Combining Energy Storage and Real-Time Thermal Ratings to Solve Distribution Network Problems: Benefits and Challenges

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ABSTRACT

Energy Storage Systems (ESS) are a combination of an energy storage medium, such as a battery or super capacitor, and a power electronic interface to allow power to be exchanged with an electrical network. Real-Time Thermal Ratings (RTTR) allows network operators to take advantage of the inherent variation in network capacity as environmental conditions fluctuate, leading to an increased rating the majority of the time. Both are emerging technologies which can provide substantial benefits to distribution network operators. They can reduce power constraints, aid in the integration of renewables, and increase network reliability and resilience. ESS are expensive to install, but they are dispatchable assets, and can provide reactive power support and voltage control to their local network. RTTR are comparatively inexpensive, but the additional capacity that is released is not dispatchable. These differences suggest that a combination of ESS and RTTR could provide robust, affordable solutions to distribution network problems that neither technology could solve in isolation. In this paper, we quantify the benefits of combining ESS and RTTR to solve distribution network problems. We demonstrate that the combination of technologies is a more effective solution to many network problems than either a conventional asset based solution, or using RTTR or ESS alone, and we identify technical and regulatory obstacles which must be overcome to harness the full potential of these, and other, emerging technologies.

INTRODUCTION

Energy Storage Systems (ESS) and Real-Time Thermal Ratings (RTTR) are emerging technologies which can provide a variety of benefits to transmission and distribution networks. The benefits each technology can provide individually have been thoroughly explored; either technology can enhance security of supply [1, 2] or relieve constraints on renewable energy [3]; ESS can also provide voltage support [4], reactive power services, and ancillary services such as frequency response [5] and operating reserve.

However, the design, planning, and operation of ESS and RTTR have a number of key differences: ESS are expensive to install and have finite power and energy constraints, but are dispatchable and can export or import both real and reactive power. RTTR offers greater potential power and energy capacity than ESS, but the capacity is dependent on the local weather conditions, the geographic location of the overhead lines, and whether there are constraints on other assets, such as transformers or underground cables.

In this paper, we examine how the benefits of combining ESS and RTTR compare with the benefits of using either technology in isolation; we discuss the practicalities of combining the two technologies, with a particular emphasis on provision of distribution network security of supply and participation in ancillary service markets; finally, we present a case study based on the demand, meteorological data, and geographic location of the Smarter Network Storage (SNS) ESS installation [6], constructed by UK Power Networks in the southern England.

BENEFITS OF COMBINING ESS AND RTTR

ESS and RTTR can work in a symbiotic manner, with the RTTR providing capacity relief for the ESS, allowing it to participate in service markets the majority of the time, and the ESS providing security of supply in the event of the thermal ratings being lower than the power flows required by the local demand.

Increased Security of Supply

One of the primary reasons to deploy either RTTR or ESS on distribution networks is to replace or defer conventional network reinforcement. Both ESS and RTTR can be deployed much more quickly than new overhead lines. RTTR can be deployed at a fraction of the cost, and ESS, while expensive, can provide additional utility to both the local distribution network and the wider power system.

Figure 1 illustrates the investment deferral which can be achieved by using an ESS, RTTR, or the combination of the two. In a distribution network in the UK, reinforcement is required when the peak demand can no longer be met by the network in the event of a single circuit being unavailable due to a planned outage or a contingency situation. Typically, this will correspond to a level of *EENS* (Expected Energy Not Supplied), which is calculated using equation 1.

$$EENS = \sum_{i=1}^{N} P_i ENS_i \qquad (1)$$

EENS is the sum of the product of energy not supplied (*ENS*) in each given scenario, *i*, and the probability of each scenario occurring P_i. In general, these scenarios are too complex and numerous to be enumerated analytically, so the *EENS* is evaluated using a Monte Carlo (MC) simulation, which simulates the system a large number of times to obtain the *EENS*.

In Figure 1, a network with a reinforcement threshold corresponding to an *EENS* of around 40 MWh/year is considered; the existing demand yields an *EENS* of around 45 MWh/year, which is projected to increase as the demand grows. The results of further MC simulations, evaluating the use of RTTR, an ESS (6 MW/10 MWh), or both, show that using either technology will bring the *EENS* below the reinforcement threshold. If only one technology is deployed, the reinforcement threshold will be reached again in around 9.5 years; if both are deployed, the EENS reaches 25 MWh/year after 10 years of demand growth. Details of this analysis can be found in [1].

Increasing the Value of ESS

In the majority of circumstances, it is unlikely that an ESS will be financially justified by a single network application [7]. One of the goals of the SNS project was to demonstrate that an ESS could provide security of supply to a primary distribution substation while also participating in ancillary service markets, such as frequency response and short-term operating reserve.

By reducing the requirement for the ESS to provide the additional capacity during periods of high demand (because the capacity is provided by the increased network ratings), RTTR can reduce the amount of time, power, and energy that the ESS has to allocate to providing security of supply. These resources can then be committed to commercial services, such as frequency response, to increase the lifetime value of the ESS.

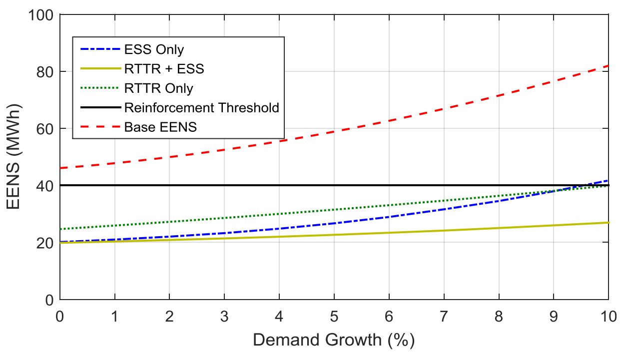

Figure 1: Example of network investment deferral for an ESS, RTTR, and the combination of both technologies [1].

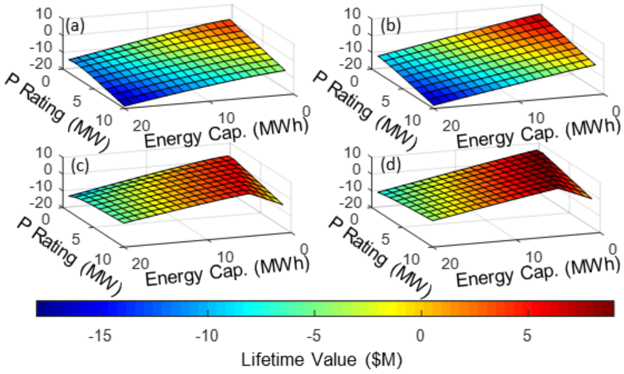

Figure 2: Surface curves showing the estimated lifetime value of energy storage with different power and energy ratings. (a) shows the value of an ESS performing only PS (Peak Shaving); (b) shows the value of an ESS and RTTR performing PS; (c) shows an ESS performing PS and FR (Frequency Response), and (d) shows an ESS and RTTR performing PS and FR [1].

Figure 2 shows how the lifetime value of an ESS of varying power and energy capacities changes in a variety of scenarios. In all cases, the ESS provides security of supply to a distribution network substation for 10 years, during which time the demand grows by 1% per year. In case (a), the ESS is installed alone and provides only peak demand reduction; in case (b), an RTTR system is also installed; in case (c), the ESS is operated alone, and provides both peak demand reduction and FR; in case (d), an RTTR system is also installed, and the ESS provides both peak demand reduction and FR. The results show that the addition of RTTR increases the value of the total system, and that participating in multiple services increases the value of the total system; the greatest lifetime value is achieved through deploying RTTR and an ESS, and providing a combination of demand reduction and FR Further details of this analysis can be found in [1].

CHALLENGES OF COMBINING ESS AND RTTR

While there are substantial benefits to combining RTTR and ESS in distribution networks, there are technical and regulatory barriers to extracting these benefits. In this section, we discuss these barriers and propose potential solutions in each case.

Scheduling Under Uncertainty

One of the key differences between ESS and conventional network assets is that ESS have a finite energy capacity. This necessitates scheduling the operation of an ESS to ensure that sufficient energy is available to fulfil committed services. However, the scheduling takes place under significant uncertainty; there are uncertainties in the power and energy requirements of both DNO and TSO procured services, some of which can be mitigated through forecasting (demand reduction), some of which cannot (FR).

Combining the operation of ESS with RTTR exacerbates this challenge, because RTTR provides an additional operational variable with stochastic properties. This increases the uncertainty under which the ESS will have to operate, potentially requiring a different approach to service selection. In the SNS project, a forecasting, optimization and scheduling system [8] was developed to ensure the service schedule for a given ESS was robust against the uncertainty in service delivery. Incorporating RTTR into such a system would require a different approach to this, including techniques such as robust optimization or optimizing to minimize regret. The goal of this scheduling is to release additional capacity to the ESS, while ensuring that system and service requirements are met, on planning and operational timescales.

Forecasting RTTR

The uncertainty associated with the incorporation of RTTR techniques can be offset somewhat through implementation of an appropriate forecasting scheme. A review of state of the art forecasting techniques for thermal ratings of overhead lines can be found in [9]. The accurate forecasting of RTTR however represents a significant challenge to the implementation of a combined system, if optimal scheduling of the EES devices is to be achieved.

In addition to the forecasting of RTTR, there is a requirement to forecast the corresponding electrical network demands, to ensure that the available network headroom can be accurately determined, and as a result the corresponding requirements to be made from available EES devices. One particular method which has often been selected for this task is the use of neural networks [10]. As part of these forecasting methods, input parameters such as ambient temperature values and historical loading values are often utilised.

The nature of operating RTTR and ESS synergistically leads to specific forecasting requirements. The majority of the time, the line ampacity is likely to be greater than the demand plus the maximum power rating of the ESS. However, it is imperative that coincident events of low rating and high demand be forecast with a high level of confidence. Forecast models may need to be robust against climate change effects (i.e. rising ambient temperatures); the probability of high-demand, low rating events may increase if these climate change effects yield behavioural changes, such as increased use of air conditioning [11].

Aggregation of Distributed ESS

Scheduling under uncertainty requires having energy available at a given site at a given time (for DNO services), and at *any* site at a given time (for a TSO service). Given this requirement, and the increase in uncertainty arising from the use of RTTR, scheduling a fleet of aggregated, distributed ESS could provide more robust fulfilment of DNO and TSO services, while minimising ESS sizes.

A key parameter, which will influence the effectiveness of aggregated ESS, is the diversity in demand, renewable generation, and overhead line rating, between geographically disparate sites. If the diversity is low, and the demand, generation, and line ratings between these sites are highly correlated, the value of aggregation will be low; however, if the diversity is high, then the value of aggregation will be much higher, as the probability of multiple sites having to offer similar services concurrently will be much lower. This diversity could also be created by aggregating ESS with a variety of applications, such as demand peak shaving, and renewable energy constraint management.

Regulatory Barriers

As an emerging technology, ESS are not explicitly covered by distribution networks regulations in the UK, and many other countries. In the UK, ESS are presently classed as a generation assets, which precludes DNOs from owning and operating them – an unforeseen consequence of unbundling [12]. Given that many of the applications for ESS arise from the needs of DNOs, and that there is no mechanism by which a DNO can procure these services from a third party, regulatory change is needed for these applications to be fulfilled by ESS outside of innovation projects. An example of a DNO service procurement framework has been developed by Scottish and Southern Energy Networks as part of a constraint management zone on a section of their network [13].

Further to this, network security of supply standards do not recognise ESS, RTTR, or a combination of the two, as making a contribution to system reliability in place of a conventional asset. The UK standard, P2/6, is currently undergoing a fundamental review – if combinations of emerging technologies are to make a contribution to security of supply in future networks, then there must be an explicit mechanism to allow this within the prevailing network standards.

CASE STUDY: SNS

Overview

SNS was an innovation project, which demonstrated that an ESS could successfully provide distribution network security of supply while participating in a range of ancillary services [6]. The ESS was built because the two incoming circuits were no longer sufficient to provide an N-1 secure connection to the substation during peak demand, based on their static ratings. However, analysis shows that using RTTR could further defer the network upgrade, and enable the ESS to participate in additional services. In this section, we discuss some of the specific technical and practical implications of deploying RTTR in parallel to the ESS.

Overhead Line Routes

The RTTR of overhead lines is governed by four meteorological variables, listed in order of significance: wind speed, wind direction, ambient temperature, and solar irradiance. Wind speed and direction are both heavily influenced by the local land coverage and orography [14]. Consequently, the route of an overhead line is significant in determining the likely uplift which can be achieved through RTTR, where the thermal bottlenecks are likely to occur, and where instrumentation to allow inference of the line ratings should be located. The routes of the overhead lines connecting the Leighton Buzzard substation (where the ESS is located) to the connection to the transmission network are shown in Figure 3.

The lines are JAGUAR ACSR (Aluminium Core Steel Reinforced) conductors, supported by wooden poles. The two green lines in Figure 3 show the lines in question; both are around 16 km in length. The lines primarily pass across open terrain with only small changes in elevation; this reduces the likelihood that there are severely sheltered sites, and the difficulty of inferring the line ratings from weather observations. Both lines pass close to areas of buildings, which can cause a reduction in the RTTR when the wind direction is such that the lines are in the lea of these areas.

Demand and Meteorological Data

The analysis, carried out in [1] and discussed in this paper assumed that the line ratings and demand varied independently. However, this is unlikely to be the case, as in the UK, there is often a correlation between high demand and low temperatures. While analysis of all the demand and temperature data from January 2010 to August 2016 did not show any significant correlation, in this paper we present analysis of a subset of these data, uring peak hours (17:00-20:30), during the months when demand peak shaving is required (October-February).

This subset of the data is shown as a plot of demand against temperature in Figure 4, with a regression line fitted to emphasise the trend. There is a negative correlation between these values, with a correlation coefficient of -0.5297; this will work to the advantage of the RTTR deployment, as high demand values are unlikely to coincide with low ratings of the overhead lines.

To illustrate this, the occurrences of demand being greater than the winter static rating (35.8 MVA), were enumerated, and the results are shown in Table 1. There were 231 such events in the dataset. The number of these occurrences which coincided with the ambient temperature being greater than 2°C – the temperature used to calculate the winter static ratings in the UK [15] – was also enumerated; there were only 16 such instances.

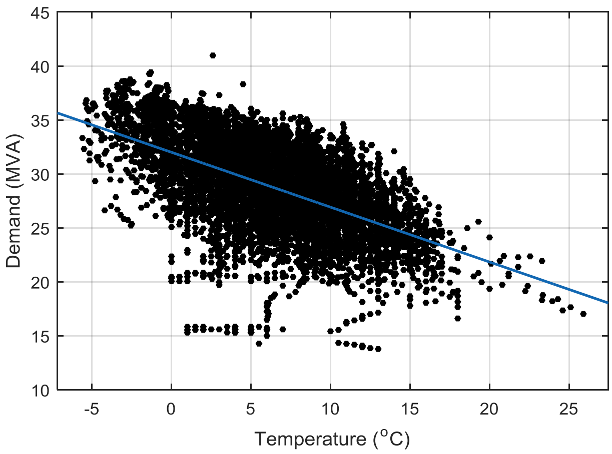

Figure 4: A plot of temperature against demand for the early evening (17:00-20:00) during the peak period (October to February)

	Exceedance Events (Half hour periods)
Total	231
With $T_a > 2$°C	16

Table 1: Exceedance events for Leighton Buzzard

Leighton Buzzard Thermally constrained Overhead lines Sundon Grid Supply Point

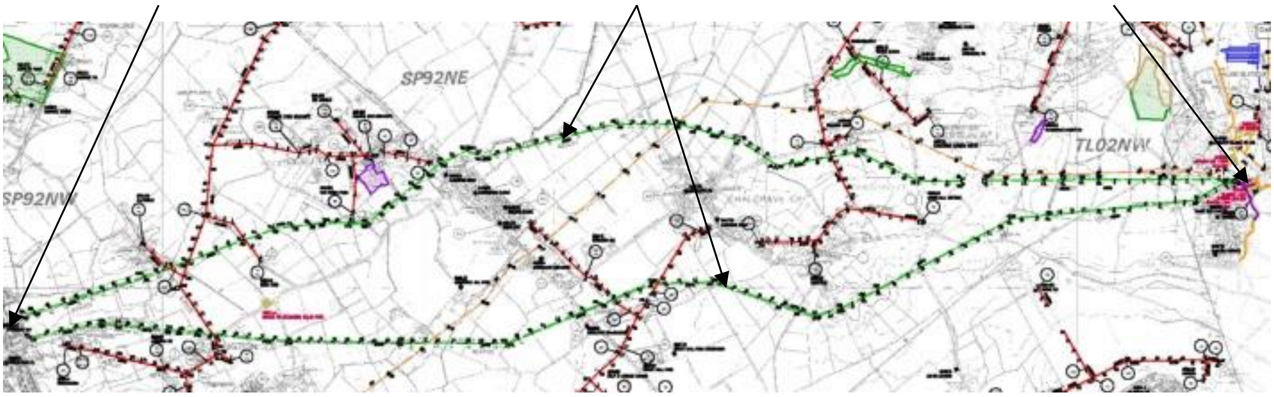

Figure 3: Overhead line routes from the Sundon grid supply point to Leighton Buzzard primary substation. The green lines show the thermally limited lines which have been reinforced by the ESS.

CONCLUSIONS

The work presented in this paper has demonstrated that while ESS and RTTR can both make valuable contributions to electrical network, their potential is further increased by co-deployment. Synergistic operation of these technologies can lead to increased network reliability, and additional service revenues, thereby strengthening the business case for ESS.

However, a number of technical and regulatory obstacles have been identified, which must be overcome before DNOs and ESS developers can take advantage of this complementarity. Prevailing security of supply standards will need to be updated to include the security contribution made by ESS and RTTR, both when deployed in isolation or combination; ancillary service markets will need to accept the reduced availability of ESS which are also providing vital security of supply functions, through either flexible contracts or clear guidelines for aggregators. Technical issues include the ability to predict with confidence coincident periods of low line ampacity and high demand and scheduling of storage resources under multiple uncertainties. The results from this paper suggest that, as a consequence of the negative correlation between ambient temperature and demand during the peak periods, these events are uncommon.

There is the potential to deliver substantial benefits to distribution networks through combination of complementary smart grid technologies. Demonstration of these combined deployments is now needed to build technical and regulatory confidence.

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