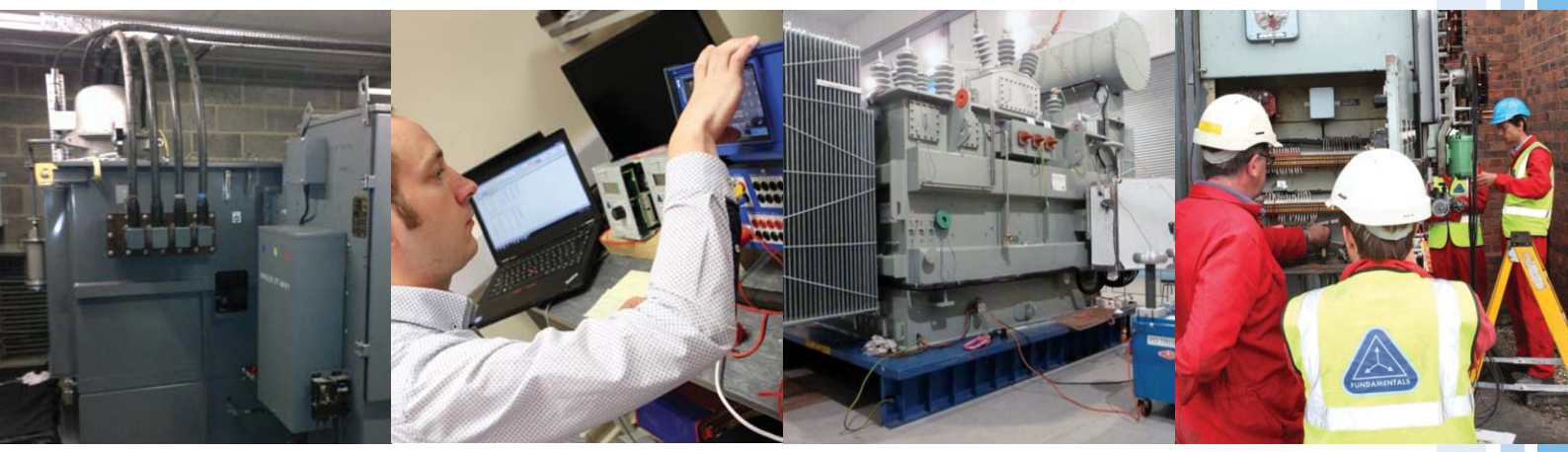
Fundamentals Ltd
Power Systems Technology

Innovation Projects

Low Carbon Network Projects

Fundamentals Ltd has been involved in a number of DNO innovation projects as part of the LCN fund framework. Voltage control and related aspects of network operation are a key factor in the development of distribution networks. This document gives a summary of some of the innovation projects worked on to give a sense of our capabilities and leading position in the field of voltage control.



- Flexible Plug and Play
- Customer Led Network Revolution
- Low Carbon Hub
- Voltage Management on LV Busbars

UK Power Networks
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NORTHERN POWERGRID

WESTERN POWER DISTRIBUTION
INNOVATION

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UK Power Networks

Flexible Plug and Play (FPP)

FPP is a second-tier LCNF project that aims to connect distributed generation (DG) onto constrained parts of the distribution network without the need for conventional network reinforcement. To achieve this, innovative technical and commercial solutions are being trialled to manage constraints and maximise network utilisation.

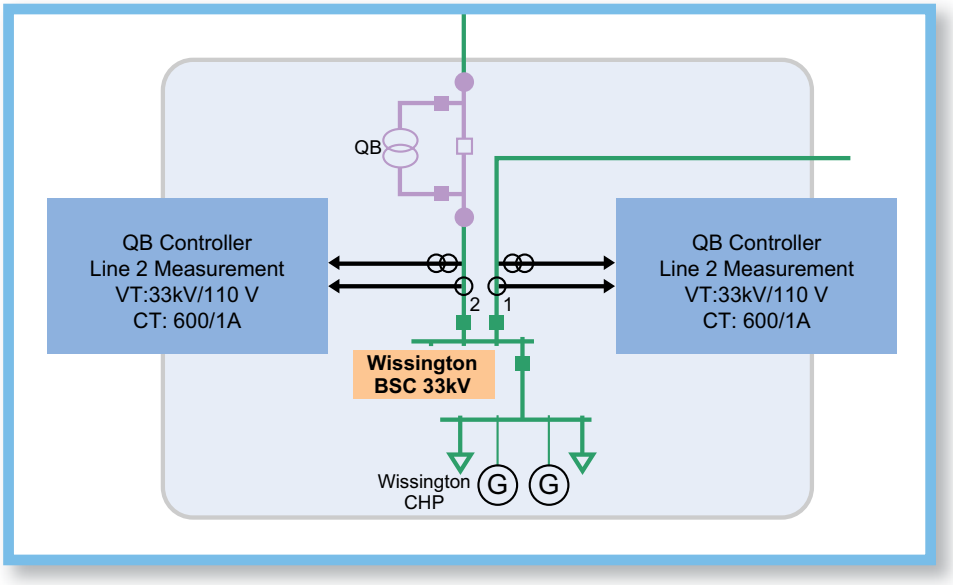
The FPP technical solution consists of several 'smart applications', one of which relates to keeping the network within operational limits by controlling interruptible distributed generators. This involved deployment of devices to manage power flows and devices to manage voltages.

Fundamentals Ltd were engaged by UKPN to design, build, install and commission these two types of 'smart' device required for the FPP technical solution.

Power Flow Management

Real (active) power flows can be influenced by adjustment of the system voltage phase angle. This is achieved by use of a type of transformer known as a quadrature booster (QB). The QB contains an on-load tap changer which enables a regulation range of phase angle and is connected to the circuit on which power flows need to be adjusted.

The goal was to achieve optimal power flow sharing between two 33 kV lines by control of the QB. In this way, more embedded generation could be accommodated without compromising thermal limits or requiring any network reinforcement.



Network diagram showing QB installed to influence power sharing between lines 1 and 2

Fundamentals Ltd designed the complete control scheme, built the panel to house the QB control relay (MR TAPCON 260), installed at site and commissioned into service. This included configuration of the IEC61850 protocol to interface with the substation RTUs and wider-scale FPP communications infrastructure.

"Fundamentals has played a key role in the successful completion of the construction phase of the Quadrature-booster project through the design, supply and commissioning of the control system for the QB. It is a great achievement, given the novelty of the device and complexity of the overall project (world first within a live site with a major industrial customer connected and within tight timescales) and we should all be proud of it"

Sotiris Georgiopoulos, Flexible Plug and Play Project Director, Future Networks, UK Power Networks

Factory acceptance testing was successfully completed at Fundamentals' factory in May 2013 and final site commissioning took place in July 2013.

Voltage Management

Management of system voltages is usually facilitated by the use of on-load tap changers in power transformers to effectively adjust the transformer ratio and therefore the output voltage magnitude.

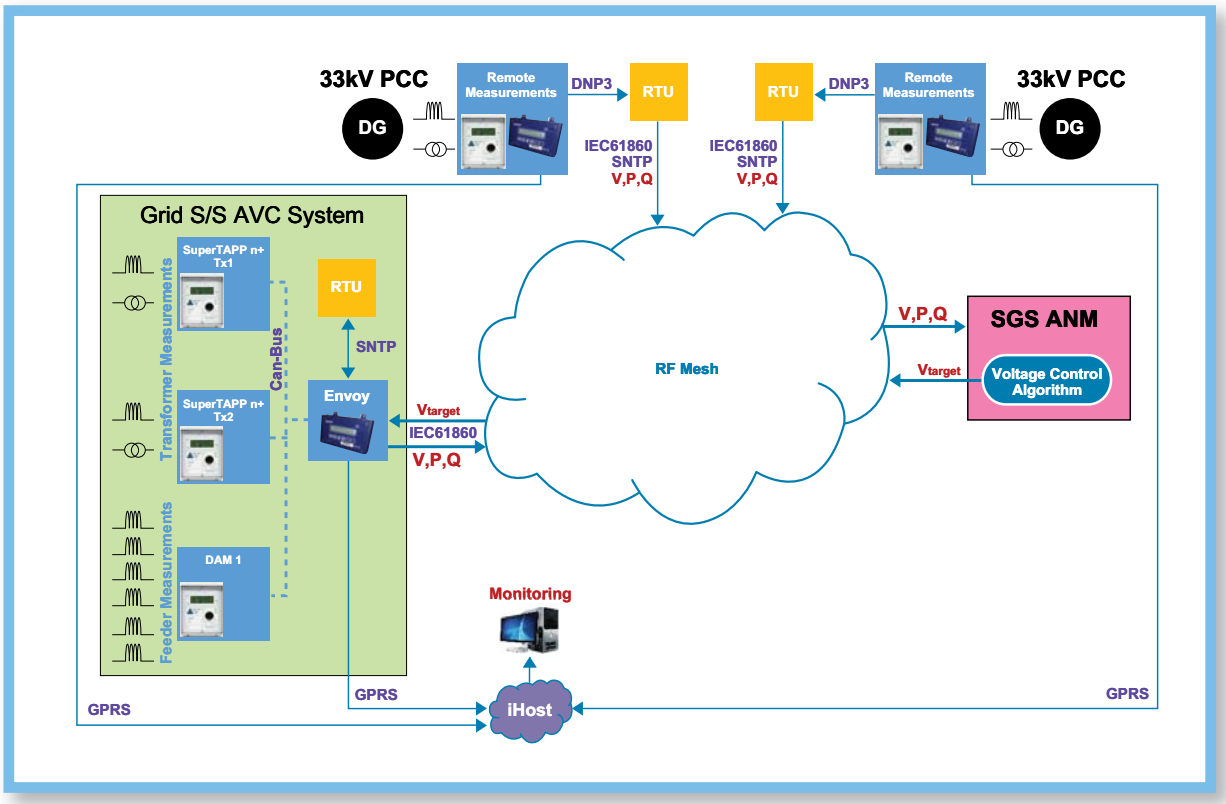
Control of on-load tap changers is provided by the Automatic Voltage Control (AVC) relay.

High levels of distributed generation (DG) can significantly affect network power flows and voltages and can introduce problems with 'traditional' AVC relays which were designed when networks only experienced uni-directional power flows (i.e. before the introduction of DG).

Fundamentals Ltd have designed and developed solutions for modern network voltage control in the form of the SuperTAPP n+ relay. The relay is already approved for use on the UKPN network, but the FPP trial aimed to build on this success to prove additional 'smart' features:

- Communication with the FPP Active Network Management (ANM) system using IEC61850 protocol
- Centralised voltage control
- Release of extra voltage headroom in order to connect more DG
- Remote voltage measurements

Voltage control schemes incorporating SuperTAPP n+ were designed, built, installed and commissioned at UKPN primary and grid substations. Site commissioning included the AVC scheme tests, SCADA interfaces and also integration into the FPP technical solution. The figure below shows the outline design for the SuperTAPP n+ voltage management scheme.



Voltage management scheme with SuperTAPP n+

Northern Power Grid

Customer Led Network Revolution (CLNR)

Traditionally, distribution network operators dealt with new loads placed on the grid by reinforcing the network. The CLNR project is a second-tier project with an objective to explore smarter alternatives which could allow conventional reinforcement and its costs to be avoided or deferred.

The project included an assessment of a number of novel 'smart grid' network technologies including energy storage, thermal ratings and voltage control. They form part of a comprehensive smart grid toolkit which is optimised and controlled by an active network management system. The learning from network trials is being shared with all UK network operators, helping create a smarter power grid that is fit for the future.

Fundamentals Ltd has been helping with voltage control and transformer thermal rating elements of the project.

Enhanced Automatic Voltage Control (EAVC)

Increased amounts of generation from renewables and disruptive loads such as electric vehicle charging and heat pumps will increase the need to be able to actively manage voltage on the distribution network. Trials of Enhanced Automatic Voltage Control (EAVC) have been assessed as a potential solution to resolve this issue.

SuperTAPP n+ EAVC panel

Fundamentals Ltd provided solutions for several EAVC applications:

- Voltage control at primary substations using the SuperTAPP n+ AVC relay to control on-load tap changers
- Voltage control of the LV network at secondary substations using the 'first-of-its-kind' regulated distribution transformers in the UK
- Voltage control of in-line regulators on the 11 kV network using the SuperTAPP n+ AVC relay
- Control of capacitor banks on the 11 kV network using the SuperTAPP n+ AVC relay

All EAVC applications integrated with the centralised control system via IEC61850 and DNP3 SCADA protocols.

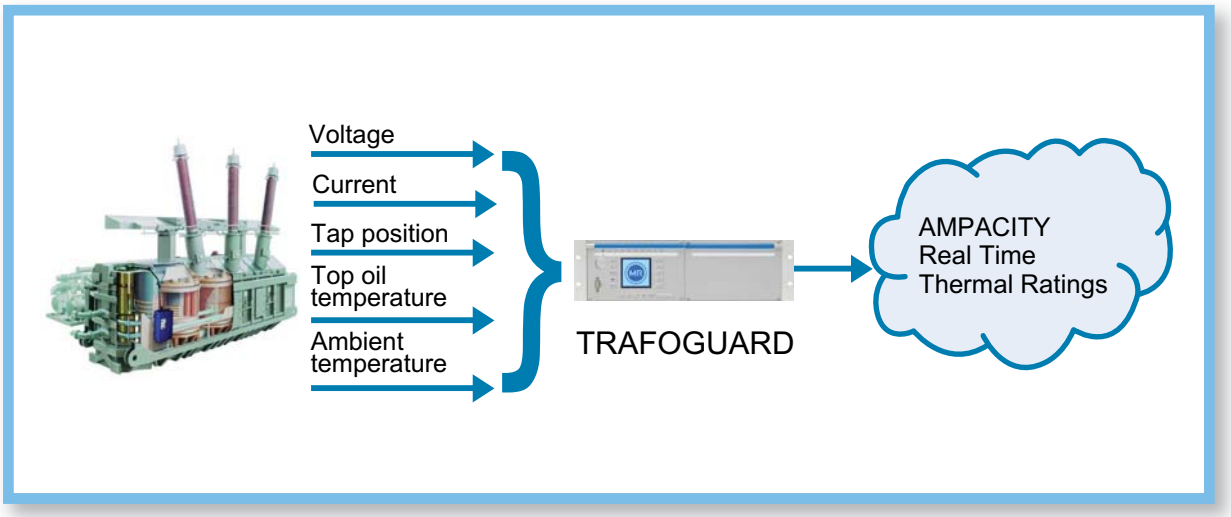
Transformer Real Time Thermal Ratings (RTTR)

RTTR systems calculate thermal ratings based on the electrical current and temperature of the equipment and the prevailing weather conditions. This gives an accurate picture of the capacity of the network in real time, supplying network planners with the information needed to relieve strain on the network and make better decisions on when and where investment in infrastructure is needed.

The link between RTTR and customer demand-side response/energy storage means that if an asset is in danger of overheating, an appropriate response can be activated to reduce the load on it.

Fundamentals Ltd supplied, installed and commissioned transformer monitoring systems on four primary transformers. The monitoring systems measured ambient and oil temperature, voltage, current and tap position which facilitated the calculation and output of the real-time thermal rating of the transformer. The calculation of 'ampacity' was based on the IEC standard transformer model and gave the following outputs:

- Maximum load transformer could support for 1 hour continuously
- Time which existing load could be supported before transformer failure or significant ageing



Transformer monitoring and 'ampacity' calculation

Western Power Distribution

The Low Carbon Hub

The Low Carbon Hub is a tier-2 project which aims to determine if there are ways of connecting significantly more generation to the existing distribution network using innovative solutions, and whether this is more cost effective and quicker than the conventional methods.

In creating an active network with multiple generators, a high degree of variability (both in terms of demand and generation) can result in less control of the network voltage profile and large unpredictable voltage fluctuations over a very short period of time.

Traditionally, passive networks operating without generation use Load Drop Compensation as a means to estimate the optimum voltage level at all points on the network and set the target voltage accordingly. This makes it very unlikely that the distribution network will operate outside of the statutory voltage limits, even with a variable demand.

In the past, intermittent generators have been connected to the distribution network without communications and have operated unmonitored. This has resulted in the network having to be designed and operated using the worst case assumptions, ensuring the network voltage will not operate outside of statutory limits.

The effect of intermittent generation can have a negative effect on voltage profiles:

- Masking the true transformer load and causing voltage errors on the AVC scheme
- Resulting in unwanted voltage rises at the Point Of Common Coupling (POCC), especially when connected to relatively weak distribution networks

The Low Carbon Hub monitors and operates the network actively; the voltage and current flows are measured at key network points and generation in-feeds. This data is processed by the Network Management System (NMS). The NMS will determine the optimum voltage set point for the relays controlling the on-load tap changers (Fundamentals-manufactured SuperTAPP n+) based on the network configuration. This is therefore a trial of a truly centralised voltage control system.

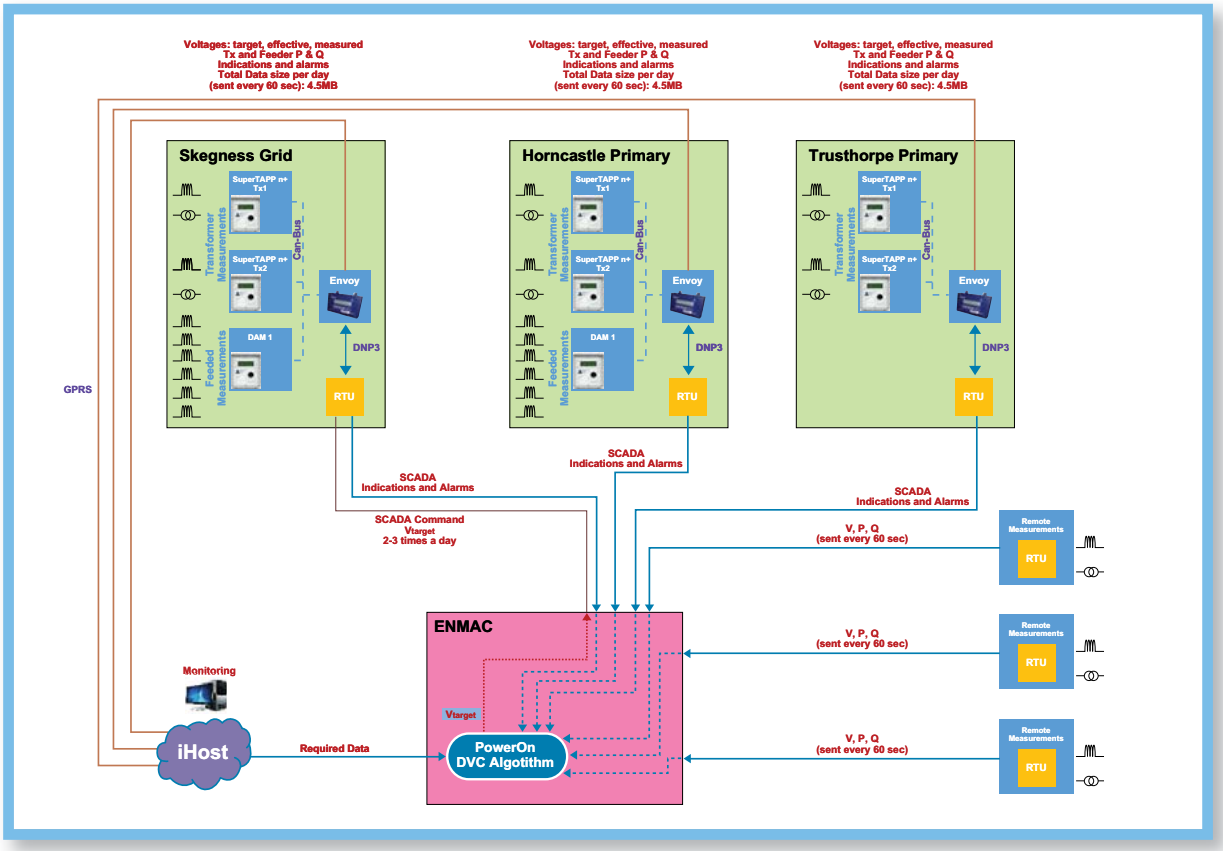
WPD selected Fundamentals Ltd as the partner to handle the following:

- Develop the interface between the NMS and the SuperTAPP n+ relays with DNP3 protocol
- Site installation and commissioning at grid and primary substations
- Implementation of remote voltage measurements into the control algorithms
- Network studies to optimise control algorithms and relay settings

The result is a system which actively manages and optimises network voltages. An outline diagram of the system is shown in the figure opposite.

Voltage Control System Demonstration Project

As distributed generation (DG) becomes more common, the growing number of connections to distribution lines may cause voltage problems due to the variable power output of the DG. As a result, this can affect the efficiency and capacities of the distribution network. There are several different solutions and devices available in the market that can help reduce voltage variation.



Dynamic voltage control with SuperTAPP n+

However, some traditional solutions are unable to cope with the rapidly varying output of renewables such as wind turbines and solar panels.

This tier-1 project aims to address the issue of voltage fluctuations seen in long distribution lines in a rural area with wind turbines connected. The objective is to find out the effectiveness of D-SVCs (Static VAr Compensator for Distribution Networks) as a system to control voltage on 11kV rural networks.

Phase 1 is already underway and is testing a single D-SVC. The second phase will examine the effect of multiple D-SVCs across two primary substations.

Fundamentals Ltd are supporting WPD with phase 2 of the project as follows:

- Installing SuperTAPP n+ voltage control relay at selected WPD primary substations.
- Facilitate all feeder measurements to enable SuperTAPP n+ advanced functionality
- Monitoring functionality to the network devices and ENMAC via DNP3
- Supporting the development of DVC with respect to voltage control functionality
- Supporting ENMAC interfacing with respect to SuperTAPP n+ control and monitoring functions.

"Fundamentals are developing and demonstrating the principles of Dynamic Voltage Control (DVC) at Skegness Grid substation as part of WPD's Lincolnshire Low Carbon Hub project. The solution uses Fundamentals expertise in voltage control relays and power systems modelling to determine if a more optimum network voltage could be applied to this often generation biased network. Fundamentals have written a robust algorithm allowing PowerOn Fusion to set network parameters and communicate over existing SCADA communications to the existing SuperTAPP n+ AVC. The additional control of these AVC's will allow the ability to lower target voltages for the two Grid transformers in a granular way."

Philip Bale, Innovation and Low Carbon Networks Engineer
Western Power Distribution

Electricity North West

Voltage Management on Low Voltage Busbars

This first-tier project deployed a range of voltage management technologies and techniques across fifteen distribution substations. These technologies were assessed in terms of their ability to effectively regulate line voltage in real time. The project sought to develop understanding of the potential for these alternative techniques to address issues of voltage regulation of low voltage networks in response to increases in low carbon loads and penetration of generation and inform the development of Electricity North West operating practices.

The project deployed a range of technologies on the Low Voltage (LV) network. Fundamentals Ltd were involved in trials of distribution transformers with on-load tap changers.

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The tap changers for these devices were purchased from Maschinenfabrik Reinhausen (MR) in Germany for whom Fundamentals Ltd act as exclusive UK & Ireland agent. MR had recently developed a prototype solution to explore market opportunities and has a long history in tap changer manufacture. Many utility companies use MR oil and vacuum tap changers at 33kV and above. The tap changer used in the project was based on the MR standard oil design with modifications to suit the dimensions and ratings of a distribution transformer.

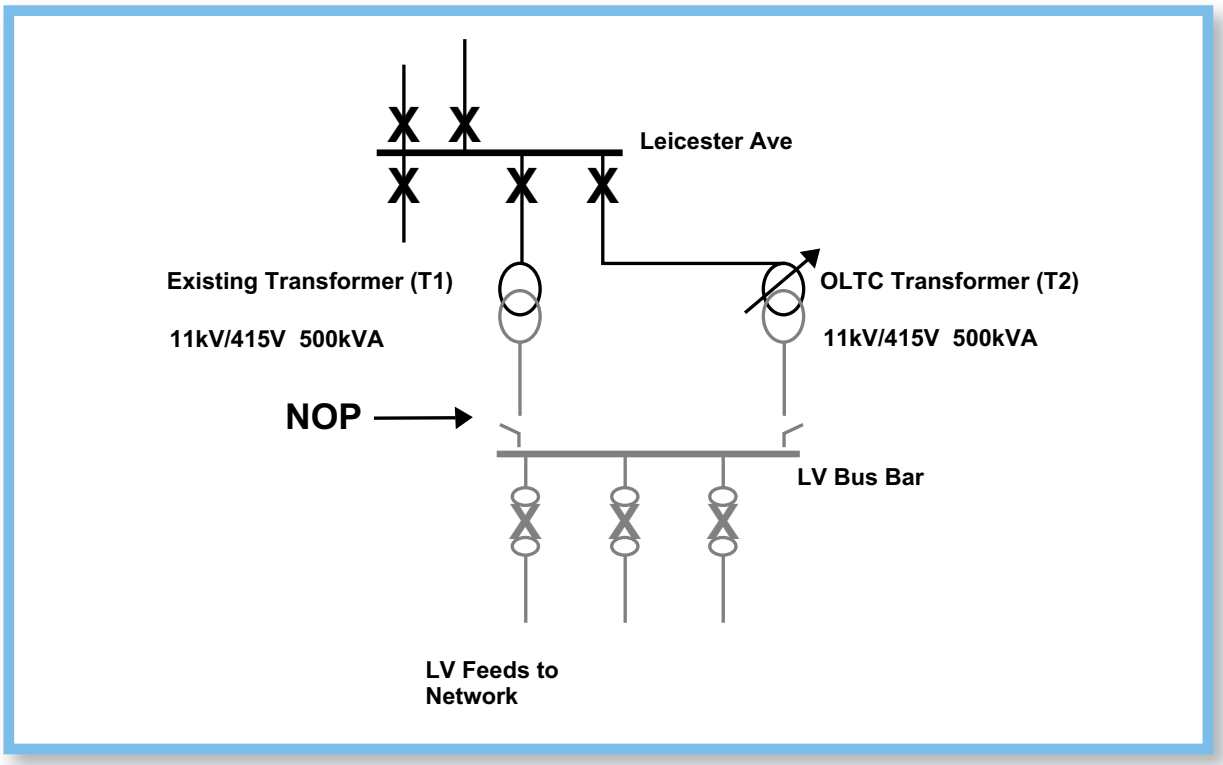
MR has now developed a new range of tap changers specifically designed for distribution transformers using vacuum technology called the GridCon iTap which will be used in future installations.

Distribution transformer with on-load tap changer: one of the first UK installations

Fundamentals Ltd carried out the design and build of the tap change control panel incorporating the AVC relay and also provided some guidance on the applied settings. This was the first time either Electricity North West or Fundamentals had devised settings for distribution transformers and there was an element of trial and error to find appropriate settings. On the day of commissioning the LV busbar voltage was measured when supplied by the existing transformer and this was used to set the relay on the new transformer. The relay was set to supply approximately 253V single phase to the LV busbars. This is a standard voltage that Electricity North West uses at distribution substations.

"Fundamentals were a key partner in the successful delivery of our First Tier project – Voltage Management on Low Voltage Busbars. As well as providing the tap change equipment they also provided technical expertise to the University of Manchester to allow them to build models of the system. Fundamentals provided on site assistance with the setting of the relays and training of our protection engineers. The project has now concluded and shows that the using on load tap changers to manage voltages on the low voltage network can provide significant benefits to DNOs"

Dr Geraldine Bryson, Future Networks Technical Manager, Electricity North West



Network diagram showing the regulated distribution transformer

Low Carbon Network Fund

As part of the electricity distribution price control that runs until 31 March 2015, the industry regulator, Ofgem (Office for Gas and Electricity Markets), established the LCN fund.

The LCN fund allows up to £500m to support projects sponsored by Distribution Network Operators (DNOs) to try out new technology, operating and commercial arrangements. The aim of the projects is to help all DNOs understand how they can provide security of supply at value for money as Britain moves to a low carbon economy.

There are two tiers of funding under the LCN Fund. The first tier allows DNOs to recover a proportion of expenditure incurred on small scale projects. The second tier of the LCN Fund is an annual competition for an allocation of up to £64 million to help fund a small number of flagship projects.

DNOs explore how networks can facilitate the take up of low carbon and energy saving initiatives such as electric vehicles, heat pumps, micro and local generation and demand side management. They also investigate the opportunities that smart meter roll out provide to network companies. As such, the LCN fund should provide valuable learning for the wider energy industry and other parties.

The core expertise of Fundamentals relates to voltage control of electrical power networks. This comes from a deep understanding and practical experience of on-load tap changers, control schemes and the electrical network itself. Building on this expertise, Fundamentals has developed a comprehensive range of products and services to fully support customers on site for power control, namely:

Products

- Voltage Control Relays
- Monitoring Systems
- Protection and Control Cubicles
- Marshalling Kiosks
- Tap Changers
- Transformer Accessories
- Compensation Systems

Services

- Protection and Control Schemes
- Design, Drawings and Engineering
- Installation
- Commissioning
- Tap Changer Maintenance
- Retrofit Solutions
- Site Surveys
- Power Systems Analysis
- Embedded Generation Studies

What next?

Fundamentals would be pleased to hear from customers with similar innovation project requirements or suggestions for new innovations in the field of Smart Grid to jointly develop viable and robust solutions.

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