# ON SITE TRIALS OF THE NEW SUPERTAPP N+ AVC RELAY – A STEP TOWARDS AN ACTIVE NETWORK

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## ABSTRACT

*This paper reports on field trials of the SuperTAPP n+ (an advanced voltage control relay (VCR) for online tap changers on transformers). This project is a collaboration between EDF Energy, Central Networks, CE Electric UK, ScottishPower, EA Technology and Fundamentals Limited. The SuperTAPP n+ relay estimates embedded generator output and total network load based on local substation measurements. These estimates are used to optimize the voltage set point at the primary substation in order to maximize voltage headroom and accommodate extra generation capacity. Four trials will be established. The initial results from the first trial demonstrate that the SuperTAPP n+ estimation algorithm is accurate and can be used to optimize voltage to an extent that a conventional VCR could not achieve. The remaining three trials will explore the relay's capabilities on different network designs and with different mixes of distributed generation.*

## INTRODUCTION

EA Technology carries out collaborative R&D projects with the UK Distribution Network Operators (DNOs) through its long standing Strategic Technology Programme. One of these projects is investigating active voltage control techniques that respond to network conditions and facilitate the connection of distributed generation (DG). This work highlighted the need for practical experience and the development of associated modelling methodologies that can be used by distribution network planners and control staff to give them the confidence to deploy the new technologies. More specifically it was proposed to undertake field trials with a group of UK DNOs of the new SuperTAPP n+ automatic Voltage Control Relay (VCR) manufactured by Fundamentals Limited.

## NEW RELAY FUNCTIONS

Voltage control of the 11kV UK distribution system is achieved by changing the tap position of the supply transformer. Where On-Load Tap-Changing (OLTC) is fitted to transformers, the tap-change operation is motorised. Similar OLTC transformers are used at 66kV & 33kV substations. Where multiple controllable voltage sources are connected together in a network (such as generators and parallel transformers), the flow of reactive power between these devices can be controlled. This is achieved in a similar manner to the automatic voltage regulators used in the control of a generator's terminal voltage, which consequently controls the reactive power output.

Circulating current will flow between transformers operated in parallel if their terminal voltages are different. Efficient operation of parallel transformers is realised through the minimisation of the unwanted circulating current. One method of minimising circulating current is to adjust the taps of paralleled transformers so that the power factor at the substation matches an assumed load power factor [1]. In this manner the transformers will be operating to minimise system losses. In the same way, reactive power can be transferred across interconnected networks, from one busbar to another, by changing tap positions.

The voltage control relay is the device used to control the tap changer on an OLTC transformer. Traditionally a measurement of the current and voltage on the secondary side of the supplying transformer is used to initiate tap changing operation. The current measurement can be used to estimate the drop in voltage at the remote end of the feeders, and boost the voltage set point if necessary. The boost in voltage to compensate for this drop is referred to as Load Drop Compensation (LDC). However, when DG is installed on any of the feeders supplied by the transformer the current supplied through the transformer is reduced. This masks the drop in voltage on the feeders without generation connected and reduces the voltage boost applied by the LDC, potentially resulting in voltages on those feeders operating outside acceptable limits. Furthermore, the generator current causes a local voltage rise, which is not seen by the VCR.

The new SuperTAPP n+ VCR estimates the current contribution from the generator. This estimation is summed with the current supplied to the feeders at the substation to estimate the total load. The total load is then used to set the LDC and the set point voltage. If the voltage needs to be reduced because of voltage rise caused by the DG, the estimated current from the generator is used to set the 'Genbias' that lowers the set point voltage [2]. Genbias and LDC are given as percentages with respect to the nominal voltage.

The estimate of generator output is made using the ratio of the load on the feeders with no generation to the load on the feeder with generation. To determine the load on feeders where the DG is connected measurements must be made when the generation is switched off. Alternatively, historical data before the DG was connected can be used.

## TRIAL SITES

Four UK DNOs, Fundamentals and EA Technology have collaborated to establish trial sites to assess the capabilities of the new relay. This will give the DNOs confidence that the relay will perform as expected. It will also identify the types of networks best suited to the application of the relay and the limits of the SuperTAPP n+. Four trials are planned, one of which is operational and data is currently being collected. The second site has been selected for installation in the near future. The project team aim to include a range of network designs to cover as many of the following situations as possible:

- generation that varies in power factor and output;
- uneven distribution of load on feeders supplied from the source substation by season and time of day/week or variations caused by different distributions of customer types;
- more than one generator on different feeders;
- reverse power through the transformer at the source substation;
- heavy load at the end of a long feeder with LDC applied;
- substations with and without LDC applied; and
- a 132kV to 33kV substation.

Monitoring at the trial sites will vary depending on the substation voltage, and/or the operational features of the VCR to be investigated, however the trials aim to verify the following:

a) that the voltages along the feeders supplied by the OLTC transformer are within acceptable voltage limits. This requires voltage measurements at the OLTC transformer and the remote ends of most heavily loaded feeder(s);
b) the accuracy of the VCR estimate of DG output is sufficient for the correct setting of the voltage set point. This requires monitoring of the relay's estimation and the actual current from the DG, the OTLC tap changes and system voltage;
c) how the performance of the estimation and SuperTAPP n+ varies with changes in the load ratio. This requires logging the feeder current, DG current and total load on the transformers; and
d) that the application of Genbias based DG output estimate provides extra level of voltage control to counter voltage rise problems.

### Trial Site 1

The criteria for the first trial site were that it should be:

- at 11kV with multiple feeders;
- be equipped with 2 parallel transformers;
- have feeders with similar load profiles; and
- have a 1-2MW generator connected to one feeder some distance from the 11kV busbar.

Ideally the system would be operating at the limit of the allowable voltage envelope before the SuperTAPP n+ was installed. Any conventional tap change scheme could be in use.

The site selected to meet most of the above criteria is a substation with two parallel transformers feeding a radial 11kV network (Figure 1). The load is a mixture of domestic and industrial load. A landfill gas generator is connected to one feeder which also supplies local load. The existing voltage control scheme at the substation maintains the voltage close to the target voltage. There is significant variation of the load on some of the feeders. This network is relatively simple and of a conventional design. The initial site was selected primarily to verify that the relay functions as expected and to evaluate the accuracy of the estimation of the generator output on a simple system.

The relay was first run in 'open loop' mode to check that it was installed properly and the generator estimation was accurate. The original VCR still controlled the tap changes. Real and reactive current, voltage and power factor are measured at the generator and at the substation where the SuperTAPP n+ relay is installed. The voltage at the remote end of the feeder with the greatest voltage drop is also monitored. The SuperTAPP n+ relay's estimation of the DG's real and reactive current and tap signals are recorded.

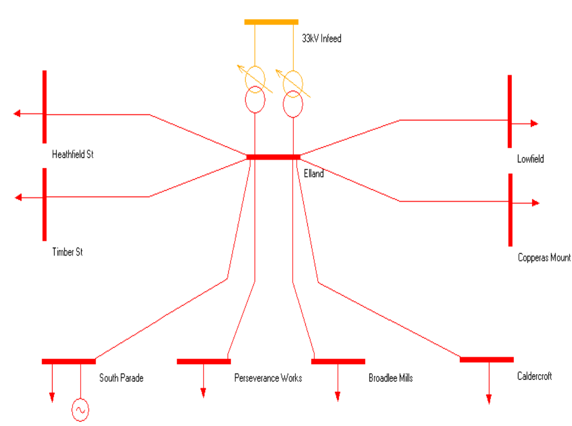


**Figure 1 Site 1 network**

## Trial Site 2

At the second site the relays will control 132kV to 33kV transformers. A number of wind farms are connected to the network and voltage rise problems could occur at times of high generation and low load, if further generators are connected in the future.

## Trial Sites 3 and 4

Sites 3 and 4 are expected to be sites on networks interconnected at the voltage level controlled by the VCR or with multiple generators.

## RESULTS

Initial results from the first site are now available. Of particular interest is the accuracy of the estimation of the DG output. The results of three days are show in Figure 2 to Figure 7 as illustrative examples of the typical behaviour. The 10th April and 17th April are days where the generator is varying its output whereas on 13th April the output of the generator is steady but the load is varying. Negative feeder current indicates an export of power exceeding the feeder load. The data shows that:

- when there are significant changes in generator output, the estimated current follows the true output well (Figure 2 and Figure 6);
- there are small variations between the relay's estimation of the generator current and the measured generator current that are due to variations in the load ratio between the feeders and are not present in the generator's true output (Figure 4); and
- the estimation follows the generator output well for a generator running off landfill gas with a steady output (Figure 2, Figure 4 and Figure 6).

Whilst there is a difference between the actual generator output and the estimated value that is often between 10% and 20%, this does not appear to have a significant impact on the Genbias facility. For example, a relay set with 5% Genbias with a 20% error on the estimate of the generator current would only give a 1% error in Genbias. Another method of assessing the impact of the error is in terms of the total current through the substation. In Figure 4 the maximum difference between the estimated and true current from the generator is around 10A. This is an error of about 20% in the estimation of the generator current. However, the total current through the substation transformers at that time was around 200A. The error in the total current drawn by the load is therefore only in the order of 5% and has little impact on the applied LDC and resulting voltage setpoint. There is also a safety feature in the form of a cap on the effect of the Genbias that limits the impact of any overestimation of the generator output.

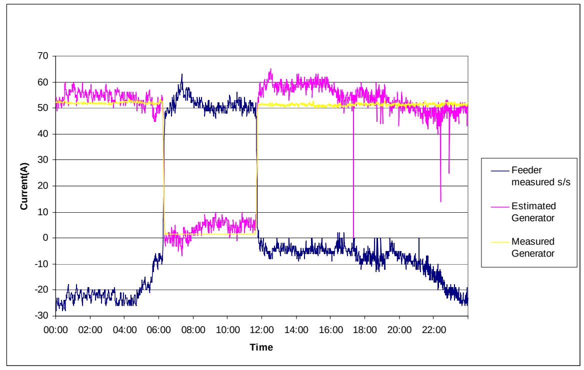


**Figure 2 Estimated generator current, measured generator current and feeder current measured at the substation - 10th April**

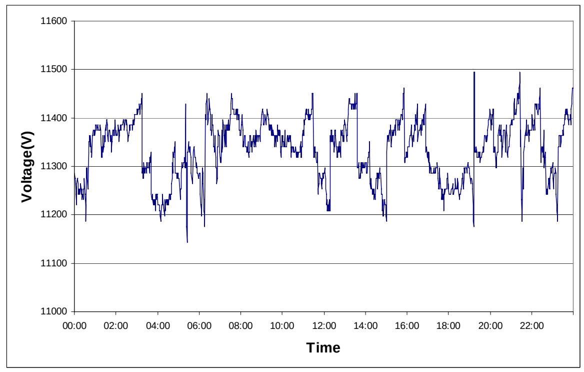


**Figure 3 Substation voltage - 10th April**

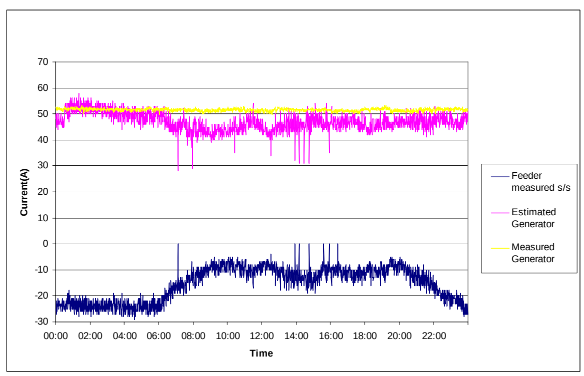


**Figure 4 Estimated generator current, measured generator current and feeder current measured at the substation - 13th April**

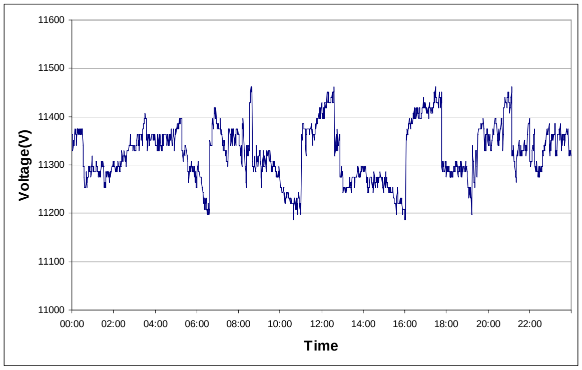


**Figure 5 Substation voltage - 13th April**

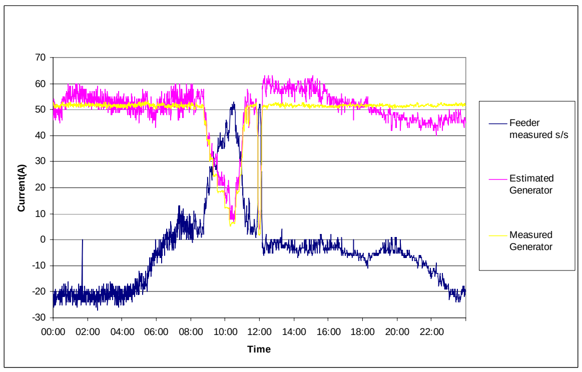


**Figure 6 Estimated generator current, true generator current and feeder current measured at the substation - 17th April**

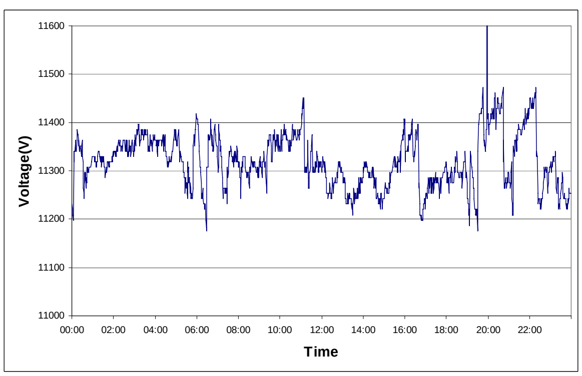


**Figure 7 Substation voltage - 17th April**

## CONCLUSIONS AND FURTHER WORK

The results obtained to date suggest that the estimation process closely estimates the output from the generator and that it correctly responds to large changes in generator output i.e. that the principle of Genbias in the SuperTAPP n+ relay works. Conventionally, a smaller voltage envelope would have been available resulting in a more restrictive limit to the generation capacity that could be connected.

Subsequent trial sites will explore the extent of the additional voltage headroom that can be achieved with the SuperTAPP n+ relay and its ability to estimate more rapidly varying output from generators such as wind turbines and on more complex networks.

In addition, a desk study of the extra voltage headroom/ generator connection capacity available by using a SuperTAPP n+ on site 1 will be carried out. The lowest acceptable voltage setting for high load/no generation and the resulting maximum generation that can be connected will be determined. It will then calculate the additional generation that can be connected using the SuperTAPP n+ resulting from its enhanced capability to vary the voltage set point. This will take into account the degree of confidence in the accuracy of the estimation of the DG output, and how it will affect the voltage setpoint and headroom. The extent to which the confidence in the DG estimation varies with the generation and load size and type will be determined during the trial programme.

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## REFERENCES

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[2] Hiscock et al, 2007, "*Advanced Voltage Control for Networks with Distributed Generation*", Proceedings of CIRED Vienna 2007. paper no. 0148.