USING SMART DISTRIBUTION TRANSFORMERS TO REDUCE BOTH INDUSTRIAL ENERGY CONSUMPTION AND PEAK DEMAND BY MEANS OF A CVR STRATEGY

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ABSTRACT

Conservation Voltage Reduction (CVR) is a known technique that increases the capacity of the network by reducing the power peak demand (peak shaving) and contributes to energy saving. Most of the studies published in this field are focused on the application of CVR in domestic networks or mixed consumers (domestic + industrial). This research analyses a real case where a distribution smart transformer is exclusively feeding industrial loads with a reactive power compensation device operating on the low voltage side. A test programme has been carried out to assess the implementation of a CVR strategy.

Research findings indicate that the behaviour of the loads is suitable for the implementation of CVR. Test results also show that the performance of the reactive compensation system is compatible with a CVR strategy making possible the implementation of a combined solution that provides the benefits of both techniques.

INTRODUCTION

This paper presents a real industrial use case of Conservation Voltage Reduction (CVR) strategy by means of a distribution smart transformer in an application where a reactive compensation system is already present. Several tests have been carried out to assess the sensitivity of the loads and the performance of a CVR implementation in different scenarios has been analyzed.

CVR STRATEGY

CVR enables the reduction of peak demand and contributes to energy saving. In order to implement CVR, it is necessary to modify the voltage at the Low Voltage (LV) side to reduce power consumption. The reduction in load and energy demand is dependent on the types of loads connected. The voltage sensitivity of equipment can be categorized into sensitive and non-sensitive, because not all types of electrical equipment respond with a reduction in energy usage with a reduction in supply voltage.

CVR is effective with constant impedance or constant current loads where a reduction in voltage leads to a reduction in power. In addition, losses will be reduced for constant impedance loads due to reduced current. However, CVR on voltage dependent (constant power) loads will lead to increased losses and thus higher power consumption overall. Also, for constant impedance resistive loads, such as space heaters, reduced voltage may reduce the current but the same amount of energy is required so there are no energy efficiency savings for the consumer.

There are guides that can help potential CVR users to determine whether this technology is suitable for their site operations [1].

Several examples of the CVR impact on electrical networks are described below:

According to a report ran by NRECA[1] and CRN[2] [2], CVR benefit with the largest and clearest payback was peak demand reduction. Loss reduction is another benefit. Energy sales also are reduced as an effect of CVR.

Electricity Northwest Smart Street Project[3] [3] trialed a CVR strategy to enable their networks and customers' appliances to perform more efficiently. As a result they achieved, a reduced energy consumption from 3% to 7%, customer power bill savings from £390 million to £780 million per annum and utility reinforcement savings of £8.6 billion over 25 years.

Kootenai Electric Cooperative (KEC) looked for other ways to help reduce its wholesale power bill without impacting its energy sales [4]. KEC implements a demand-response by a voltage-reduction system using both peak shaving and valley filling. By dropping the voltage down to 116V on a 120V base, the demand dropped 5.2%.

Pee Dee electric Cooperative is using CVR to reduce peak demand cost [5]. Reducing the voltage by 3% during peak load conditions would reduce peak demand by 2.1% to 2.4%.

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[1] The National Rural Electric Cooperative Association

[2] NRECA's Cooperative Research Network

[3] https://www.enwl.co.uk/innovation/smart-street

According to a Pacific Northwest National Laboratory report [6], CVR provides peak load reduction and annual energy reduction of approximately 0.5% - 3% depending on the specific feeder. When extrapolated to a national level (USA) it can be seen that a complete deployment of CVR, 100% of distribution feeders, provides a 3.04% reduction in annual energy consumption.

Furthermore, a 2018 gtmresearch report [7] confirms that although 8.5% of USA circuits are already using CVR schemes, an additional 31.5% of the remaining circuits have a high CVR potential.

According to [8], by 2030 with an uptake of 50% of both electric vehicles and heat pumps in a representative UK LV distribution network, a reduction in load of 3.2% was seen for a 6% voltage reduction. It can help reduce the strain on the network during peak load periods by managing load profiles and therefore defer network reinforcement.

The benefits of CVR specifically for peak load reduction are represented by the ratio of the percentage reduction in demand to the percentage reduction in voltage [8], known as the CVR factor:

$$CVR = \%\Delta D / \%\Delta V$$

Where D can be defined as active or apparent power.

CVR strategy, at [8], was realised through a reduction in voltage at the HV/LV substation transformer. This is achieved through a change to the tap settings of the HV/LV transformer.

As can be seen in the state of the art, there is no previous published experience in the use of smart distribution transformers to apply a CVR strategy in industry, let alone to use it in coordination with reactive power compensation devices.

SMART DISTRIBUTION TRANSFORMER AT INDUSTRY

The most common voltage control technique on the distribution network is to use smart distribution transformers with on-load tap changer (OLTC), which is able to maintain the secondary voltage stable by switching automatically to the suitable tap position.

A new compact smart distribution transformer with a patented (flat) OLTC, an innovative solution for distribution networks, has been developed and tested in both internal [9, 10] and external laboratories [11, 12], where it successfully passed all the required tests from International Standards. Although the standard for OLTC sets a mechanical endurance test with 500.000 operations, the new OLTC reached 1.000.000 operations due to its balanced vacuum contactor operation.

Figure 1. First smart distribution transformer in the field

The first pilot of the smart transformer was installed in Ormazabal Cotradis (January 2017), one of the industrial facilities of Ormazabal (Loeches, Madrid) where distribution transformers are manufactured, to keep the voltage stable and to test CVR strategies taking into account the reactive compensation.

The reactive compensation system includes capacitors that are designed for a specific operating voltage. Therefore, a lower voltage will lead to a loss of the intended power factor correction. On the other hand, a higher voltage may cause damage to the capacitor by exceeding the design limits and the device will, eventually, become ineffective in correcting power factor.

By June 2019 (30 months into operation), it is expected to reach roughly 45.000 operations (18.000 per year) with an average of 50 per day. So far, to our knowledge, it is the smart distribution transformer with the highest number of operations; at least in Europe[4].

This first smart transformer pilot was specially designed (steps of 1%) and configured (algorithm) to perform an extensive number of operations.

TESTS

In order to evaluate the impact of the CVR strategy on power consumption, several tests were performed comparing different scenarios (See Table I).

In Test-A the effect of the reactive power compensation system is analyzed by connecting and disconnecting the capacitors while the OLTC is at tap 5.

In Test-B and Test-C the OLTC performs a sequence of tap changes covering the whole tap range to assess the behavior of the system during voltage variations in two different scenarios: with capacitors disconnected (Test-B) and connected (Test-C).

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[4] Usually from 3 to 8 operations per day.

TEST	CAPACITORS	OLTC	DESCRIPTION
Test-A	ON-OFF-ON-OFF-ON	Locked at tap 5	Capacitors connected and disconnected while OLTC is locked at rated position.
Test-B	OFF	Tap change (3 sec)	Tap change covering the whole range (Tap 1 to 9 and tap 9 to 1)
Test-C	ON	Tap change (3 sec)	Tap change covering the whole range (Tap 1 to 9 and tap 9 to 1)
Test-D	ON	Tap change (10 sec)	Tap change every 10 sec covering the whole range (Tap 1 to 9 and tap 9 to 1)

Table I. Tests cases

Test-D includes the same tap change sequence as in Test B and C but with a time period of 10 seconds between each tap change and a higher sampling frequency in order to analyze the impact of possible transient effects between tap changes.

As shown in Figure 2 the smart transformer feeds two factories, each one focused on different fabrication processes. The reactive power compensation system balances the high inductive loads coming from the transformers coil curing process of Factory Cotradis-2. The power consumption, as well as the voltages and currents, are measured by a Power Analyzer located at the LV output of the transformer. A remote sensor is also installed for monitoring the voltage at the point where the reactive power compensator is located.

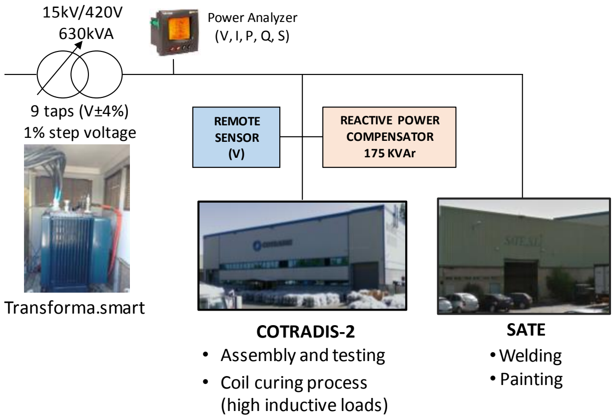

Figure 2. Low voltage diagram

On the other hand, in order to have a better understanding of the test results, the active and reactive power consumptions have been analyzed without CVR strategy. This data provides information about the daily load pattern and the load fluctuations for short and long time periods.

It is important to assess how these power fluctuations could affect the sensitivity analysis of the system during voltage variations. In this case, the OLTC has a voltage step of 1% with an actuation time of 3 seconds. Taking this into account, as shown in Figure 4, there are power fluctuations above the step voltage (>1%) and quicker than the actuation time (<3sec), whose influence is not negligible. Hence, in this specific application, the CVR factor [10] would not be a useful parameter for measuring the sensitivity, as the values obtained would not precisely quantify the benefits of applying a CVR strategy.

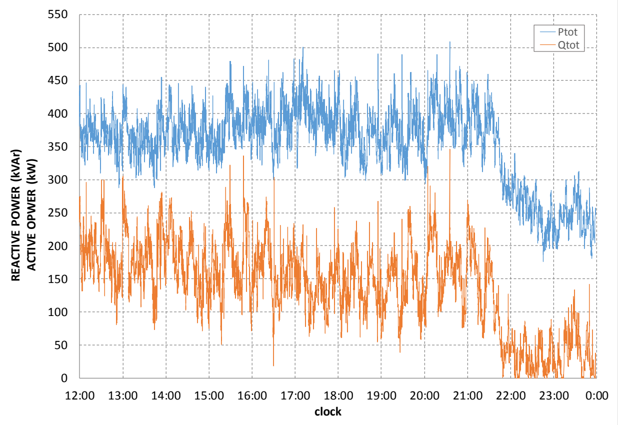

Figure 3. Load sample for half a day

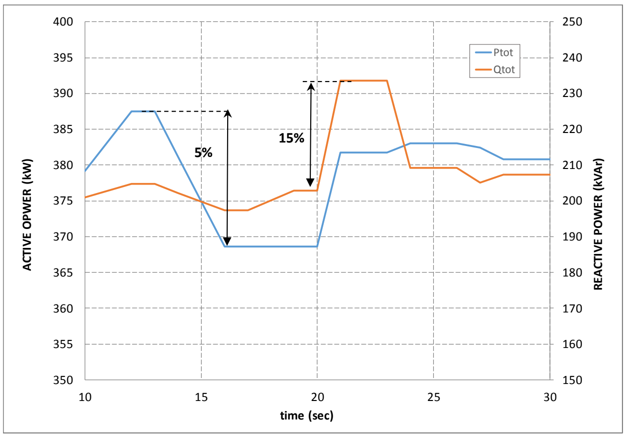

Figure 4 Load sample for a short period of time

RESULTS

The results obtained from Test-A show the benefits of using the capacitors as the reactive power consumption is reduced significantly (>100kVAr). On the other hand, the connection and disconnection of the capacitors has not such a direct influence on the active power. Regarding the voltage measurements, it can be seen that having the capacitors connected reduces the voltage drop (≈1V) between the smart transformer and the reactive compensation system.

The results from Test-B show that the voltage variation made by the smart transformer has a direct influence on both active and reactive power consumed by the factory loads. The defined tap change sequence generates a symmetric voltage profile that is copied by the active and reactive powers. It can also be seen that the total voltage variation range has a bigger influence on the reactive power (ΔQ_{tot}>30%) than on the active power (ΔP_{tot}>10%).

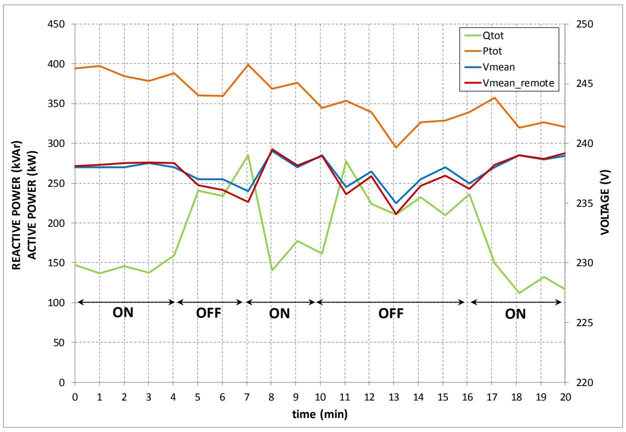

Figure 5 Test-A results

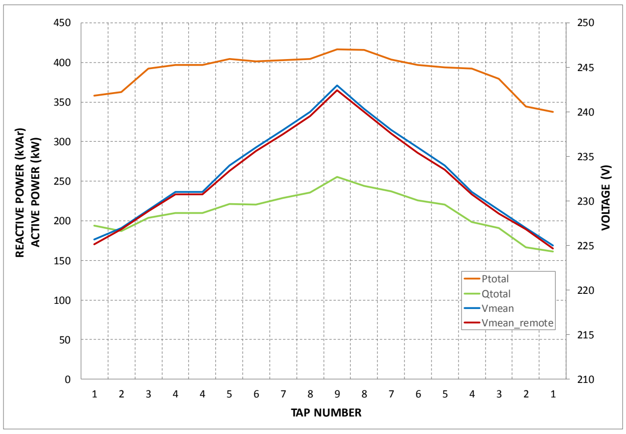

Figure 6 Test-B results

In Test-C the same tap sequence is carried out but with the capacitors connected. The measured reactive and active powers also copy the symmetry of the voltage profile, showing also in this scenario that the voltage variation produced by the smart transformer has influence on P and Q. This fact confirms that a CVR strategy is compatible with the reactive power compensation system, taking advantage of the additional Q reduction provided by the capacitors.

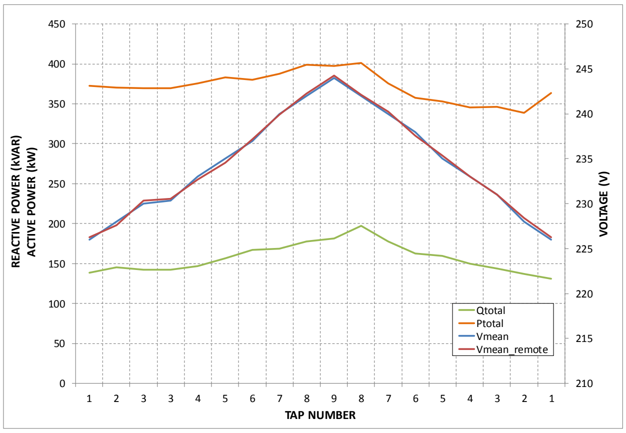

Figure 7 Test-C results

In Test-D, the time period between tap changes is increased (from 3 sec to 10 sec) as well as the sampling frequency in order to check that no transient effects that could affect the assessment of the CVR implementation are found between tap changes. The results obtained are consistent with the previous tests since P and Q show the same behaviour with respect to the voltage profile.

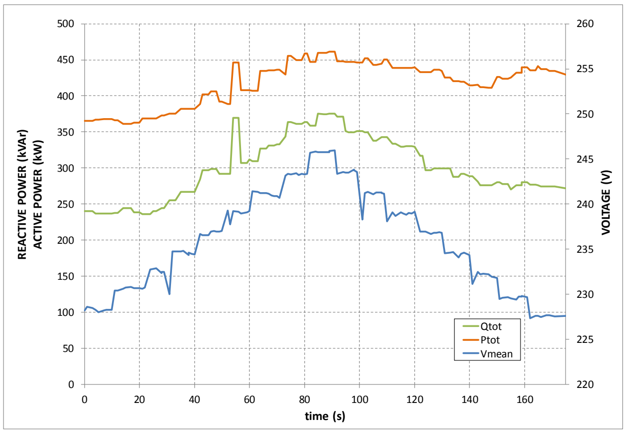

Figure 8 Test-D results

Table II summarizes the trade-off between the different tested scenarios, where the configuration used for Tests-C&D is shown as the most efficient solution.

TEST	P	Q	Comments
Test-A	≈	↑↓	• The benefits of the reactive compensation system are measured
Test-B	↓	↑	• P and Q can be reduced applying CVR • However, the overall Q value is increased as the reactive power compensator is OFF
Tests-C&D	↓	↓↓	• P and Q can be reduced applying CVR • Reactive power compensator is ON providing an additional reduction of Q

Table II. Summary of test results

CONCLUSIONS

The implementation of CVR strategies by means of a smart transformer, in combination with a reactive power compensation system has been tested in a fully industrial application.

Prior to the tests, an analysis of the loads (without CVR) has been carried out where both active and reactive power fluctuations were found not to be negligible in magnitude and time as compared with the voltage step and actuation time of the smart transformer. This fact affects the calculation of the CVR factor and reveals that in this kind of industrial application the CVR factor is not a useful parameter for quantifying the benefits of a CVR strategy.

The results obtained from the test campaign show a direct influence between the voltage regulation and active and reactive power confirming that the loads are sensitive and hence compatible with a CVR strategy. The same behaviour is seen when the capacitors are connected substantiating the compatibility between CVR and the reactive compensation system. It can therefore be concluded that the implementation of a strategy that combines CVR and reactive compensation devices would provide the benefits from both techniques. On the other hand, in order to optimize the energy efficiency, it is important to bear in mind that the capacitors are designed for a specific operating voltage which is defined as the voltage set point for the smart transformer.

Further technical/economic analyses must be performed in order to assess the convenience of any of the former scenarios. These findings are expected to help industry to determine the benefits of using smart distribution transformers for CVR strategies, taking into account existing energy saving devices.

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