INTELLIGENT LIMITING VOLTAGE VARIATIONS IN AUTONOMOUSLY CONTROLLED NETWORKS

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ABSTRACT

One of the main objectives of the control in a MV network with a large amount of distributed generation is to obtain an optimal voltage profile for the LV customers. This can be achieved by forced active power flows in the network using an intelligent node and by intelligent control of the HV/MV transformer. Forced active power flow gives good results in networks with long feeders. The effect is especially noticed by customers at the end of the feeder. For customers close to the HV/MV substation an intelligent HV/MV transformer control can be more effective. In this paper a system combining both controls is proposed. This is based on actual measurements of specific feeder currents and a representative network model. Calculations have been performed on a realistic model of a certain MV/LV network.

INTRODUCTION

Networks containing a large amount of distributed generation can be transformed into autonomously controlled networks (AN) with the implementation of power electronics and storage [1]. The AN considered in this paper consists of several feeders of a typical Dutch MV substation. The total maximum load of the AN is about 20 MW which corresponds to about 30% of the substation maximum load. The AN is fed by the same HV/MV transformer as the rest of the MV network (RN) containing mainly normal loads (Figure 1). The total network (TN) consists of underground cables.

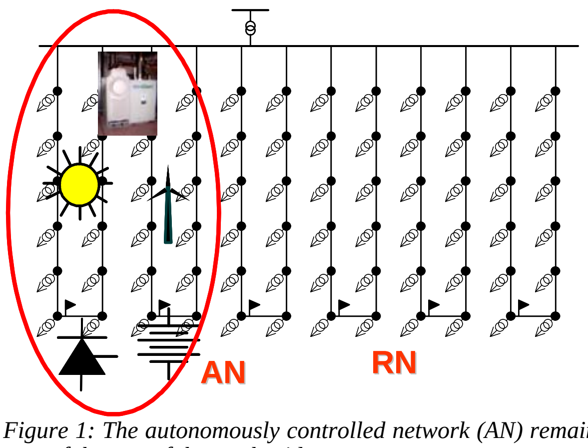

Figure 1: The autonomously controlled network (AN) remains part of the rest of the total grid

In the AN there is a near equilibrium of consumed and generated energy. This equilibrium in energy does not explicitly mean equilibrium in power. The non-coinciding of load and generation results in large variations of the voltage. The variations are noted most by customers at the end of LV networks. One of the main tasks of the control in the AN is to limit these voltage deviations.
The paper describes a proposal for an intelligent control system which is able to limit the voltage variations at the customers LV connection. This is obtained by controlling the voltage profile in the MV network.

PROBLEM DESCRIPTION

Due to the mainly resistive behaviour of MV and LV cables, the variation in load and generation results in a variation of voltages. The relative voltage variations are largest in the low voltage networks especially at the ends of the LV feeders. As the MV/LV transformers are not equipped with an on load tap changer, the variations can only be limited by controlling the MV voltage. In the case that the load exceeds the generation, the overall MV voltage must be increased. In the opposite case, the overall MV voltage must be decreased. There are however some challenges.

- In MV and LV cable networks voltage control by means of reactive power is not effective due to the low X/R ratio.
- The traditional control of the on load tap changer (OLTC) of the HV/MV transformer can not be used as it is based on a constant MV voltage eventually depending on the total transformer current.
- On load (electronic) tap changers installed on all MV/LV transformers is not practical due to restricted space in the Ring Main Units.
- The controls have to work with local measurements and limited communication. The number of extra measurements (e.g. at LV connections) must be limited or even avoided.

Possible solutions must be found in controlling the active power flows in the MV network and by intelligent OLTC of the HV/MV transformer.

CONTROL

A radial network structure eventually combined with active transfer of load between feeders is shown to be a good solution to limit voltage variations in networks with DG [2], [3]. This can be improved by combining this transfer with storage capabilities in a so called intelligent node. The effect of the control for LV networks close to the HV/MV

transformer is however negligible. This can be improved by intelligent control of the HV/MV transformer [4], [5].
In this paper a combination of the two controls is suggested. One is located at the substation and one at the end of two feeders of the AN (Figure 2).

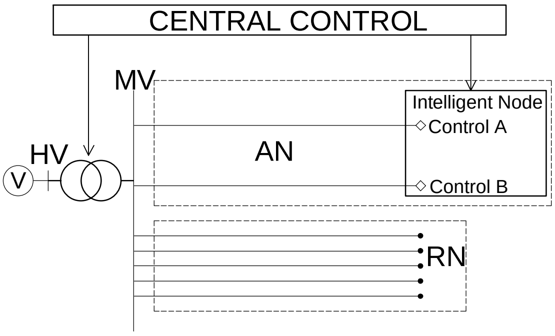

Figure 2: The lay out of the voltage control

It will be shown that these intelligent controls not only improve the voltage profile in the AN but also in the RN.
A good measure for the voltage profile is the deviation from a reference voltage for all considered customers.

$$Dev = \sum_i \left(V_i - V_{ref}\right)^2$$

The optimal voltage profile is then found by minimising this deviation, the so called "MinDev" method.

$$MinDev = \min \sum_i \left(V_i - V_{ref}\right)^2$$

This means that the controls have to work in such a way that the sum of all absolute LV deviations from the nominal voltage is minimized.

CALCULATIONS AND RESULTS

Network model

Calculations are performed on a realistic model of a certain MV/LV network (Figure 3).

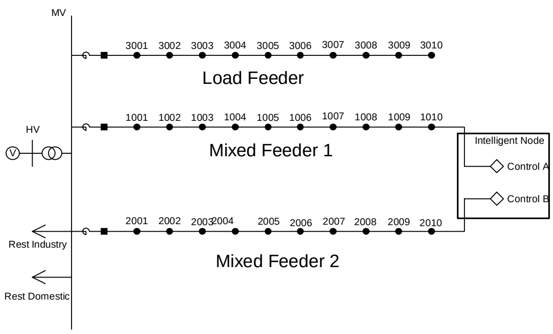

Figure 3: Model of the MV network

Three MV feeders with their load (and generation) were modelled in detail. Together with the intelligent node the Mixed Feeder 1 and Mixed Feeder 2 represent the AN. One feeder (Load Feeder) contains only load and represents a typical feeder of the RN. The rest of the load is modelled on the MV bus bar of the substation. All three feeders contain 10 MV/LV transformers feeding LV networks. The distance between each transformer is 1000 meters. For each LV network only one cable is modelled in detail (Figure 4). At the end of that cable the load and generation of that feeder is concentrated (L_E, G_E). The rest of the load and generation connected to the MV/LV transformer is concentrated on the LV side of this transformer (L_B, G_B).

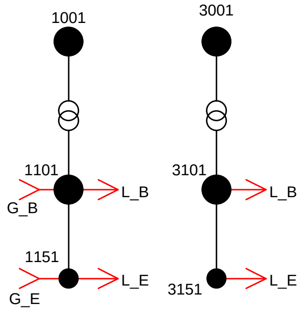

Figure 4: Model of the LV network

The length of the LV cable is 450 meters which represents a typical length for TN grounded LV cable networks. The maximum load will give 6% voltage drop over the LV cable.

Load and generation

The network is subjected to a scenario of load and generation for a typical week, as shown in Figure 5.

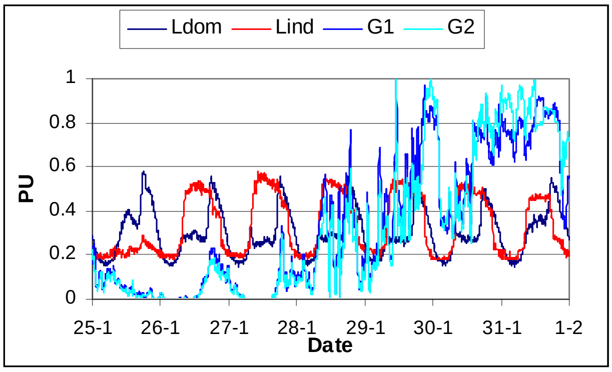

Figure 5: Load and generation

These scenarios are based on real measurements (5 minutes average). The load data is obtained from typical feeders containing either domestic (L_{dom}) or industrial (L_{ind}) loads. The generation data (G1 and G2) is obtained from two wind farms. The data of these wind farms is scaled in such a way that at low load and high generation, the loading of the mixed feeders equals the negative value of the maximum load. At that moment there is some voltage drop in the load feeder while there is maximum voltage rise in the mixed feeder. The figure shows that at the beginning of the week there is hardly any generation. At the end of the week however there is maximum generation in the network.

Control Actions

Several control actions were examined:

- **Base**. In this case only the OLTC is working, keeping the MV bus bar voltage at a value of 1.05 pu.
- **OPT1**. The tap of the transformer and the intelligent node are used to obtain a minimum voltage deviation in the AN.
- **OPT2**. The tap of the transformer controls the MV bus bar voltage at 1.05 pu, while the intelligent node tries to obtain a minimum voltage deviation in the AN.
- **OPT3**. The tap of the transformer and the intelligent node are used to obtain a minimum voltage deviation in total network (both the AN and the RN).

The effect of the control actions on the voltage deviation are shown in Figure 6 (for the total network), Figure 7 (the AN) and Figure 8 (the RN).

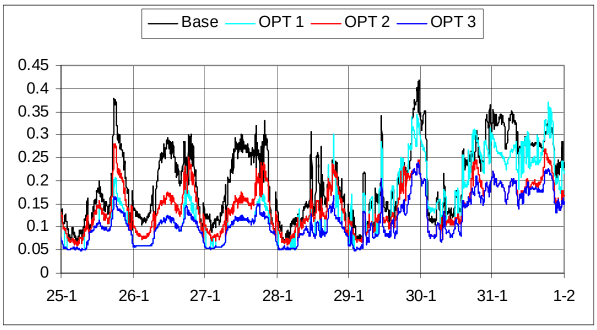

Figure 6: Voltage deviation in the total network due to several control actions

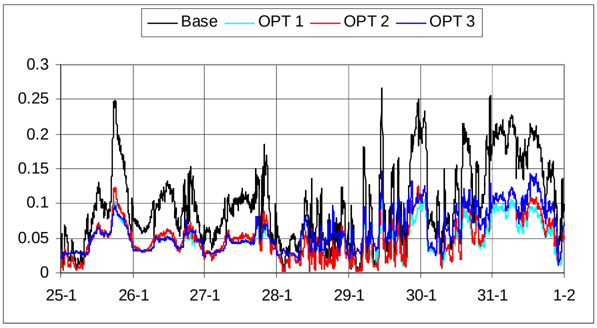

Figure 7: Voltage deviation in the AN due to several control actions

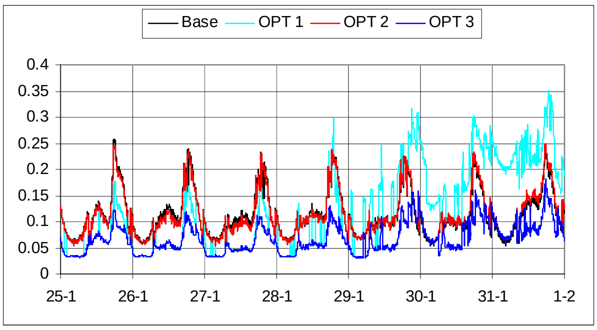

Figure 8: The voltage deviation in the RN due to several control actions

Another way to see the influence of the optimization methods is to use the Power Quality Classification method as introduced in [6]. From the values over a week of measurement the mean value and the standard deviation for each point can be calculated. These can be plotted in a graph easily showing the quality graduated from A (very good) to F (very poor). This is shown in Figure 9.

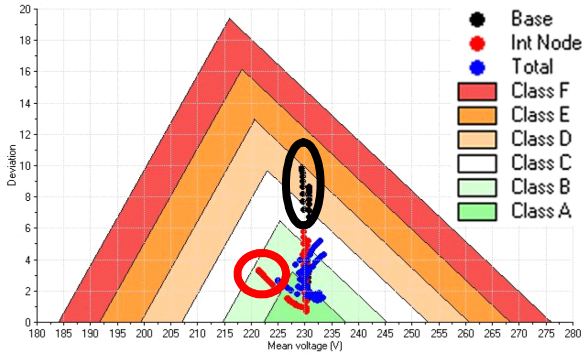

Figure 9: Classification of the results

In the base case many points lay in the class-D zone (black circle). The OPT2 method brings all points within the class-C zone. There is however no influence on the points in the load feeder (red circle). The OPT3 method moves about all points of the load feeder towards the class-A zone with hardly any drawback for the points in the mixed feeders.

It became clear that action OPT1 at some moments gives a worse overall performance than the base case. Furthermore its influence on the AN performance is hardly better than with OPT3. As a result this control action will no longer be considered.

Both actions OPT2 and OPT3 drastically improve the network performance. OPT2 sometimes is better for the performance of the AN (28-1, 29-1), but it does not improve the performance of the RN. OPT3 also improves the performance of the RN. On the moments it is worse for the AN than OPT2, the deviation is still rather small.

REQUIREMENTS FOR THE CONTROLS

The above described control actions use information of all LV customers in the network in order to obtain an optimal voltage profile. The question is whether the control could use only local measurements to obtain the same results.

Requirements for the transformer control

The voltage of the MV bus bar for OPT3 is shown in Figure 10 (high load) and Figure 11 (low load and high generation). At high load situations, the voltage is dependent on the load (blue line). At low load the voltage is dependent on load and generation (red line). In order to obtain an intelligent control, the control must be able to distinguish load from generation. When measuring all feeders separately, typical load feeders can be recognized. These loads have a high predictability. In the other (mixed) feeders the generation can be seen as a difference between the expected and measured load.

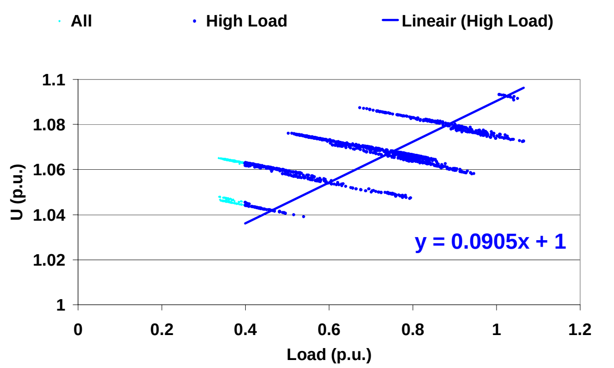

Figure 10: Transformer voltage as function of load during high load situations and little generation

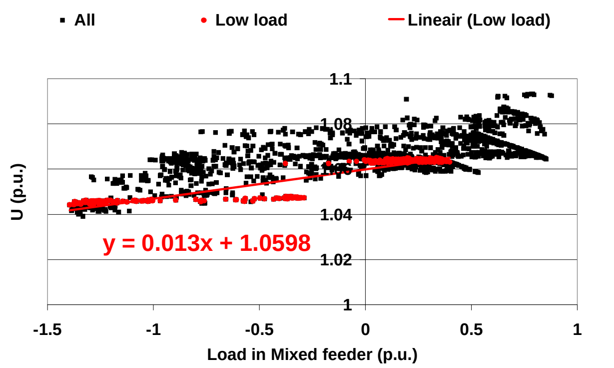

Figure 11: Transformer voltage as function of difference between load and generation during low load situations

Requirements for the intelligent node control.

The voltage at the terminals of the intelligent node as a function of the loading (load and generation) of the connected feeder is shown in Figure 12. At both connections, the voltage is almost linear with the loading. The slope of the curve is a measure for the cable resistance. When the control of the intelligent node is able to estimate the amount of load and generation in its feeder it should be able to create the correct set points for its terminals.

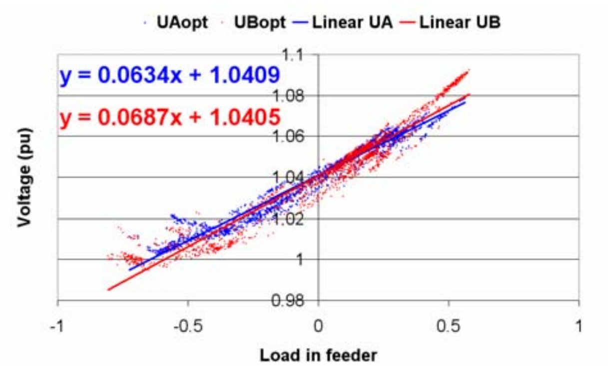

Figure 12: Terminal voltage of the intelligent node as function of the loading of the connected feeders

Future research

The proposed control in this paper should work with an estimation of load profiles and with local measurements of current and voltage. The main objective for future studies on this subject is to distinguish load and generation at the off going feeders of the MV bus bar and to estimate the amount of load and generation in de feeders connected to the intelligent node. Global investigations on this approach show promising results [7].

CONCLUSIONS

Without additional measures the non-coincidence of load and generation in distribution networks results in large voltage variations. The combination of using intelligent nodes and intelligent control of the on load tap changer makes it possible to give drastic reduction of these variations. The intelligent node uses power flow control between feeders containing both load and generation. The transformer control is based on compounding. In high load situations this compounding is based on load alone. In low load situations the compounding is based on a combination of load and generation. The control can work with local measurements only.

LITERATURE

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