The Design and Deployment of a Quadrature Booster on UK Power Networks' 33kV Distribution Network

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Abstract

Although Quadrature Boosters are a mature technology on electricity transmission networks having developed in the 1960s, available information and references show that, prior to UK Power Networks' innovative Quadrature Booster trial that commenced in January 2012 none had been deployed on the distribution network.

This paper presents the UK Power Networks experience in the design and deployment of a Quadrature Booster at 33kV distribution network through the 'Flexible Plug and Play' project. The paper particularly focuses on the Quadrature Booster design characteristics, the network single line diagram and the layout adopted, and the control and operational strategy considerations to effectively manage an identified network constraint using this device. The challenges in modelling studies and testing on such a device are also presented. The paper also discusses (1) the identified network constraint, (2) available options to address the problem, (3) how the network constraint is being addressed or managed, (4) the design, installation, testing and commissioning of this innovative asset to explain the process which UK Power Networks, the involved project partners and contractors undertook, and (5) the benefits and learning accrued from delivering the Quadrature Booster solution.

Introduction

It is widely recognised that 'smarter' ways of managing distribution network assets include improved utilisation of existing assets. The intended effect is to defer the immediate need for traditional reinforcement where possible.

UK Power Networks was awarded funding in 2011 under Ofgem's (GB Energy Regulator) Low Carbon Network Fund mechanism, for the 'Flexible Plug and Play' project. The project aims to facilitate faster and cheaper connection of anticipated growth in distributed generation onto the distribution network without the need for traditional network reinforcement by, instead, managing network constraints and maximising network utilisation. The project will achieve this through the integration of smart devices, smart applications and smart commercial arrangements. Flexible Plug and Play is a £9.7 million project, sited in UK Power Networks' Eastern Power Network covering parts of Cambridgeshire and Norfolk. The project commenced in January 2012. It is a three year project with the first 18 months set for design and deployment phase, and the second 18 months phase dedicated for structured trials. It will conclude in December 2014.

Quadrature Boosters are phase shifting transformers used to control the flow of active power in electrical networks. They can be used to either enhance (boost) or restrict (buck) flow of active power as required. They consist of two separate three-phase transformer units specially connected; a shunt unit and a series unit. The shunt connected transformer is also called the main or exciting transformer and is fitted with an On-Load Tap Changer to extract a component of system voltage typically in the range of ±20% of the nominal system voltage (on 33kV, 132kV, 275kV or 400kV systems). The voltage component is induced in quadrature i.e. 90 degrees to the system base voltage in the series transformer to affect the output voltage angle. The series unit is a coupling transformer and is connected in series of the main transmission circuit and would ideally have a rating equivalent to the circuit rating.

The control of power flow using Quadrature Boosters follows basic principles in electrical power systems. When power flows between two systems, there is a voltage drop and a phase angle shift between the source and the load that depends on the magnitude and power factor of the load current. If the systems are connected together in two or more parallel paths so that a loop exists, any difference in impedances will cause unbalanced line loading [1].

Quadrature Boosters are a mature technology at transmission level. Over the years, Quadrature Boosters have been used to control power flow on parallel three-phase transmission networks across the world where capacity is constrained by one of the parallel circuits. They have been used in the UK transmission network since 1969 when the first 275kV unit was installed [2]. By 2011 a total of nineteen Quadrature Boosters were connected to National Grid's network at 275kV (750MVA – 860MVA units) and at 400kV (2000MVA – 2750MVA units) [3]. Other examples include Quadrature Boosters on interconnectors between France – Italy and the Netherlands – Germany [4].

The use of a Quadrature Booster on the distribution network is one of the smart devices being trialled within the Flexible Plug and Play project. For this purpose, a 30MVA rated Quadrature Booster was installed at UK Power Networks' Wissington 33kV substation to overcome an existing constraint due to sub-optimal load sharing on two 33kV parallel circuits emanating from the substation. The Wissington 33kV substation is located within the Wissington British Sugar site in Norfolk, UK. The study case is an interconnected 33kV network. Interconnected networks give rise to power flows towards the lowest source impedance, which can result in thermal overloads.

Wissington 33kV Distribution Network Problem

The Wissington 33kV substation provides a point of connection for Wissington British Sugar, a beet processing factory which also operates a Combined Heat and Power (CHP) electricity generation plant that generates power for the local factory demand and for export of excess power to the 33kV distribution network. For some time, the generation output has been constrained to seasonal export limits due to thermal constraint on one of the 33kV circuits. Under Standard Running Arrangement shown in Figure 1 below, the Wissington site connection is via three 33kV circuits of equal thermal rating, which runs interconnected with four 132/33kV grid sites – March Grid, Swaffham Grid, Walsoken Grid, and King's Lynn South Grid. The Quadrature Booster trial seeks to demonstrate the smart approach to network management to address the thermal constraint.

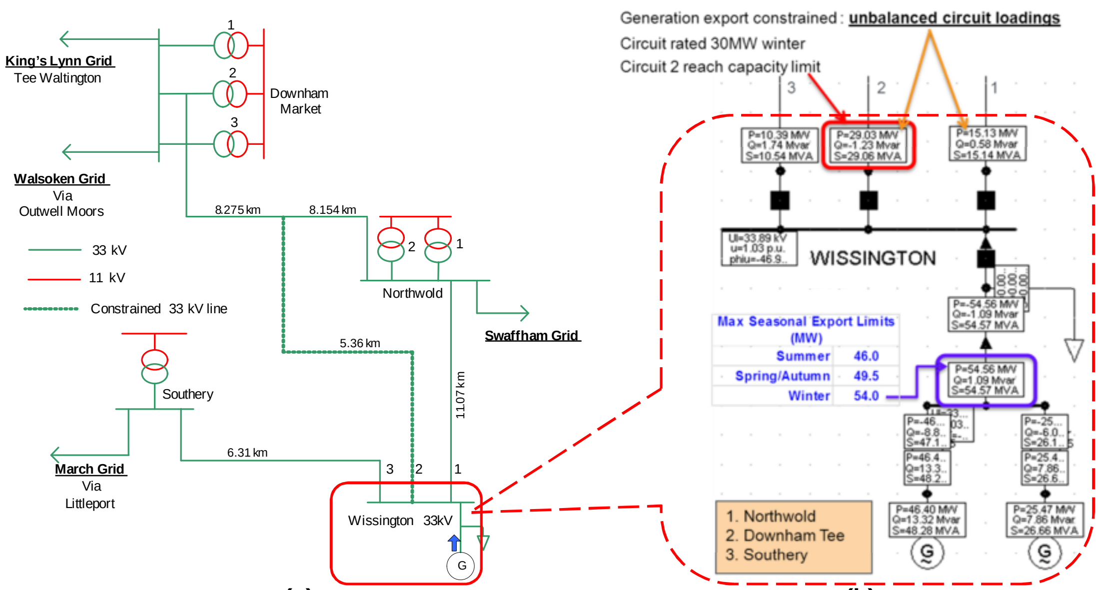

Figure 1: (a) Simplified Wissington 33kV Network, and (b) related Load Flow indications

The Wissington CHP installed total capacity is shown below:

- Generator – 95.2MVA / 0.85PF (80.9MW)
- Turbine – 70MW

Generation export is shared across the three circuits according to their electrical impedance which, amongst other factors, is related to their relative route lengths. The Northwold No.1 (11km) and Downham Market teed No.2 (5.36km) circuits operate in parallel with differing source impedances resulting in unbalanced load sharing. Power transfer is limited by the path of least impedance – the teed circuit. This constraint restricts the seasonal export to approximately 54MW in winter which is 23% below the installed generator turbine capacity (70MW).

The CHP generation normally runs at full export during the annual sugar beet campaign period which generally stretches from middle September to March. This is when the constraint conditions usually occur. The full capacity of all the lines cannot be used because, as shown on the load flow in Figure 1 above, the teed circuit reaches its full capacity limit when the other two lines are loaded to approximately half their full capacity. To manage this constraint the CHP generation is equipped with a Distributed Control System (DCS), a protection and monitoring scheme, which allows British Sugar, as part of the 'Use of System and Connection Agreement', to operate a generator automatic turndown scheme which takes into account the Wissington 33kV outgoing feeder circuit breakers' status as well as the analogue measurements on the lines [5]. The generator automatic turndown scheme is activated to reduce the CHP plant output in order to prevent the Downham Market teed No.2 circuit exceeding thermal limits.

British Sugar confirmed that there are opportunities across the year when they could operate the CHP plant at higher generation capacity but are unable to do so because of the thermal restriction from the electrical load flow along the Downham Market teed No.2 circuit. In the past UK Power Networks has considered enquiries for increasing the export limits. The following two 'Business as Usual' options and indicative costs were offered as the feasible options:

1. Build a new 33kV overhead line from Wissington to Swaffham Grid at a cost of circa £3 million, liable to a planning consent (Section 37) and a potentially lengthy public enquiry process estimated to take at least 3 years.
2. Lay a new 33kV underground cable from Wissington to Swaffham Grid at a cost of circa £6 million, but would not be subject to planning consent (Section 37).

None of the solutions above were considered viable cost effective business opportunity to British Sugar and therefore British Sugar continue to run the CHP plant within the prevailing export constraints. To increase utilisation of the existing 33kV line capacities and provide a cost effective solution, it is desirable to force the Northwold No.1 circuit to carry more power regardless of its higher impedance. In this framework therefore, a device that would relieve congestion on the Downham Market teed No.2 circuit is required.

The Technical Solution

The Quadrature Booster trial was primarily driven by the need to alleviate thermal constraint arising from load imbalance between two parallel circuits. Subject to confirmed capacity headroom created by the trial, this could be used to increase generation export limit placed on the Wissington CHP generation, should British Sugar succeed in applying for a review of the existing export/import arrangement. It is reported that the Wissington CHP plant achieves the best CHP rating under the UK government CHP environmental quality assurance scheme [6]. As such, further increments of generation exports can provide valuable contribution to the electricity generation fleet.

To increase utilisation of the 33kV line capacities out of Wissington, the parallel circuits required to be augmented with series-connected impedance addition/reduction capabilities. The added (or compensated) impedance is chosen such that the current is shared between the parallel lines. Two possible conventional options were considered:

1. Use of a series reactor to boost impedance in the lower impedance line. This was discounted because a series reactor would add a predetermined fixed reactance in the lower impedance circuit to limit power flow to a desired level. Series reactors are mainly used as current limiting devices to reduce fault currents to required levels.

2. Use of series capacitors connected in the higher impedance circuit (to lower the impedance). This was also discounted because, compared to reactors, a number of additional items of equipment are required in series capacitor installations to prevent damaging over-voltages, which can occur during power system faults.

It was also considered that due to increased generation activities in the area, it is possible that more generation would connect on this network in the future and this would require a new impedance value to be added. A Quadrature Booster was considered the preferred 'smarter' solution. Load balancing on the lines is achieved through discrete on-load controllable steps using a mechanical tap changer, in accordance with the principle that active power flow (P) through a transmission line under steady state conditions is proportional to the sine of the difference in voltage phase angle of the sending (Vs) and receiving (Vr) end, and inversely proportional to the apparent reactance of the line, Xℓ [7].

$$P = \frac{|Vs|.|Vr|\sin\delta}{X\ell}$$

By manipulating the voltage phase angle δ by inserting a phase shift angle ±α using a Quadrature Booster that can either increase or decrease the original angle δ the circuit impedance and therefore the power flow can be controlled. The reactive power is also influenced but to a less extent.

Control of the active power can also be achieved by manipulating the voltages using asymmetrical phase shifting transformers. This method has a large impact on the reactive power, and is therefore deemed less effective compared to changing the phase angle of the voltages [8]. A phase shifting transformer produces an output voltage with an altered phase angle and amplitude compared to the input voltage. A Quadrature Booster creates an output with an altered phase angle only with no significant change to voltage amplitude compared to the input voltage. A true Quadrature Booster has the injected -90 degree quadrature remaining constant throughout the tap range, and was used for the Wissington trial.

Quadrature Booster Design

The 33kV lines out of Wissington substation are 200mm^2 Steel Cored Aluminium (SCA) conductor construction type with static seasonal ratings of 23MVA and 30MVA in summer and winter respectively. It is assumed that the full rated 30MVA (winter) of the line to which the Quadrature Booster is connected flows through one winding of the series transformer. The rating of the shunt-connected transformer is less than rated power as it is required to supply reactive compensation only. The Quadrature Booster rating capacity is therefore 30MVA to match the line rating.

A number of assumptions were made in the preliminary studies to model and calculate the effect of the Quadrature Booster on power flow, fault levels and protection system using the power systems modelling software package Power Factory (Version 14.0) from DigSILENT. The model comprises the 132kV networks connected to Walpole Grid Supply Point, 33kV networks, and 33/11kV transformers, including loads and distributed generators. Quadrature Boosters can be modelled in two ways:

1. Detailed modelling requires that both the series and shunt transformers must be simulated. This would provide detailed analysis of what is happening between the interconnections of the series, exciting, regulating and booster windings.
2. Using a two winding transformer is considered a sufficient approximation of a Quadrature Booster for load flow, short circuits, and time domain simulations. This is the option which was used to model the Wissington Quadrature Booster.

The modelling and design challenges were compounded by the fact that there were no known Quadrature Boosters or phase shifting transformers being used at this rating and voltage. Additionally, the Quadrature Booster is not a standard element within UK Power Networks' Power Factory modelling. As such, a template was required to enable it to be effectively modelled. Initially a typical template was adopted and customised to suit the Wissington Quadrature Booster parameters.

From modelling studies and protection calculations, and feasibility evaluations regarding design and manufacture, the initial Quadrature Booster characteristics were specified by UK Power Networks. The indicative functional requirements were provided as modelling data Table, and included design parameters shown in Table 1.

Nominal frequency	50Hz
Nominal Quadrature Booster voltages	33kV / 33kV
Nominal throughput power	30MVA
Overload current	575A – limited to line winter rating
Rated impedance at nominal tap	6.34% on 30MVA at full tap (buck/boost)
Voltage shift type	Asymmetrical
On load regulation angle	± 12^o max
Short circuit current rating	25kA (busbar fault current = 10.7kA)
Cable connection type	Cable box on both ends

Table 1: Initial functional parameter specification for the Quadrature Booster

The following were some of the key initial assumptions made:

- Input terminals are connected to the source (Wissington 33kV busbar)
- A single core type Quadrature Booster in a single tank
- Quadrature Booster with zero series impedance at nominal tap
- Phase to phase faults covered by a differential overcurrent scheme
- Existing distance protection and directional earth fault protection transferred to new current transformers and voltage transformers on the line side of the Quadrature Booster
- Surge arrestors fitted to the overhead line connection

The maximum no load impedance was calculated to comply with existing protection regimes on the network. Initially it was assumed that it will be feasible for the manufacturer to design a single core Quadrature Booster. For this type of Quadrature Booster, the series impedance is zero at nominal tap. The maximum voltage vector was assumed to be 20% (0.2pu), giving a maximum angle of $\sin^{-1}(0.2)$ = 11.5^{o}. Network studies showed maximum impedance (Z_m) at full tap (buck/boost) of 2.3 ohm between pairs of windings. This is the difference in impedance to the tee point from Northwold or Wissington. It was therefore deemed a suitable value for an equivalent reactor that could be expected to equalise the load currents between Northwold No.1 and Downham Market teed No.2 circuits. The transformer rated impedance in percent (%Z) is given by the following formula.

$$\%Z = Zm \times \frac{Irated}{Vrated} \times 100\% = Zm \times \frac{100xMVA}{kV \times kV}$$

An impedance of 2.3 ohm equates to: $\%Z = 2.3 \times \frac{100\times 30}{33\times 33} \approx 6.34\%$ on 30MVA

Feedback from the manufacturer showed that it would be technically challenging to design a suitable single core Quadrature Booster because such a unit is prone to fault current withstand problems [9]. To have a single core Quadrature Booster sensibly sized with a reasonable sized on-load tap changer, the manufacturer indicated that the busbar short circuit current would have to be limited to around 7kA, which is below the available 10.7kA fault current level at Wissington 33kV busbar. Instead with a two core Quadrature Booster, it was possible to work to the 25kA equipment fault rating, and at lower than 6.34% maximum impedance.

During further development of the Quadrature Booster, detailed Specifications and Technical Schedules were prepared based on inputs from UK Power Networks and the project partners, and relevant technical standards. Stage reviews were carried out throughout the design, manufacturing and testing of the Quadrature Booster. A two core three-phase Quadrature Booster complete with new on-load tap changer was designed and installed in series on the 'weaker' Downham Market teed No.2 circuit. A simplified single line diagram, showing the Quadrature Booster connected using a 5-panel 33kV switchboard, is shown in Figure 2 below.

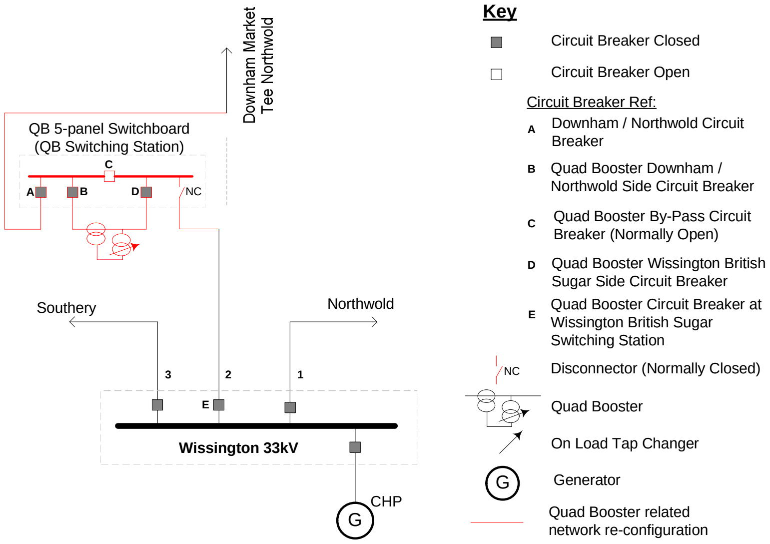

Figure 2: Simplified Single Line Diagram

The intended effect is to buck real power flowing through the Downham Market teed No.2 circuit and force additional power to flow through Northwold No.1 circuit to achieve a closely balanced load sharing between the two circuits without exceeding thermal limits. The network configuration shown in Figure 2 allows the following operational flexibilities:

- Normal operation under Standard Running Arrangement with the by-pass circuit breaker OPEN
- When the Quadrature Booster is out of service (circuit breakers B and D OPEN), the connection to Downham Market teed No.2 circuit is in service through the by-pass circuit breaker (CLOSED).

Protection Design

Installation of a Quadrature Booster on the interconnected 33kV network required a protection rethink. The load flow is subject to changes in voltages and impedances. The network already has some existing issues with protection setup. Protection studies showed that a Quadrature Booster could be connected to the Downham Market teed No.2 circuit, using the existing distance protection settings, and the existing directional earth fault protection.

The protection of the Quadrature Booster and its connection to the network was designed Business as Usual by UK Power Networks and Carillion Utility Services delivery team with validation support from Alstom Grid and Mott MacDonald. The overall protection was split into the following schemes:

1. Quadrature Booster primary windings unit protection,
2. Quadrature Booster secondary windings unit protection,
3. Overfluxing protection,
4. Gas and oil operated protection,
5. Quadrature Booster earth fault backup protection,
6. Busbar unit protection,
7. Overall Quadrature Booster and busbar backup protection.

These schemes overlap with each other and with the existing line and switchgear protection schemes to create the necessary cross over as well as discrimination required for 33kV protection schemes.

A number of challenges were encountered. The Quadrature Booster primary and secondary windings unit protection schemes and the earth fault back up scheme are based on recommendations within the IEEE C57.135-2001 Standard. However it was noted that the current transformer wiring in the standard for the secondary winding protection had an error when applied to this Quadrature Booster. This was resolved and a modern relay was used to simplify the connection by applying the necessary correction factors internally. External support (from Alstom) was received in modelling the Quadrature Booster and the unit protection schemes using a Real Time Digital Simulator (RTDS) to validate the stability and sensitivity of the protection design. The RTDS equipment can model networks and protection functions in real time, and is usually used to develop and test relays. It can also be used to carry out work on modelling transmission and distribution systems before they are developed, or if unusual circumstances require investigation.

Overfluxing protection was applied to reduce the risk of damage caused by core flux going out of limit under certain running conditions. This is an issue that is likely to be present if operating on the extremities of the tapping range and under load imbalance or open circuit faults on the 33kV network. Because of the risk of overfluxing, tap 18 and 19 are blocked and the tap position operations include the following safeguards:

- Electrical controls to prevent electrically raising (tap raise) of the tap changer beyond tap 17, and lowering (tap lower) below tap 10 (which is boost region – and not required for the Wissington application).
- An indication/trip signal is provided should an operator manually (via hand crank) increase the tap from position 17 to 18, or lower from position 10 to 9.

The gas and oil operated protection schemes applied, such as Buchholz and Pressure Relief Device, are in line with standard practice for primary and grid transformers. An additional scheme was also introduced to carry out online condition monitoring through the bespoke Dynamic Rating Management for transformers (DR-C50) and online Dissolved Gas Analyses (DGA) by a Morgan Schaffer Calisto 9 device. This enhanced monitoring will help in assessing the suitability of the Quadrature Booster design in this trial project.

The busbar unit protection scheme comprises of two zones of circulating current protection to detect and discriminate for fault in the 33kV switchgear. The overall Quadrature Booster and busbar backup protection is a differential scheme using a single IDMT relay. This provides a specific zone backup scheme for both scenarios – when the Quadrature Booster is in service or being bypassed.

Control of the phase shifting is accomplished using a TapCON260 relay configured specifically for the Wissington Quadrature Booster operation. In order to build an interface with the existing Wissington generator protection, a 'tap in progress' volt-free indication signal was provided to British Sugar to trigger masking the generator far field protection scheme when the Quadrature Booster is changing tap position, and ensure the generator ignores any changes in the line currents for which it would normally conceive as line faults and respond by initiating a reduction in generation output. Also, a number of operational restrictions were built into the Quadrature Booster Engineering Operating Standard. For example, it is necessary to set the Quadrature Booster to nominal tap, when the Northwold No.1 circuit is out of service (isolated), leaving a low fault level in-feed to the Downham Market teed No.2 circuit from Wissington.

Quadrature Booster architecture

The diagram below shows simplified scheme architecture for the Wissington Quadrature Booster.

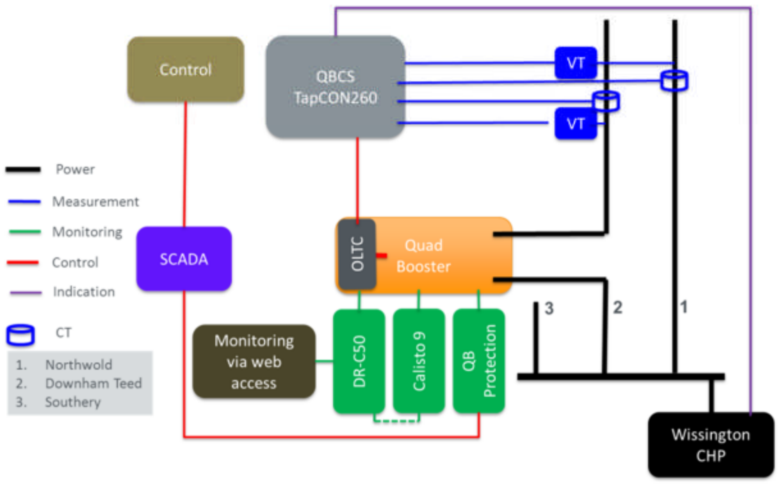

Figure 3: Simplified Quadrature Booster architecture

The Quadrature Booster Control System (QBCS) controls the active power (MW) flows in order to achieve improved power flow sharing between Northwold No.1 and Downham Market teed No.2 circuits, by comparing the power flows in the two circuits and tapping up or down to minimise the power difference between the two circuits. The current reference is provided by looping into the instrumentation single phase current transformer (CT) circuit on each of the lines. The voltage reference is provided by tapping into the non-protection part of the voltage transformer (VT) circuit on each of the lines. The VT is installed on the load side of the Quadrature Booster in the case of line 2. If the current or voltage value is missing from any one of the controlled circuits (Northwold No.1 and/or Downham Market teed No.2), the QBCS is programmed to revert to fail safe mode by returning the on-load tap changer to nominal tap.

Features of the Flexible Plug and Play Quadrature Booster

"Asymmetric Quadrature Booster" concept (small phase angle shift) was used. Figure 4 below shows pictures of the general views of the Quadrature Booster in 3-dimensional design, and on test bay at factory. Two-core design with its flexibility to control on-load tap changer step voltage and current was adopted. Due to the small throughput power and voltage rating, the shunt and series transformer units were housed in the same tank, together with the on-load tap changer. The physical size of the Quadrature Booster is approximately that of a 30MVA primary substation transformer.

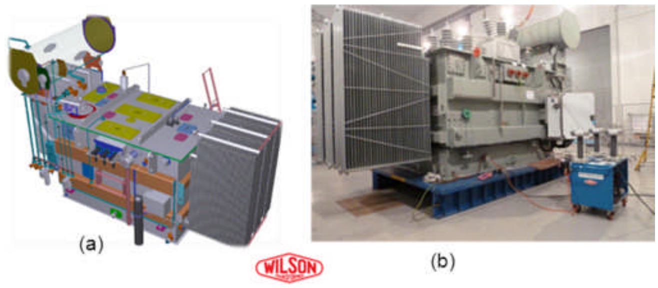

Figure 4: General views – (a) 3D visual; and (b) in test at the factory (Jan 2013)

The windings were designed for the worst short circuit forces at the nominal tap position when the main transformer offers negligible reactance. Full type testing was undertaken at the Factory Acceptance Testing, including lightning impulse which was tested with the main and series transformers connected inside the tank and voltage applied in turn to the supply and load terminals. Specified phase angle shift under load was estimated based on expected percentage regulation under site power factor and load testing was carried out at unity power factor under no load.

Deployment

The Quadrature Booster was delivered in partnership with Wilson Transformer Company and Fundamentals. Wilson Transformer Company designed and manufactured the Quadrature Booster at their factory in Melbourne, Australia. The Quadrature Booster was delivered on site at Wissington (UK) in April 2013. With support from Maschinenfabrik Reinhausen (MR), Fundamentals supplied and commissioned the QBCS based on MR's TapCON260 relay. UK Power Networks' internal Capital Programme and Integrated Delivery Team (Carillion Utility Services) carried out the design, and construction and installation works on site. Civil and mechanical construction works commenced in January 2013. The Quadrature Booster was commissioned in July 2013.

(a) (b) (c)

Figure 5: (a) Delivery to site (Apr 2013), (b) during construction (May 2013), and (c) as installed

The installation of a Quadrature Booster on existing 33kV network at Wissington had a number of implications to content with – system protection, control, and space requirements.

The DR-C50 was installed in a wall mounted cubicle measuring 600 X 600 X 350mm and is located in the switchroom for convenient connection to the CTs and VTs. It is designed to perform condition and performance monitoring of the Quadrature Booster. It also monitors tap changer performance – tap position statistics, motor energy monitoring, waveform capturing of the motor voltage and current during a tap change (which requires inputs from the on-load tap changer drive circuits, on the transformer). The Calisto 9 DGA device is mounted on the Quadrature Booster, and the data is provided via the standard DR-C50 webpages, in a similar manner to the other existing DRMCC sites within the UK Power Networks' distribution network where Wilson Transformer Company UK has fitted similar installations. The C50 version (DR-C50) is a new device that required configuration for the Quadrature Booster – and falls into the innovation category.

<u>Test</u>

The trial will monitor:

- Phase angle of incoming circuit to the Quadrature Booster
- Phase angle of output of Quadrature Booster
- VT and CT's of the circuits – which gives the voltage, current, and enable real power, reactive power to be derived

Expected Network Benefits

Tests on the Quadrature Booster connected live on the network were carried out in August 2013. As comparatively shown in Figure 6 and Figure 7 below, the test results corroborate indications from modelling that showed that balancing the load through the Northwold No.1 and Downham Market teed No.2 circuits achieves approximately 10MW of additional capacity headroom at the Wissington 33kV network transfer boundary. The additional network capacity provides an opportunity for the CHP generation to potentially increase power export or connection of other potential generation schemes down the lines.

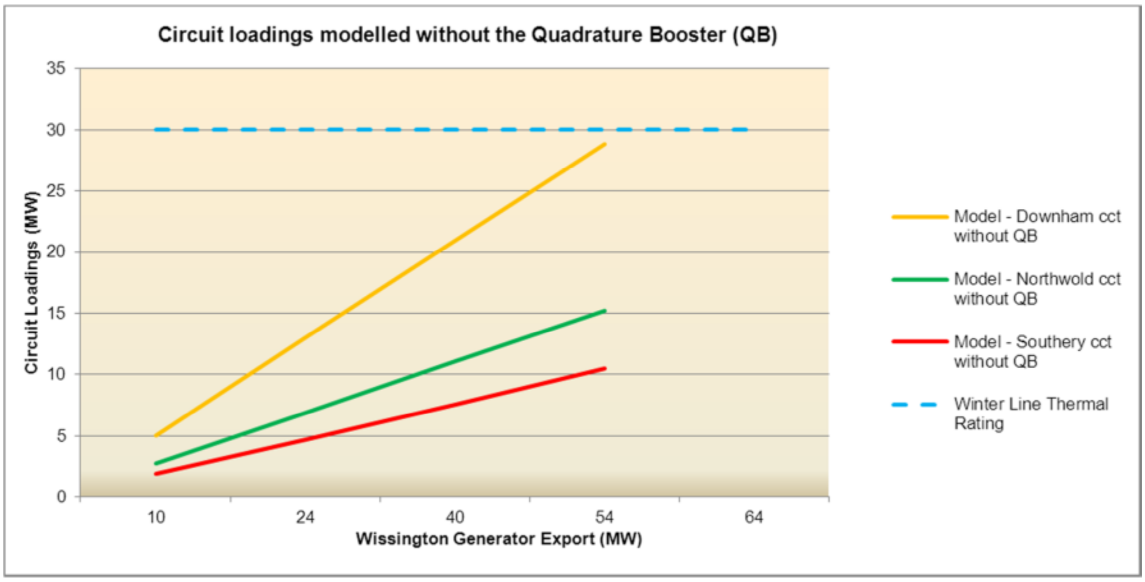

Figure 6: Modelled circuit loadings without Quadrature Booster

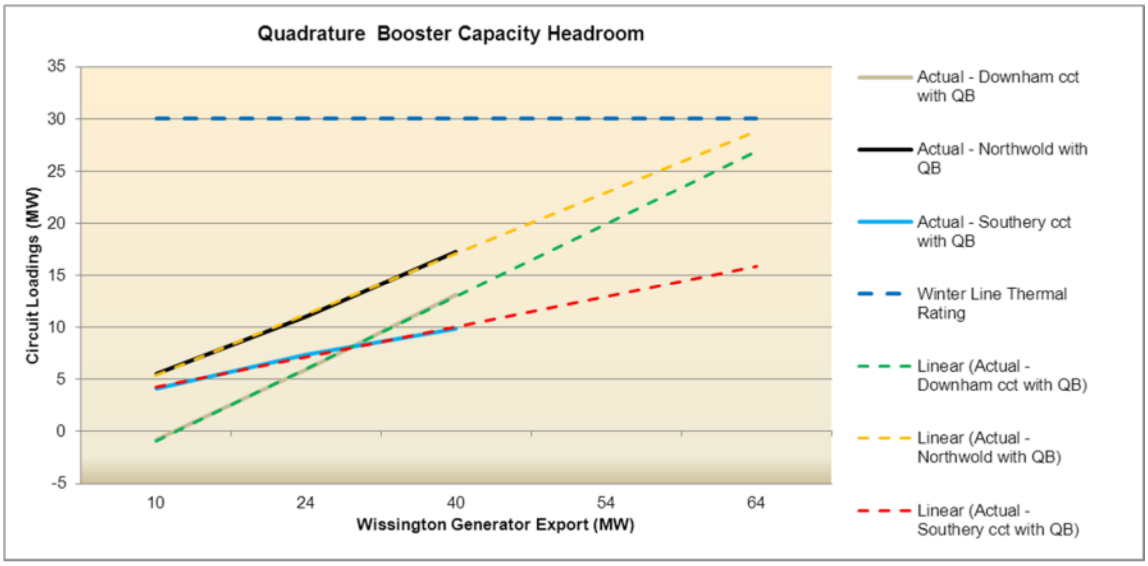

Figure 7: Graphs showing measured line loadings - and extrapolations

Figure 7 above shows the recorded load flow of the three circuits under different generation export scenarios with the Quadrature Booster in-service in the Downham Market teed No.2 circuit. For consistency, the graph data presented in the graphs in Figure 7 above are based on the Quadrature Booster set at tap 11.

The Flexible Plug and Play Quadrature Booster project cost is circa £1.6 million. This is the total forecasted cost for the project including design, construction and installation costs for the Quadrature Booster, the new 33kV switchgear and switchroom and all associated control and protection systems. This cost is expected to reduce significantly for future installations as research and development costs are eliminated. In the example of Wissington British Sugar, the Quadrature Booster solution at distribution level is attractive as the estimated costs are clearly favourable compared to the costs of conventional network reinforcement options.

<u>Learning</u>

Throughout the project, there has been significant collaboration between Wilson Transformer Company, Fundamentals, Carillion Utility Services, British Sugar and UK Power Networks. This collaboration has provided key learning points. The Quadrature Booster trial case has already provided significant technological and reputational enhancement. Lessons learnt so far include the following:

- The Quadrature Booster can be used on 33kV network
- It is potentially an attractive technology to increase network capacity headroom compared to network reinforcement.
- Additional due diligence required when dealing with Quadrature Boosters, which is over and above the norm – especially the modelling which proved to be challenging. It is now known that a frequent problem with the design of Quadrature Boosters is the difficulty with arranging the leading/lagging correctly.

Conclusions

Large distributed generators can highlight capacity sharing issues on the distribution network which had not previously been considered as a constraint on demand customers. By using a Quadrature Booster, a smarter and active management of load sharing between parallel 33kV circuits at Wissington will provide capability for improving utilisation of the existing circuits.

To our knowledge, this is the first Quadrature Booster to be deployed on the distribution network. Consequently significant new knowledge is being generated throughout the entire process from conception, design, installation, commissioning and ultimately to post-go-live maintenance. The knowledge is vital as there is great potential for replication by other distribution network operators.

The Quadrature Booster was commissioned and energised in July 2013. Knowledge gained so far shows that the design and installation of the Quadrature Booster on the 33kV network will provide a technological and reputational advantage for UK Power Networks and the project partners. As an innovation project a number of challenges were encountered. Diligent bespoke design which required continuous liaison between parties involved is one of the success factors. Although a Quadrature Booster provides a smarter way of managing load sharing constraints, it also introduces two lots of transformer losses – series and shunt transformers, although these losses are less than a conventional 30MVA power transformer.

Based on the results from live test whish are graphically shown in Figure 7 it is clear that the Quadrature Booster is operating as expected. An improved balancing of the Northwold No.1 and Downham Market teed No.2 circuits is evident, with potential to accommodate a projected generation export of 64MW as shown in Figure 7. Further evidence will be gathered during the trial to confirm the result. British Sugar indicated their interest in taking advantage of the increased export limits if the Quadrature Booster trial proved a success. However, the amount of increased generation levels is likely to vary across the year, and would be dependent on economics – mainly the day gas and electricity prices, which routinely fluctuate from time to time.

There is great potential for replication of the Quadrature Booster scheme. Future costs are expected to fall significantly as costs for research and development are eliminated.

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LCN Fund
Low Carbon Networks

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