INTELLIGENT DISTRIBUTION SUBSTATION IMPROVES POWER QUALITY

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ABSTRACT

This paper reports the built up experience in improving the power quality (PQ) in the low voltage distribution grid by means of an intelligent distribution substation.

Today's distribution networks face numerous challenges. Fluctuating loads and increasing penetration of distributed generation lead to extra voltage variations and changes in power flows and as result to an increase of uncertainty for planning and grid operation. The need for new technologies, which can manage these challenges and still provide a reliable and sustainable power supply, has become essential.

The Dutch DSO Alliander, in consortium with Dutch industries, has developed and installed the Intelligent Distribution Substation (IntDS) with a goal to investigate how the combination of power electronics and storage can manage above stated issues and improve power quality in low voltage (LV) distribution grids.

Field tests were performed in order to proof the functionality of the control systems and the impact of these controls on the power quality in the connected LV grid.

These field tests demonstrate a significant improvement of a number of power quality aspects both at the LV bus-bar of the IntDS and at the point of common coupling (PCC) of the LV customers.

INTRODUCTION

Introduction of power electronics and potentially disturbing loads in distribution grids can result in the decreasing of power quality (PQ). Moreover distributed generation leads to extra voltage variations and changes in power flows. At the same time the growing life standards and the increasing sensibility of a number of devices cause higher expectations towards PQ levels. The need for new technologies that can manage these challenges has become apparent.

In order to investigate the benefits of the combination of power electronics and storage devices in managing the above stated issues, the Dutch DSO Alliander, in consortium with Dutch industries, has developed and installed the Intelligent Distribution Substation [1].

The goals to be achieved by the IntDS are:

- Limiting of slow voltage variations in the LV grid by means of the smart transformer;
- Reducing/compensating harmonic voltage distortion by means of the inverter control;
- Obtaining information about power flows in the LV grid with distributed generation.

THE INTELLIGENT DISTRIBUTION SUBSTATION

The intelligent distribution substation is based on a standard MV/LV substation. It is extended with intelligent components, in order to improve the performance of the LV grid.

<u>**"Intelligent" components**</u>

The "intelligent" components of the IntDS (Figure 1) are:

- The Smart Transformer: a distribution transformer (10kV/400V) with a coupled power electronic voltage regulation and control;
- The electricity storage system, connected to LV bus-bar by means of a bidirectional inverter (ESI);
- The measurement system: all ingoing, outgoing and internal feeders are equipped with voltage and current monitoring devices. This measuring system is based on the SASensor philosophy [2].

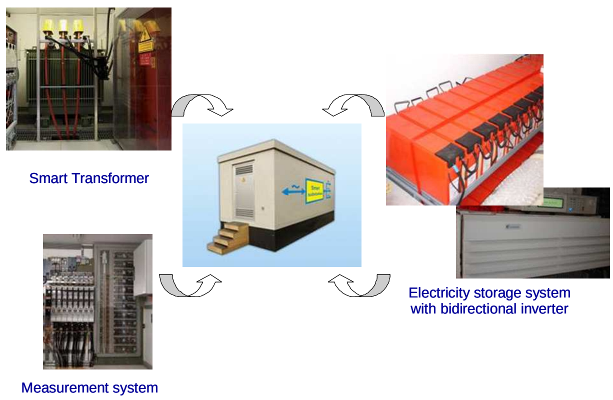

Figure 1 The intelligent components of the IntDS

The IntDS is placed in a district, where a large amount of domestic customers have installed micro Combined Heat and Power (μCHP) installations (Figure 2).

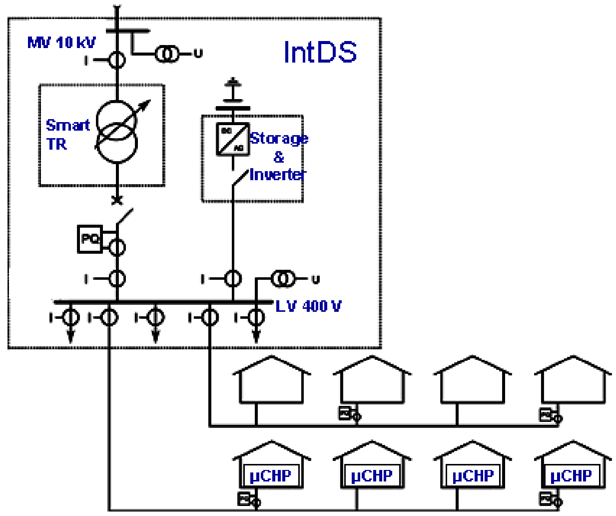

Figure 2 Overview of the IntDS and the connected LV feeders including measuring devices

In order to monitor the effect of the control actions on the point of common coupling (PCC) of the LV customers, a number of the houses is equipped with remotely read PQ measuring devices.

Possibilities for Power Quality improving

The IntDS has possibilities to improve PQ aspects in the LV grid such as:

- Voltage control;
- Reduction of harmonic distortion;
- Compensation of voltage dips;
- Compensation of flicker.

Several of these possibilities are tested in a field test.

Voltage control

For the voltage control the electronic tap changer of the Smart Transformer is activated. This ensures a constant voltage level on the LV rail of the IntDS.
The set-point for the voltage control has to be determined in such way that the optimal voltage level will be achieved at all PCC's of the LV customers.

Harmonic distortion reduction

The voltage harmonic distortion at the LV side of the IntDS can be reduced by:

- Resistive harmonic damping (RHD) by the ESI. The harmonics are absorbed by means of a virtual impedance, created by de ESI. This control has effect up to the 13th harmonics;
- Passive harmonic damping by the ESI. The filter capacitors of the ESI take part in the filtering of harmonics.

Harmonic voltages are caused both by the background harmonic voltages from the feeding MV grid and by the harmonic currents in the LV-cables and the feeding MV/LV transformer.

Because the harmonic controller is located on the LV bus-bar, the IntDS is only able to reduce the harmonic voltage caused by the MV-grid.
In LV grids the 3th, 5th and 7th harmonic voltages are the most dominant. The main target for the harmonic control is reducing these dominant harmonics.
As the 3th harmonic voltage is hardly present at the MV level, the effect of the control will be noticed mostly on the 5th and 7th harmonic voltages.

Voltage dips compensation

Compensation of voltage dips at the LV side of the IntDS is performed by means of the Smart Transformer and the ESI. Voltage dips however only occur a few times per year on an LV bus-bar of a distribution substation. So, this functionality is hard to test.

Flicker compensation (LV side)

The flicker level at the LV side of the IntDS can be improved by:

- The electronic tap changer of the Smart Transformer;
- The flicker compensation control of the bidirectional inverter (ESI) of the storage system.

FIELD TESTS

In order to evaluate the ability of the IntDS on improving network performance, a test program is developed. This test program contains a number of situations, where the impacts of the controls of the IntDS are examined. This test program considers tests of every control individually, followed by combinations of the controls.

Test program

The next tests are performed:

- Voltage control;
- Reduction of harmonic distortion;
- Flicker reduction.

Up to now tests were performed to show the performance of each individual control. The effect on the PQ level was monitored both on the LV bus-bar of the IntDS and on the PCC's of the LV customers, already equipped with PQ measuring devices.
The next tests will be performed to demonstrate the influence of the combined controls on the PQ level at the LV bus-bar of the IntDS and the PCC's of the LV customers.

Test results

A number of the tests were performed in the period from September to November. The effect of the various controls is described both for the LV bus-bar and at the PCC's of two LV customers with µCHP's.

Voltage control

Figure 3 shows the minimum, maximum and average voltage per day on the LV bus-bar of the IntDS. The picture demonstrates clearly the effects of the voltage control. During the test period (from 2-9 until 13-10) the voltage control was activated with three different set-points for the bus-bar voltage. With the activated voltage control the voltage variations on the bus-bar are reduced significantly.

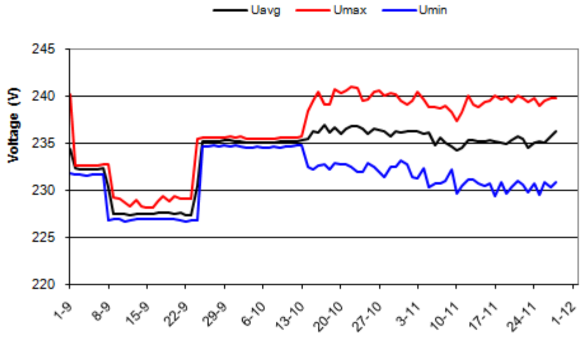

Figure 3 Voltage on the LV bus-bar

Figure 4 and Figure 5 show the voltages at the PCC's of two different LV customers. Also here the effect of the voltage control is clearly visible. The voltage control reduces the daily voltage variations. These variations are about 10 V, when the control is disabled, and are less than 5 V, when the control is enabled. The figures also show the influences of different set-points at the average voltage. The ideal set-point must be depended, based on measurements at more PCC's in the LV grid.

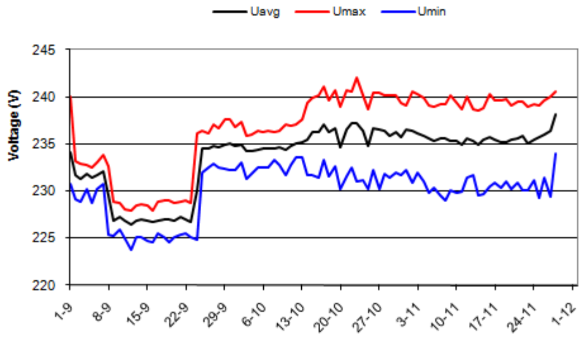

Figure 4 Voltage level at PCC of LV customer-1

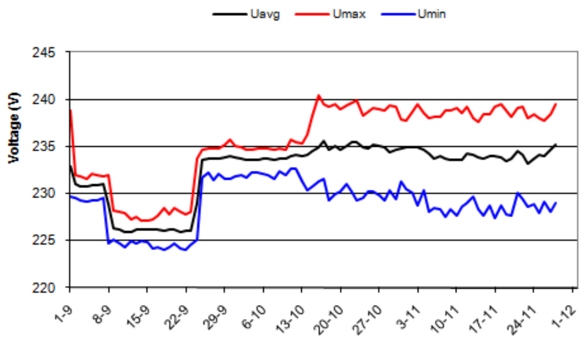

Figure 5 Voltage level at PCC of LV customer-2

Reduction of harmonic distortion

Figure 6 shows the maximum value per day of the harmonic levels on the LV bus-bar. The influence of the harmonic reduction control is clearly visible. When the control is enabled (in the test period from 29-10 until 14-11), the level for the 5th harmonic and for the THD drops by about 1%. The level for the 7th harmonics drops by about 0.5%. It is also visible that the 3rd harmonic is low and not influenced.

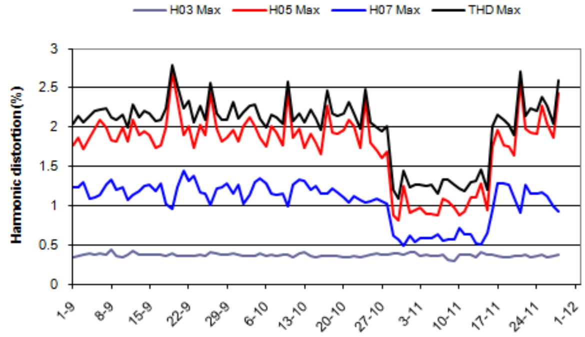

Figure 6 Harmonic voltage at the LV bus-bar

Figure 7 and Figure 8 show the harmonic levels at the PCC's of two different LV customers. Also here the reduction of about 1% can be noticed in the 5th and the 7th harmonic as well as in the THD level. As expected, the 3rd harmonic voltage is not influenced.

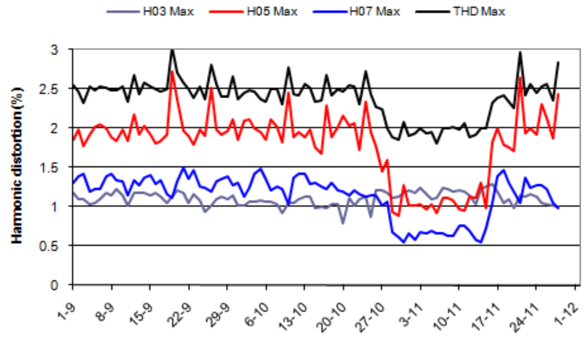

Figure 7 Harmonic voltage at PCC of LV customer-1

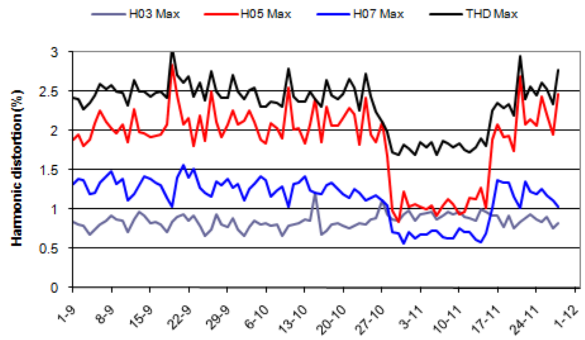

Figure 8 Harmonic voltage at PCC of LV customer-2

Flicker reduction

Figure 9 shows the levels for flicker (the average and maximum level per day for both Pst and Plt) on the LV bus-bar. This figure demonstrates the ability of the bidirectional inverter (ESI) to reduce the over-all flicker level as well as the peaks. It must be noticed, that the over-all flicker level is already low at the bus-bar.

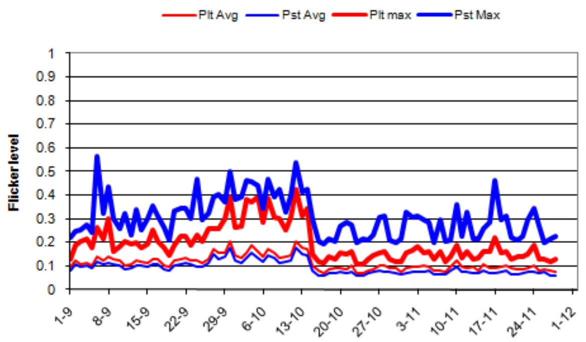

Figure 9 Flicker level at the LV bus-bar

Figure 10 and Figure 11 show the flicker levels at the PCC's of two different LV customers. From these pictures it can be seen, that the flicker compensation hardly influences the flicker level at the LV customers. The IntDS can only compensate the background flicker, originating from the MV grid. However, the main part of flicker in the LV grid originates from the loads in the LV grid and can therefore not be compensated.

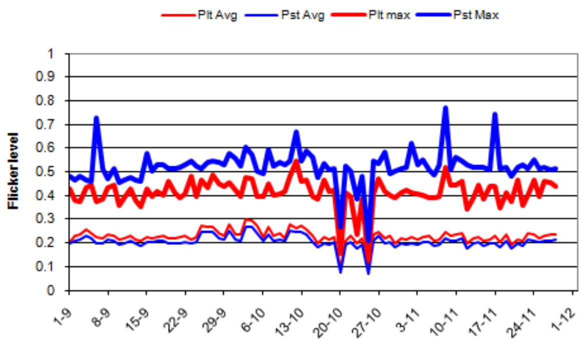

Figure 10 Flicker level at PCC of LV customer-1

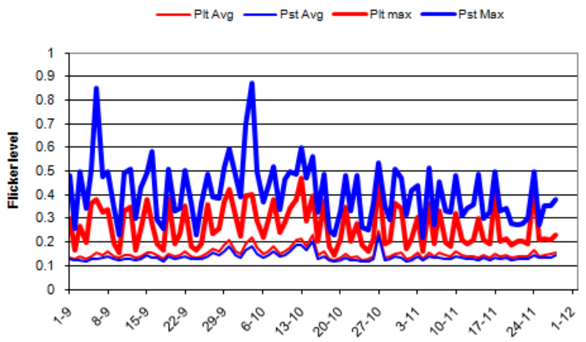

Figure 11 Flicker level at PCC of LV customer-2

FUTURE STUDIES

As the performed tests proof the properly functioning of each individual PQ control, the next step will be to investigate the combined operation of these controls.

In the last period of the project more measurement equipment is installed in the LV grid, both at customers with µCHP's and customers without µCHP's. In this way the influence of the µCHP's on the power quality in the LV grid can be investigated.

The results of various tests and investigations will be used for determining the optimal set-points of the IntDS controls.

CONCLUSIONS

The intelligent substation, equipped with the combination of power electronics and storage, has proved to be safe in operation and to improve LV grid performance.

The first field test results demonstrate already a significant reduction of voltage variations, harmonic and THD levels both at the LV bus-bar of the IntDS and at the LV customers.

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