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DER reactive services and distribution network losses

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Danny Pudjianto[1] ✉, Predrag Djapic[1], Goran Strbac[1],
Evert T. van Schalkwyk[2], Biljana Stojkovska[3]

[1]*Electrical and Electronic Engineering Imperial College London, London, UK*
[2]*UK Power Networks, London, UK*
[3]*National Grid ESO, Warwick, UK*
✉ *E-mail: d.pudjianto@imperial.ac.uk*

Abstract: Managing synergies and conflicts between voltage support services and network losses is essential for the cost-effective integration of distributed energy resources (DERs). This study presents the results of studies investigating the impact of using DER reactive power services on distribution network losses. By using year-round optimal power flow analysis, a spectrum of studies on a number of distribution network areas in the southeast of Great Britain was performed to calculate distribution losses under different control scenarios. The studies demonstrate that the use of DERs to provide reactive services to the transmission system may increase distribution network losses. On the other hand, DER reactive services can also be optimised to minimise distribution losses. The studies also analysed the impact of optimising tap changing transformer settings on the distribution network losses reduction.

1 Introduction

Voltage management at transmission traditionally relied on the system services provided by large-scale transmission connected generators or reactive compensators. However, given the considerable capacity of distributed energy resources (DERs) that has been installed in the system, DERs should also have the opportunities to provide voltage control services to the transmission network competing on the level of playing field with traditional sources.

The Power Potential project [1] was designed to demonstrate the ability of DERs to provide voltage control services to the transmission network. In the southeast of Great Britain, a substantial increase in embedded generation connected to the distribution network has resulted in voltage control challenges for the system operator. Power Potential is a joint project between the regional distribution network operator (UK Power Networks) and the system operator (National Grid ESO). UK Power Networks, in collaboration with National Grid ESO, has developed an advanced DERs Management System dispatch platform that acts as the central enabler for this project. The vision of Power Potential lies in creating a reactive power market for voltage control services to the transmission system between the DERs connected to the distribution system and National Grid ESO [2].

However, the use of DERs to provide voltage management to the transmission system does make an impact on distribution network losses. On the other hand, enabling DER reactive services may also create opportunities to reduce network losses [3] in addition to supporting distribution network operation and reducing the impact of high distributed generation penetration on distribution/transmission voltages [4, 5]. In this context, the main objectives of this paper are: (i) to assess the impact of Power Potential's activities on distribution network losses and (ii) to quantify the benefit of using the control platform to minimise network losses.

2 Methodology

Distribution network losses arising from different operating and control scenarios have been compared and analysed. The AC-based security-constrained optimal power flow (OPF) algorithm was used to calculate annual distribution network losses on a specific area of the southeast Great Britain distribution system for different scenarios and to evaluate the impact of DER reactive services on these losses. We further included different transformer tap changing strategies while adhering to voltage and thermal limits to our analyses. To minimise losses, the OPF balances local reactive power demand and production. In order to derive the benefits of reactive and voltage optimisation on losses, we use counterfactual scenarios where DER reactive services are not used for the management of losses. One of the counterfactual scenarios excludes voltage optimisation via transformer settings.

An AC-based security-constrained OPF algorithm is employed to calculate network losses for different operating control scenarios and to evaluate the impact of Power Potential and losses minimisation-led DER reactive services on network losses. The OPF model is formulated to minimise the total cost of MW and Mvar generation by optimising a set of network control devices (i.e. tap-changing transformers, shunt compensators) as well as active and reactive production from generators/energy storage while maintaining the integrity of the system by operating within the voltage and thermal limits.

Since the total electricity production needs to be equal to the total electricity loads and the losses, minimising the electricity generation from the slack generator considering the MW output of all other generators are set according to its schedule is equal to the minimisation of losses. Only the MW output of a slack generator can vary to balance the supply and load on the system, taking into consideration system losses.

To minimise losses, the OPF minimises the current flowing in the system by improving the voltage profile of the system and balancing locally the energy demand and production as much as possible. The voltage profile can be improved by optimising the settings of tap-changing transformers, shunt compensators, or using DER reactive services.

To calculate the impact of DER's reactive services on network losses across different operating conditions, we carried out a range of year-round hourly OPF analyses. In total, there are 8760 simulation runs per case study to determine the annual system losses taking into consideration the variability in demand and generation output. The system backgrounds used for the analysis are described in the next section. Only the intact systems are

Table 1 List of scenarios

Scenario	DER reactive services included	Sub-scenarios of transformer tap setting		
		Fixed	Taps optimised for losses	Suboptimal for losses
Counterfactual	no	√	√	√
Power Potential	to support transmission voltages	–	√[b]	–
DER Q service	to reduce losses	√[a]	√[b]	–
Value of DER Q service	to reduce losses	–	√	–

Notes: √indicates the studies that have been carried out.
[a]The study is compared to the counterfactual with fixed tap settings.
[b]The study is compared to the counterfactual with the tap setting being optimised for losses. For the cases with an optimised tap, [T] is added to the scenario name.
Note: [T] indicates the case with transformer tap optimization.

considered in this losses analysis. When there are planned or unplanned outages, losses are generally higher, but it is assumed that annual losses contributed by this situation are substantially smaller than intact system losses.

There are three main operating scenarios used in this analysis; they are summarised as follows:

- *Counterfactual scenario*. This represents a scenario where DERs do not provide any reactive services nor voltage control to transmission and distribution system operators. The losses from the reference/counterfactual scenarios are used as a reference to determine the impact of employing different operating control strategies.
- *Power Potential scenario*. In this scenario, DER provides reactive services by injecting or absorbing a certain level of reactive power to support transmission and distribution voltages.
- *Network losses minimisation scenario*. In this scenario, DER reactive services are optimised only to minimise system losses (not providing voltage control to the grid although it generally improves the voltage profile in the system and therefore, indirectly contribute to the transmission grid voltage management as well).

In order to determine the impact of different operating schemes, the distribution network losses obtained in the second and third operating scenarios have been compared with the counterfactual where DER reactive services are not used for the management of losses. One of the counterfactual scenarios excludes voltage optimisation via transformer settings. In this modelling, we only apply the cost of losses. The cost associated with the use of DER reactive services is not considered. The impact of optimising transformer settings has also been investigated. The full set of scenarios used is shown in Table 1. It should be noted that within the 2020 Power Potential trial, there is no optimisation of transformer settings, either for losses or to maximise reactive power services. However, these are potential development area for the future, so has been considered in this study.

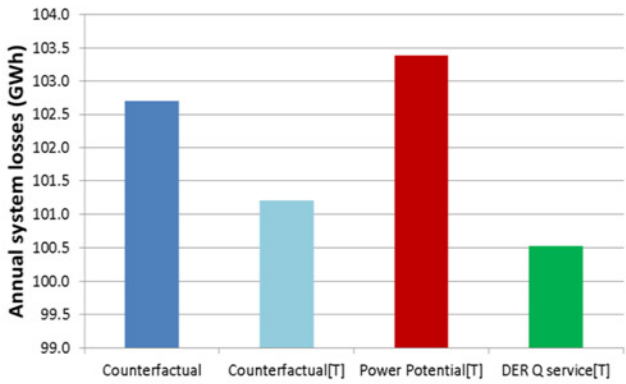
In quantifying the value of DER Q service, we apply different prices for utilising DER reactive services in different cases and analyse the impact of DER reactive utilisation and distribution network losses. For the sake of this study, it is assumed the DER reactive prices are uniform across all DER sites. The study uses three different costs of losses (£40, £60, £80/MWh losses), and six different prices of DER reactive power services (£0.01, £0.05, £0.1, £0.2, £0.3, and £0.5/Mvarh). By using this approach, we can estimate how an average loss-driven reactive price could be estimated.

3 Results

Power Potential uses DER reactive services to support transmission voltages, not considering at present the impact on distribution network losses. These services are used primarily during high and low load conditions, and to provide dynamic support during system events. During high loading conditions, DERs are required to inject reactive power to support network voltages. Conversely, during low load conditions, DERs are required to absorb reactive power to prevent voltages from exceeding maximum limits. Therefore, the impact of Power Potential will change over time.

The analysis suggests using loss optimisation routines can reduce annual distribution losses from 103.4 GWh/y (Power Potential [T] case) down to 100.5 GWh/y (DER Q service[T]) representing up to 2.8% (2.9 GWh) reduction in losses, as shown in Fig. 1. Most of Power Potential's DERs are connected to 132 or 33 kV networks close to substations. Network losses in those circuits are a relatively small proportion of total distribution losses, which predominantly occur in low-voltage and high-voltage networks.

Operating Power Potential's DER reactive services in a preventive mode tend to drive higher utilisation of the reactive power services, which leads to higher additional losses, as shown in Fig. 2. The case with 100% utilisation (the same as Power Potential [T] in Fig. 1) is



Note: [T] indicates the case with transformer tap optimisation

Fig. 1 *Impact of Power Potential on distribution losses*

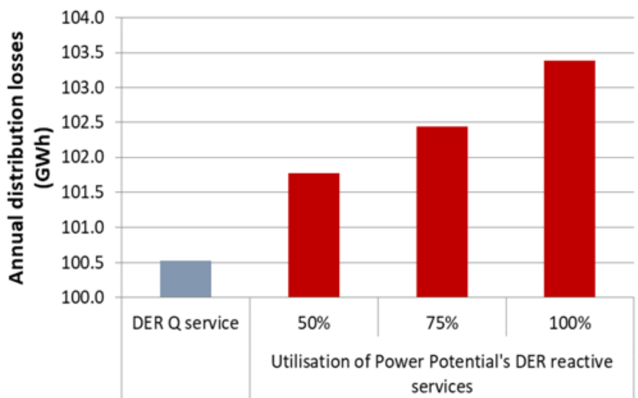


Fig. 2 *Impact of different utilisation of Power Potential's DER reactive services*

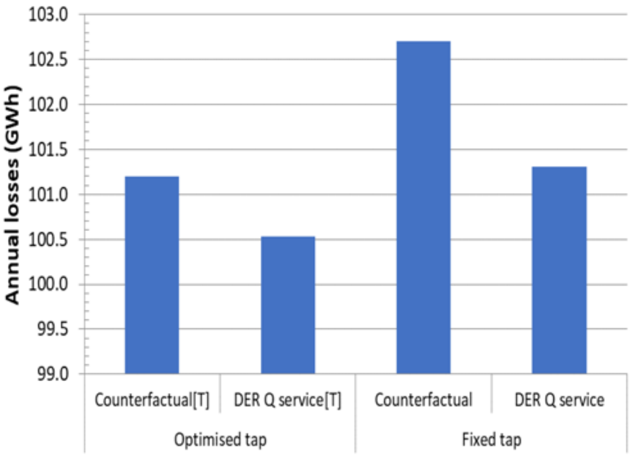


Fig. 3 *Annual distribution losses in different scenarios*

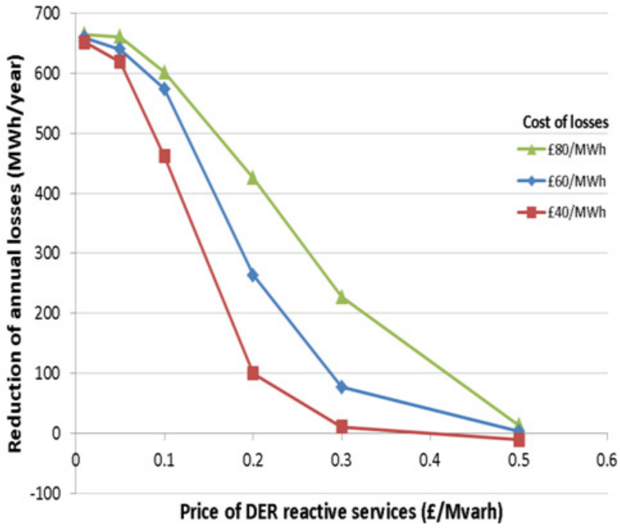


Fig. 4 *Reduction of annual distribution losses as a function of reactive service bids*

an extreme case, e.g. when all DER reactive services are operated in a preventive mode.

As DERs operate with voltage-droop control and adjust their reactive power output accordingly in a corrective mode, the impact on losses is likely to be smaller than 2.8%, obtained by comparing the losses in the rightmost column (103.4 GWh/y) and the leftmost column (100.5 GWh) in Fig. 2. By using the corrective mode, the conflict between the Power Potential objective and network losses minimisation would be significantly reduced. In other words, if voltage control is delivered through corrective control (rather than preventive), reactive power sources could be used to achieve both objectives: minimise network losses under normal operating and deliver post fault voltage control.

3.1 Applications of DER reactive services in loss minimisation

DER reactive service and optimisation of tap-changing transformers can reduce losses and therefore, these two approaches can provide alternative solutions to reduce losses. The impact of DER reactive services on network losses can be higher if transformer tap settings are not optimised to reduce losses. This can be observed from the results presented in Fig. 3.

The amount by which the test system's annual distribution network losses can be reduced is relatively limited, i.e. 0.6% of the network losses (i.e. 674 MWh/y – the difference between the first and second column in Fig. 3) in the counterfactual scenario with optimised transformer tap settings since the test system used in this study involves mainly 132 kV and a few 33 kV circuits where the distribution network losses are relatively small. We also observe that the network losses reduction, driven by the provision of DER-based reactive service, is higher in high-demand periods and lower in low-demand periods. The use of DER reactive services may occasionally increase distribution network losses marginally. Still, the overall system losses reduce because the reduction in transmission losses can offset the increased distribution losses.

3.2 Losses-driven value of reactive power services

The OPF minimises the total system operating costs that can be achieved by utilising reactive services to offset network energy losses. This process, therefore, strikes a balance between the cost of reactive services for loss-reduction purposes, and the cost of losses. Therefore, the amount of losses that can be optimally reduced depends primarily on the bids of reactive services and the cost of losses. The study uses three different costs of losses (£40, £60, £80/MWh losses), and six different prices of DER reactive power services for losses reduction (£0.01, £0.05, £0.1, £0.2, £0.3, and £0.5/Mvarh) as shown in Fig. 4.

When the price of DER reactive services is close to zero, the level of losses reduction converges to around 650 MWh/y; the maximum losses reduction obtained when the DER reactive services are used to minimise losses. With higher costs associated with DER provision of reactive power service, DER services are less utilised, and therefore, the reduction in network losses would be lower. With a higher cost of losses, DER reactive services are more utilised, and this can reduce network losses.

The analysis excludes the value of reactive power for transmission voltage management and the costs of the enabling system. To gain visible network losses reduction (e.g. <100 MWh per annum as shown in Fig. 4), and assuming the cost of losses is £60/MWh, the value of DER reactive services should be <£0.3/Mvarh for their reactive services for both availability and utilisation cost. With a higher cost of losses assumption, the value of reactive power services increases and therefore, DERs could bid higher. For example, to reduce losses by 200 MWh/y, in the system with the assumed cost of losses of £60/MWh, the reactive bids should be around £0.23/Mvarh. If the cost of losses assumption is £80/MWh, the reactive bids can be up to £0.32/Mvar, as depicted in Fig. 4.

4 Conclusion

Since the deployment of DER reactive services to support transmission voltage control does not consider distribution losses, the use of DER services to support transmission losses may increase the test system's annual distribution losses slightly by up to 2.1%. Operating DER reactive services in a preventive mode lead to high utilisation of the services. As an alternative approach, DER reactive services can be operated in a corrective mode; this allows DER based reactive services to be used to reduce losses, and when needed, DER reactive power output can be re-dispatched to support transmission voltages (e.g. during contingent conditions). This mitigates the conflict between the use of DER reactive services to support transmission voltages and network loss reduction objectives.

DER reactive service and optimisation of tap-changing transformers can both reduce losses, and therefore, these two approaches can provide alternative solutions for reducing losses. The optimisation model also balances the savings that can be achieved by using reactive services to reduce losses with the cost of the services. Therefore, the amount of losses that can be optimally reduced depends primarily on the cost related to the provision of reactive services and the cost of losses.

5 Acknowledgments

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