# CONSERVATION VOLTAGE REDUCTION AND VOLTAGE OPTIMISATION ON IRISH DISTRIBUTION NETWORKS

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## ABSTRACT

*Conservation Voltage Reduction, reducing the supply voltage by a small percentage such that customer equipment and distribution transformers may operate more efficiently, has been shown in the US to be very beneficial in delivering Energy Savings. ESB Networks, is trialling the effect of this on Irish Networks with positive results emerging from early stages trials.*

*This paper looks at the actual results of the triled and considers these results in the context of expected results through modelling and simulation and comparison to international results.*

## INTRODUCTION

In 2009 ESB Networks (ESBN) became a partner in the Electric Power Research Institute (EPRI) Smart Grid Demonstration, a three year programme investigating a range of efficiency and supply quality and security solutions for distribution networks. Only the second utility outside of North America to partake in these trials, ESB Networks plays a key role in determining the suitability of solutions in the context of Irish physical, economic and cultural conditions.

ESB Networks has a history of commitment to operational efficiency through innovation. In the late 1990's ESB Networks adopted the strategy of reinforcing the MV network by converting from 10kV to 20kV, almost quartering distribution losses, more than doubling capacity and offering an effective solution to voltage drop.

Voltage management and optimization is increasing in complexity with energy efficiency and the integration of renewable energy sources becoming priorities. Ireland will have the highest penetration of wind generation in the EU by 2020, already seeing instantaneous penetrations of up to 50% with over half of the wind generation in Ireland is connected to the distribution network.

An operational strategy which may deliver energy efficiency is conservation voltage reduction (CVR). This comprises reducing the supply voltage by a small percentage such that customer equipment and distribution transformers may operate more efficiently. It has been reported that CVR could deliver a 2% reduction in 2030 electricity demand in the US if universally applied [2].

## CVR FIELD TRIALS

### Test Networks

ESBN field trials are being carried out at two medium voltage networks. The first location is in Kerry, the south west of Ireland, on two adjacent rural 20kV outlets, named Sneem and Waterville. The second location is an Urban network in Dublin City, Sallynoggin 38/10kV substation with eight outlets. The rural networks are predominantly overhead while the urban network is completely underground cable. All of the test networks are dominated by domestic load, with a small amount of small commercial (hospitality and small shops) and minimal industrial load.

The rural Kerry outlets form a 20kV loop with a normally open point midway comprising of over 470KM network serving 4500 customers. This network has a high level of remote monitoring and communications, The Urban test network – Sallynoggin feeds almost 8500 customers. Ion Meters are installed at the station to provide high accuracy measurement of load and also to trigger the CVR.

### Pre-analysis

The rural networks were modelled in detail using Open DSS, a distribution system modelling tool developed by EPRI. Based on measured historical loading of the network, domestic smart meter data collected during the Irish Smart Metering Customer Behavioural Trial 2009 – 2010, downline switch and recloser loading data and annual load on distribution transformers, 8760 hourly power flow calculations were performed to determine load and voltage conditions on the network both under regular and conservation voltage reduction conditions.

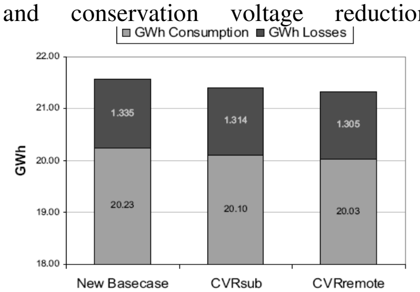


**Figure 1: Modelled demand and loss results for the rural networks**

The results in **Error! Reference source not found.** show the potential reduction both in demand and distribution losses. With a 3% voltage reduction, end of line voltages would be maintained within standard under all loading conditions. This simulation estimates that the expected reduction is a combined demand reduction and loss reduction.

"CVR sub" refers to a static reduction in substation and downline voltage regulator nominal sending voltages to achieve a flat 3% reduction along the outlets. "CVR remote" refers to variable reduced setpoints based on a feedback loop with end-of-line voltage measurement. This would allow the voltage to be reduced more significantly without risk of dropping below network voltage standards. However it would require significantly more investment in monitoring and control, which would need to be justified based on the results of the less complex CVR Sub demonstration.

## Implementation

### Control

On the rural Kerry networks a 3% reduction is being applied from the station busbar and all of the downline voltage regulators. The downline regulators, have inbuilt 2%, 3% or 4% CVR settings while the station transformer controller can give a reduction of 3%, 6% or 9%. This is in line with the level of control advised in [3]. CVR is triggered remotely. In the Dublin (Sallynoggin) Urban network CVR is applied through a 2.5% reduction in sending voltage from the substation. There is existing relay to achieve this, as the legacy of a 5% voltage reduction scheme run in Dublin in 2000. ION power quality meters installed at the transformers to measure trial performance triggers the CVR relay based on a pre-programmed schedule.

### Scheduling and control data

To obtain valid comparison data the voltage reduction is implemented on alternate days such that loading effects specific to particular days of the week could cancel out over time and allowing analysis of the data in 2-weekly periods so that variation with time of year could also be monitored. On the rural outlets the voltage reduction is run on alternate days such that there is control data for each day as the proximity of these networks means that any environmental effects will impact on both.

The voltage reduction is triggered during the night valley to ensure that any thermostatically controlled loads would not be split over the switching period, thereby reducing the impact of load transfer from a CVR to non-CVR period.

ION power quality meters, SCADA load measurements and advanced downline fault passage indicators delivering voltage and current measurements for all phases are being used to measure the load. Smart meters with GPRS communications are being installed at various points along the network to confirm the delivered end user voltage at different network points and to ensure that end of line voltages are kept within standard. The load data from these devices will also be used to determine the source of any observed demand efficiency, indicating the impact specific to domestic load as opposed to results which also reflect distribution system loss performance.

## INITIAL RESULTS

The results are based on analysis of the total energy drawn each day over consecutive 2 week periods, with each period containing a sample of each day of the week under CVR and non-CVR conditions. The CVR factor measures the response of both active and reactive power to voltage variation as in the formulae below.

$$CVRp = \frac{\%\Delta P}{\%\Delta V} \qquad CVRq = \frac{\%\Delta Q}{\%\Delta V}$$

Table 1 shows the measured active and reactive CVR factors over the period September 2011 – February 2012.

| Network | CVRp | CVRq |
|---|---|---|
| **Waterville (rural)** | 0.58 | 6 |
| **Sneem (rural)** | 0.83 | |
| **Sallynoggin (urban)** | 0.98 | 6.6 |

**Table 1: Measured CVR factors**

Investigation of any relationship between temperature and performance was inconclusive – only in cases extreme temperature deviation could any correlation be found, No statistically sound relationship could be established. The results have proven consistent over the trial period to date, as illustrated in Figure 2.

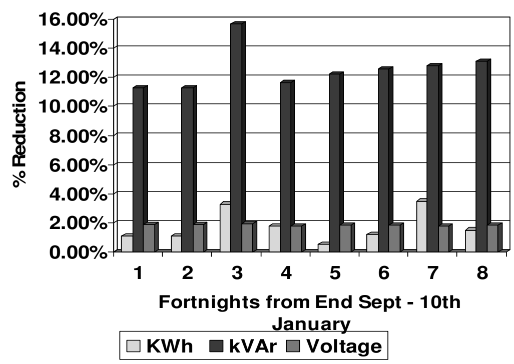


**Figure 2: Sallynoggin results over 16 week period**

## ANALYSIS

The CVR factor of 0.98 observed in the Sallynoggin trial is in line with a 5.3% load reduction encountered in a Dublin voltage reduction scheme in 2000 with a 5% voltage reduction.

Active demand reduction

Average active CVR factors of 0.5 – 0.98 have been observed. Constant power, impedance and current loads on the network will behave differently to the voltage reduction.

| Appliance | % of Irish annual load | CVR factor |
|---|---|---|
| **Wet appliances** | 9.68 | 0.01 |
| **Refridgeration** | 12.48 | 0.63* |
| **Lighting** | 17.71 | 1.41* |
| **Circulation pump** | 3.91 | 0.08 |
| **Weighted Average CVR** | 43.76 % | 0.79 |
| **Average CVRf (assuming no other applicable load)** | | 0.347 |

**Table 2: ESBN analysis of domestic load stock with CVR factors [4]**

Table 2 shows an analysis of the CVR factor of a range of high penetration domestic appliances in Ireland. These results suggest that domestic load that can be identified to give reductions would deliver savings corresponding to a network CVR factor of 0.347. However, the identified loads make up just 43.76% of total loads and other loads such as electrical space heating, water heating, that are time controlled, shower pumps and other domestic loads would also contribute to energy reductions with CVR.

Measurements of CVRf for a small domestic fridge and incandescent lamp (currently ~92% of Irish lighting stock) (Table 3) which make up most of the known contributors to CVR, gave largely linear results over the range 210 V – 250 V, thus these CVR factors should also be those found for the field trial reduction of 3% (230 V – 223 V).

| | Reduction 239 V - 220 V | CVRf | Reduction 239 V - 210 V | CVRf |
|---|---|---|---|---|
| Small domestic fridge | 5.00 | 0.63 | 7.70 | 0.63 |
| Incandescent lamp | 11.20 | 1.41 | 17.10 | 1.41 |

**Table 3: Measured % demand reduction with voltage for domestic fridge and lighting [4]**

**Reactive demand reduction**

The reduction in reactive power is notably higher than that in active power. With network power factors measured at 0.98 – 1, there is little reactive load on these networks. There is no industrial load on the networks thus no significant motor loading. The source of this reactive power reduction is thought to be due to the response of distribution transformers. A 1981 study undertaken by EPRI examined the change in reactive power with voltage for various sizes and manufacturers of distribution transformers [5] The $CVR_q$ obtained ranged from 7.07 to 10.25 as voltage was reduced from 240V to 230V. The response was very non-linear. Figure 3 illustrates an example from these measurements.

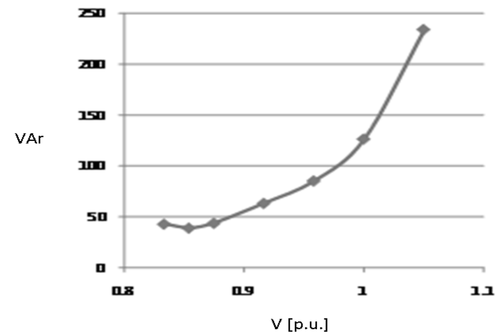


**Figure 3: Example of distribution transformer reactive demand variation with voltage**

Reconciliation with international experience

Measurement of CVR factors for a range of sites (domestic, commercial and industrial) using on-site voltage regulators, undertaken by the NEEA [6] gave results as illustrated in Table 4. .

| | |
|---|---|
| Average Residential | 0.76 |
| Average Industrial | 0.41 |
| Average Commercial | 0.99 |

**Table 4: Measured CVR factors from NEEA OVR trials**

Field trials on networks dominated by domestic load have given results as in Table 5. The CVR factors obtained by Southern California Edison are higher than obtained by ESBN, likely driven by high levels of air conditioning on these networks which are not present in Ireland. The weighted average Hydro Quebec result is significantly lower, though this is likely influenced by high levels of thermostatic heating loads in winter. However, Table 6 illustrates that the residential CVR factor measured in summer, without this heating load, is in line with ESBN experience.

| | CVR Factor | Notes |
|---|---|---|
| **Hydro Quebec** | 0.4 | Weighted average residential |
| Southern California Edison | 1.47 | 98% Residential, 2% Commercial |
| | 2.33 | 80% Residential, 20% Commercial |

**Table 5: North American CVR field trial results [7]**

| Type | summer CVR | winter CVR |
|---|---|---|
| Residential, all electric | 0.67 | 0.06 |
| Residential, not all electric | 0.67 | 0.12 |
| Commercial | 0.97 | 0.80 |
| Small industries | 0.10 | 0.10 |
| overall | 0.67 | 0.20 |

**Table 6: CVR factors measured by Hydro Quebec [8]**

Trials in Snohomish County, US, gave results as in

| Circuit ID | % UG | Peak [MW] | Avg load [kW] | CVRf |
|---|---|---|---|---|
| **12-239** | | 5 | 1557 | 0.513 |
| **12-240** | | 7 | 3577 | 1.103 |
| **12-253** | | 8 | 3909 | 0.623 |
| **12-267** | | 9 | 4115 | 0.336 |
| **12-1748** | 90 | 5 | 2419 | 0.676 |
| **12-1749** | 80 | 4 | 2233 | 0.548 |
| **12-1750** | | 5 | 4475 | 0.893 |
| **12-1151** | 90 | 5 | 2511 | 0.514 |
| **12-584** | 10 | 8 | 3160 | 0.641 |
| **12-585** | | 3 | 1148 | 0.707 |
| **12-586** | | 5 | 2166 | 0.525 |
| **12-587** | | 5 | 2686 | 0.572 |
| **Sneem** | <2 | 2.1 | 1156 | 0.83 |
| **Waterville** | 1 | 1.8 | 1385 | 0.57 |
| **Sallynoggin** | **100** | 13.1 | 6105 | 0.98 |

Table 7 [1]. The CVRf of 0.33 – 0.676 for domestic networks and 0.893 - 1.103 for commercial outlets are closely in line with ESBN results.

| Circuit ID | % UG | Peak [MW] | Avg load [kW] | CVRf |
|---|---|---|---|---|
| **12-239** | | 5 | 1557 | 0.513 |
| **12-240** | | 7 | 3577 | 1.103 |
| **12-253** | | 8 | 3909 | 0.623 |
| **12-267** | | 9 | 4115 | 0.336 |
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**Table 7: Comparison of ESBN and Snohomish PUD CVR trials**

## Potential benefits and interactions

ESB Networks have estimated from these initial trials that energy reductions of 1.7% could be achieved through CVR, however this will need to be clarified based on further evidence.

Distributed generation on Irish networks poses a challenge in terms of voltage regulation, with reverse power flows leading to increased voltages. However this will effect less than 10% of the MV network outlets.

## FUTURE WORK

The field trials described will continue to run until September 2012, enabling analysis of a year of data. Additionally, smart meters being installed on the test networks will enable further analysis of the impact on domestic loads. It is also planned to install MicroPlanet LV voltage regulators at a small number of distribution transformers to analyse the effects of local voltage regulation and local conservation voltage reduction.

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