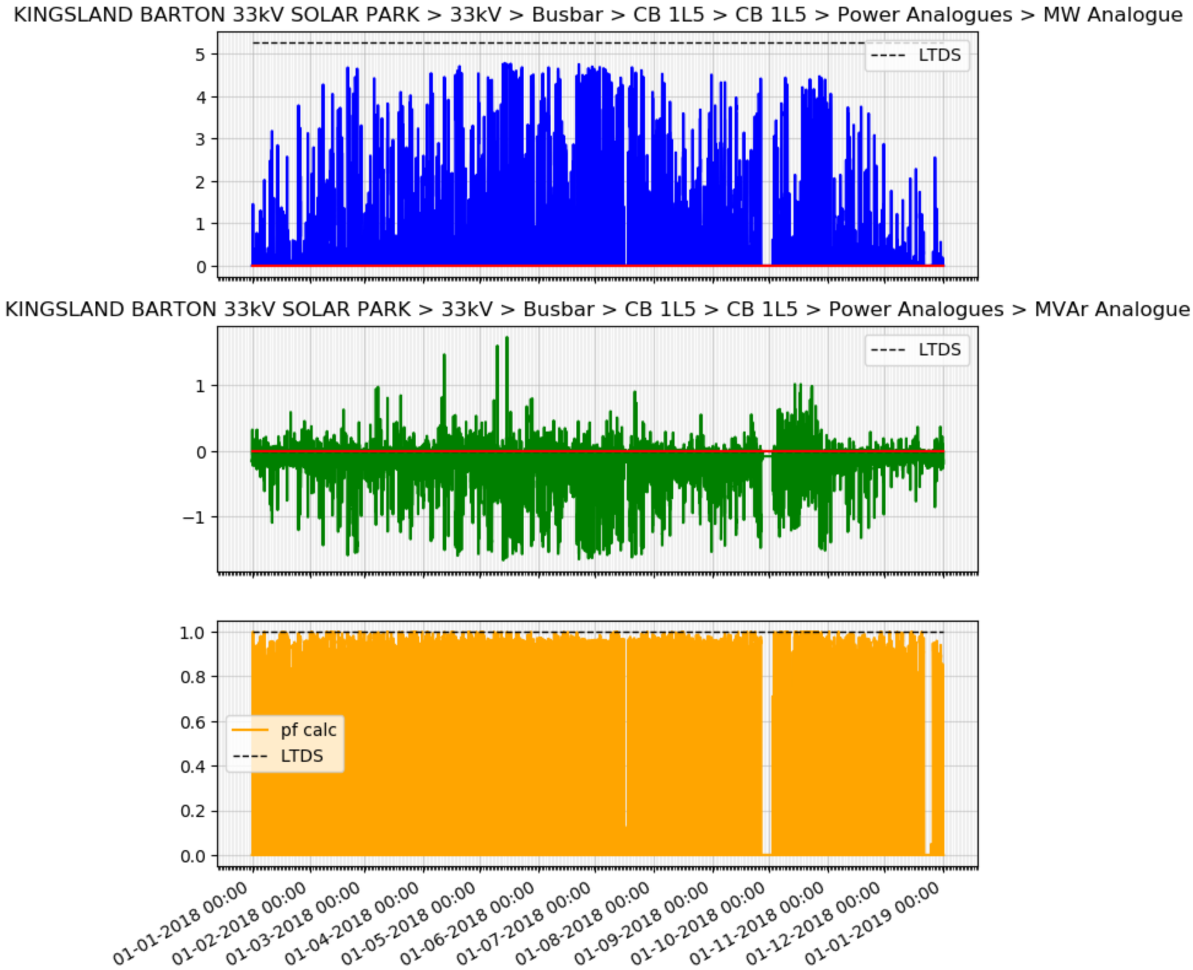
CAPELANDS FARM 33kV SOLAR PARK



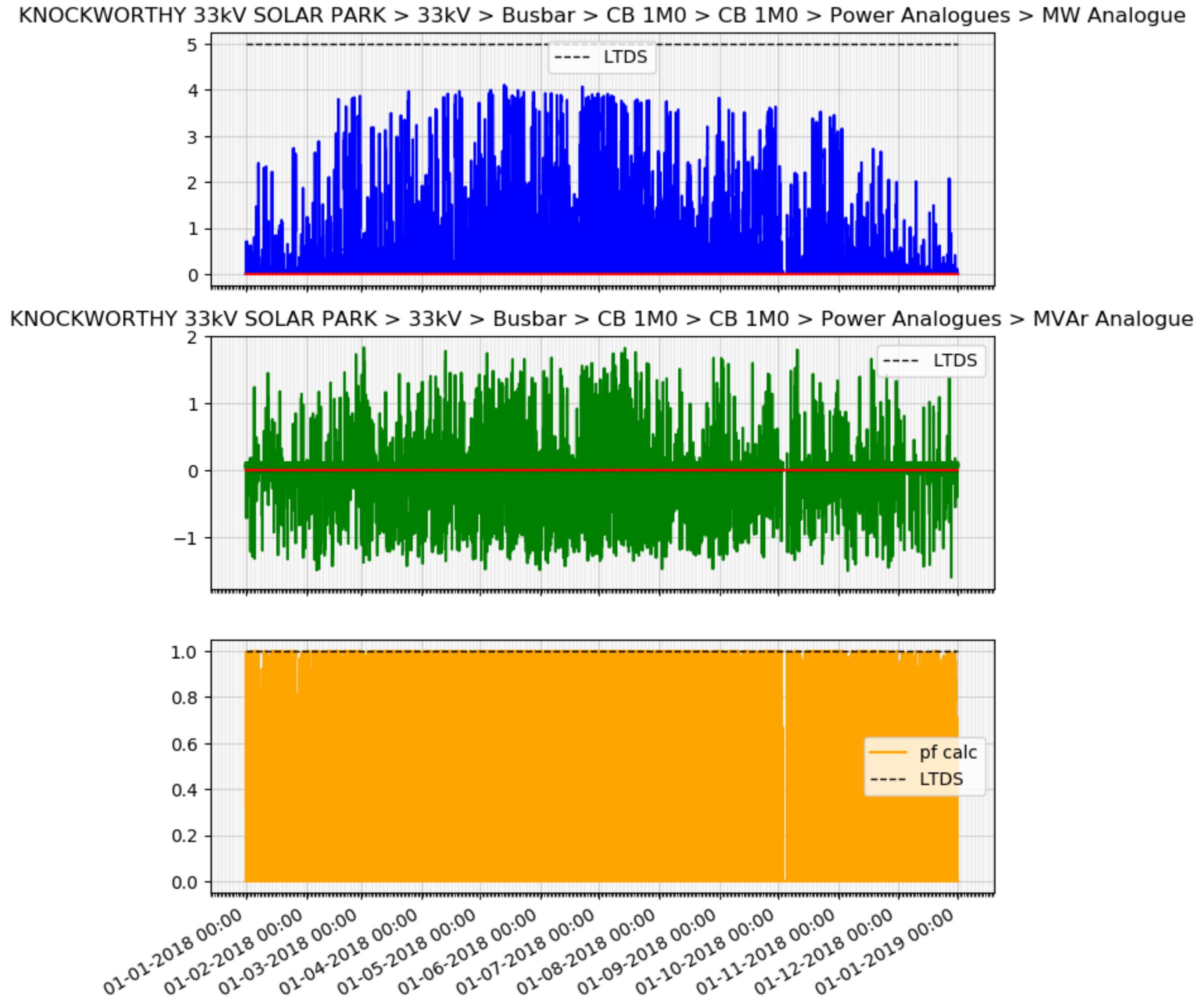
DARRACOTT MOOR WINDFARM



KINGSLAND BARTON 33kV SOLAR PARK

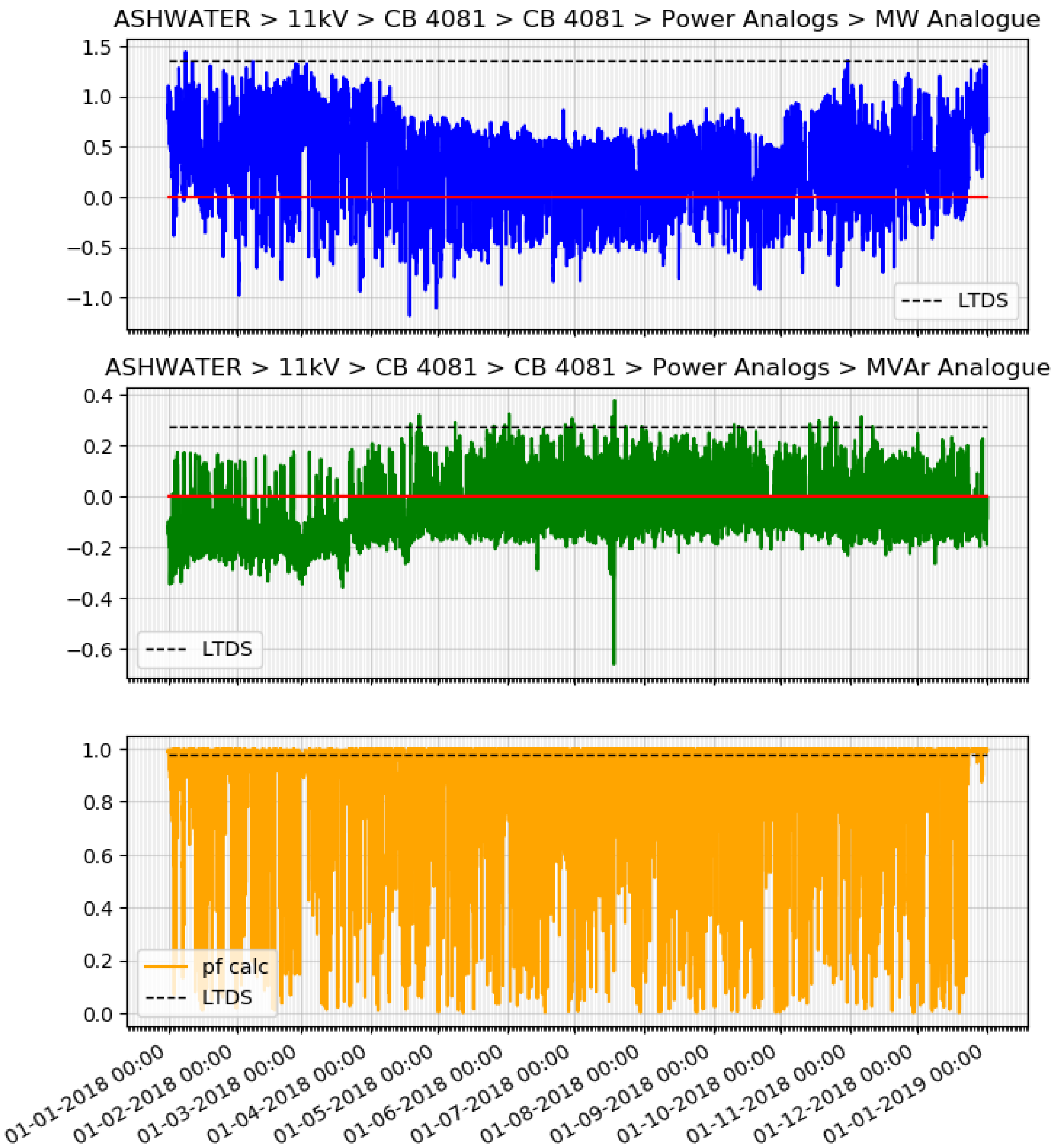


KNOCKWORTHY 33kV SOLAR PARK

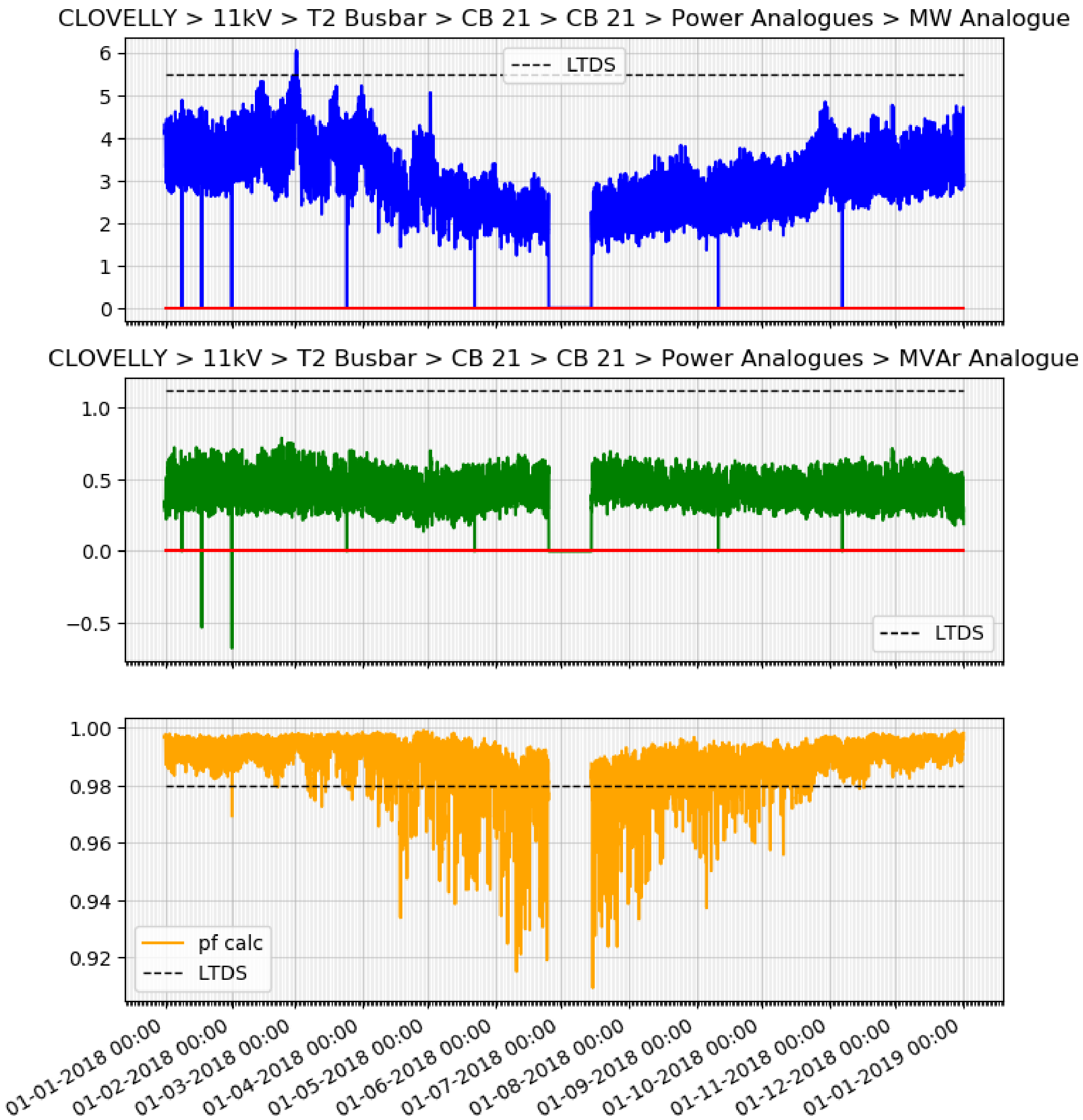


Pyworthy Load

ASHWATER

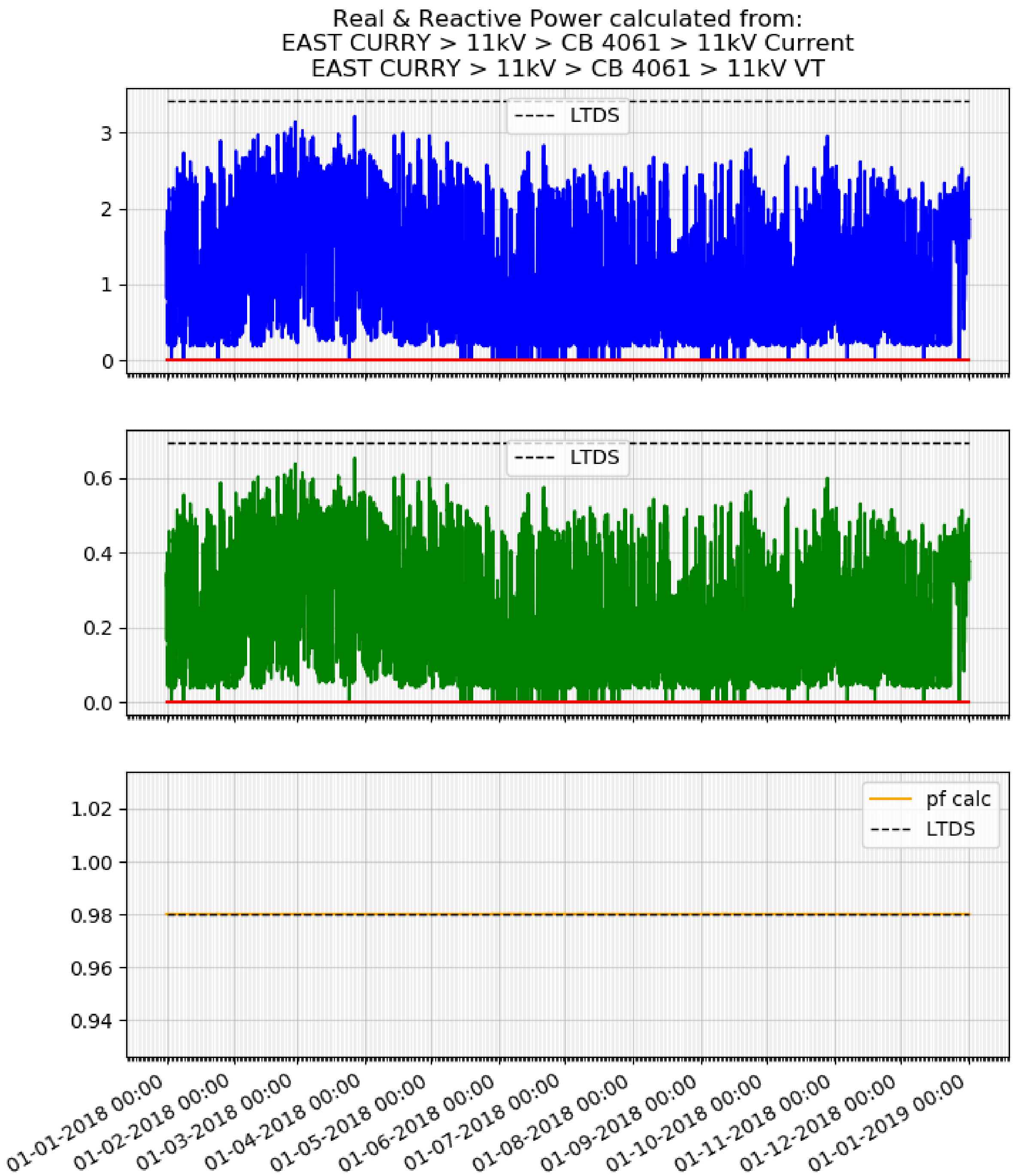


CLOVELLY

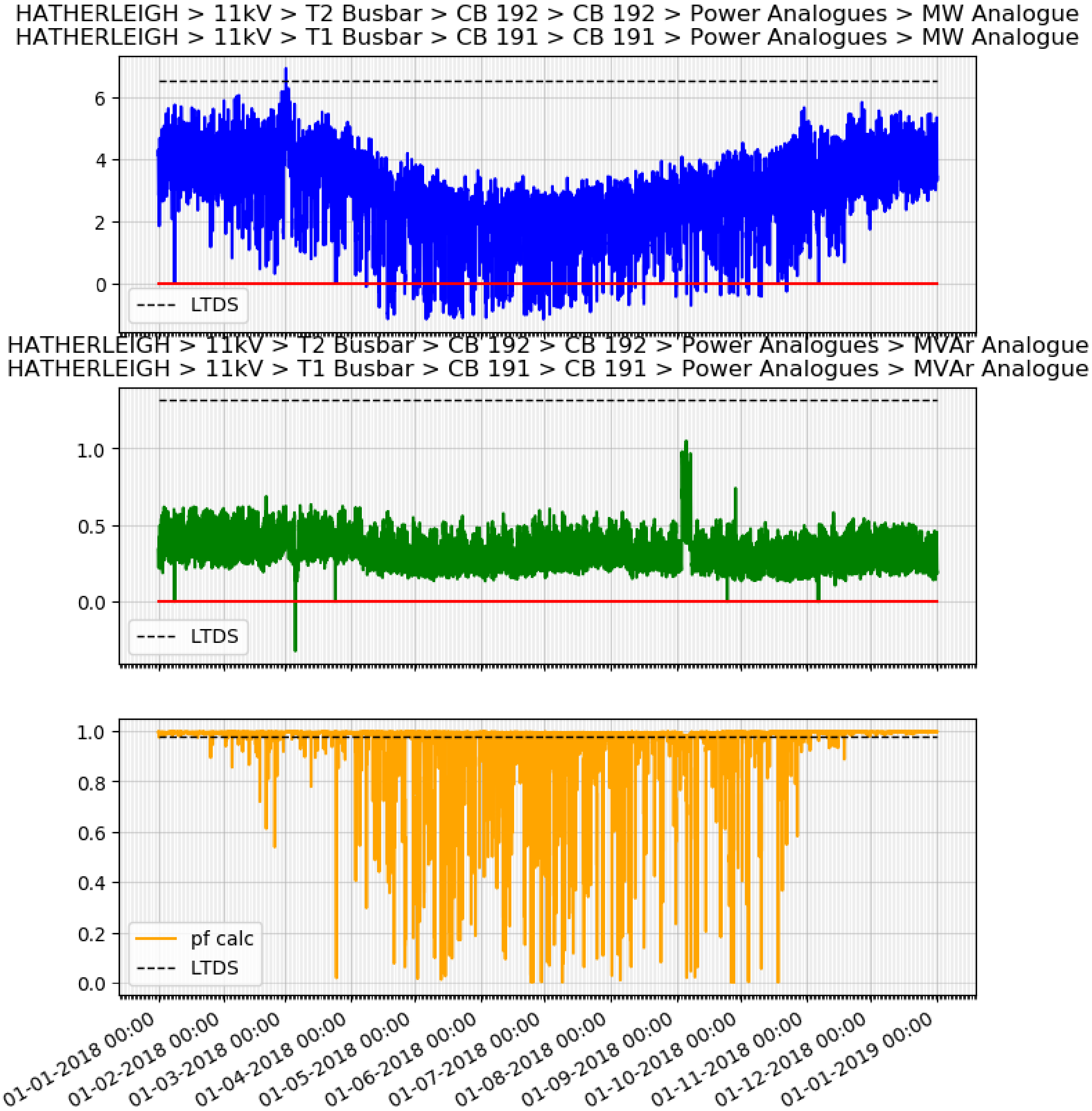


CLOVELLY > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MW Analogue
LTDS
6
5
4
3
2
1
0
CLOVELLY > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MVAr Analogue
1.0
0.5
0.0
−0.5
LTDS
1.00
0.98
0.96
0.94
0.92
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

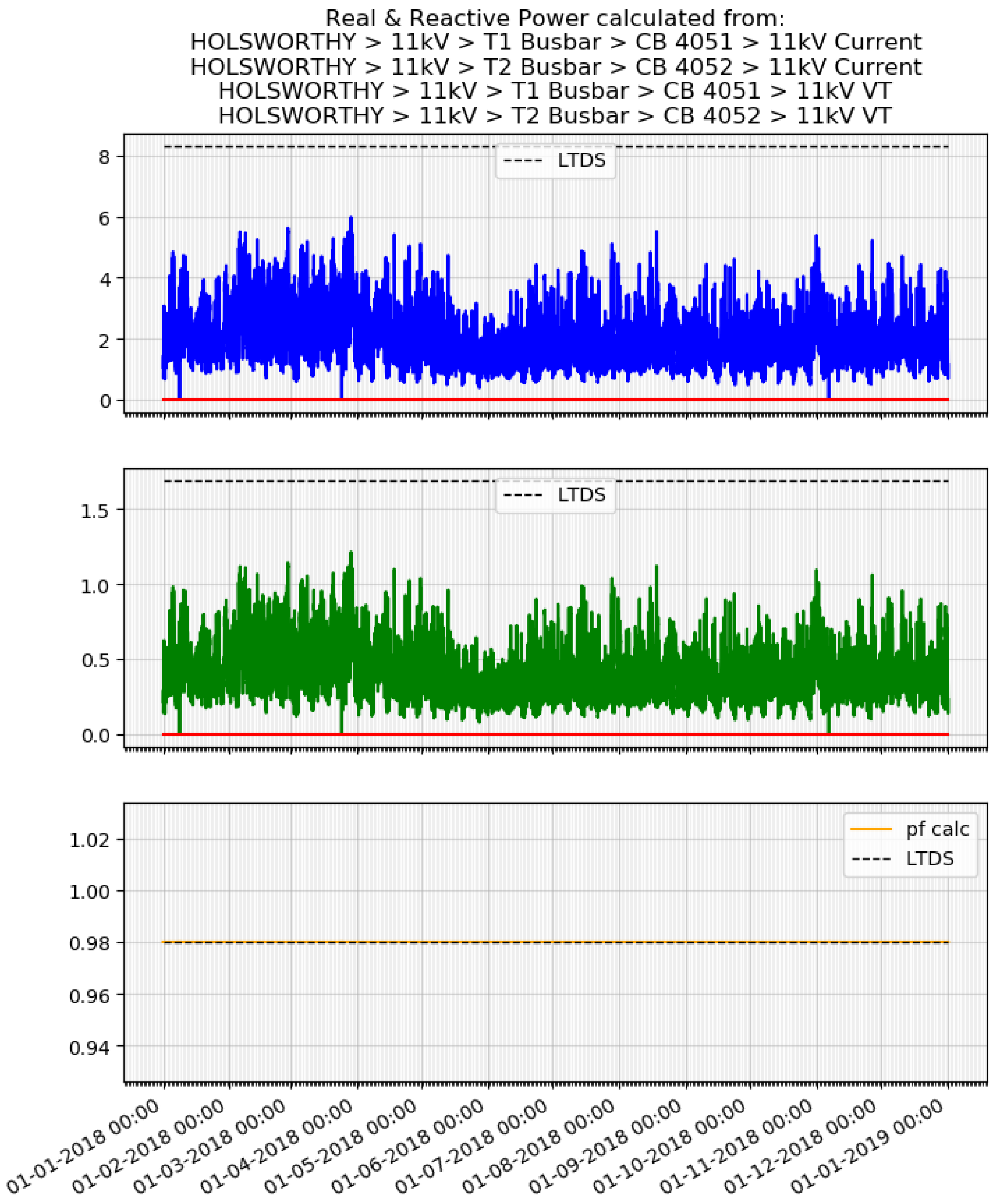
EAST CURRY


Real & Reactive Power calculated from:
EAST CURRY > 11kV > CB 4061 > 11kV Current
EAST CURRY > 11kV > CB 4061 > 11kV VT
LTDS
3
2
1
0
LTDS
0.6
0.4
0.2
0.0
pf calc
LTDS
1.02
1.00
0.98
0.96
0.94
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

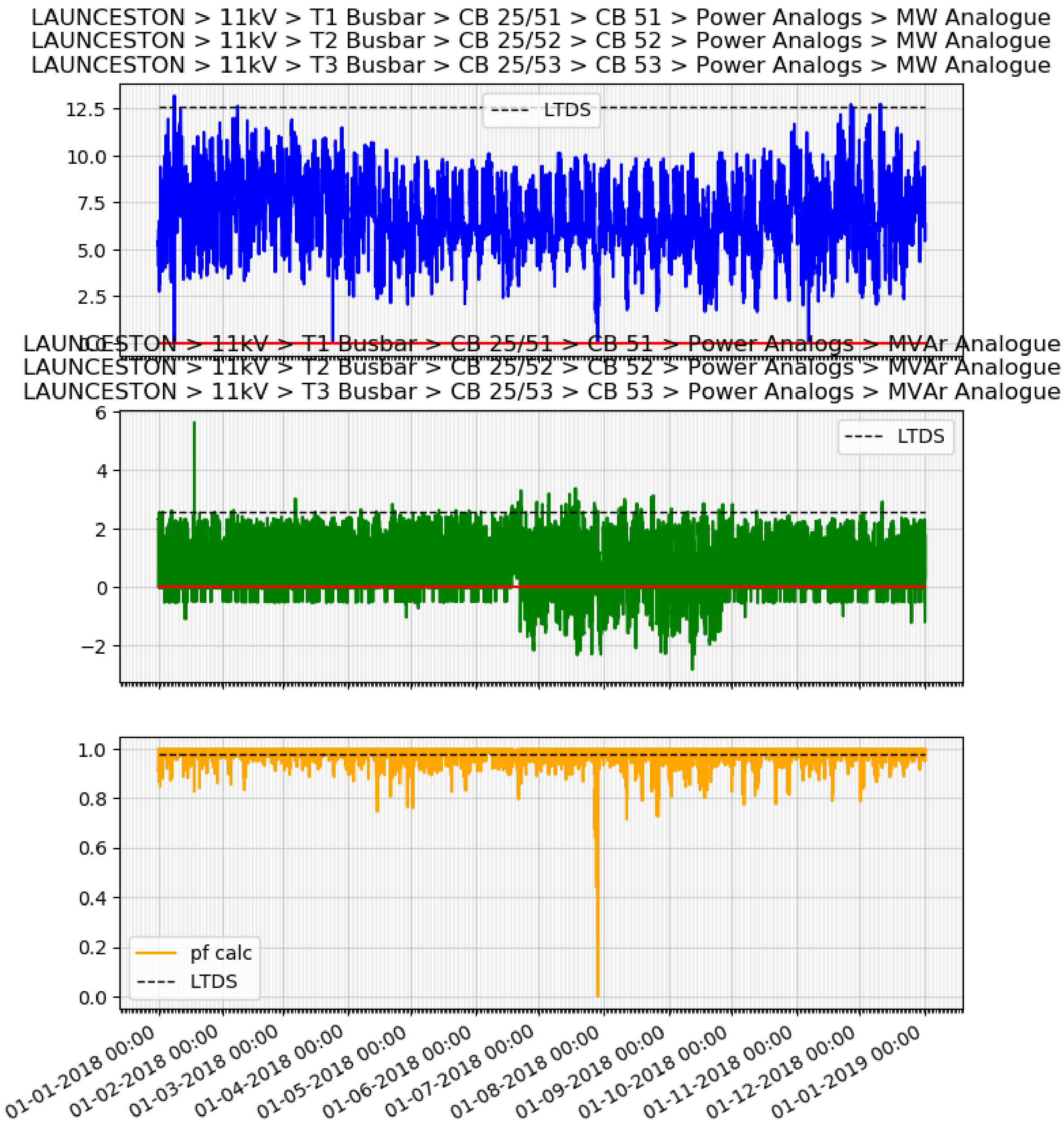
HATHERLEIGH



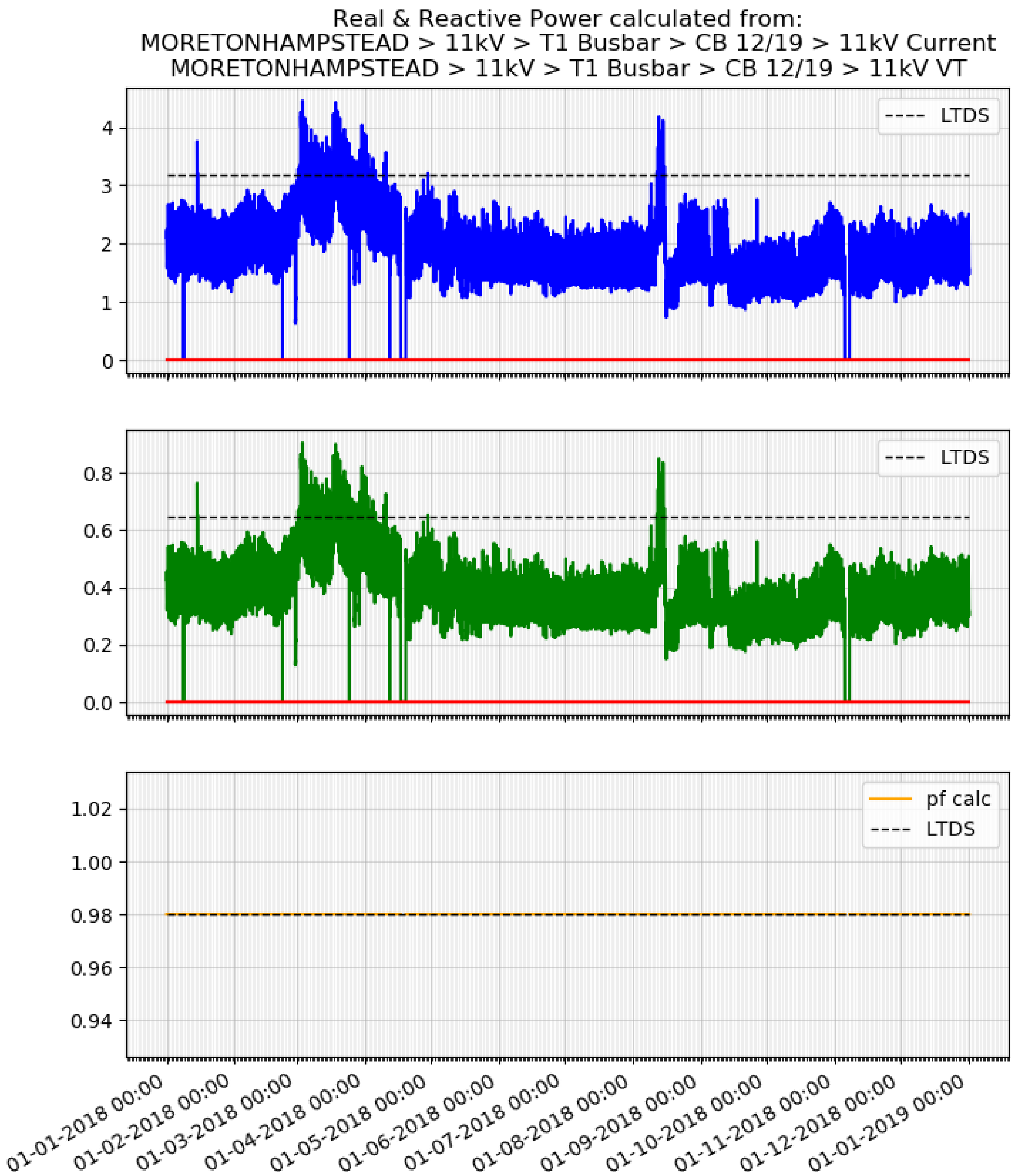
HOLSWORTHY


Real & Reactive Power calculated from:
HOLSWORTHY > 11kV > T1 Busbar > CB 4051 > 11kV Current
HOLSWORTHY > 11kV > T2 Busbar > CB 4052 > 11kV Current
HOLSWORTHY > 11kV > T1 Busbar > CB 4051 > 11kV VT
HOLSWORTHY > 11kV > T2 Busbar > CB 4052 > 11kV VT
LTDS
LTDS
pf calc
LTDS
0
2
4
6
8
0.0
0.5
1.0
1.5
0.94
0.96
0.98
1.00
1.02
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

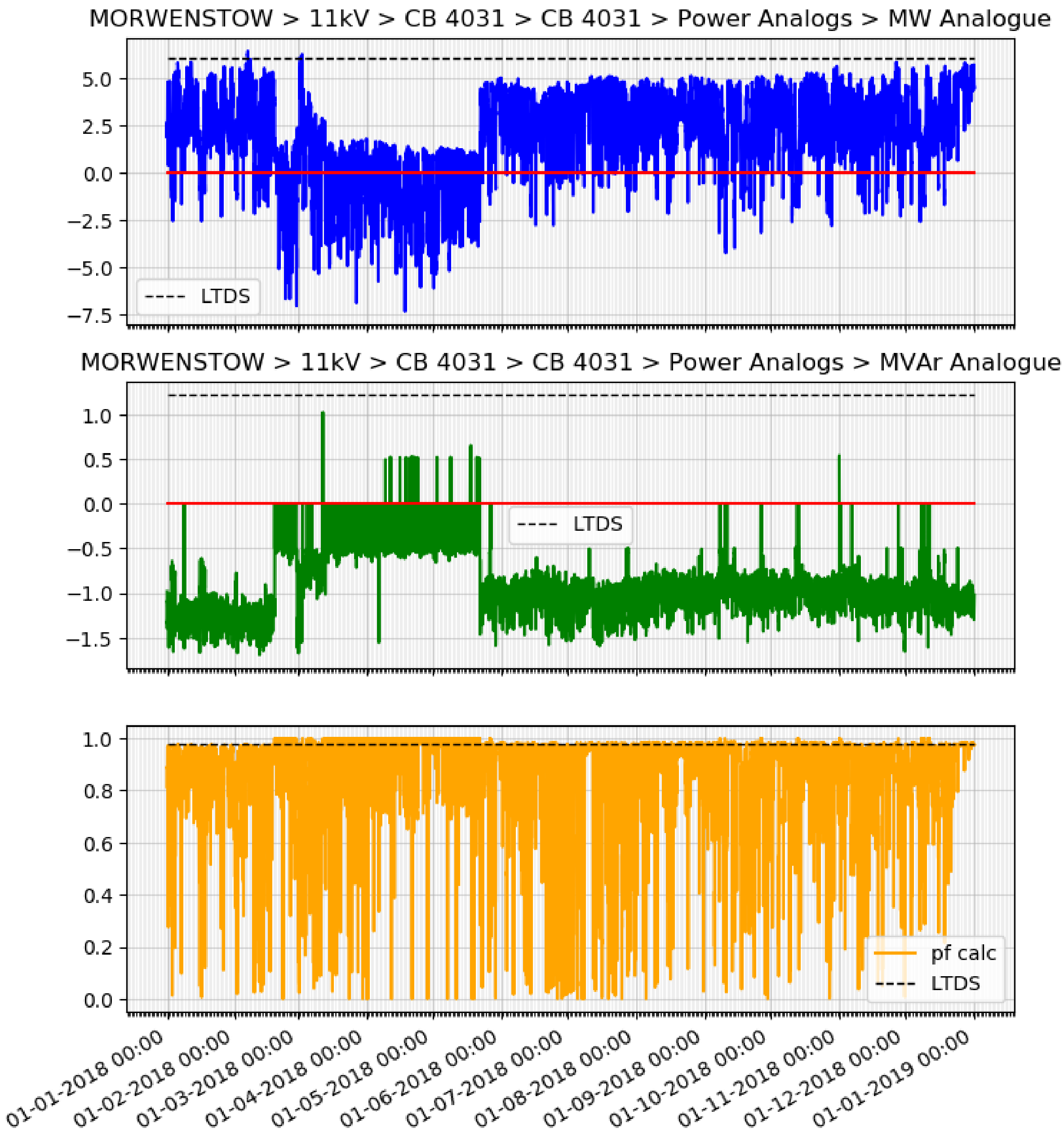
LAUNCESTON


LAUNCESTON > 11kV > T1 Busbar > CB 25/51 > CB 51 > Power Analogs > MW Analogue
LAUNCESTON > 11kV > T2 Busbar > CB 25/52 > CB 52 > Power Analogs > MW Analogue
LAUNCESTON > 11kV > T3 Busbar > CB 25/53 > CB 53 > Power Analogs > MW Analogue
LTDS
12.5
10.0
7.5
5.0
2.5
LAUNCESTON > 11kV > T1 Busbar > CB 25/51 > CB 51 > Power Analogs > MVAr Analogue
LAUNCESTON > 11kV > T2 Busbar > CB 25/52 > CB 52 > Power Analogs > MVAr Analogue
LAUNCESTON > 11kV > T3 Busbar > CB 25/53 > CB 53 > Power Analogs > MVAr Analogue
LTDS
6
4
2
0
−2
1.0
0.8
0.6
0.4
0.2
0.0
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

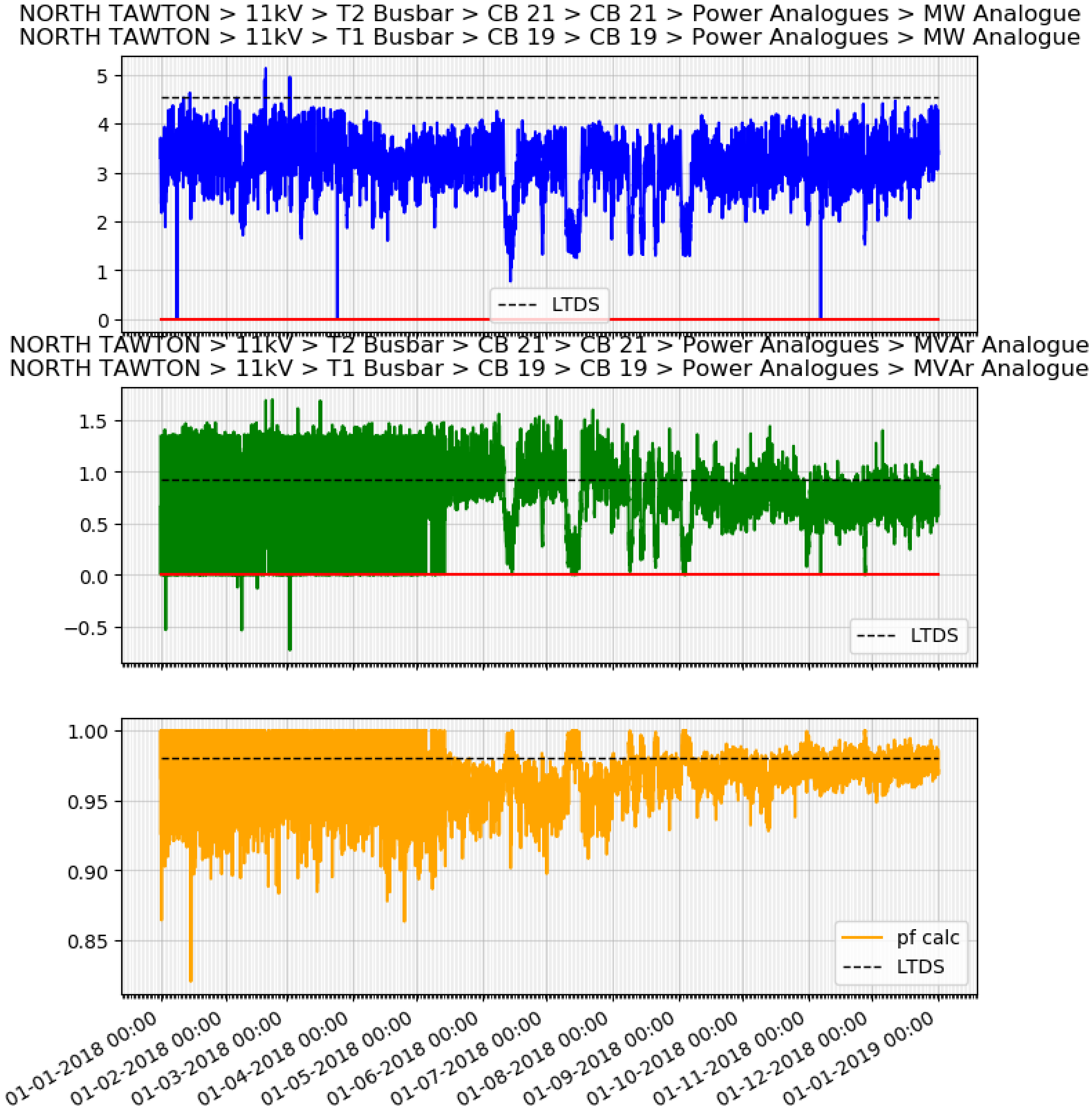
MORETONHAMPSTEAD



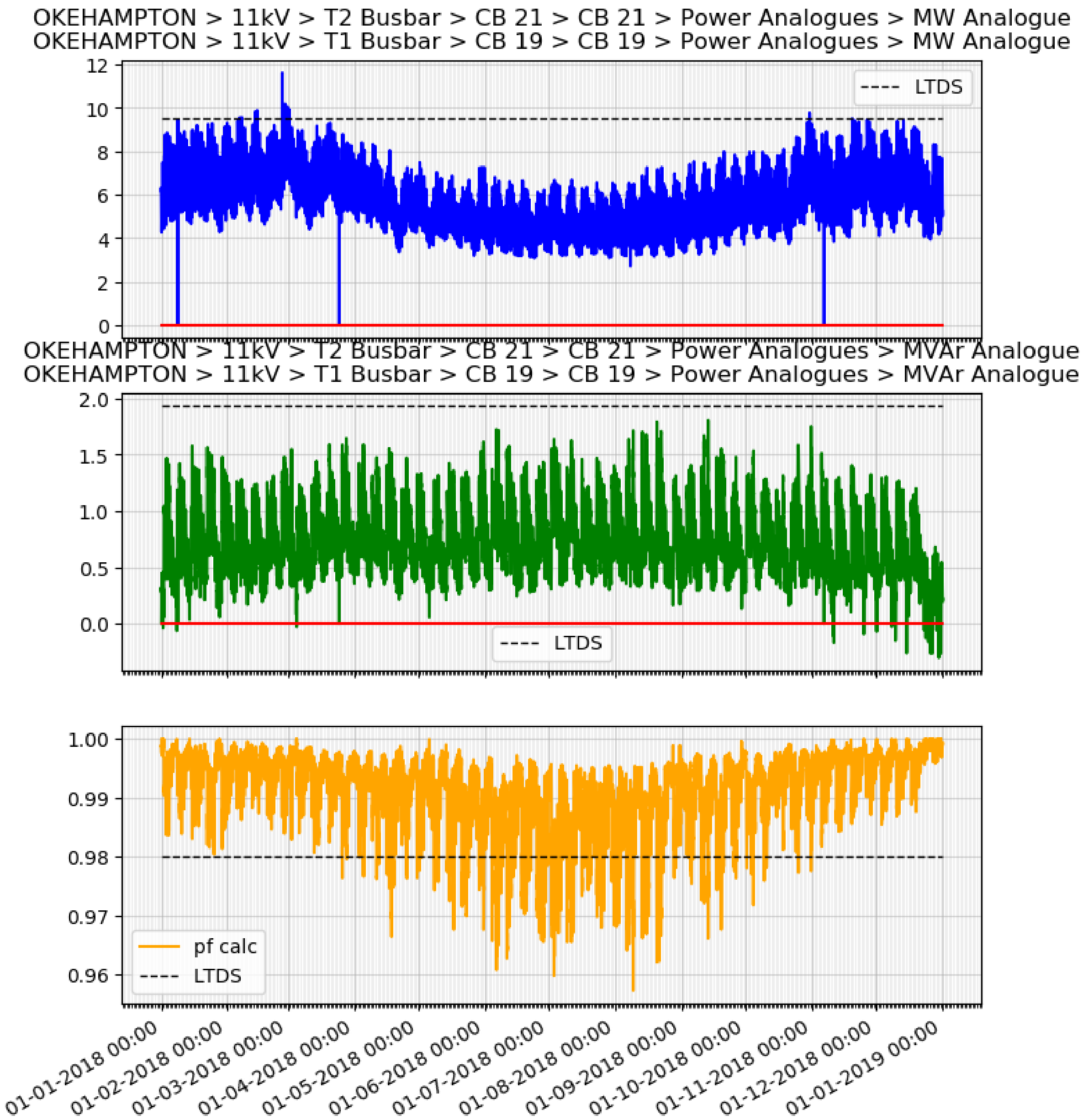
MORWENSTOW


MORWENSTOW > 11kV > CB 4031 > CB 4031 > Power Analogs > MW Analogue
LTDS
MORWENSTOW > 11kV > CB 4031 > CB 4031 > Power Analogs > MVAr Analogue
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

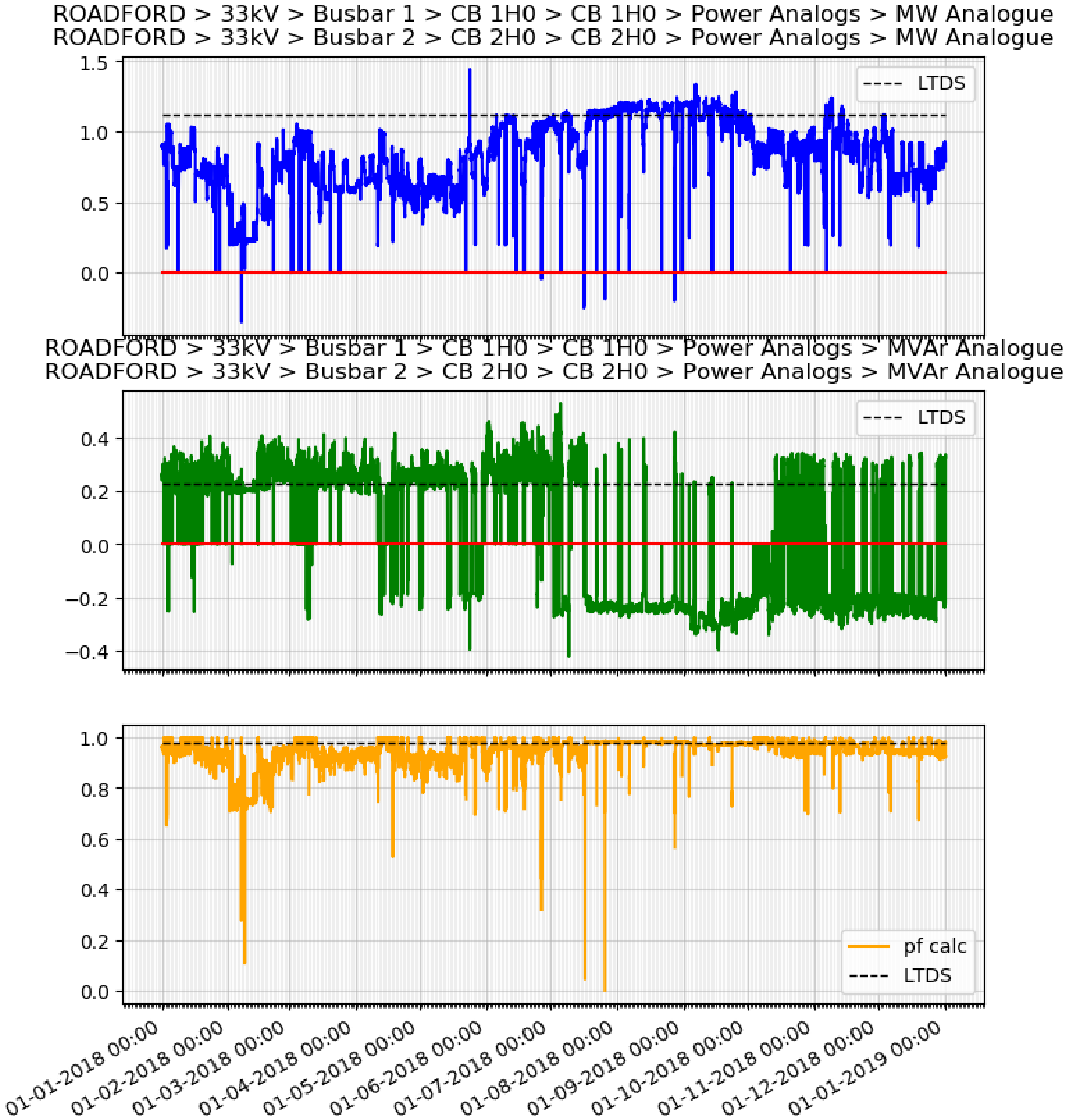
NORTH TAWTON



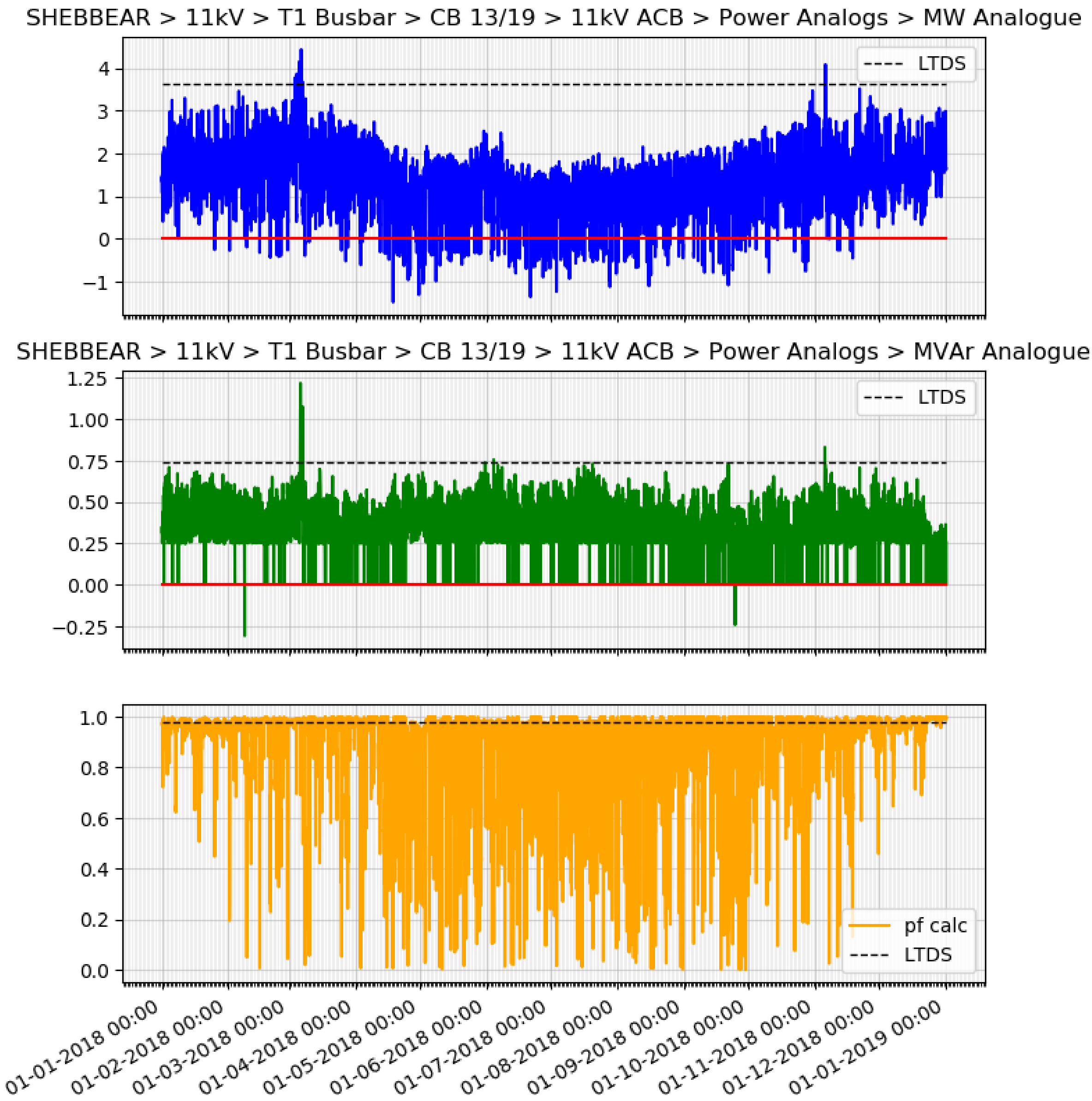
OKEHAMPTON


OKEHAMPTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MW Analogue
OKEHAMPTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MW Analogue
LTDS
OKEHAMPTON > 11kV > T2 Busbar > CB 21 > CB 21 > Power Analogues > MVAr Analogue
OKEHAMPTON > 11kV > T1 Busbar > CB 19 > CB 19 > Power Analogues > MVAr Analogue
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

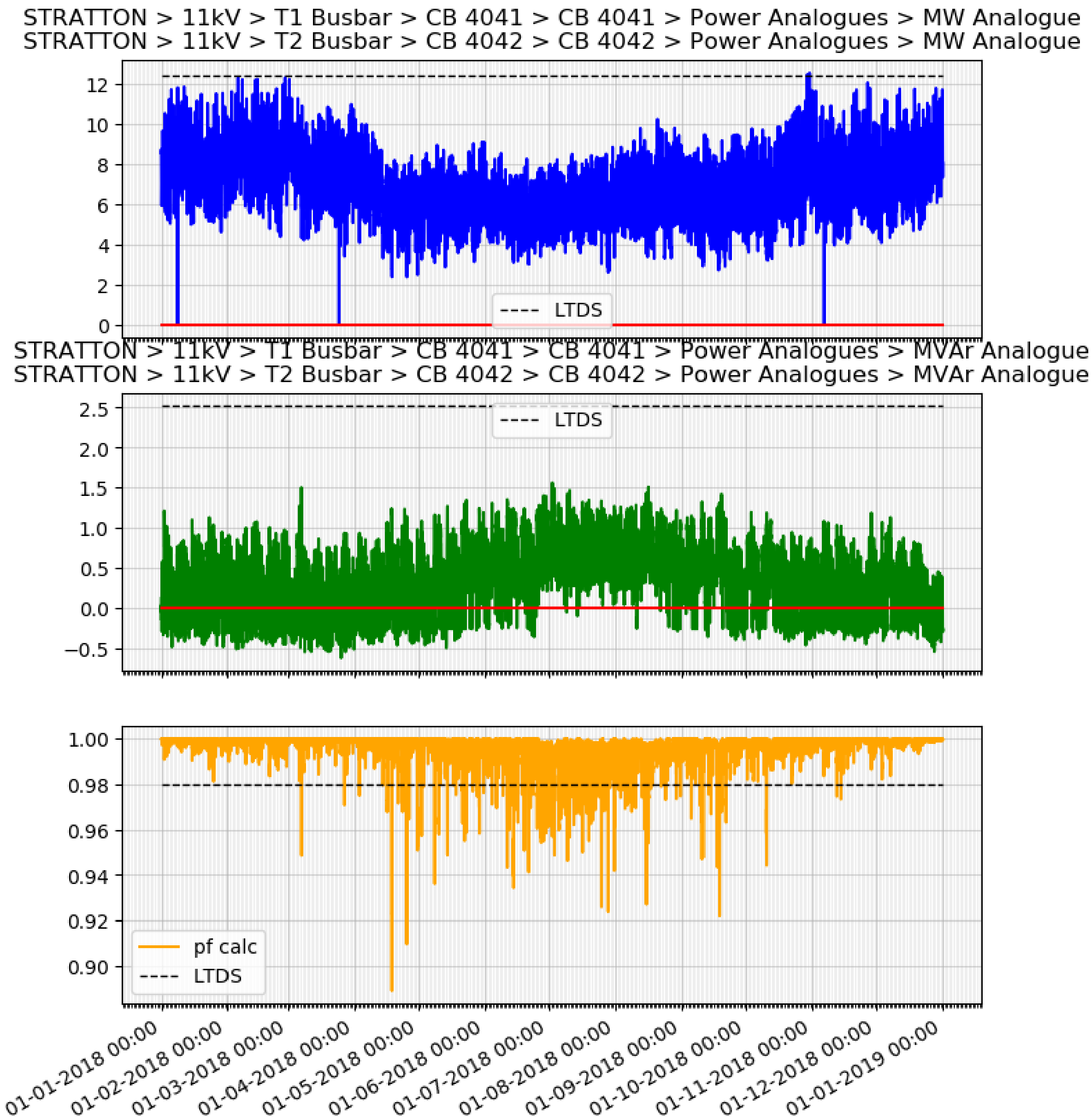
ROADFORD


ROADFORD > 33kV > Busbar 1 > CB 1H0 > CB 1H0 > Power Analogs > MW Analogue
ROADFORD > 33kV > Busbar 2 > CB 2H0 > CB 2H0 > Power Analogs > MW Analogue
LTDS
ROADFORD > 33kV > Busbar 1 > CB 1H0 > CB 1H0 > Power Analogs > MVAr Analogue
ROADFORD > 33kV > Busbar 2 > CB 2H0 > CB 2H0 > Power Analogs > MVAr Analogue
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

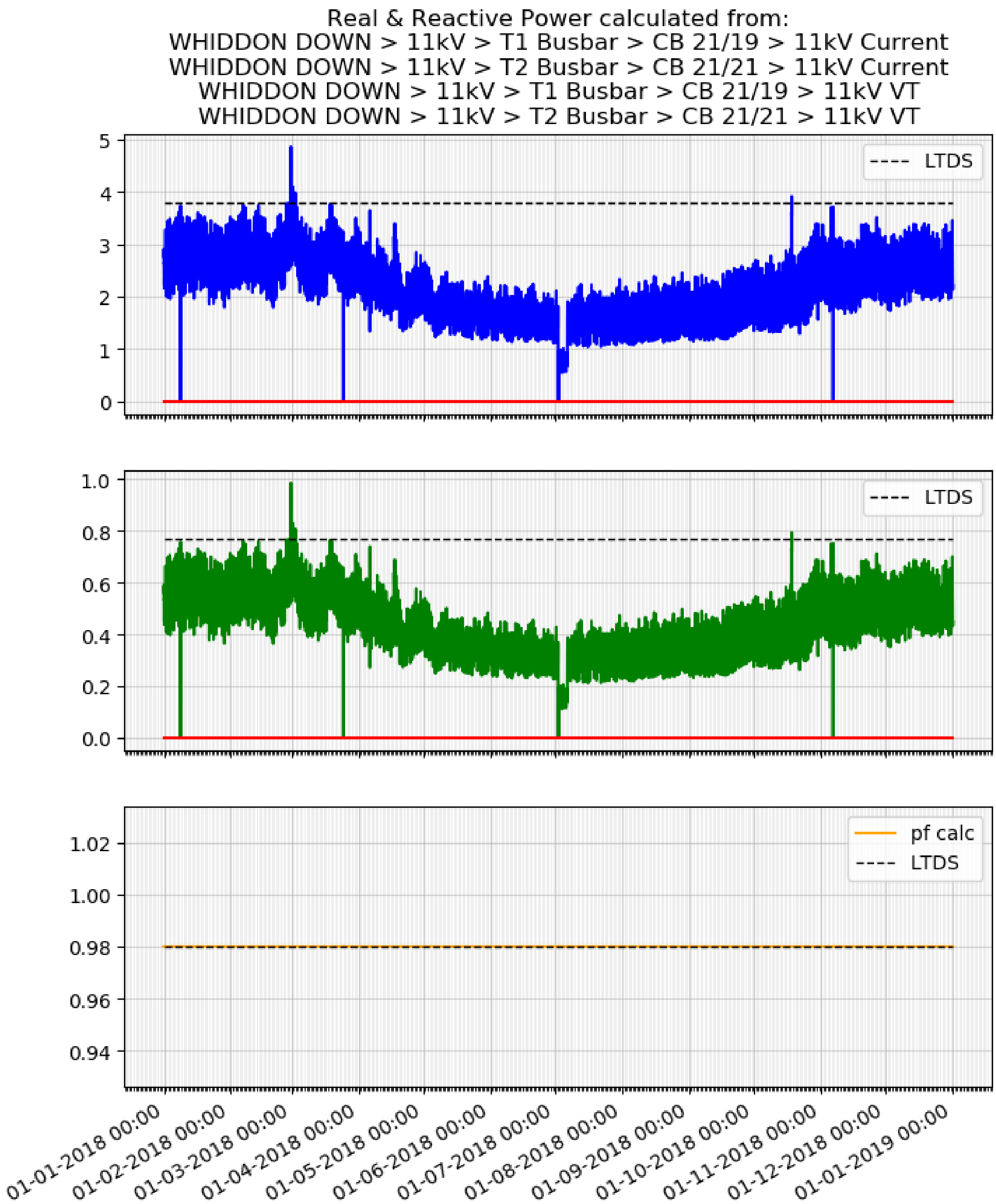
SHEBBEAR


SHEBBEAR > 11kV > T1 Busbar > CB 13/19 > 11kV ACB > Power Analogs > MW Analogue
LTDS
SHEBBEAR > 11kV > T1 Busbar > CB 13/19 > 11kV ACB > Power Analogs > MVAr Analogue
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

STRATTON

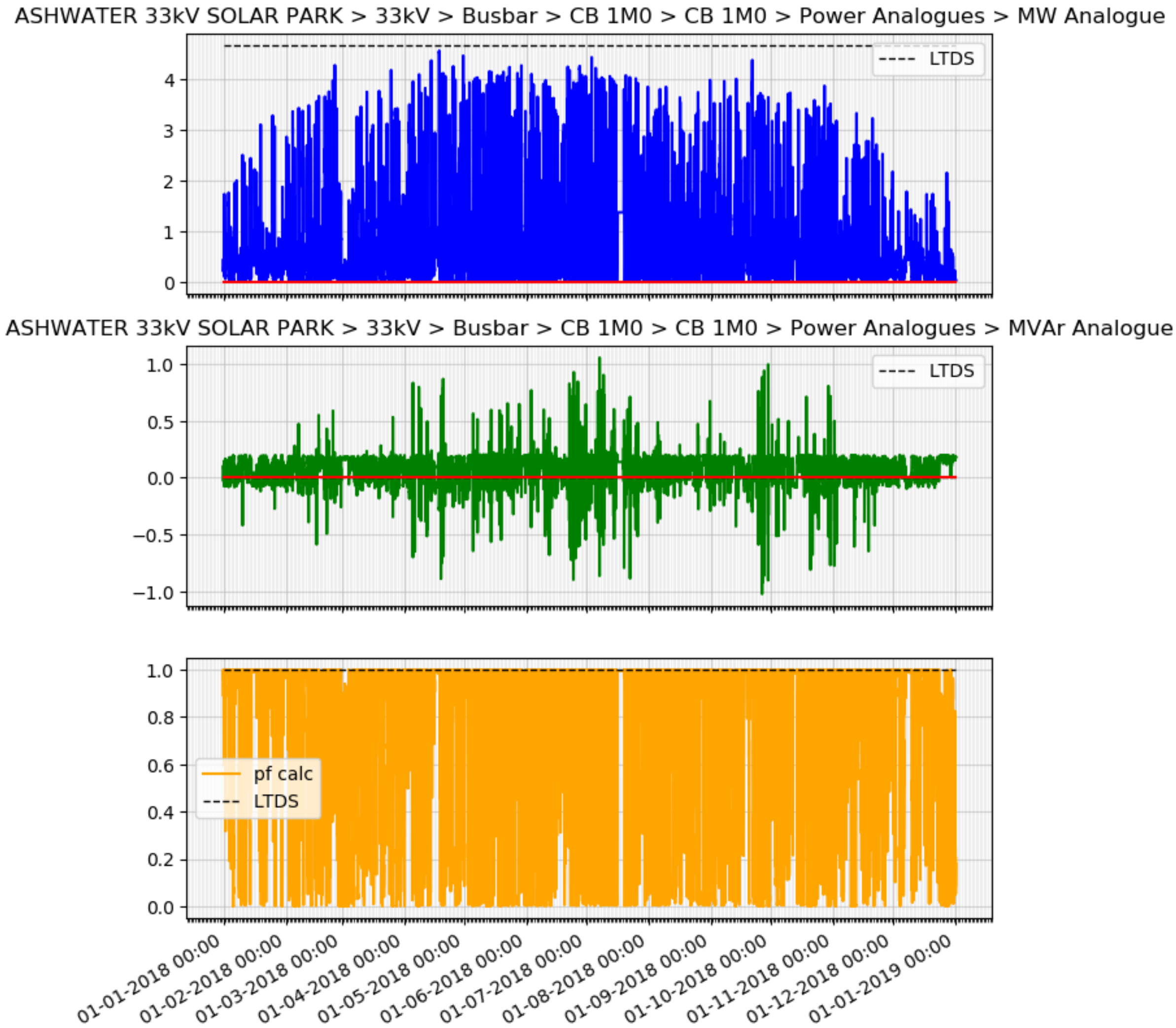

STRATTON > 11kV > T1 Busbar > CB 4041 > CB 4041 > Power Analogues > MW Analogue
STRATTON > 11kV > T2 Busbar > CB 4042 > CB 4042 > Power Analogues > MW Analogue
LTDS
STRATTON > 11kV > T1 Busbar > CB 4041 > CB 4041 > Power Analogues > MVAr Analogue
STRATTON > 11kV > T2 Busbar > CB 4042 > CB 4042 > Power Analogues > MVAr Analogue
LTDS
pf calc
LTDS
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

WHIDDON DOWN

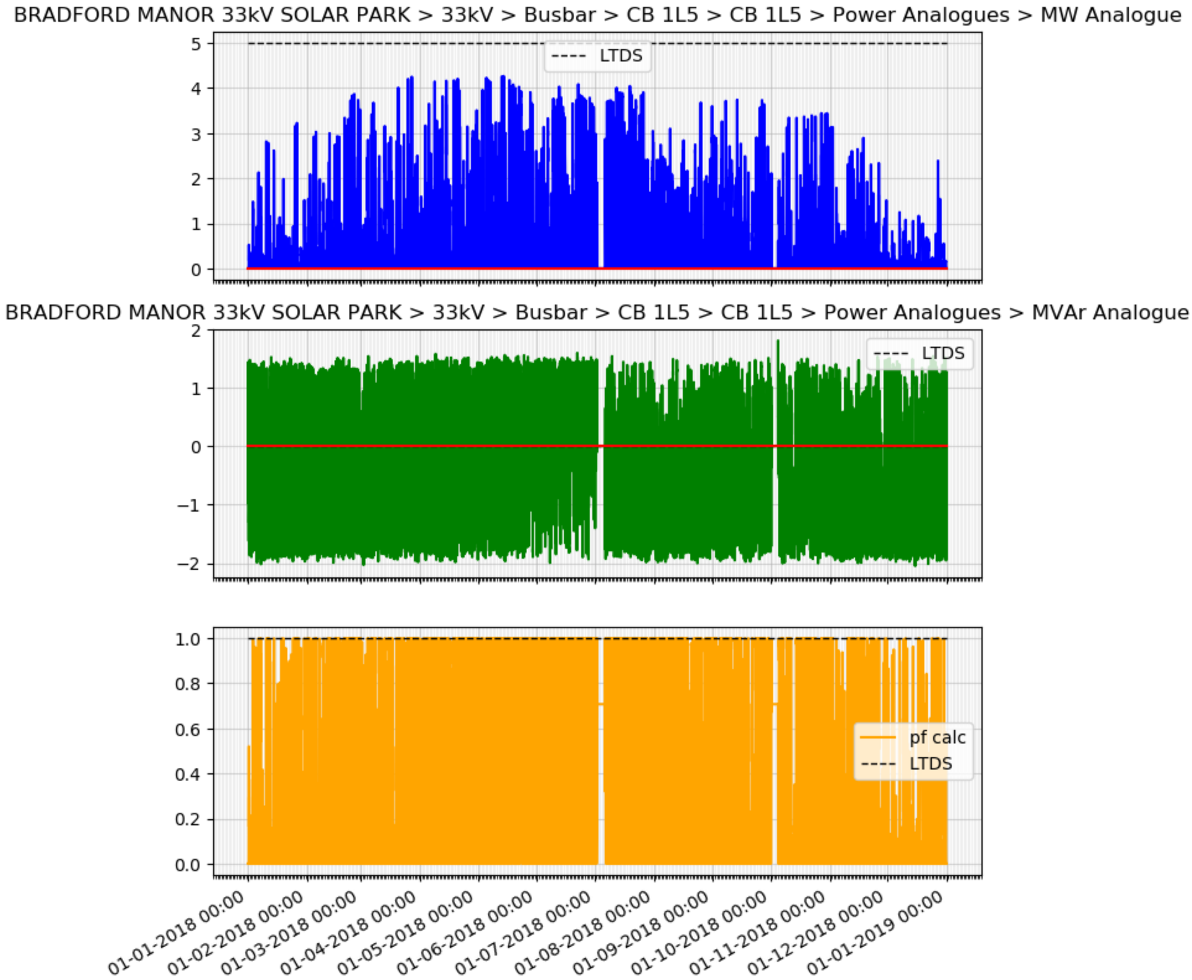


Pyworthy Generation

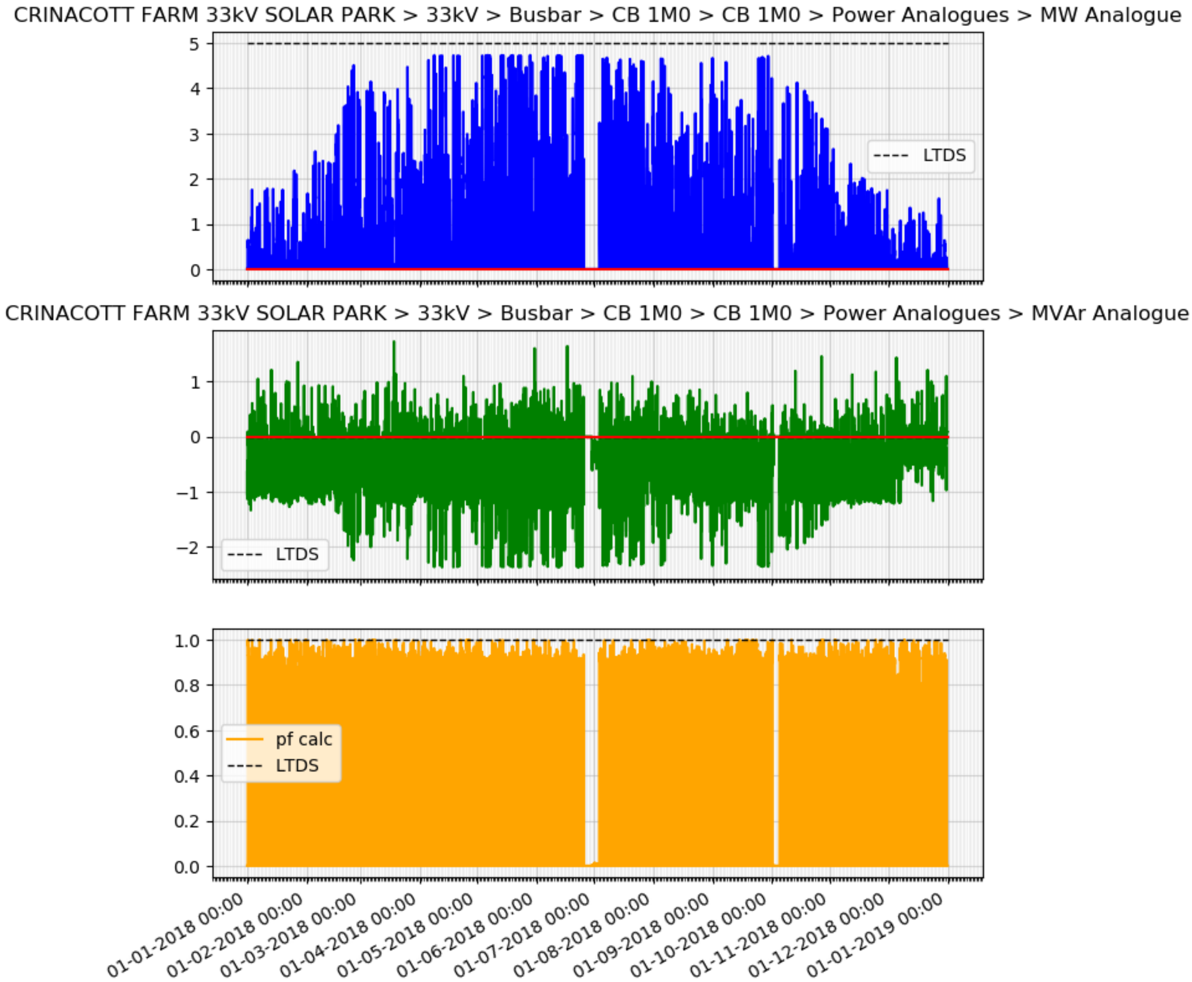
ASHWATER 33kV SOLAR PARK



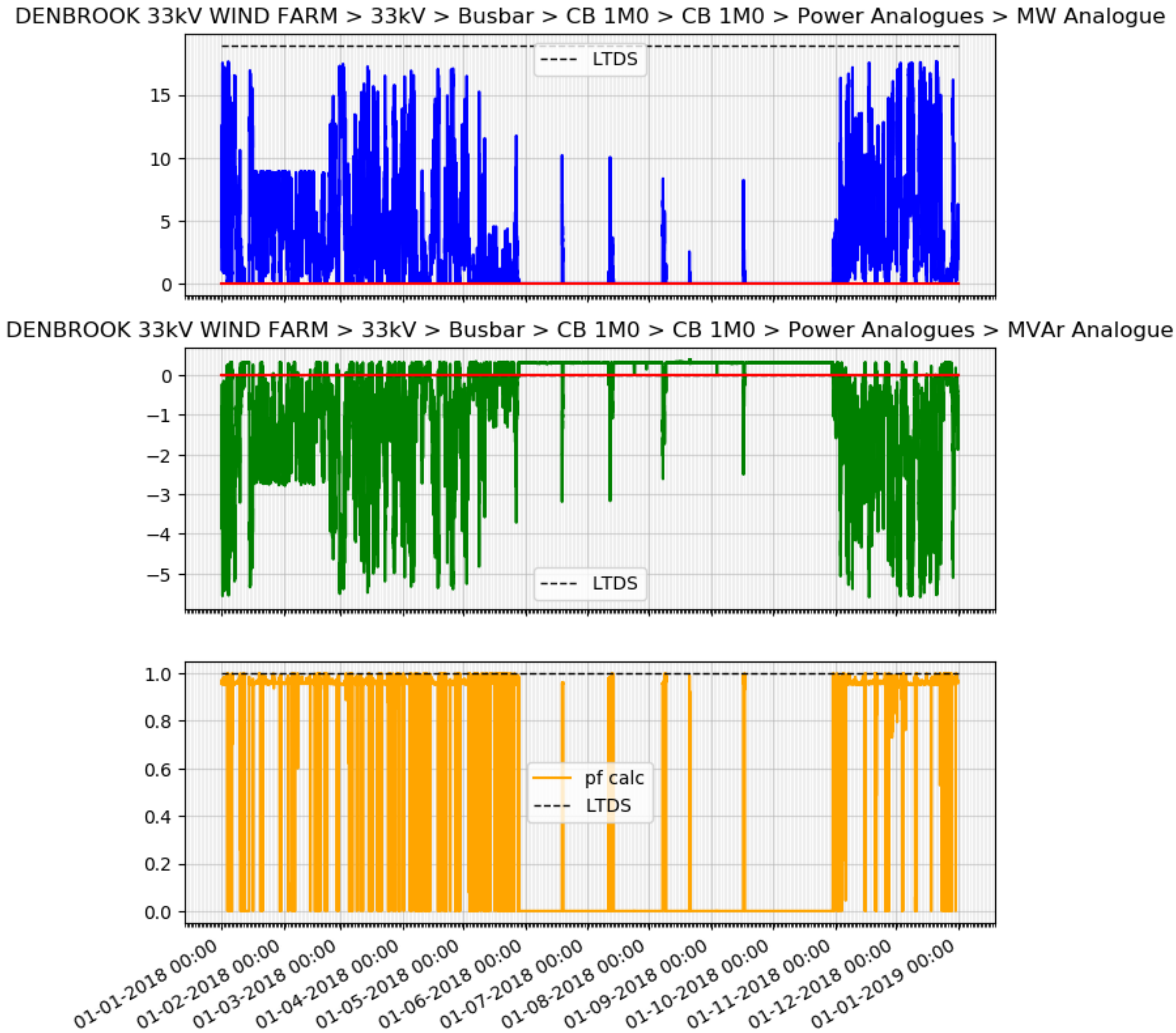
BRADFORD MANOR 33kV SOLAR PARK



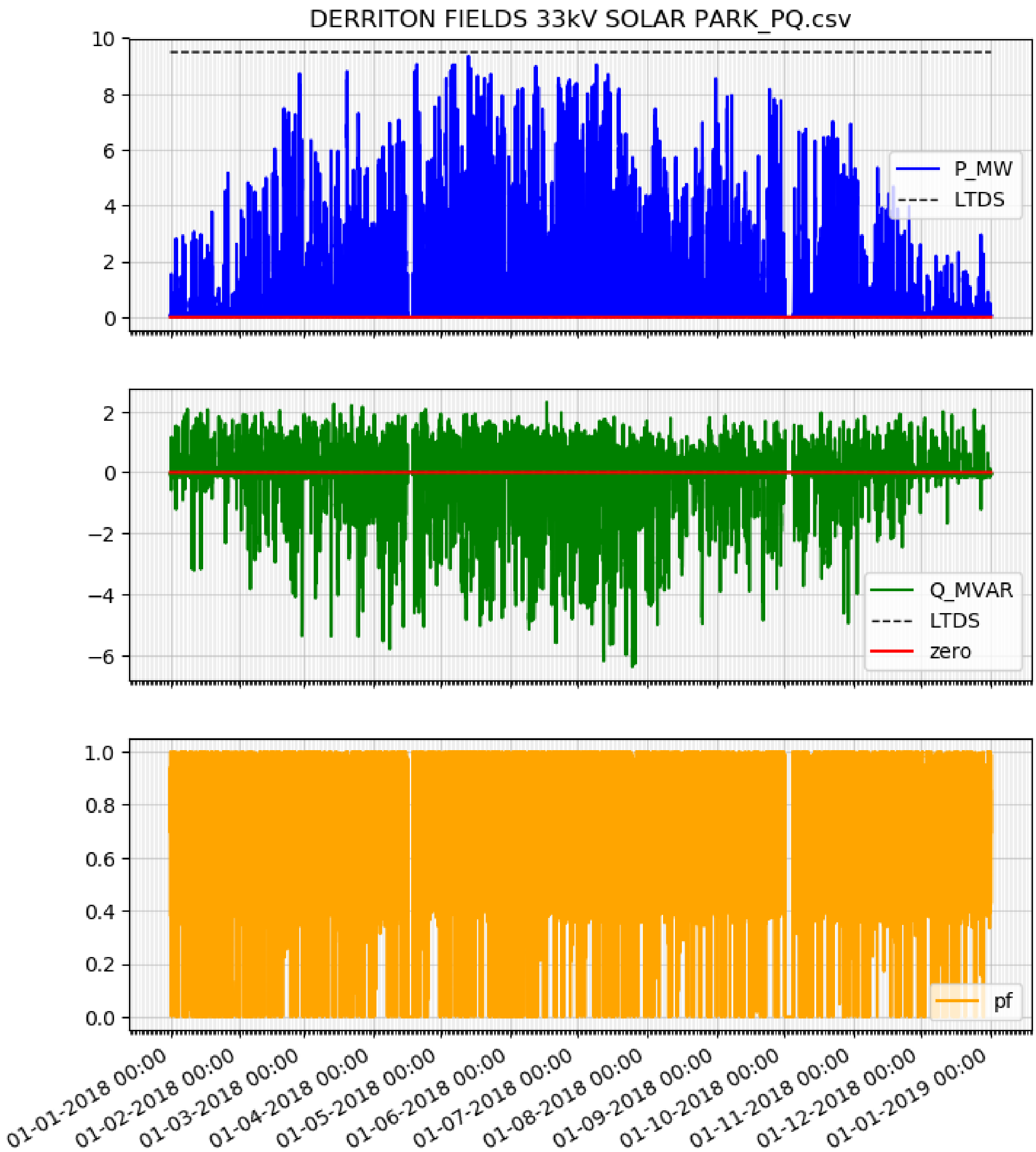
CRINACOTT FARM 33kV SOLAR PARK



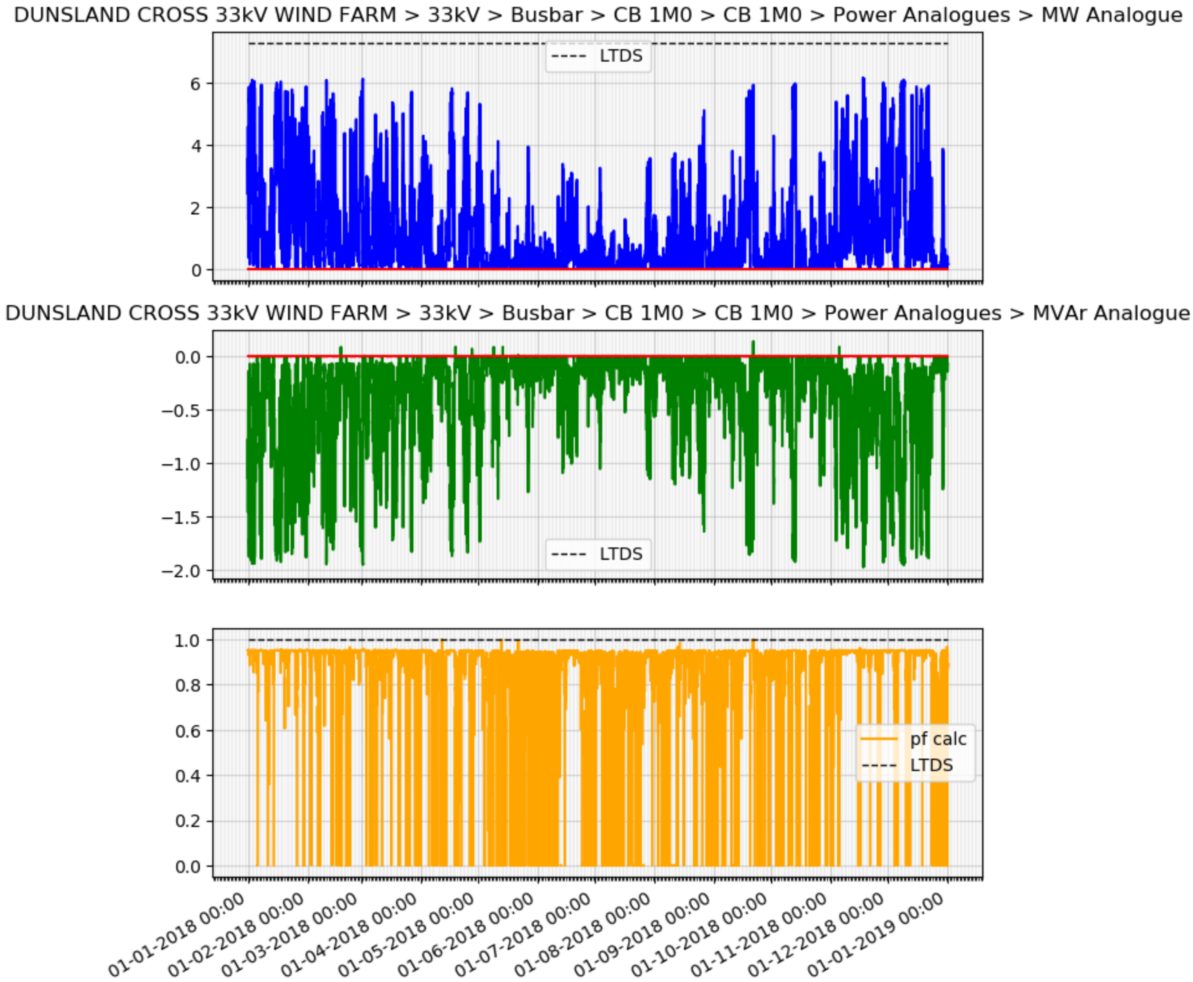
DENBROOK 33kV WIND FARM



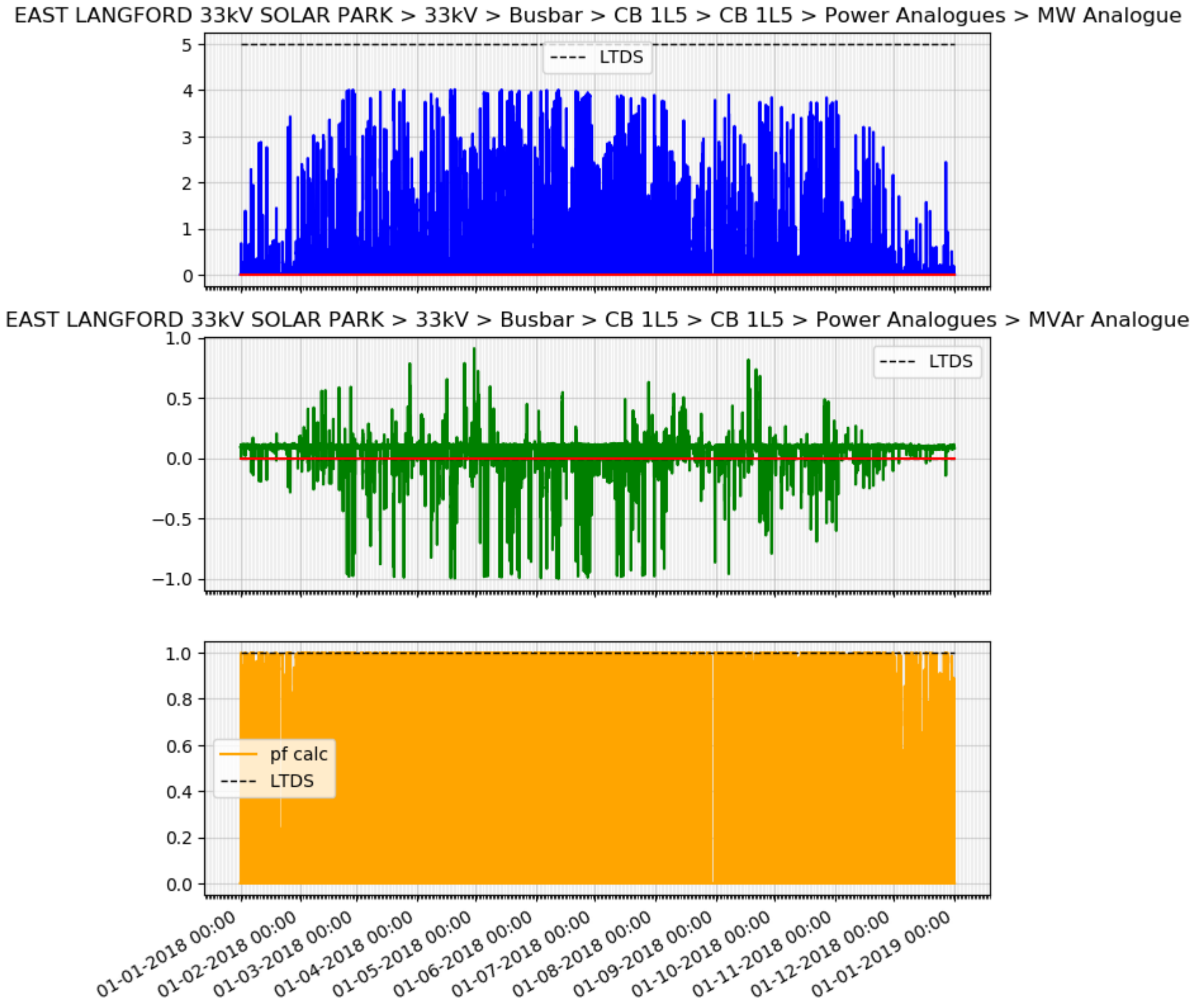
DERRITON FIELDS 33kV SOLAR PARK



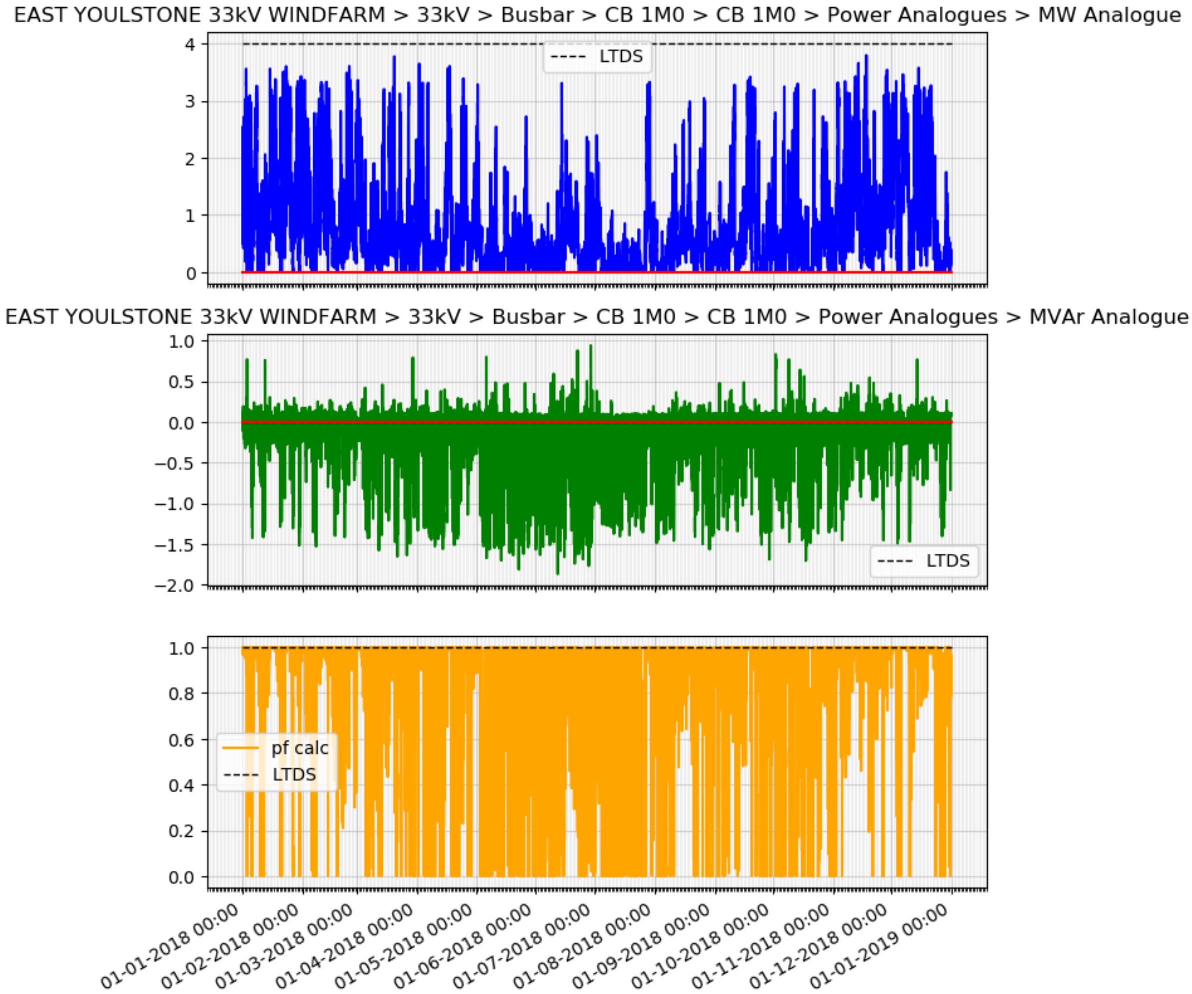
DUNSLAND CROSS 33kV WIND FARM



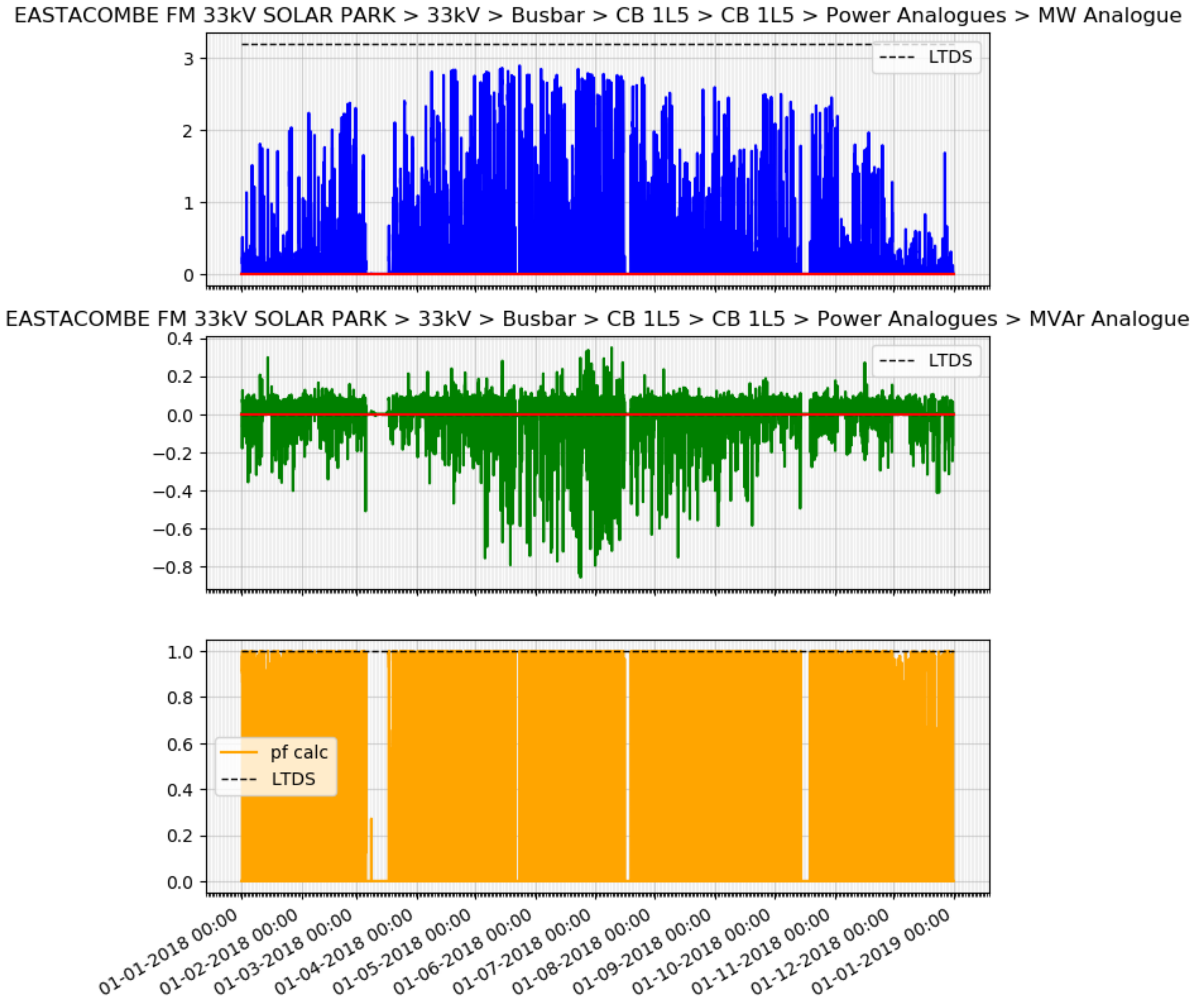
EAST LANGFORD 33kV SOLAR PARK



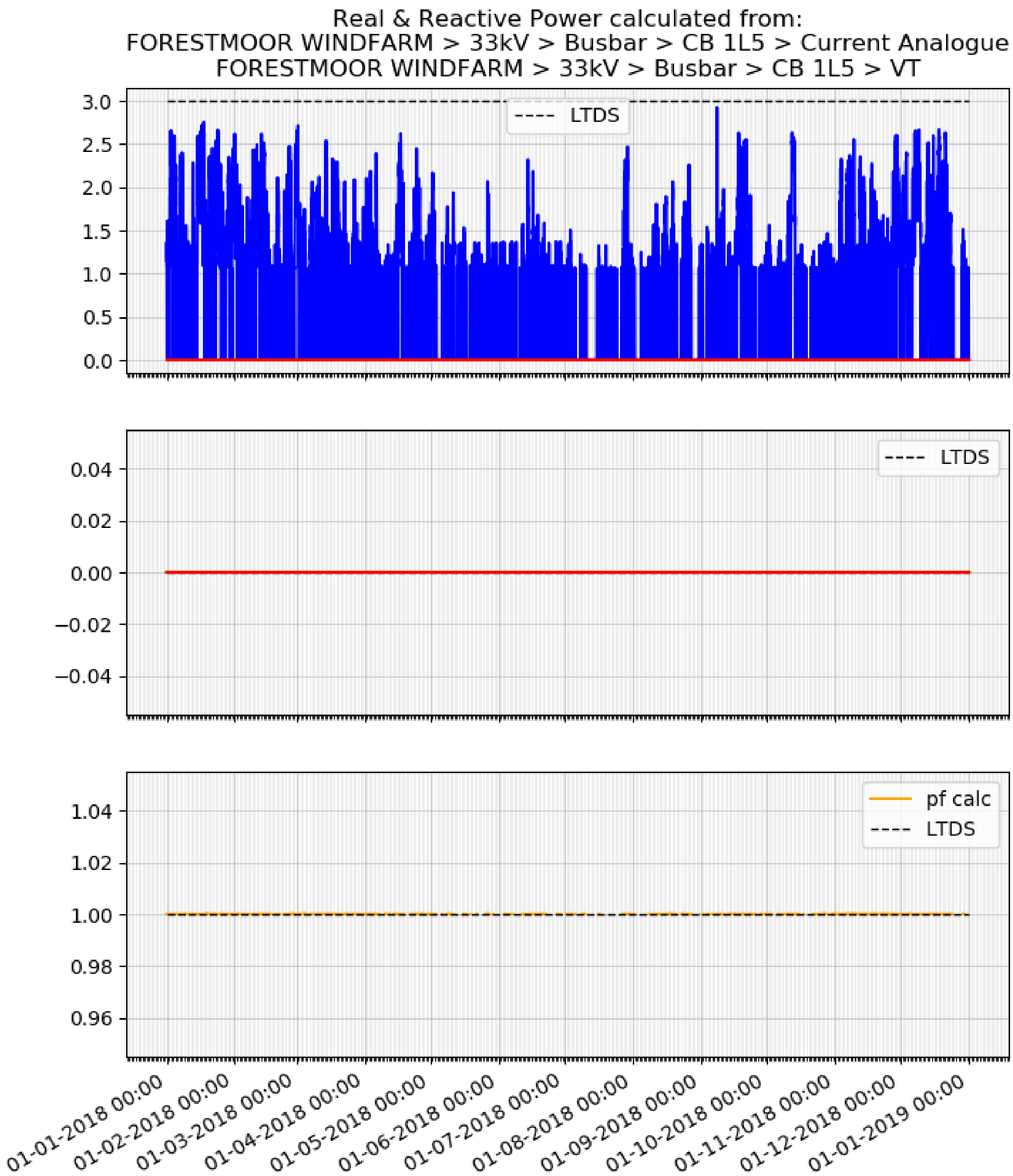
EAST YOULSTONE 33kV WINDFARM



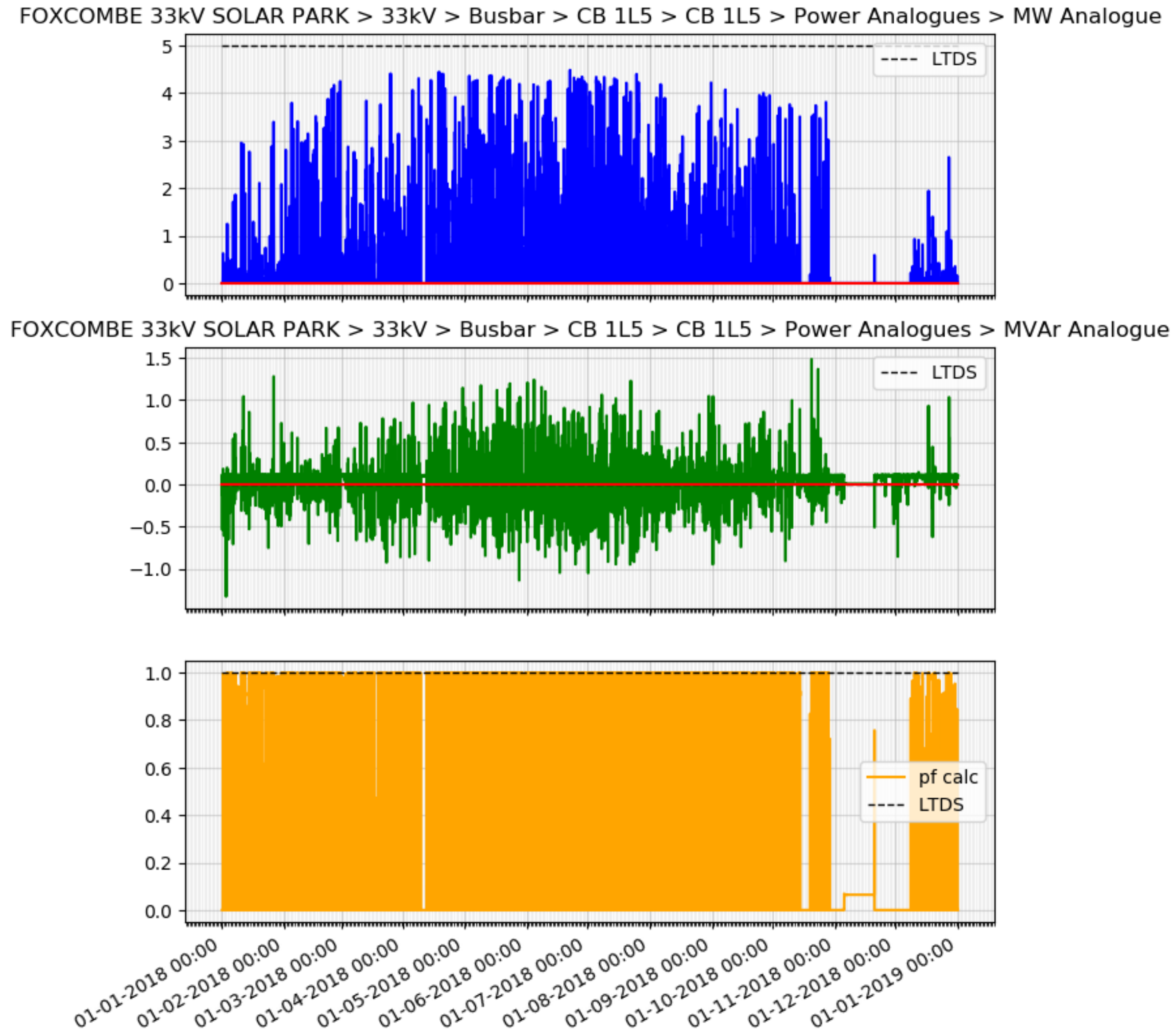
EASTACOMBE FM 33kV SOLAR PARK



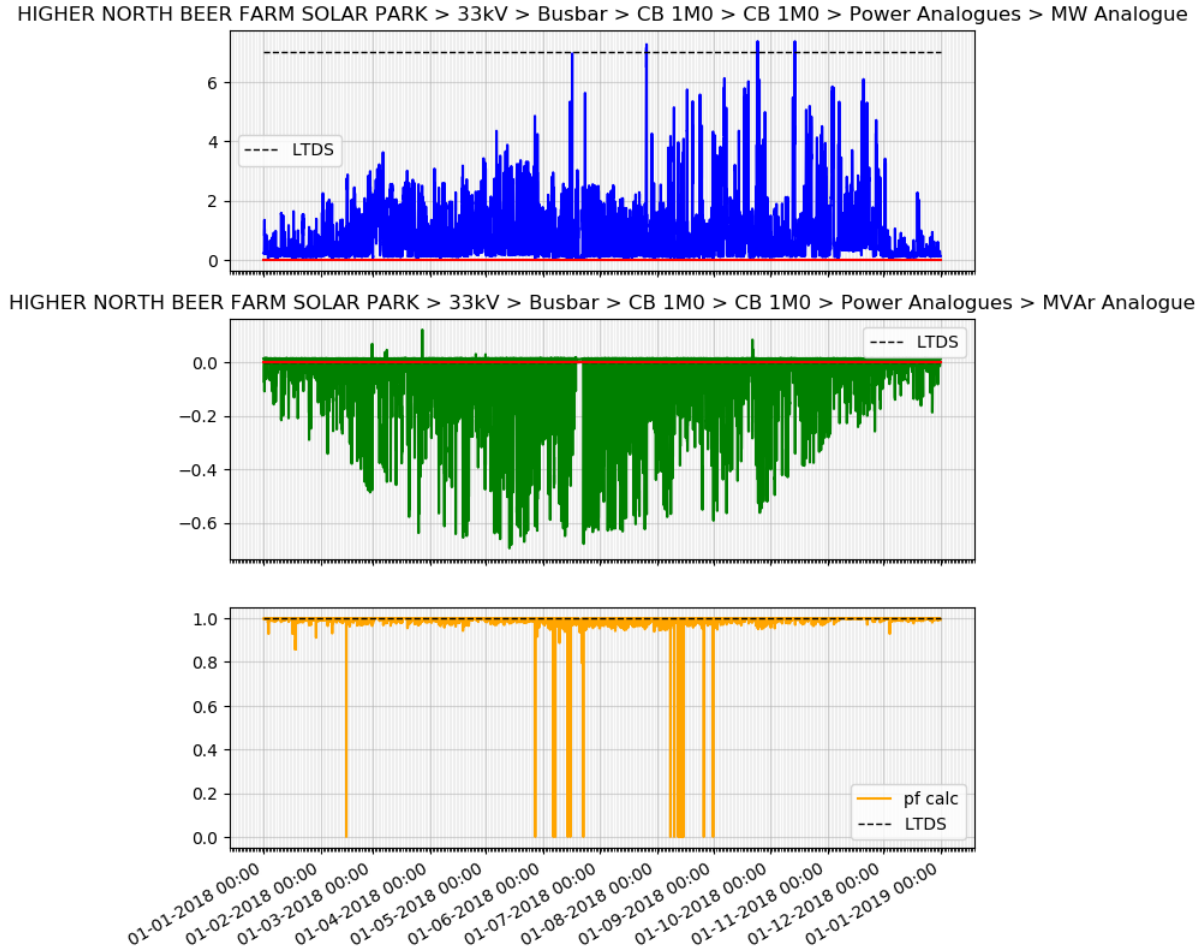
FORESTMOOR WINDFARM



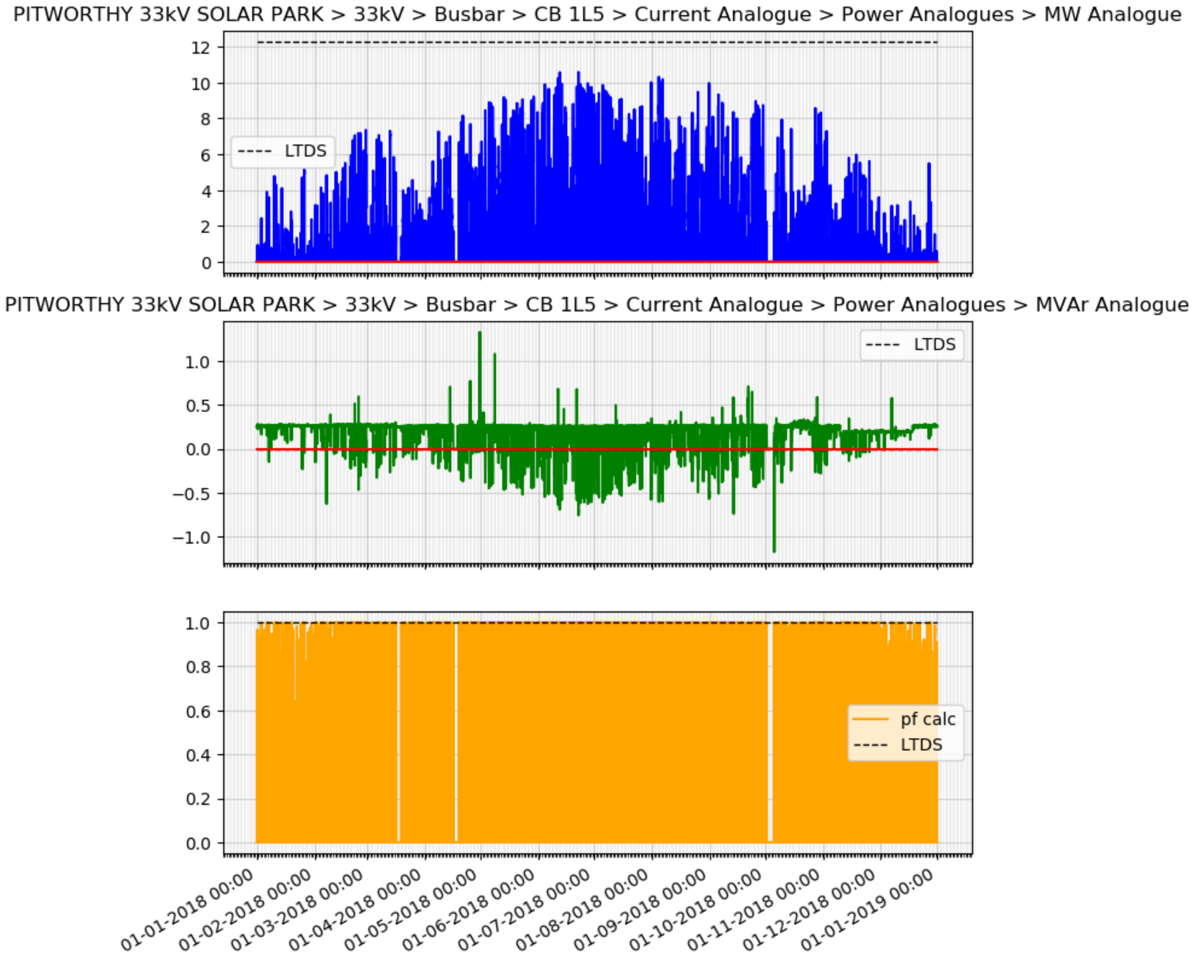
FOXCOMBE 33kV SOLAR PARK



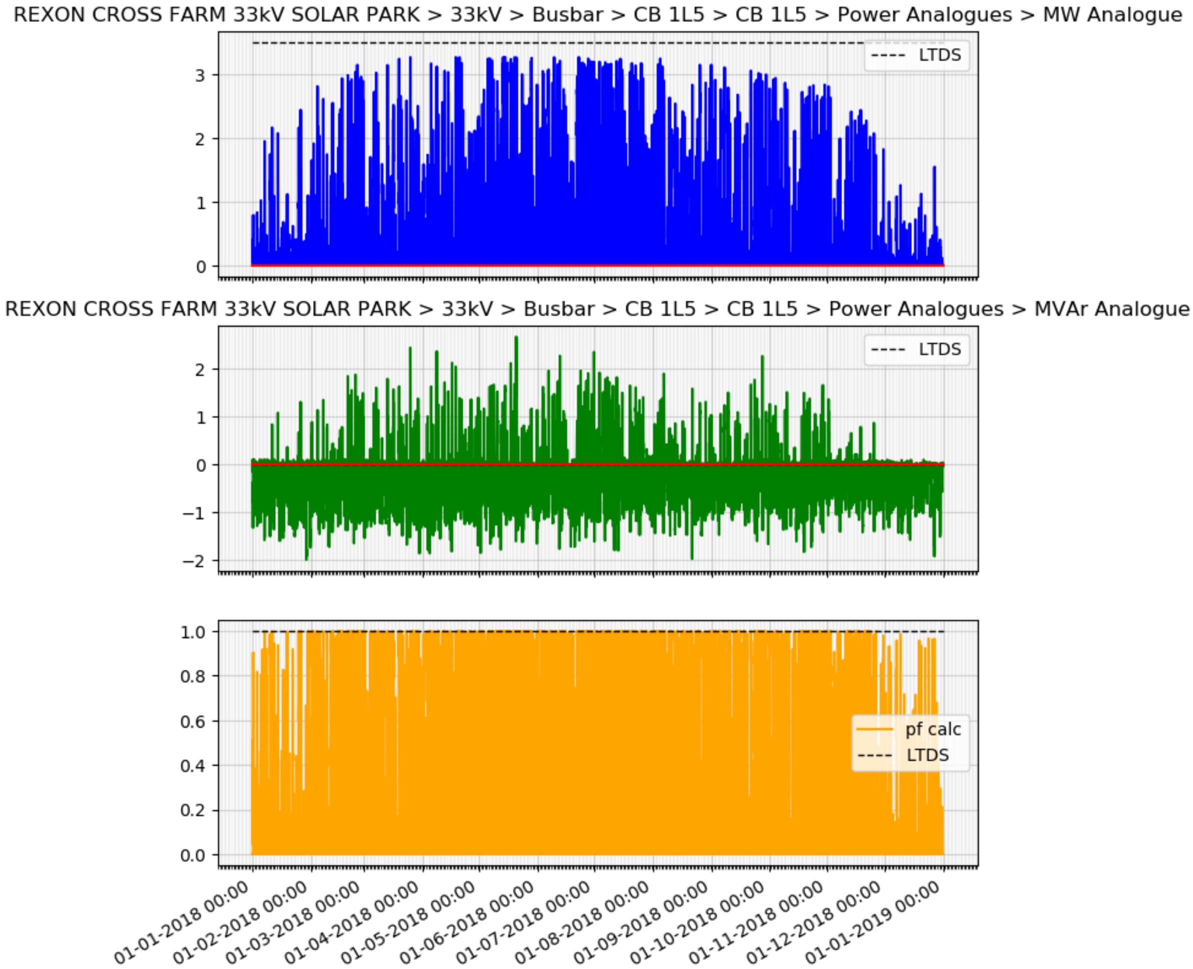
HIGHER NORTH BEER FARM SOLAR PARK



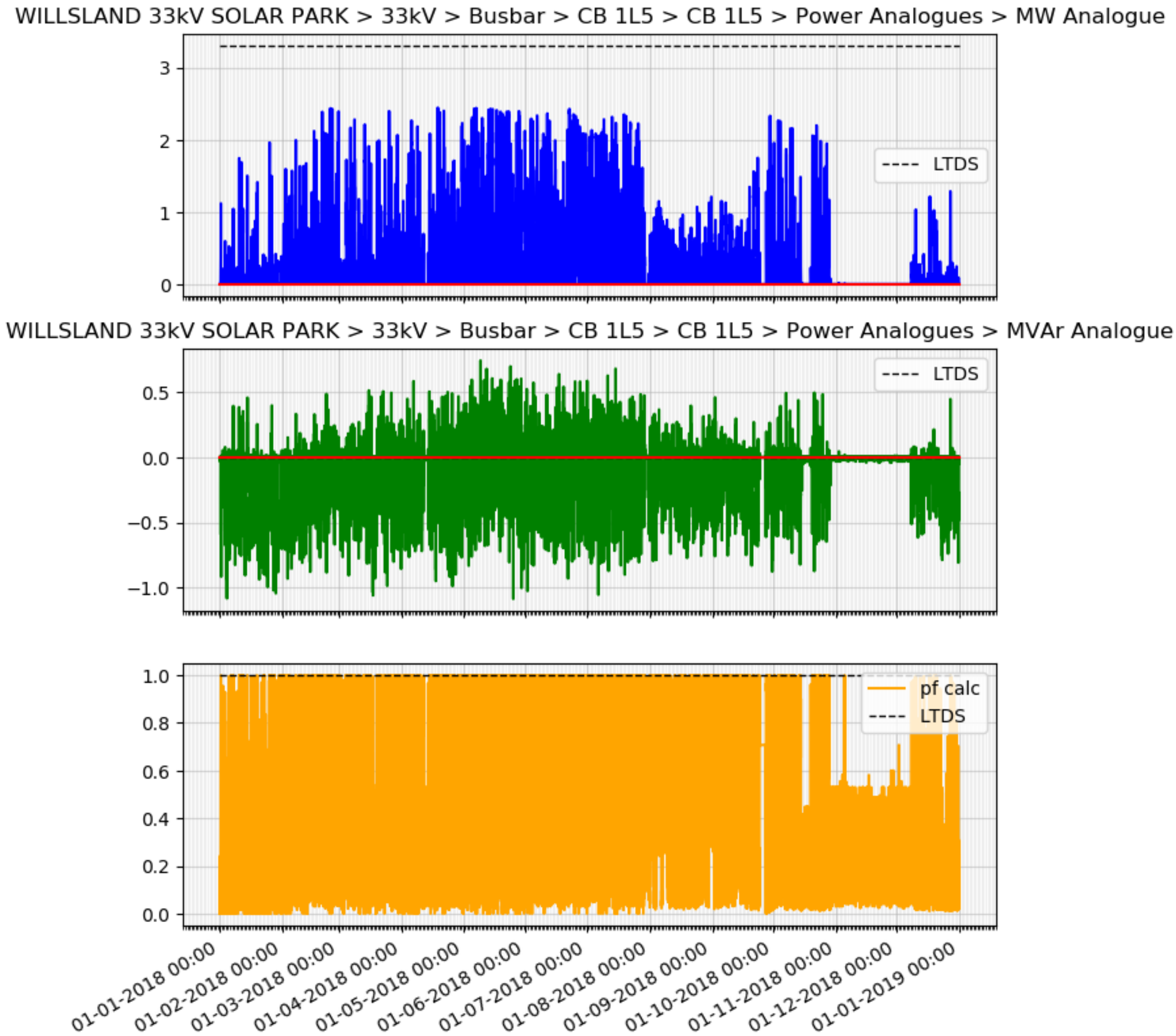
PITWORTHY 33kV SOLAR PARK



REXON CROSS FARM 33kV SOLAR PARK

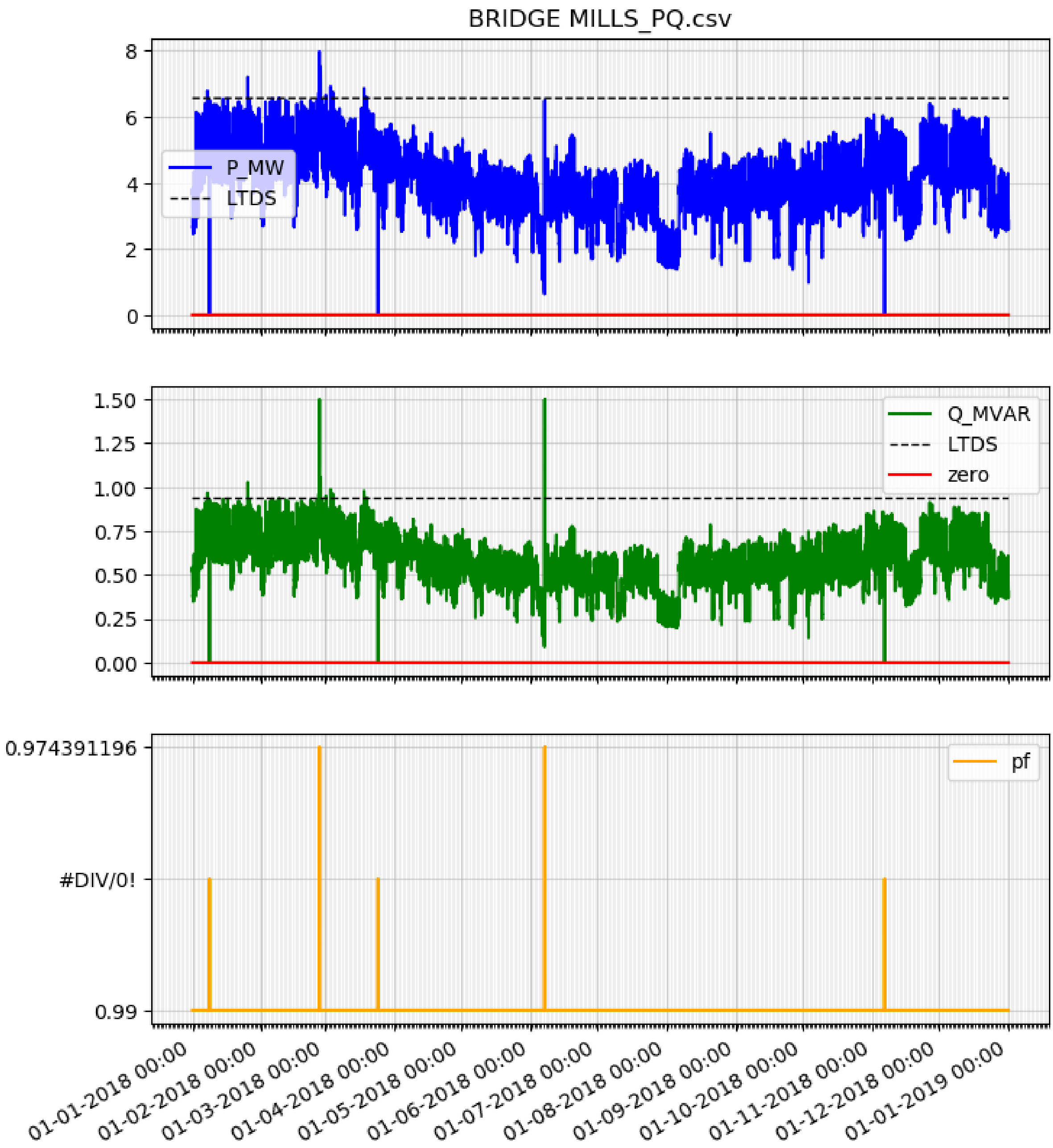


WILLSLAND 33kV SOLAR PARK

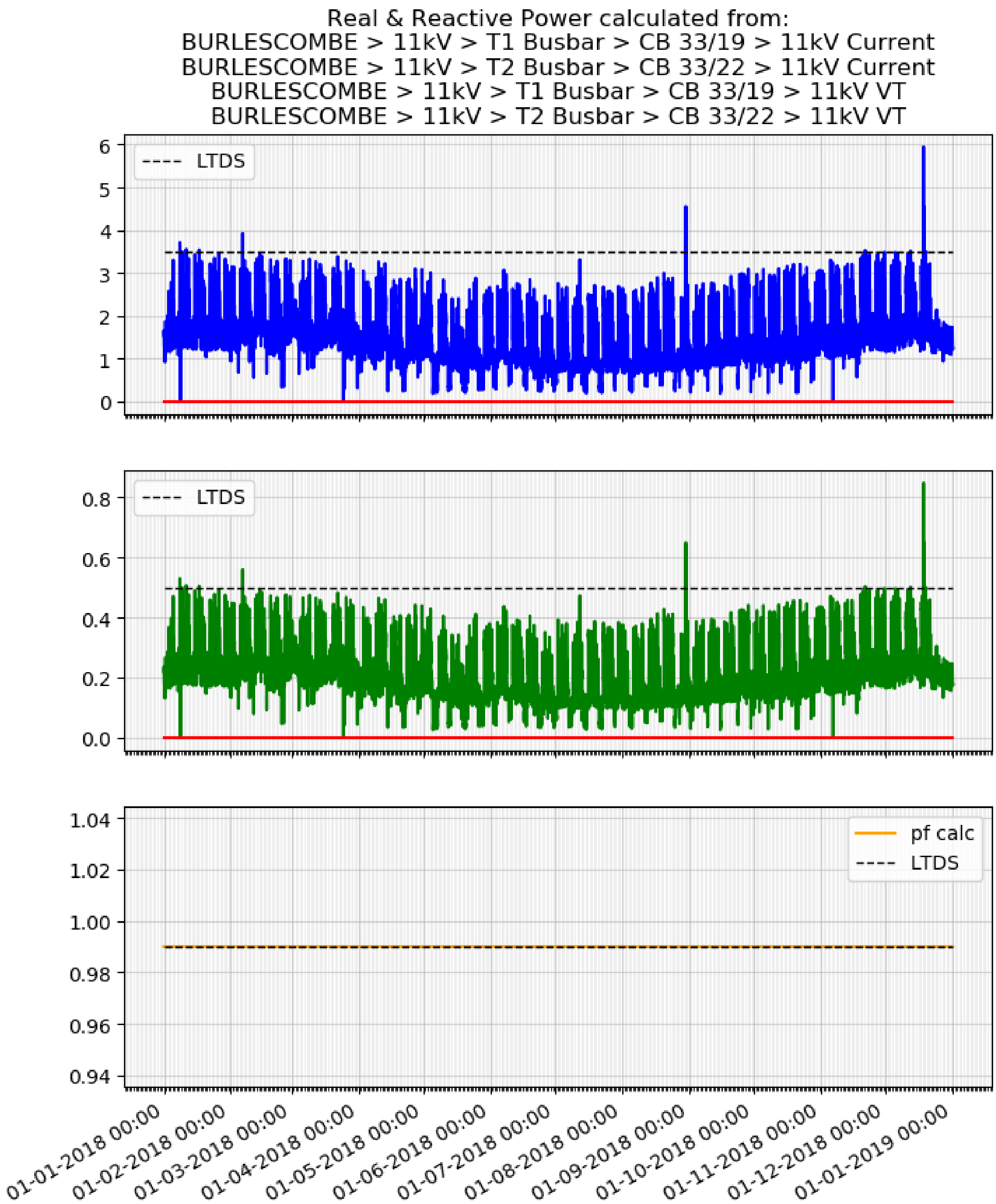


Tiverton Load

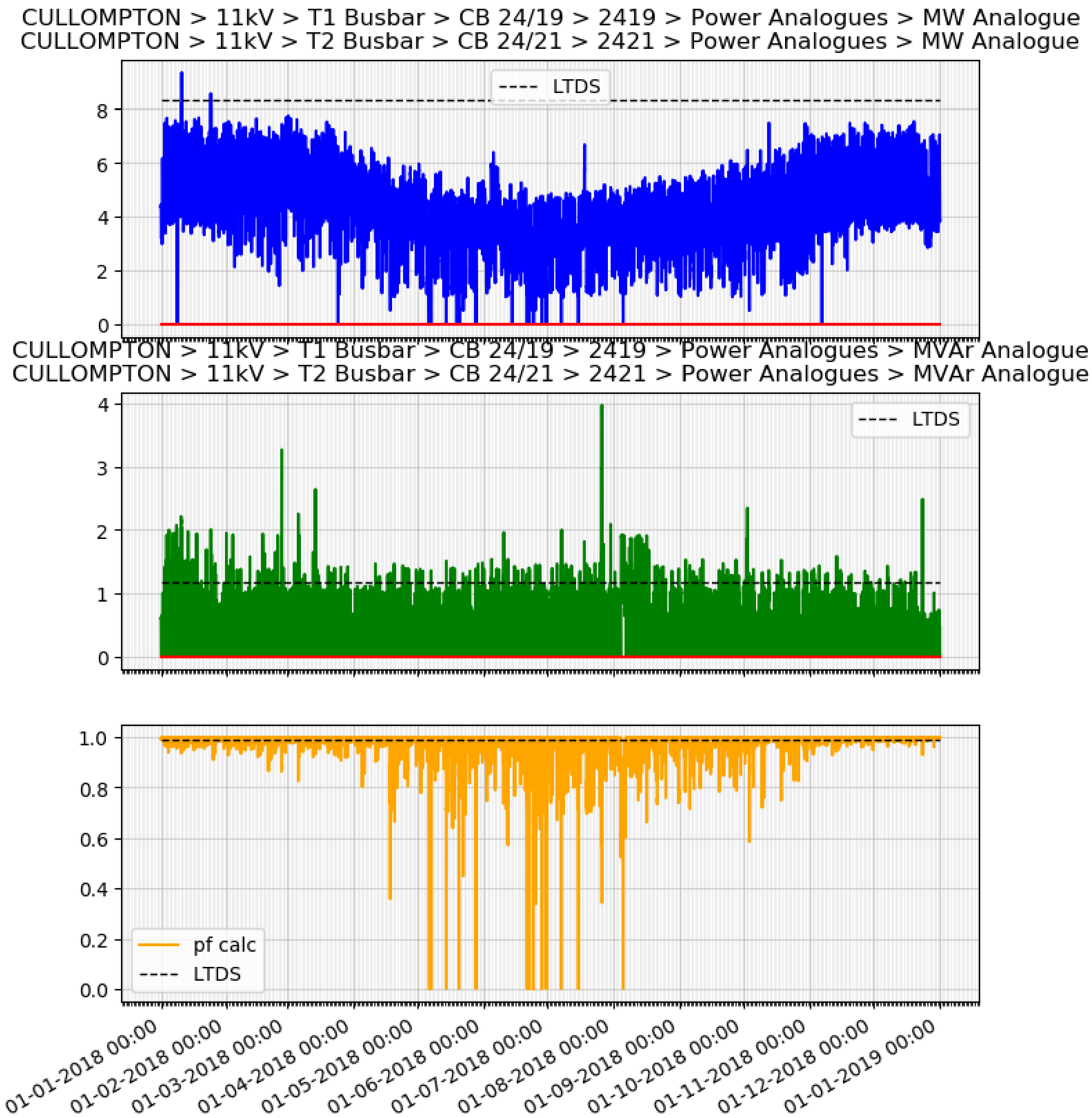
BRIDGE MILLS



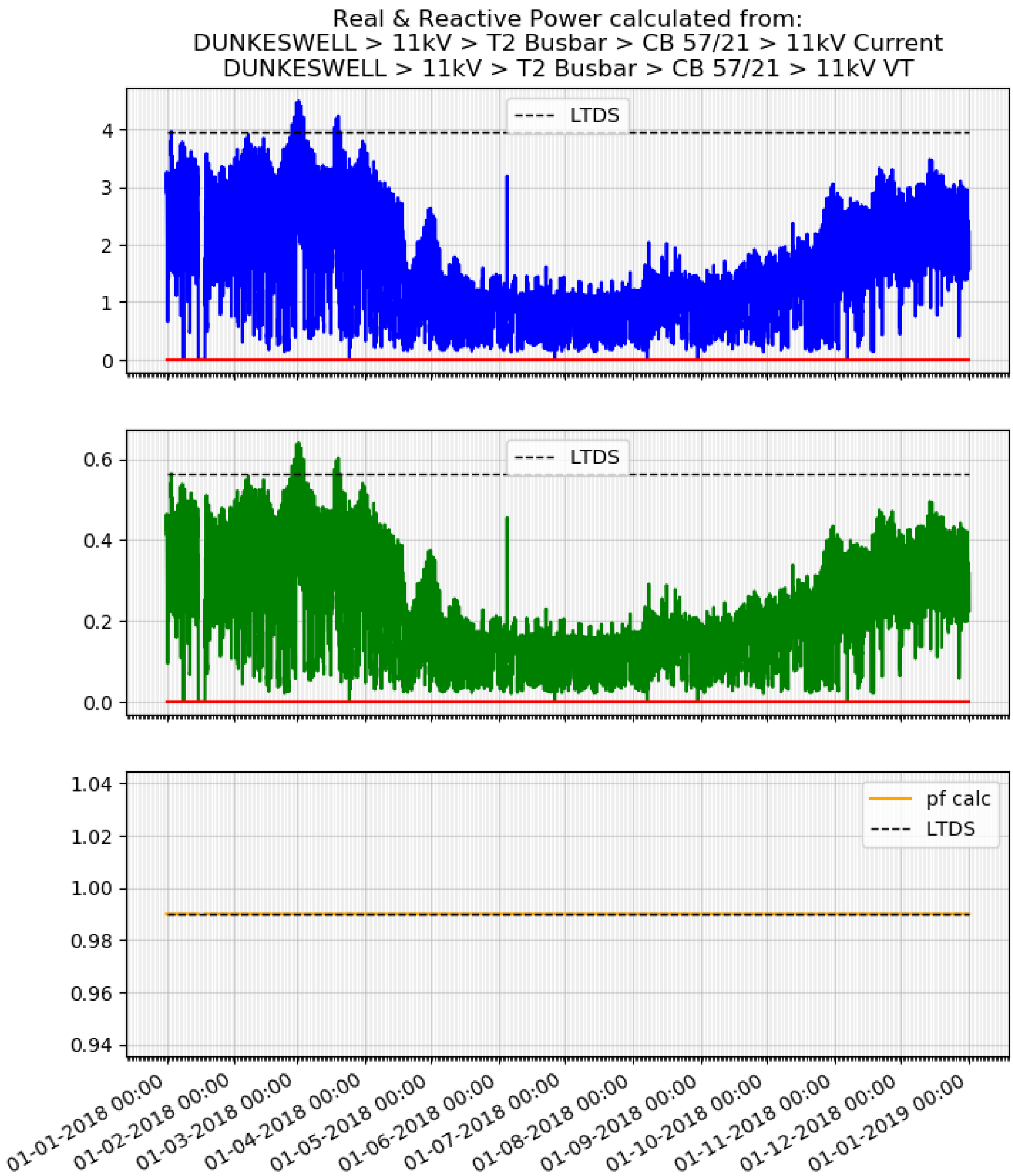
BURLESCOMBE



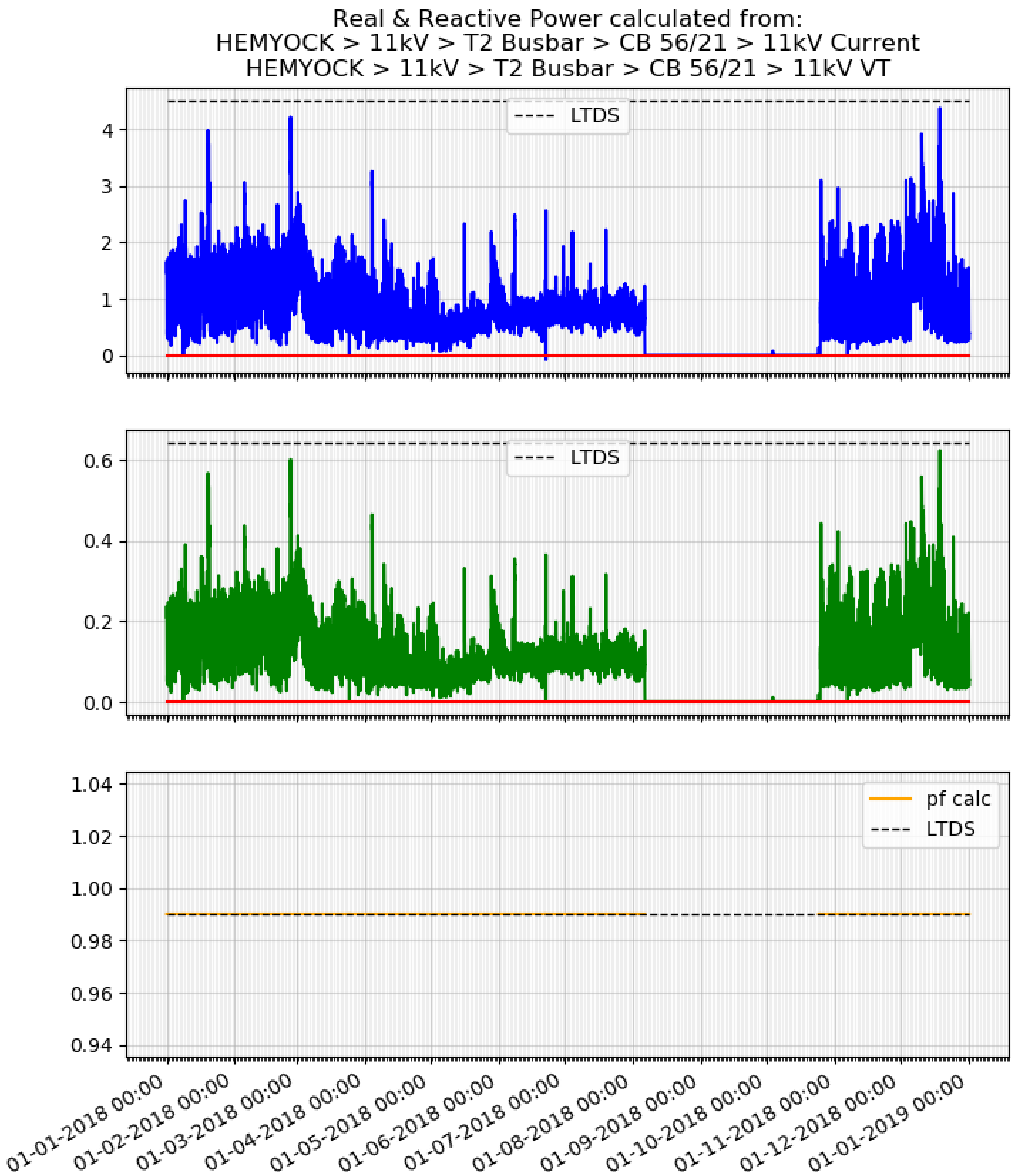
CULLOMPTON


CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MW Analogue
CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MW Analogue
LTDS
0
2
4
6
8
CULLOMPTON > 11kV > T1 Busbar > CB 24/19 > 2419 > Power Analogues > MVAr Analogue
CULLOMPTON > 11kV > T2 Busbar > CB 24/21 > 2421 > Power Analogues > MVAr Analogue
LTDS
0
1
2
3
4
pf calc
LTDS
0.0
0.2
0.4
0.6
0.8
1.0
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

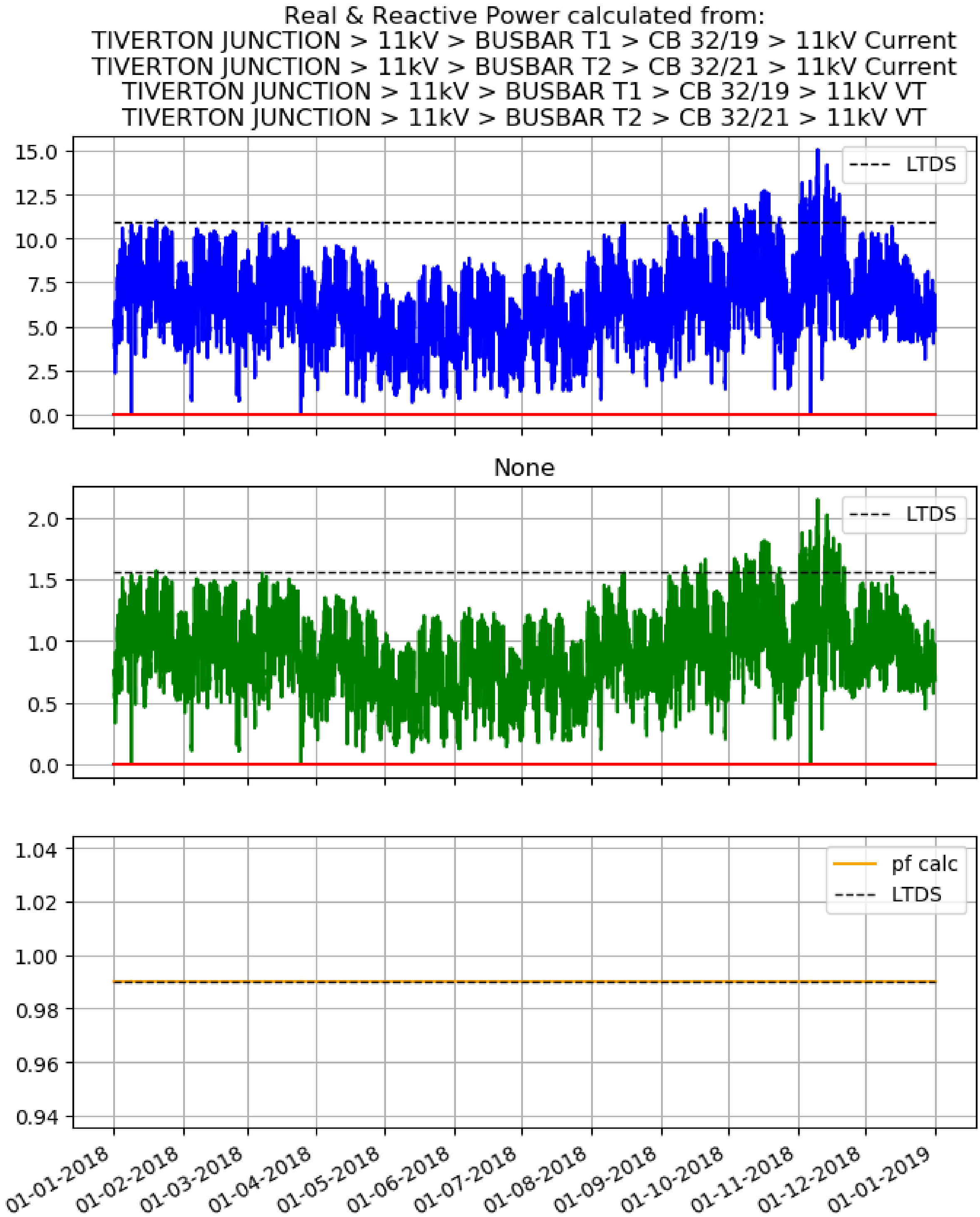
DUNKESWELL


Real & Reactive Power calculated from:
DUNKESWELL > 11kV > T2 Busbar > CB 57/21 > 11kV Current
DUNKESWELL > 11kV > T2 Busbar > CB 57/21 > 11kV VT
LTDS
4
3
2
1
0
LTDS
0.6
0.4
0.2
0.0
pf calc
LTDS
1.04
1.02
1.00
0.98
0.96
0.94
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

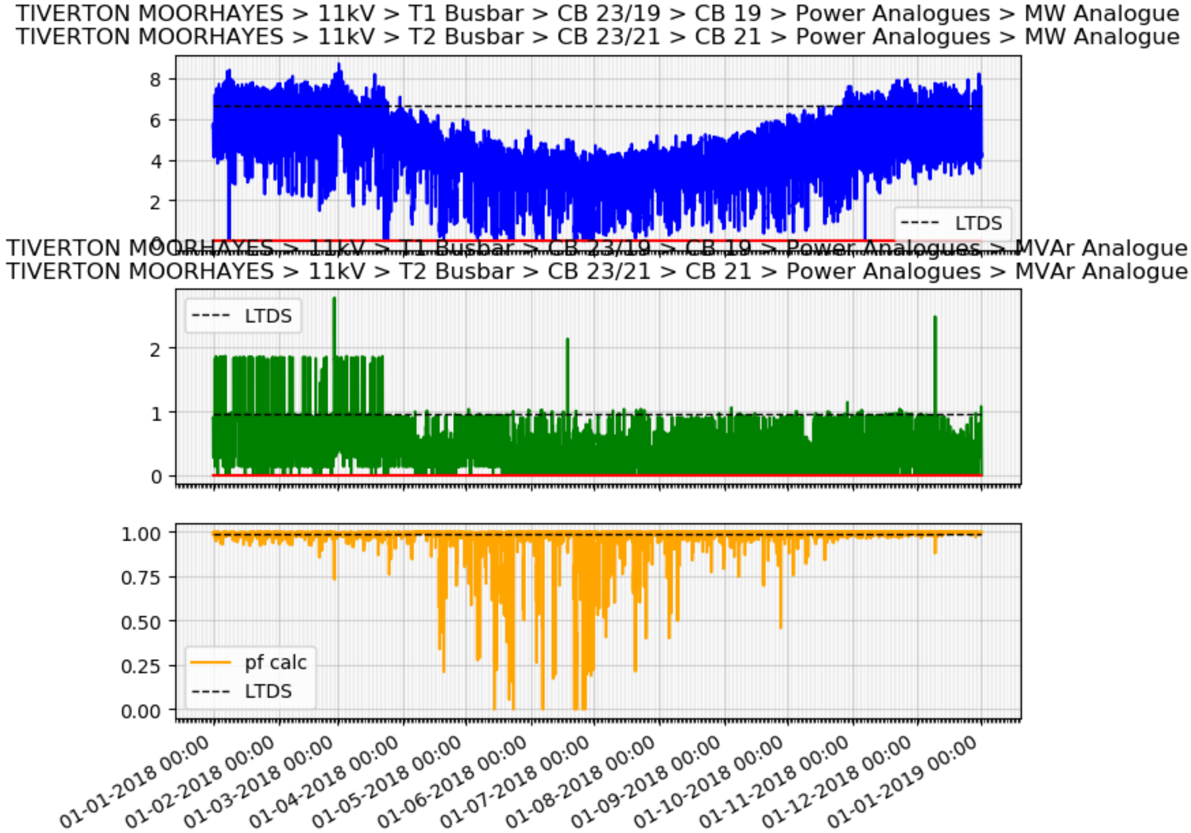
HEMYOCK


Real & Reactive Power calculated from:
HEMYOCK > 11kV > T2 Busbar > CB 56/21 > 11kV Current
HEMYOCK > 11kV > T2 Busbar > CB 56/21 > 11kV VT
LTDS
pf calc
01-01-2018 00:00
01-02-2018 00:00
01-03-2018 00:00
01-04-2018 00:00
01-05-2018 00:00
01-06-2018 00:00
01-07-2018 00:00
01-08-2018 00:00
01-09-2018 00:00
01-10-2018 00:00
01-11-2018 00:00
01-12-2018 00:00
01-01-2019 00:00

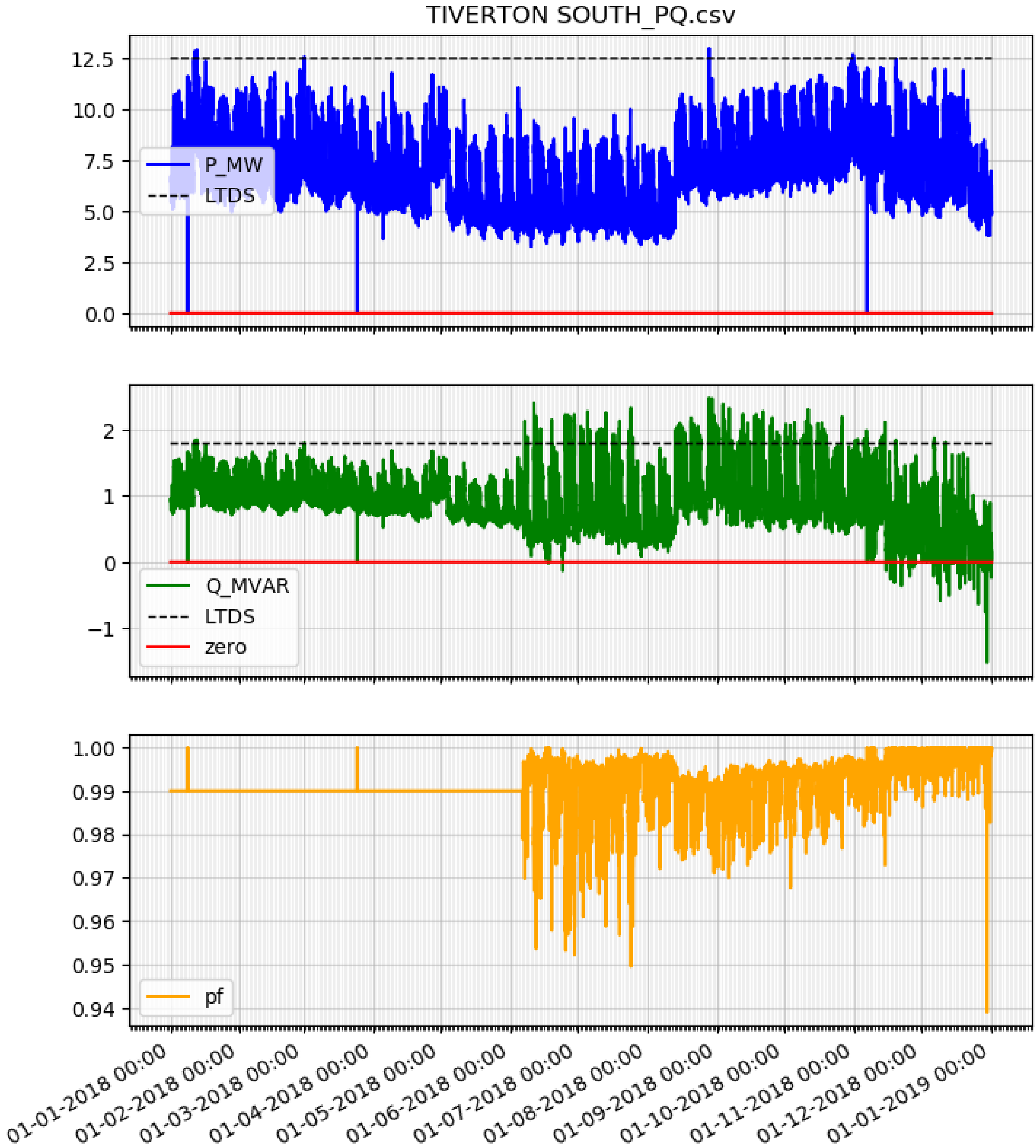
TIVERTON JUNCTION



TIVERTON MOORHAYES

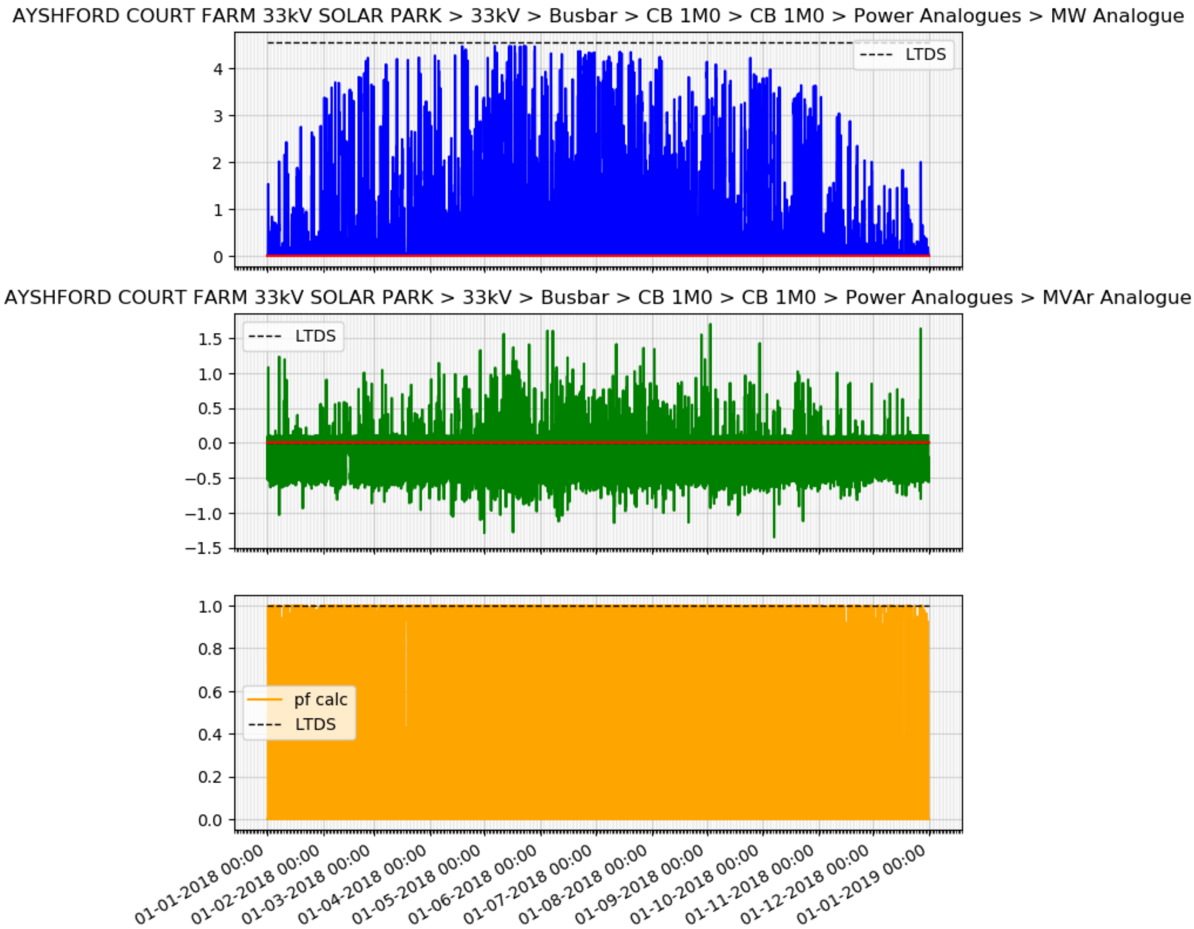


TIVERTON SOUTH

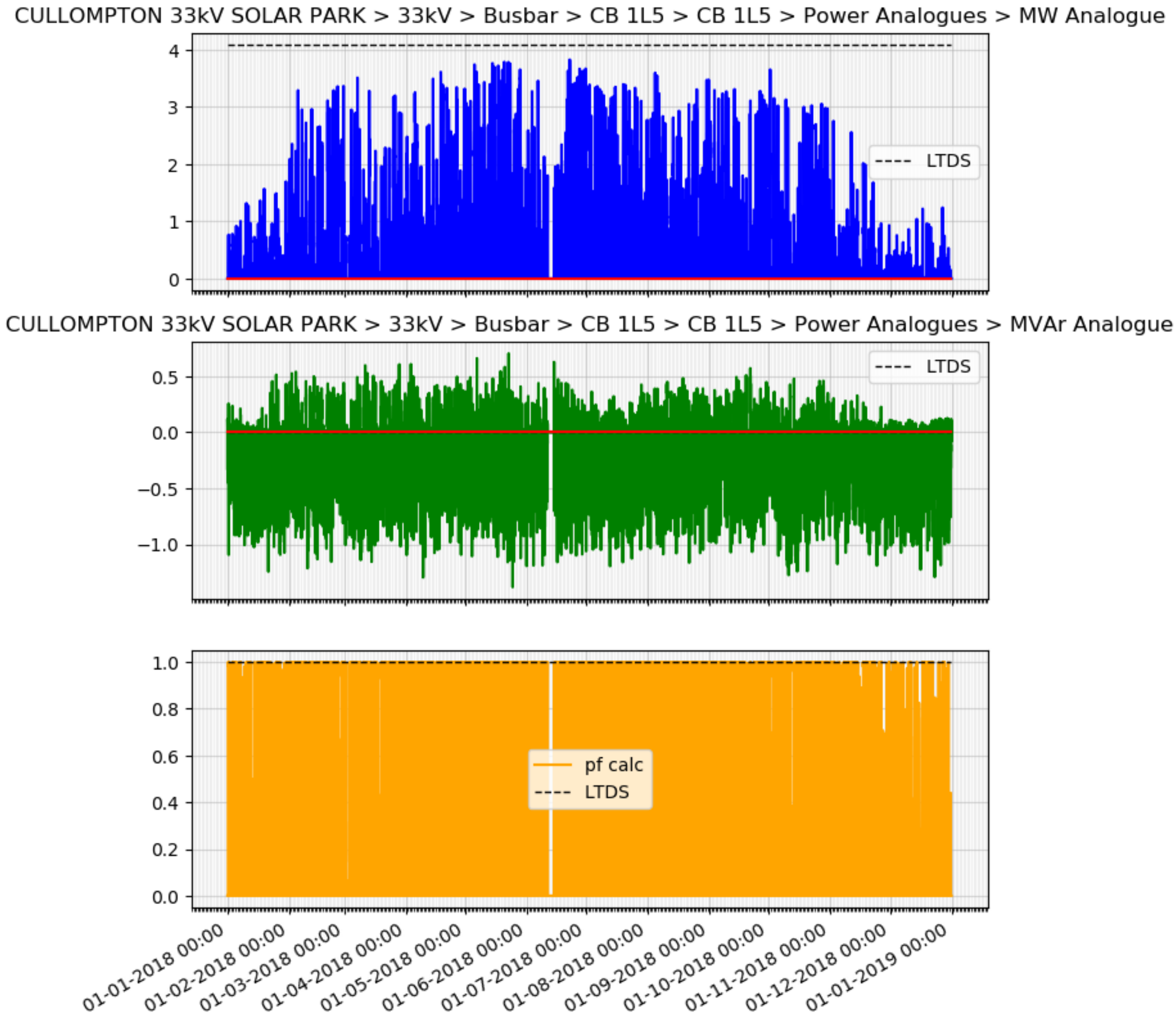


<u>Tiverton Generation:</u>

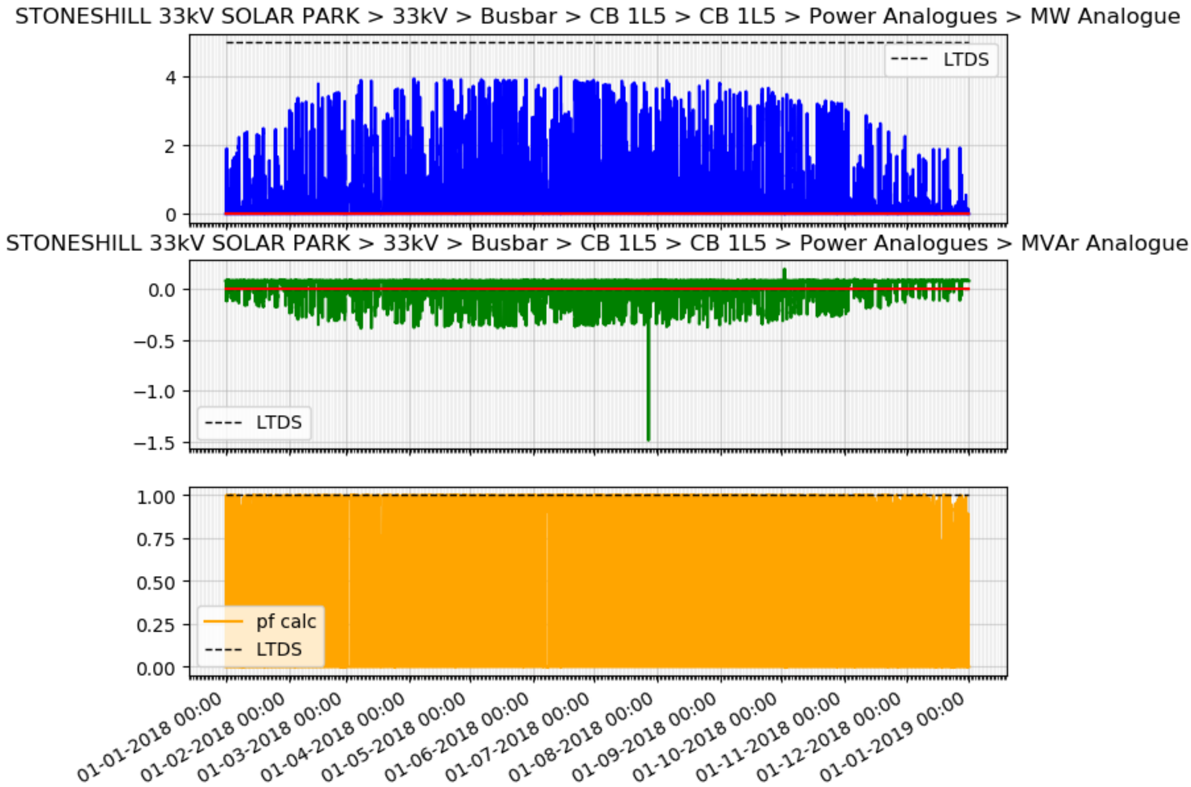
AYSHFORD COURT FARM 33kV SOLAR PARK



CULLOMPTON 33kV SOLAR PARK



STONESHILL 33kV SOLAR PARK



Appendix D – Timeseries data mapping to PSS/E

Barnstaple 33kV BSP Loads:

	PSS/E Model data			
Site CSV file (P & Q from tag rules)	No. Loads	Bus Number	Bus Name	Id
AARONSONS.csv	1	7000	AARO3	1
BRATTON FLEMING.csv	1	7097	BRAF5	1
GREAT TORRINGTON.csv	1	7750	TORR5K	1
HEDDON CROSS.csv	1	7361	HEDX5	1
LYNTON.csv	1	7456	LYNT5	1
MIDDLE BARLINGTON.csv	1	7486	MIDB5	1
ROCK PARK.csv	1	7625	ROCP5	1
ROUNDSWELL.csv	1	7633	ROUN5	1
SOUTH MOLTON.csv	1	7666	SMOL5	1
TINKERS CROSS.csv	1	7731	TINX5	1
TINKERS CROSSK.csv	1	7732	TINX5K	1

Barnstaple 33kV BSP Generation:

	PSS/E Model data			
Site CSV file (P & Q from tag rules)	No. Gens	Bus Number	Bus Name	Id
BATSWORTHY CROSS 33kV WIND FARM.csv	1	10415	BATS3	W1
BEAFORD 33kV SOLAR FARM.csv	1	9355	BEAF3	P1
BRATTON FLEMING 33kV SOLAR PARK.csv	1	9560	BRAT3	P1
CAPELANDS FARM 33kV SOLAR PARK.csv	1	9995	CAPE3	P1
DARRACOTT MOOR WINDFARM.csv	1	9035	DARM3	W1
KINGSLAND BARTON 33kV SOLAR PARK.csv	1	9730	KING3	P1
KNOCKWORTHY 33kV SOLAR PARK.csv	1	9400	KNOK3	P1

Pyworthy 33kV BSP Loads:

	PSS/E Model data						
Site CSV file (P & Q from tag rules)	No. Loads	Bus Number	Bus Name	Id	Bus Number	Bus Name	Id
ASHWATER.csv	1	7025	ASHW5	1			
CLOVELLY.csv	1	7188	CLOV5	1			
EAST CURRY.csv	1	7285	ECUR5	1			
HATHERLEIGH.csv	1	7350	HATH5	1			
HOLSWORTHY.csv	1	7379	HOLS5	1			
LAUNCESTON.csv	2	7423	LAUN5J	1	6093	LAUN5K	1
MORETONHAMPSTEAD.csv	1	7503	MORH5	1			
MORWENSTOW.csv	1	7506	MORW5	1			
NORTH TAWTON.csv	1	7985	NTAW5	1			
OKEHAMPTON.csv	1	7552	OKEH5	1			
ROADFORD.csv	1	7623	ROAD3	1			
SHEBBEAR.csv	1	7649	SHEB5	1			
STRATTON.csv	1	7712	STRA5	1			
WHIDDON DOWN.csv	1	7827	WHID5	1			

Pyworthy 33kV BSP Generation:

	PSS/E Model data			
Site CSV file (P & Q from tag rules)	No. Gens	Bus Number	Bus Name	Id
ASHWATER 33kV SOLAR PARK.csv	1	9265	ASWR3	P1
BRADFORD MANOR 33kV SOLAR PARK.csv	1	9210	BRPV3	P1
CRINACOTT FARM 33kV SOLAR PARK.csv	1	9650	CRPV3	P1
DENBROOK 33kV WIND FARM.csv	1	9635	DENB3	W1
DERRITON FIELDS 33kV SOLAR PARK.csv	1	9790	DERF3	P1
DUNSLAND CROSS 33kV WIND FARM.csv	1	10040	DUNX3	W1
EASTACOMBE FM 33kV SOLAR PARK.csv	1	9190	EAST3	P1
EAST LANGFORD 33kV SOLAR PARK.csv	1	9180	ESLA3	P1
EAST YOULSTONE 33kV WINDFARM.csv	1	9515	EYWF3	W1
FORESTMOOR WINDFARM.csv	1	8990	FORG3	W1
FOXCOMBE 33kV SOLAR PARK.csv	1	9445	FOXC3	P1
HIGHER NORTH BEER FARM SOLAR PARK.csv	1	9270	HNBF3	P1
PITWORTHY 33kV SOLAR PARK.csv	1	9625	PITW3	P1
REXON CROSS FARM 33kV SOLAR PARK.csv	1	9655	RCPV3	P1
WILLSLAND 33kV SOLAR PARK.csv	1	9185	WILL3	P1

Tiverton 33kV BSP Loads

	PSS/E Model data			
Site CSV file (P & Q from tag rules)	No. Loads	Bus Number	Bus Name	Id
BRIDGE MILLS.csv	1	7117	BRIM5	1
BURLESCOMBE.csv	1	7136	BURL5	1
CULLOMPTON.csv	1	7238	CULL5	1
DUNKESWELL.csv	1	7271	DUNK5	1
HEMYOCK.csv	1	7367	HEMY5	1
TIVERTON JUNCTION.csv	1	7733	TIVE5	1
TIVERTON MOORHAYES.csv	1	7735	TIVM5	1
TIVERTON SOUTH.csv	1	7737	TIVS5	1

Tiverton 33kV BSP Generation

	PSS/E Model data			
Site CSV file (P & Q from tag rules)	No. Gens	Bus Number	Bus Name	Id
AYSHFORD COURT FARM 33kV SOLAR PARK.csv	1	9370	AYSH3	P1
CULLOMPTON 33kV SOLAR PARK.csv	1	9830	CMPV3	P1
STONESHILL 33kV SOLAR PARK.csv	1	9850	STFA3	P1

Tiverton Moorhayes 11kV Primary

Generation values will be randomly allocated between 0 MW to the rated MW of to the two solar farms in the Tiverton Moorhayes 11kV primary between the hours of 7 am and 7pm.

The total Tiverton Moorhayes 11kV generation will be added to the Tiverton Moorhayes 11kV load from SCADA and then will be will be distributed to the 11kV individual load based on the original load distribution in the Tiverton Moorhayes 11kV PSS/E model.

Bus Number	Bus Name	Id	P%	Q%
95001	313648	1	0.15%	0.15%
95003	315525	1	0.15%	0.15%
95005	313653	1	0.04%	0.05%
95007	313651	1	0.07%	0.08%
95008	315234	1	0.02%	0.02%
95010	313687	1	0.07%	0.08%
95012	313688	1	0.05%	0.05%
95014	314886	1	0.07%	0.08%
95016	315304	1	0.02%	0.02%
95018	313683	1	0.05%	0.05%
95020	315684	1	0.05%	0.05%
95022	316138	1	0.05%	0.05%
95026	315346	1	0.02%	0.02%
95028	315346	1	0.02%	0.02%
95029	315305	1	0.05%	0.05%
95031	312403	1	0.07%	0.08%
95033	316139	1	2.14%	2.14%
95034	312401	1	0.30%	0.29%
95036	313659	1	0.05%	0.05%
95038	313673	1	0.04%	0.05%
95040	313670	1	0.04%	0.05%
95042	313675	1	0.07%	0.08%
95044	313667	1	0.04%	0.05%
95046	316275	1	0.07%	0.08%
95048	313665	1	0.07%	0.08%
95050	315258	1	0.05%	0.05%
95052	313677	1	0.07%	0.08%
95054	313679	1	0.04%	0.05%
95056	313671	1	0.04%	0.05%
95058	314885	1	0.07%	0.08%
95060	311920	1	0.07%	0.08%
95062	315782	1	1.49%	1.48%
95064	311897	1	0.07%	0.08%
95066	313817	1	0.94%	0.93%
95068	313668	1	0.07%	0.08%
95070	314889	1	0.04%	0.05%

Bus Number	Bus Name	Id	P%	Q%
95072	314890	1	0.04%	0.05%
95074	311919	1	0.30%	0.29%
95076	311728	1	0.94%	0.93%
95078	315335	1	0.07%	0.08%
95079	313650	1	0.07%	0.08%
95081	313652	1	0.07%	0.08%
95083	318054	1	2.38%	2.37%
95086	317188	1	0.07%	0.08%
95088	316538	1	0.05%	0.05%
95090	314888	1	0.07%	0.08%
95091	313850	1	0.30%	0.29%
95093	315914	1	0.05%	0.05%
95094	314523	1	0.04%	0.05%
95096	315519	1	0.07%	0.08%
95098	314887	1	0.04%	0.05%
95100	314884	1	0.04%	0.05%
95102	313678	1	0.07%	0.08%
95104	313681	1	0.07%	0.08%
95106	313680	1	0.04%	0.05%
95108	315671	1	0.05%	0.05%
95109	313647	1	0.04%	0.05%
95111	313646	1	0.07%	0.08%
95113	313649	1	0.05%	0.05%
95115	316298	1	0.15%	0.15%
95117	313656	1	0.04%	0.05%
95119	313657	1	0.07%	0.08%
95120	316341	1	0.05%	0.05%
95121	312404	1	0.15%	0.15%
95122	314525	1	0.15%	0.15%
95124	312399	1	0.04%	0.05%
95126	313499	1	0.05%	0.05%
95127	313685	1	0.04%	0.05%
95129	313682	1	0.05%	0.05%
95130	313684	1	0.07%	0.08%
95131	315699	1	0.07%	0.08%
95132	313664	1	0.04%	0.05%

Bus Number	Bus Name	Id	P%	Q%
95134	313663	1	0.07%	0.08%
95135	313945	1	0.04%	0.05%
95137	314858	1	0.07%	0.08%
95139	313654	1	0.15%	0.15%
95141	313655	1	0.07%	0.08%
95143	315663	1	0.05%	0.05%
95145	313662	1	0.07%	0.08%
95147	313674	1	0.07%	0.08%
95148	313661	1	0.04%	0.05%
95150	313660	1	0.04%	0.05%
95151	316329	1	0.05%	0.05%
95152	314891	1	0.07%	0.08%
95153	315494	1	0.04%	0.05%
95154	313686	1	0.07%	0.08%
95156	313676	1	0.07%	0.08%
95158	312402	1	0.15%	0.15%
95160	312400	1	0.15%	0.15%
95161	313672	1	0.04%	0.05%
95168	314462	1	0.04%	0.05%
95170	312148	1	0.04%	0.05%
95172	315550	1	0.07%	0.08%
95174	312133	1	0.04%	0.05%
95176	312141	1	0.15%	0.15%
95178	315452	1	0.04%	0.05%
95180	312149	1	0.15%	0.15%
95182	314464	1	0.04%	0.05%
95184	317040	1	0.15%	0.15%
95186	312144	1	0.94%	0.93%
95187	312143	1	0.15%	0.15%
95189	313410	1	0.15%	0.15%
95191	315617	1	0.05%	0.05%
95193	311804	1	0.04%	0.05%
95195	311805	1	0.30%	0.29%
95197	314380	1	0.30%	0.29%
95199	312150	1	0.04%	0.05%
95201	312134	1	0.02%	0.02%
95203	312135	1	0.05%	0.05%
95205	312652	1	0.15%	0.15%
95207	311815	1	0.07%	0.08%
95209	312140	1	0.05%	0.05%
95211	312152	1	0.07%	0.08%
95213	312155	1	0.04%	0.05%
95215	311820	1	0.07%	0.08%
95217	311819	1	0.05%	0.05%

Bus Number	Bus Name	Id	P%	Q%
95219	311821	1	0.05%	0.05%
95221	312730	1	0.02%	0.02%
95223	316034	1	0.05%	0.05%
95225	314507	1	0.07%	0.08%
95226	311812	1	0.05%	0.05%
95228	311814	1	0.04%	0.05%
95230	311780	1	0.07%	0.08%
95232	311778	1	0.07%	0.08%
95234	315739	1	0.15%	0.15%
95236	311779	1	0.04%	0.05%
95238	311782	1	0.04%	0.05%
95240	315498	1	0.05%	0.05%
95242	314212	1	0.04%	0.05%
95244	311807	1	0.04%	0.05%
95246	316825	1	0.05%	0.05%
95248	311834	1	0.05%	0.05%
95250	311833	1	0.04%	0.05%
95252	315702	1	0.05%	0.05%
95254	312192	1	0.15%	0.15%
95256	312191	1	0.05%	0.05%
95258	314228	1	0.05%	0.05%
95260	311830	1	0.07%	0.08%
95262	312197	1	0.04%	0.05%
95264	312199	1	0.02%	0.02%
95266	316992	1	0.05%	0.05%
95268	311842	1	0.04%	0.05%
95270	314211	1	0.04%	0.05%
95271	312153	1	0.07%	0.08%
95273	312154	1	0.07%	0.08%
95275	311816	1	0.05%	0.05%
95276	313621	1	0.04%	0.05%
95278	313622	1	0.07%	0.08%
95280	311818	1	0.05%	0.05%
95282	311822	1	0.05%	0.05%
95284	311824	1	0.15%	0.15%
95286	311817	1	0.05%	0.05%
95288	313860	1	0.05%	0.05%
95289	315857	1	0.05%	0.05%
95291	311841	1	0.07%	0.08%
95293	315640	1	0.05%	0.05%
95295	312188	1	0.07%	0.08%
95297	315784	1	0.04%	0.05%
95299	311828	1	0.15%	0.15%
95301	312213	1	0.05%	0.05%

Bus Number	Bus Name	Id	P%	Q%
95303	316356	1	0.05%	0.05%
95305	312196	1	0.07%	0.08%
95307	311844	1	0.15%	0.15%
95309	315883	1	0.30%	0.29%
95311	313962	1	0.15%	0.15%
95313	311855	1	0.05%	0.05%
95315	311825	1	0.04%	0.05%
95317	311826	1	0.30%	0.29%
95319	315689	1	0.05%	0.05%
95321	317131	1	0.30%	0.29%
95323	311857	1	0.04%	0.05%
95325	311827	1	0.07%	0.08%
95326	312217	1	0.04%	0.05%
95328	312215	1	0.04%	0.05%
95330	312203	1	0.07%	0.08%
95332	313806	1	0.04%	0.05%
95334	314020	1	0.05%	0.05%
95335	316915	1	2.97%	2.96%
95337	315728	1	0.05%	0.05%
95338	311852	1	0.05%	0.05%
95340	311851	1	0.07%	0.08%
95342	311863	1	0.15%	0.15%
95344	315278	1	0.05%	0.05%
95346	311845	1	0.15%	0.15%
95348	314671	1	0.05%	0.05%
95350	312221	1	0.04%	0.05%
95352	312222	1	0.04%	0.05%
95354	312220	1	0.15%	0.15%
95356	316293	1	0.07%	0.08%
95358	311853	1	0.05%	0.05%
95360	314672	1	0.07%	0.08%
95361	313913	1	0.07%	0.08%
95363	315209	1	0.04%	0.05%
95365	311850	1	0.04%	0.05%
95367	311743	1	0.07%	0.08%
95369	311823	1	0.05%	0.05%
95371	311856	1	0.60%	0.59%
95374	311865	1	0.05%	0.05%
95376	311864	1	0.15%	0.15%
95378	311746	1	0.07%	0.08%
95380	311744	1	0.07%	0.08%
95382	313519	1	0.07%	0.08%
95384	311742	1	0.07%	0.08%
95386	311854	1	0.05%	0.05%

Bus Number	Bus Name	Id	P%	Q%
95388	311860	1	0.07%	0.08%
95390	311862	1	0.30%	0.29%
95392	311829	1	0.07%	0.08%
95394	314540	1	0.05%	0.05%
95395	311840	1	0.15%	0.15%
95397	314395	1	0.15%	0.15%
95399	311871	1	0.04%	0.05%
95401	313515	1	0.05%	0.05%
95403	311861	1	0.04%	0.05%
95404	314676	1	0.04%	0.05%
95405	311866	1	0.04%	0.05%
95407	311867	1	0.05%	0.05%
95409	314479	1	0.15%	0.15%
95410	311859	1	0.05%	0.05%
95412	315132	1	0.04%	0.05%
95414	312210	1	0.07%	0.08%
95416	312211	1	0.04%	0.05%
95418	311739	1	0.30%	0.29%
95420	315577	1	0.15%	0.15%
95422	312209	1	0.07%	0.08%
95424	311836	1	0.15%	0.15%
95426	311835	1	0.15%	0.15%
95428	311873	1	0.15%	0.15%
95430	313500	1	0.30%	0.29%
95431	315957	1	0.07%	0.08%
95433	316077	1	1.31%	1.30%
95435	311869	1	0.05%	0.05%
95437	311872	1	0.30%	0.29%
95439	311870	1	0.15%	0.15%
95441	311839	1	0.07%	0.08%
95442	311837	1	0.15%	0.15%
95444	312355	1	0.30%	0.29%
95446	314286	1	0.60%	0.59%
95448	316622	1	0.15%	0.15%
95450	316621	1	0.15%	0.15%
95452	316594	1	0.05%	0.05%
95454	316148	1	0.15%	0.15%
95456	315916	1	0.15%	0.15%
95458	316207	1	0.07%	0.08%
95460	311721	1	0.07%	0.08%
95462	311718	1	0.15%	0.15%
95464	311731	1	0.30%	0.29%
95466	311712	1	0.04%	0.05%
95468	216963	1	0.07%	0.08%

Bus Number	Bus Name	Id	P%	Q%
95470	311720	1	0.07%	0.08%
95472	311716	1	0.15%	0.15%
95474	311717	1	0.07%	0.08%
95476	313400	1	0.07%	0.08%
95478	311732	1	0.07%	0.08%
95480	315126	1	0.15%	0.15%
95482	314698	1	0.15%	0.15%
95484	311722	1	0.02%	0.02%
95486	311723	1	0.07%	0.08%
95488	315469	1	0.30%	0.29%
95490	316021	1	0.30%	0.29%
95492	312351	1	0.05%	0.05%
95494	315517	1	0.05%	0.05%
95496	311715	1	0.89%	0.89%
95498	311726	1	0.60%	0.59%
95499	311727	1	1.49%	1.48%
95503	311713	1	0.07%	0.08%
95505	312356	1	2.38%	2.37%
95507	311734	1	0.07%	0.08%
95509	316307	1	0.07%	0.08%
95511	317196	1	4.46%	4.45%
95514	312352	1	0.60%	0.59%
95516	316765	1	0.94%	0.93%
95517	316847	1	2.38%	2.37%
95518	312202	1	0.07%	0.08%
95520	312185	1	0.02%	0.02%
95522	314583	1	0.15%	0.15%
95524	312201	1	0.07%	0.08%
95526	316941	1	1.49%	1.48%
95528	311781	1	0.04%	0.05%
95529	316918	1	0.94%	0.93%
95531	317212	1	3.57%	3.56%
95534	312357	1	1.49%	1.48%
95536	312353	1	2.38%	2.37%
95538	317265	1	0.15%	0.15%
95539	317021	1	0.60%	0.59%
95540	311847	1	0.30%	0.29%
95541	312014	1	0.05%	0.05%
95543	316076	1	0.05%	0.05%
95544	313847	1	0.15%	0.15%
95545	311777	1	0.07%	0.08%
95547	316425	1	0.30%	0.29%
95549	315291	1	0.05%	0.05%
95551	311785	1	0.07%	0.08%

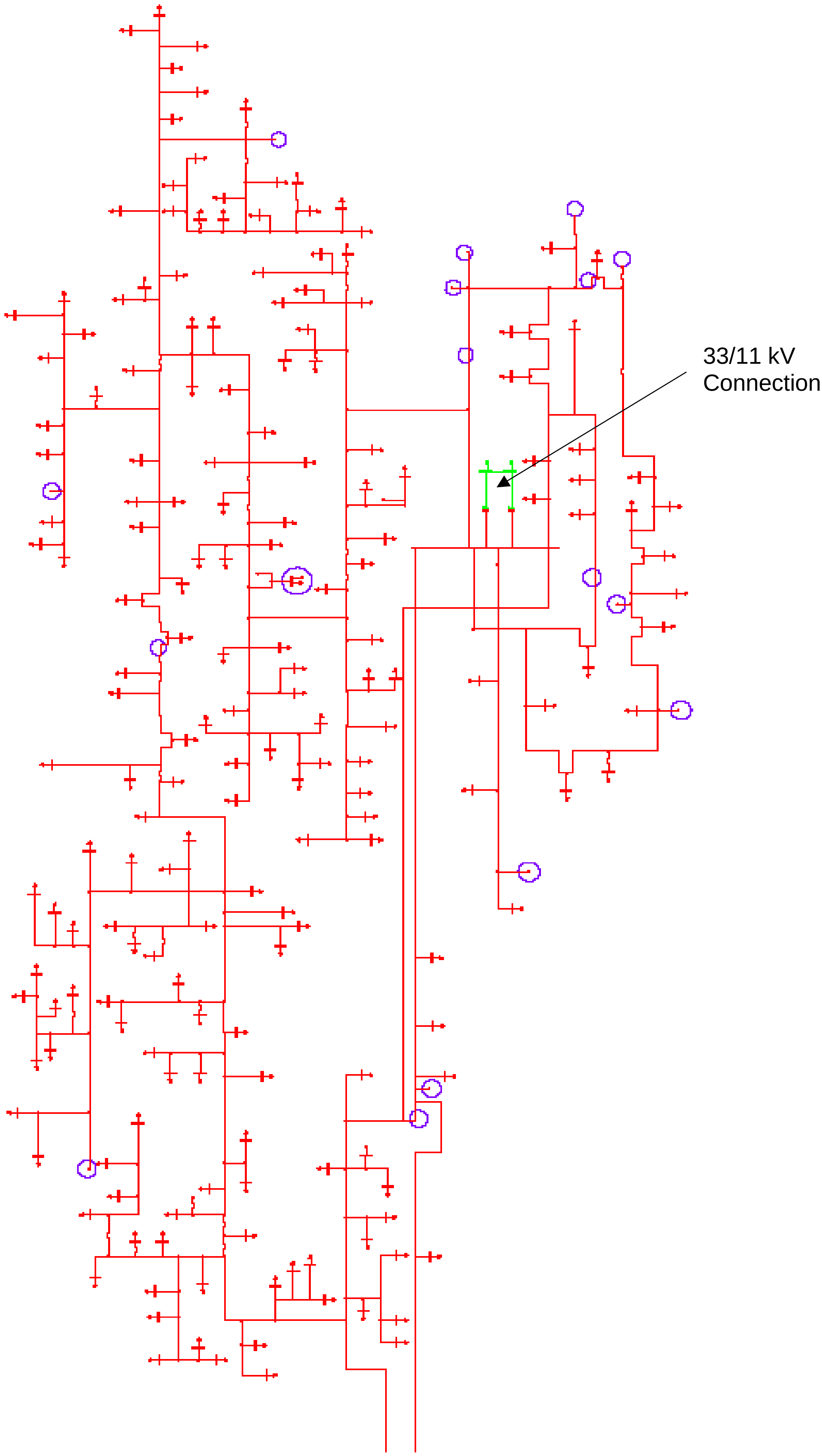
Bus Number	Bus Name	Id	P%	Q%
95553	311783	1	0.04%	0.05%
95555	312350	1	0.04%	0.05%
95556	315800	1	0.05%	0.05%
95557	311868	1	0.30%	0.29%
95558	312212	1	0.04%	0.05%
95559	315040	1	0.07%	0.08%
95560	317364	1	0.15%	0.15%
95562	317385	1	0.30%	0.29%
95564	316954	1	0.05%	0.05%
95565	312729	1	0.15%	0.15%
95567	312208	1	0.07%	0.08%
95569	312216	1	0.07%	0.08%
95571	317412	1	0.07%	0.08%
95572	312195	1	0.30%	0.29%
95574	312223	1	0.04%	0.05%
95576	311745	1	0.07%	0.08%
95578	315005	1	0.05%	0.05%
95579	315004	1	0.07%	0.08%
95581	311741	1	0.07%	0.08%
95583	316658	1	0.05%	0.05%
95584	316334	1	0.05%	0.05%
95585	314108	1	0.15%	0.15%
95586	315150	1	0.15%	0.15%
95588	312206	1	0.07%	0.08%
95590	312207	1	0.30%	0.29%
95591	312219	1	0.04%	0.05%
95593	313689	1	0.07%	0.08%
95594	313520	1	0.07%	0.08%
95595	313912	1	0.07%	0.08%
95597	315314	1	0.07%	0.08%
95599	314214	1	0.30%	0.29%
95601	311874	1	0.04%	0.05%
95603	316042	1	0.07%	0.08%
95605	316041	1	0.05%	0.05%
95606	316556	1	0.15%	0.15%
95608	311719	1	0.07%	0.08%
95612	311737	1	0.30%	0.29%
95614	315068	1	0.05%	0.05%
95615	313750	1	0.07%	0.08%
95616	311738	1	0.15%	0.15%
95617	311735	1	0.07%	0.08%
95618	311733	1	0.15%	0.15%
95620	315374	1	0.05%	0.05%
95622	314807	1	0.07%	0.08%

Bus Number	Bus Name	Id	P%	Q%
95624	311729	1	0.07%	0.08%
95626	311730	1	0.15%	0.15%
95627	315424	1	0.60%	0.59%
95628	213544	1	0.07%	0.08%
95630	316970	1	0.05%	0.05%
95632	213545	1	0.04%	0.05%
95634	213798	1	0.04%	0.05%
95635	316393	1	0.05%	0.05%
95637	316394	1	0.07%	0.08%
95638	316912	1	0.07%	0.08%
95639	312160	1	0.05%	0.05%
95641	312159	1	0.04%	0.05%
95643	316908	1	0.05%	0.05%
95644	313878	1	0.05%	0.05%
95646	311811	1	0.15%	0.15%
95648	312147	1	0.04%	0.05%
95649	312145	1	0.02%	0.02%
95651	312146	1	0.04%	0.05%
95652	311806	1	0.07%	0.08%
95654	312158	1	0.15%	0.15%
95656	314584	1	0.04%	0.05%
95657	315458	1	0.05%	0.05%
95661	312161	1	0.15%	0.15%
95665	312157	1	0.15%	0.15%
95667	312156	1	0.05%	0.05%
95669	312142	1	0.05%	0.05%
95671	312527	1	0.15%	0.15%
95675	311808	1	0.04%	0.05%
95676	313854	1	0.15%	0.15%
95678	311784	1	0.15%	0.15%
95680	315207	1	0.05%	0.05%
95682	315274	1	0.05%	0.05%
95684	315710	1	0.07%	0.08%
95685	312163	1	0.05%	0.05%
95687	312162	1	0.07%	0.08%
95688	312151	1	0.30%	0.29%
95690	312136	1	0.04%	0.05%
95692	312139	1	0.05%	0.05%
95693	312190	1	0.15%	0.15%
95695	312138	1	0.07%	0.08%
95697	312137	1	0.15%	0.15%
95698	315226	1	0.05%	0.05%
95700	311813	1	0.07%	0.08%
95702	312526	1	0.07%	0.08%

Bus Number	Bus Name	Id	P%	Q%
95704	316453	1	0.05%	0.05%
95706	315319	1	0.07%	0.08%
95707	312189	1	0.05%	0.05%
95708	312187	1	0.04%	0.05%
95710	312193	1	0.04%	0.05%
95711	311832	1	0.05%	0.05%
95713	316441	1	0.05%	0.05%
95715	316013	1	0.05%	0.05%
95716	312186	1	0.07%	0.08%
95717	312200	1	0.02%	0.02%
95719	312198	1	0.05%	0.05%
95720	315108	1	0.04%	0.05%
95722	311846	1	0.30%	0.29%
95724	311843	1	0.05%	0.05%
95726	316061	1	0.05%	0.05%
95727	315956	1	0.07%	0.08%
95729	315444	1	0.05%	0.05%
95730	314258	1	0.07%	0.08%
95732	312194	1	0.04%	0.05%
95733	312224	1	0.04%	0.05%
95734	312214	1	0.05%	0.05%
95736	312218	1	0.07%	0.08%
95737	312204	1	0.04%	0.05%
95739	312205	1	0.07%	0.08%
95741	311858	1	0.07%	0.08%
95743	311848	1	0.15%	0.15%
95745	311849	1	0.15%	0.15%
95746	316620	1	0.05%	0.05%
95756	316524	1	0.94%	0.93%
95757	316366	1	2.38%	2.37%
95759	316365	1	0.94%	0.93%
95761	315875	1	1.49%	1.48%
95763	316706	1	0.60%	0.59%
95765	316200	1	2.38%	2.37%
95768	316859	1	0.94%	0.93%
95770	316858	1	1.49%	1.48%
95772	314443	1	0.94%	0.93%
95774	317020	1	0.94%	0.93%
95779	312380	1	0.94%	0.93%
95783	316532	1	0.15%	0.15%
95788	315579	1	0.30%	0.29%
95793	315089	1	0.94%	0.93%
95795	313751	1	1.49%	1.48%
95797	313658	1	1.49%	1.48%

Bus Number	Bus Name	Id	P%	Q%
95799	312385	1	1.49%	1.48%
95801	312384	1	0.94%	0.93%
95803	313833	1	0.89%	0.89%
95805	312382	1	0.60%	0.59%
95807	314454	1	0.94%	0.93%
95809	312383	1	1.49%	1.48%
95811	316888	1	1.49%	1.48%
95815	314400	1	1.49%	1.48%

Appendix E – Tiverton Moorhayes 11kV PSS/E SLD



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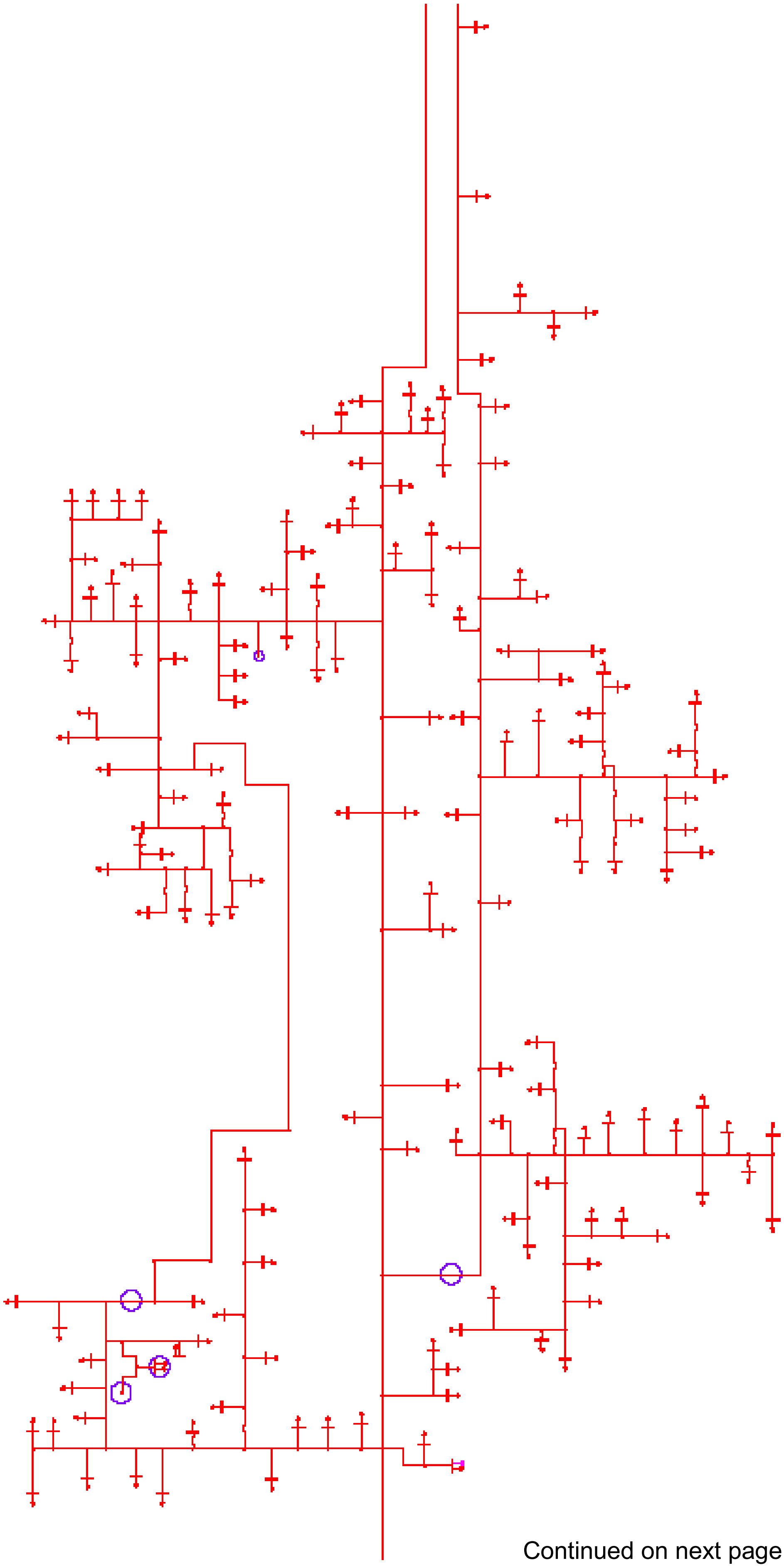

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