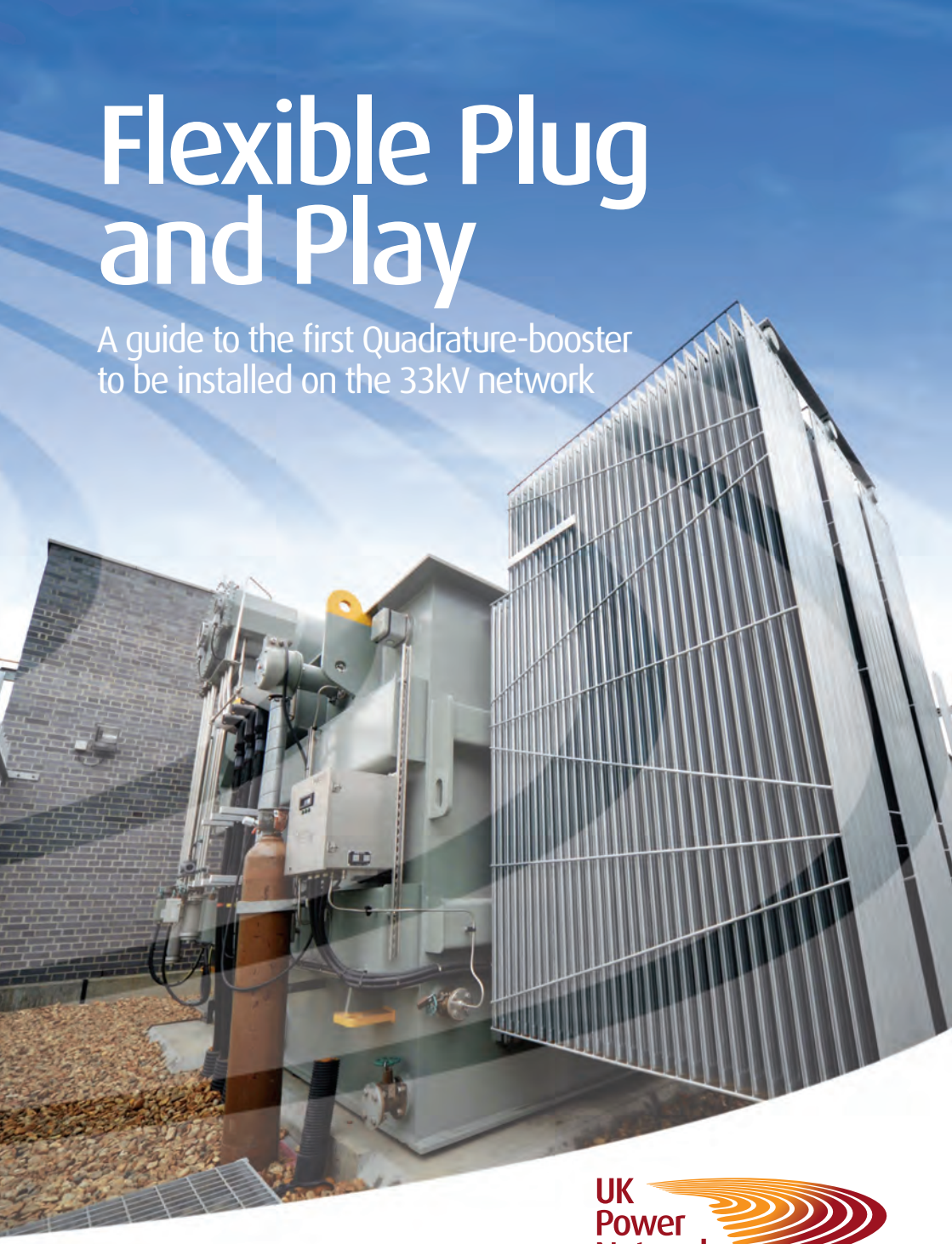
Flexible Plug and Play

A guide to the first Quadrature-booster to be installed on the 33kV network



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Glossary

Term	Description
Apparent power	The total power in an AC circuit, that is the product of the dissipated and absorbed power in the circuit
Boost	Increase flow of active power in a circuit
Buck	Reduce flow of active power in a circuit
CHP	Combined Heat and Power - a generator that converts fuel (usually gas) into both electricity and useful heat
Commissioning	A generic term used to describe the process of assuring that all systems and their components (in this case associated with the Quadrature-booster) have been installed and configured in accordance with the system design
Constraint (to the network)	A limiting factor that prevents the connection of further generation or consumers to the electricity network in its current configuration
Distributed generation	Electricity generated from many small energy sources such as wind farms, solar farms, CHP etc
Distribution Network Operators (DNOs)	Companies that are responsible for the distribution of electricity to homes and businesses from the National Grid, via overhead lines and underground cables
Electrical impedance	A measure of the opposition to time-varying electric current in an electric circuit
Export/output	The electricity produced by a generator
Flexible Plug and Play	The UK Power Networks' three year innovation project (2012-14) that is trialling new technologies and commercial agreements in order to connect renewable generation to the network in a faster and cheaper way. More information at **www.flexibleplugandplay.co.uk**

Term	Description
Flexible Plug and Play trial area	An area of UK Power Networks' distribution network, approximately 30km diameter (700km^2) between Peterborough and Cambridge in the East of England
Long Term Development Statements	Publically available statements about the distribution networks that provide key information to help companies who are considering connecting to our network
Low Carbon Network Fund (LCNF)	A funding mechanism introduced by Ofgem to promote research and development for smart distribution networks
MVA	Megavolt-ampere is a unit of measure of apparent power in an electrical circuit
Ofgem	The Office of Gas and Electricity Markets: the regulator for the electricity and gas companies in Great Britain
Quadrature-booster	A specialised form of transformer used to control the flow of real power in parallel circuits on a three-phase electricity distribution network. Also known as a Quad-booster or a phase-shifting transformer
Reverse power flow	The flow of electricity away from the consumer, which is opposite to how the electricity network was originally designed
SCADA	A tool used at UK Power Networks to manage their networks
Section 37 planning consent	Section 37 of the Electricity Act 1989 relates to the requirement to obtain consents for overhead lines and takes into account the views of the local planning authority, local people, statutory bodies (such as the Environment Agency), and other interested parties
Tap	The Tap determines the number of turns of the transformer winding that are connected in the circuit

Preface

UK Power Networks is the company responsible for operating and maintaining the electricity distribution networks in London, the South East and East of England. They are leading a project, Flexible Plug and Play, that has installed the first Quadrature-booster on the 33kV network.

This guide explains what a Quadrature-booster is, how it works and when and where an electricity distribution company could install one.

More detailed learning reports and technical papers on this subject can be found on the project website **www.flexibleplugandplay.co.uk**.

Background

In Great Britain, the electricity network has traditionally been designed to provide the link from centralised generation to the consumers of electricity, with electricity flowing one-way - from the power stations to the consumer. With the increase in locally generated electricity from new low carbon technologies, such as wind turbines and photovoltaic panels, electricity Distribution Network Operators (DNOs) are facing a new challenge - to accommodate bi-directional electricity flow. Where there are high concentrations of distributed generation connected to the electricity network issues such as reverse power flows and thermal constraints can occur. This becomes a particular problem where the network is constrained, as further connections may necessitate upgrades to the networks that can be costly with prohibitive timescales.

The favourable conditions in the East of England have contributed to this area becoming a hub for both wind and solar power production in recent years. Consequently UK Power Networks has seen an increase in the number of connection requests for distributed generation in the region. As a result, a number of areas are subject to thermal and voltage constraints and experiencing issues with reverse power flow.

Flexible Plug and Play is a three year innovation project running from January 2012 to December 2014 aimed at finding faster and cheaper ways of connecting distributed generation to the electricity distribution network. The project's budget is £9.7million, of which £6.7million has been funded by Ofgem's Low Carbon Networks Fund, the remaining £3million has come from UK Power Networks and its project partners. The project has a trial area of approximately 30km diameter (700km squared) between Peterborough and Cambridge in the East of England.

In order to **speed up** distributed generation connections and **reduce the associated costs**, Flexible Plug and Play is trialling new, smart control and monitoring technologies to improve the use of the existing network. **The Quadrature-booster is one of the smart technologies being trialled**.

In addition to the smart control and monitoring technologies, Flexible Plug and Play will also offer 'flexible' (or non-firm/ interruptible) connection agreements that can reduce the cost of connection. The distributed generation customer will be offered a point of connection on a constrained part of the network within the trial area, UK Power Networks will manage the export of the generation using smart control technologies', ensuring the network is kept within its operational limits and the constraint is not breached.

This guide will focus on the Quadrature-booster.

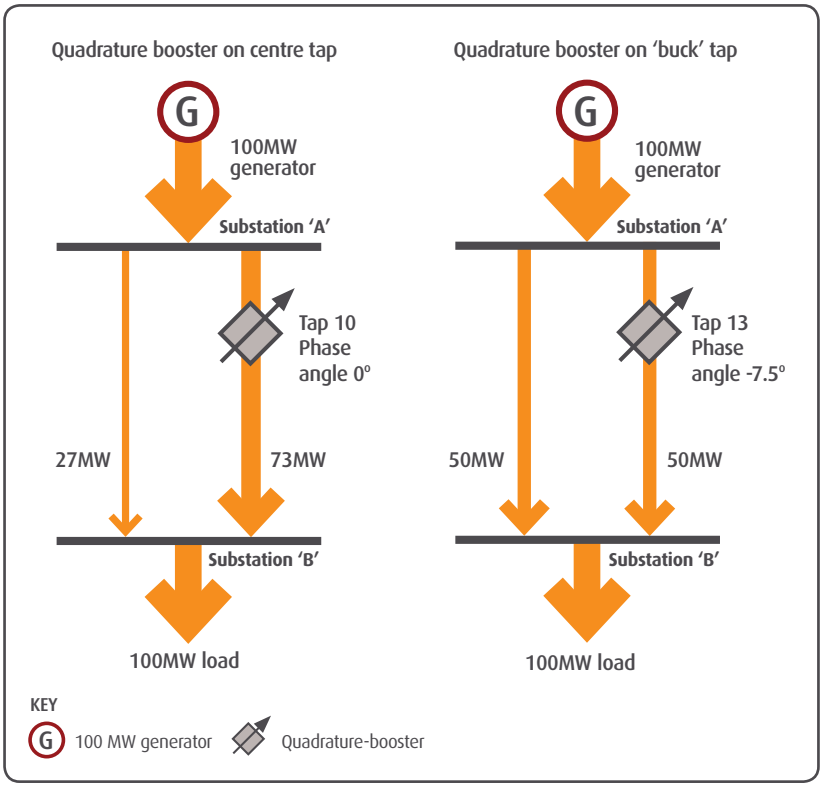
What is a Quadrature-booster and how does it work?

In the UK the Quadrature-booster is also known as the Quad-booster and this is often shortened to QB. The Quadrature-booster is a mature piece of technology that has been used by the electricity transmission company, National Grid, since the 1970s.

A Quadrature-booster is essentially two transformers (classified as one) that are connected at a specific point on the network where there are parallel lines with different loads. This imbalance in load can cause constraints. The Quadrature-booster helps by shifting load from the overloaded line to the one with more available capacity. This is achieved by controlling phase angles of the voltage on one of the lines which alters the distribution of power flow through both circuits. The degree of change is varied using a 'tap' controlling device (On Load Tap Changer).

In simple terms, the Quadrature-booster, through its balancing process, increases and improves the utilisation of existing network assets potentially deferring the need for expensive reinforcement or upgrade.

The Quadrature-booster is controlled by a device located in the substation which is hard wired to the Quadrature-booster's On Load Tap Changer and automatically manages the power flows. The Quadrature-booster control system operates 24 hours a day constantly comparing the load on the parallel circuits to ensure they are balanced. If the load becomes unbalanced, the system sends a signal to the On Load Tap Changer, to 'tap up' or 'tap down' (buck or boost) the Quadrature-booster. This carefully changes the position of the tap, which in turn increases or decreases the electricity flow, thus balancing the lines and creating additional capacity on the network. The Quadrature-booster can also be operated remotely from a centralised control centre.



The diagram above illustrates how a Quadrature-booster works. On the left the Quadrature-booster is shown on 'centre tap', the lines out of balance - one line has 73MW and the other has 27MW. On the right the Quadrature-booster control system has moved the tap to position Tap 13, a phase angle of -7.5°, which reduces the flow of active power in the overloaded circuit (bucks the power) balancing the flow in each line so that both now carry 50MW.

The Flexible Plug and Play Quadrature-booster

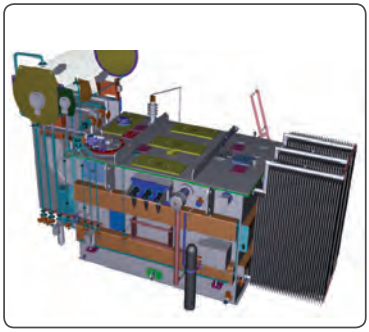
Within the Flexible Plug and Play trial area the Wissington substation in Norfolk, situated at the British Sugar site, was indentified as a suitable point on the 33kV network to trial the Quadrature-booster.

The suitability of the site was primarily driven by a generation export constraint on a Combined Heat and Power (CHP) plant installed at the Wissington British Sugar site (a sugar beet processing factory). The CHP electricity generation plant has an installed turbine capacity of 70MW.

There are three electricity lines that feed the Wissington factory. The three lines are referred to as Northwold, Downham Market and Southery. The constraint on the network is as a result of two of the three lines, Downham Market and Northwold, being in parallel but having different characteristics or 'impedances'. The difference in impedance between these two lines results in an imbalance in the power flow on these circuits. The consequence of this imbalance is that the CHP export capacity has to be reduced in order to prevent the Downham Market line becoming overloaded, even though there is additional capacity available on both the Northwold and Southery circuits. In addition, no other generation connections are possible in the area fed by these lines as the network is considered 'full' due to the constraint on the Downham Market line.

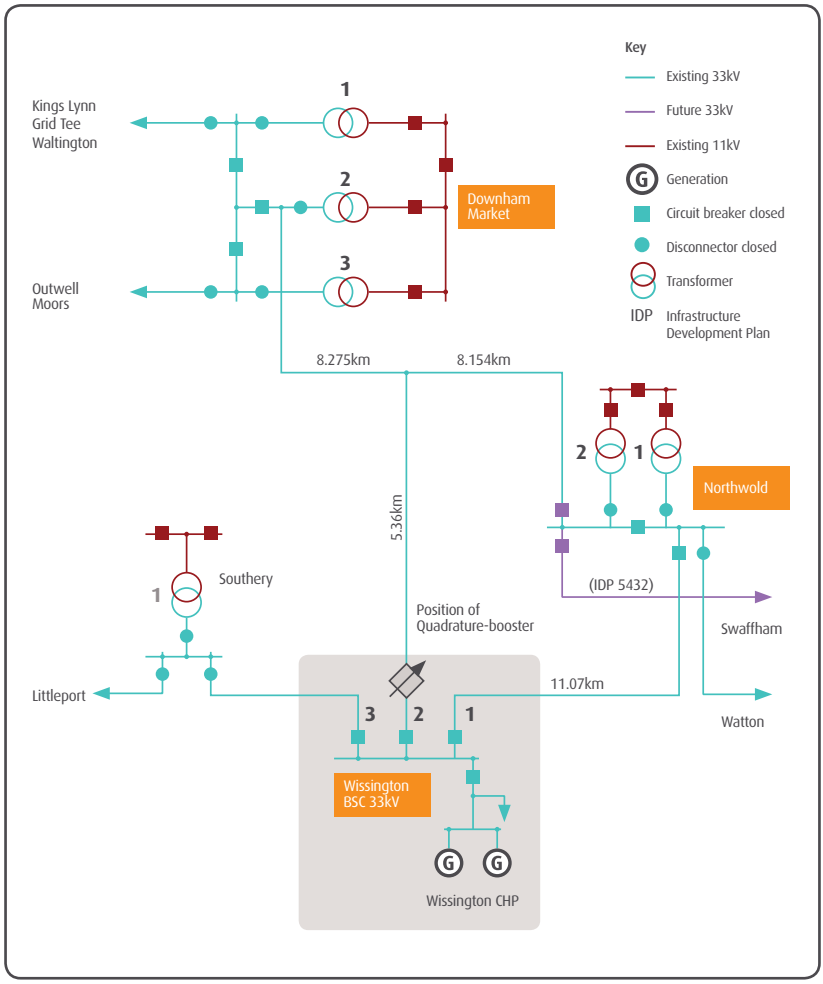
This sub-optimal load sharing on parallel lines makes the British Sugar site the perfect location to trial the Quadrature-booster.

3D design of Quadrature-booster

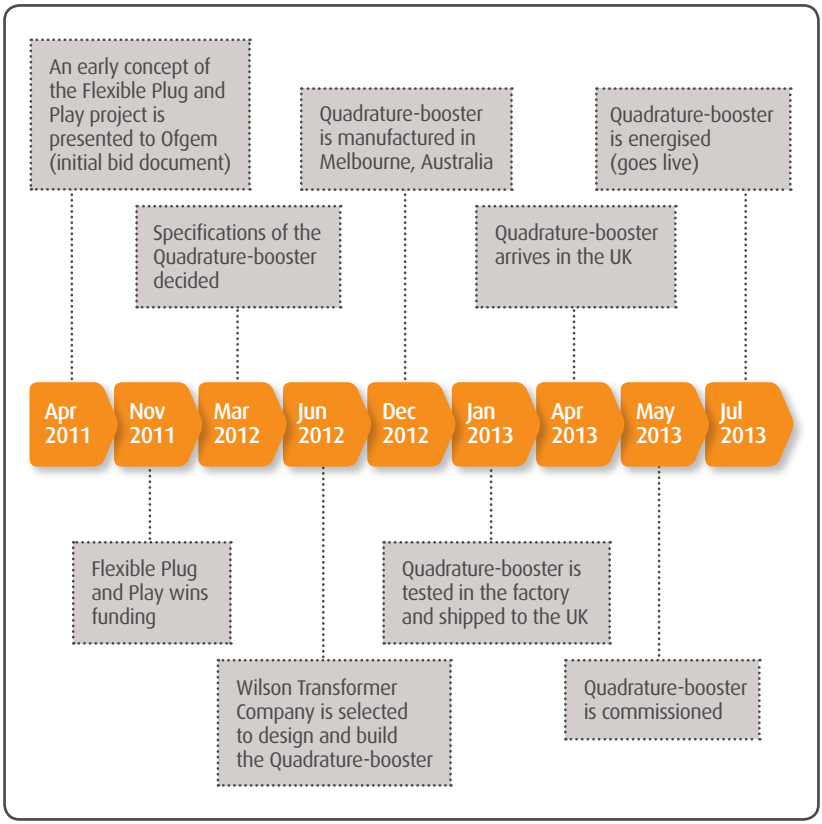


Quadrature-booster during installation

Schematic illustration of existing distribution network around the Wissington British Sugar substation



Installation timeline for the first Quadrature-booster on the 33kV network



The Quadrature-booster was installed in spring 2013 and energised in July 2013. To date (January 2014) the live tests are showing that the Quadrature-booster is working as expected. The live trial will continue for one year to test that the device can consistently increase the network capacity by up to 10MW.

Quadrature-booster versus traditional network reinforcement

In order to increase the available capacity on the network in the Wissington area, two options have been previously considered:

1. A new 33kV overhead line from Wissington to Swaffham at a cost of around £3million. This overhead line would be liable to Section 37 of the Electricity Act 1989, which defines the requirement to obtain planning consent with a possible three year public enquiry.

2. A new fully underground 33kV cable between Wissington and Swaffham at a cost of around £6million but avoiding the need to obtain planning consent.

In comparison, the cost of installing the Flexible Plug and Play Quadrature-booster has been £1.6million. This has included project management costs, civil works, the electrical installation, the Quadrature-booster itself, the Quadrature-booster control system and the necessary protection scheme. The overall installation time for the Quadrature-booster, from specification to design and installation took just 16 months.

Future Quadrature-boosters for the 33kV network are likely to be cheaper now that the R&D costs of design and specification have been covered, the timescales will also be reduced. It is also worth noting that this design can be replicated for 132kV networks.

Although the trial improves the export capacity for British Sugar, the increased capacity on the network provided by the Quadrature-booster will be available to any customer wanting to connect to that specific part of the network. To ensure full transparency, UK Power Networks has updated its Long Term Development Statements (LTDS) to show this increased network capacity in the Wissington area. The exact capacity will be released after the trial. Long Term Development Statements provide key information to help companies considering where best to request connections to the network.

What are the differences between the Flexible Plug and Play 33kV Quadrature-booster and those used on the transmission network?

Transmission companies install Quadrature-boosters at 275kV or 400kV. The Flexible Plug and Play Quadrature-booster, specially designed by Australian company Wilson Transformer Company, is a 30MVA, 33kV single tank design delivering a phase shift of ±12 degrees between incoming and outgoing terminals, with a summary of the key differences being described below:

Flexible Plug And Play 33kV Quadrature-booster	Transmission Quadrature-booster
The Flexible Plug And Play Quadrature-booster is smaller at 30MVA	Transmission Quadrature-boosters are typically larger, between 750MVA and 2750MVA
The Flexible Plug And Play Quadrature-booster has two component transformers which are installed in one tank	Transmission Quadrature-boosters are made of two transformers installed in separate tanks
The Flexible Plug And Play Quadrature-booster has an **automatic** control system to control load balancing. This device is called the Quadrature-booster Control System	The transmission Quadrature-booster is controlled manually as the power being shifted at each tap-change is significantly larger than on a distribution network

Key points

We hope this guide has provided a good overview of the Quadrature-booster - what it is, how it works, what it will achieve and why UK Power Networks has installed one as part of the Flexible Plug and Play project.

Here are some key points:

- The Quadrature-booster is a smart technology that is used to balance power flow on parallel lines by forcing electricity from an overloaded line to a line with more capacity
- The Quadrature-booster is automatically controlled by the Quadrature-booster Control System
- The Flexible Plug and Play Quadrature-booster is the first to be installed on the 33kV distribution network
- The Flexible Plug and Play Quadrature-booster will create up to 10MW of additional capacity
- UK Power Networks will carry out cost-benefit analysis to investigate installing others on its networks
- The principles that have been learnt from installing the Flexible Plug and Play Quadrature-booster can also be applied at 132kV

Further information

If you would like to know more about the Quadrature-booster and the Flexible Plug and Play project please visit the project website

flexibleplugandplay.co.uk

Information about other UK Power Networks innovation projects can be found at

ukpowernetworks.co.uk/innovation

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