Improvement of Local Flexibility through DER

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Abstract: Through the use of a holistic control applied to a smart distribution transformer with on-load tap changer (OLTC), this study compares various control strategies for the coordinated operation of distributed energy resources (DERs), including photovoltaic (PV), wind, battery energy storage systems (BESS), and load demand management, particularly in the case of flexible loads and electric vehicles (EVs). The study aims to enhance equipment health index (HI), minimize power losses, and raise low-voltage (LV) grid hosting capacity (HC). The DISCOVERER (Distributed and Intelligent System for Coordination and Optimization of Voltage to Empower Renewables and Electric Resources) project's findings are presented in this paper.

1 Introduction

An increasing number of distributed generation units on low-voltage (LV) networks create concerns regarding its effects on the power quality and voltage level. In this context, researchers [1, 2] investigate innovative solutions aiming to avoid additional investments and improve network performance by means of coordination control, while keeping voltage within the statutory limits set by EN 50160 [3].

The majority of the proposed methods to prevent voltage constraint problems focus on decreasing the voltage rise along with LV feeders due to reverse power flow. Benefits of local control of reactive power have been reflected in multiple studies [4, 5].

Bernier *et al.* [6] have researched voltage noncompliance problems that might arise from the integration of a large-scale photovoltaic (PV) system into a rural distribution network. Subsequently, a sequential control scheme has been proposed that coordinates reactive power absorption and active power curtailment of PV inverters to mitigate such problems. However, curtailment should be the very last option to deal with the integration of renewables.

In addition, Huang et al. [7] explain that curtailment occurs both as a consequence of constrains in distribution grids, but also as a precautionary measure to secure the stability of the system. Avoiding curtailment of this generation would require investing in battery energy storage system (BESS) solutions, which are very costly if used for just a few hours annually as reported in [8].

Optimal BESS location and sizing and its efficient dispatch can provide support during network contingencies, as experimentally assessed in [9]. In the same research is also demonstrated that batteries located in the distribution network optimise the integration of renewable energy in the grid, whereas minimising the losses and maximising the utilisation of network assets. Moreover, this effect increases when BESSs are operated with voltage control.

Another major challenge of active distribution systems consists in voltage unbalances, particularly, due to the massive deployment of distributed energy resources (DERs), electric vehicles (EVs) and BESSs. Recently, a group of researchers proposed an unbalanced control strategy to eliminate voltage non-compliance [10]. It has been shown that independent single-phase control can considerably improve network performance contributing to increase renewable energy source penetration. The researchers highlight the point that additional improvements can be achieved when a distribution transformer with an on-load voltage regulation is installed in the secondary substations.

Even though a voltage management algorithm proposed for unbalanced LV networks [11] demonstrates the improvement of voltage quality by using an on-load tap changer (OLTC) per-phase of a transformer, research has been based on multiple simulations [12, 13] with very few field tests carried out in this area due to the complexity of the technology used.

To assess these emerging technologies and solutions in an integrated environment with the perspective to enable flexible demand-response management, storage, EVs and renewables integration operating under stable and secure conditions, several pilot projects have been launched [14, 15].

The first rural smart grid project experiment SMAP [14] with distributed PV growth based on smart meters shows that although the reactive power management by PV inverters can increase the PV hosting capacity, the increase is more considerable when the secondary substation is equipped with an OLTC transformer.

RESOLVD demonstration project [15] aims to improve the efficiency and the hosting capacity (HC) of distribution networks while reducing uncertainty in grid operation by means of a BESS with single-phase inverters, located inside the transformer substation.

Finally, Ulasenka *et al.* [16] have proved the efficiency of a symmetric voltage regulation approach for coordinated operation of smart transformer with OLTC and PV inverters to increase the hosting capacity. Based on the outcome further lines of investigation have been identified.

For instance, this research work will improve the current knowledge regarding the coordination of the technologies capable of providing a distributed voltage balance in the LV distribution network with no need for grid extension. In this way avoiding technologies miscoordination that can cause undesired additional losses and curtailment, the hosting capacity limitation and the over operation of distribution transformers with OLTC, distributed batteries or inverters.

2 Test setup

This section covers the description of two different approaches proposed for assessment in two leading European Smart Grid laboratories.

The Fraunhofer IEE SysTec laboratory provided the infrastructure to test the behaviour of the smart distribution transformer with OLTC and PV inverters in a closed-to-field testbed for the DISCOVERER project. A voltage regulation system (VRS) based on optimal power flow (OPF) using the network topology and real-time (RT) measurements from different nodes were analysed for this network setup (Fig. 1).

However, access to RT measurements of all the flexibilities in a distribution network is difficult, even sometimes unavailable. Thus, for the network setup, applied for the HOLISTICA project in the DTU SYSLAB, the topology of the network was omitted in the control system, and the OPF was reduced to follow simpler and closer to RT control rules (Fig. 2).

Furthermore, more complex distributed energy sources and load were connected. These units were holistically controlled from the secondary substation equipped with the on-load voltage regulated smart transformer. In addition, a three-phase balancer was used to mitigate voltage variations caused by single-phase loads or power injection.

3 Methodology

The methodology principles were tested in advance using mathematical models and power flow simulations. However, a controlled lab environment is a step forward for analysing realistic device performance. To clearly assess the benefits of the proposed techniques, a set of representative key performance indicators (KPIs) are defined:

Fig. 1 *Setup in Fraunhofer IEE SysTec laboratory*

Fig. 2 *Setup in the DTU SYSLAB*

† Increase grid hosting capacity for distributed generation.
† Power losses reduction.
† Improve grid stability by means of DER coordination algorithm to minimise the number of OLTC operations.

Test scenarios and control strategies

Rural (R) and urban (U) grid scenarios using four voltage control strategies based on RT measurements from different nodes are considered:

† no control (NC),
† tap control (T-control),
† reactive power control (Q-control),
† holistically combined tap and reactive power control (QT-control).

Additionally, different levels of distributed generation penetration (σ, 0–200%) were proposed to be analysed. However, for laboratory usage optimisation, only the full (σ = 200%) generation penetration was tested and the lower levels were extrapolated from the latter.

A test configuration is the combination of a grid scenario (R, U) and a control strategy (NC, T, Q, QT), thus totalling eight test configurations.

Test cases

For every test configuration, a full-load generation profile grid was tested, by modifying the total power consumption percentage (α, 0–100%), and limiting the total active power percentage (β, 0–100%). This allows the analysis of different realistic load and generation profiles based on other studies and actual measurements.

Each load-generation case was created by dispatching six cases of α and β proportionally to the nominal power between the generators and loads available in the test configuration. As a result, 36 cases

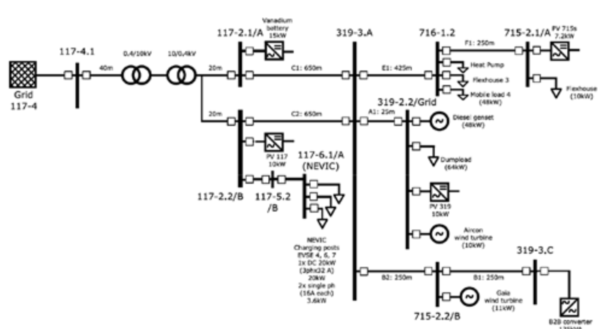

Fig. 3 *Flexible network single-line diagram*

Table 1 Benchmarking of the control strategies for rural network with network topology (Fraunhofer IEE)

HC,% enhancement: QT control (HC2) versus NC (HC1)					
Load, kW	20	40	70	90	110
$\frac{(HC_2-HC_1)}{HC_1}$,%	83.34	83.34	83.34	205.57	516.70

Table 2 Benchmarking of the control strategies without network topology (DTU)

Control strategy	HC,%	Losses reduction,%
NC	0.00	0.00
T	61.65	2.56
Q	63.27	6.31
QT	61.07	9.35

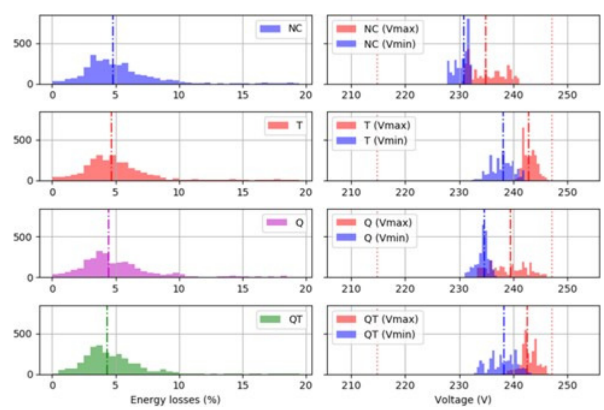

Fig. 4 *Results of the DTU SYSLAB test*

were performed for each configuration setup. In total, 288 tests were carried out at the DTU SYSLAB during a 6-day period.

Furthermore, afterwards a 24-h test configuration, including almost all the resources available in the laboratory, was performed, as shown in Fig. 3, in order to test the viability of the control system in a close-to-real flexible environment.

4 Results

A contribution of each approach was assessed in the achievement of the proposed KPIs.

The results of Fraunhofer IEE SysTec tests (DISCOVERER) are presented in Table 1, where the percentage evaluation of the HC for both NC and QT strategies is explained for the following load – PV generation cases:

- {0; 20; 40; 60; 80} kW of PV generation.
- {0; 20; 40; 70; 90; 110} kW of load.

However, due to network constraints (resistive elements and three-phase balanced system), reactive power control and phase-balancing had a limited effect.

The outcomes of the DISCOVERER project opened the opportunity for further research with the idea to include more distributed resources, such as BESS, wind turbines and EV charging stations to an unbalanced LV network with dynamic loads and a higher reactive power presence.

The HOLISTICA project, carried out at SYSLAB of DTU, takes into account all the above technologies and more advanced characteristics of the network. Besides laboratory scenarios (rural and urban grid), a flexible network was built for the validation setup in order to prove the efficacy of the control system. A complex unbalanced laboratory scenario was built, where load and generation units act freely.

The impact of each approach was evaluated by comparing the HC of the network, the reduction of power losses and the increment of grid stability, whereas streamlining the number of OLTC operations.

Results from Table 2 shows that an application of *T* control increases the nominal hosting capacity by 61.65%; and, by adding a combined QT of distributed generation units, power losses can be reduced 9.35% (Fig. 4).

5 Conclusion

This paper assessed the effectivity of different voltage control strategies in recreated LV networks with DERs. It was experimentally demonstrated that the smart distribution transformer with OLTC can be considered an essential element to increase the efficiency of distribution networks by the provision of optimal grid flexibilities and reliability. Thereby, maximising the integration of renewables, whereas delaying expensive and long-term grid reinforcement – especially when it is coordinated with existing distributed generation, batteries and EV.

This holistic control strategy, managing efficiently existing DER, would avoid the need for dedicated power electronics and BESS at the transformer substation level – to deal with the massive implementation of distributed PV and EV.

The approach, based on DER operation and coordination, is complementary to the local flexibility markets, which alleviates congestion in a market-based manner.

6 References

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