February 2024

# Recommendations for the deployment of DSO projects

2024 EDITION

CurrENT

Enabling Network Technology throughout Europe

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## Executive Summary

CurrENT recognises that one of the greatest challenges to developing the distribution network is the introduction of new technologies. This guide document provides a series of recommendations to Distribution System Operators to support the deployment of a range of mature, commercially available, innovative grid technologies.

The paper has utilised deployment issues from published sources and from currENT members' first-hand experience and considers the impact and interaction that these innovative grid technologies deployment will have with these. These issues include the limited bandwidth of DSO company skills and resources, standards and specifications, the challenges with the existing regulation and business models, along with the need for certainty in roles and responsibilities.

From these both general and technology-specific recommendations are made for the more efficient, simplified deployment of a range of innovation grid technologies.

Key recommendations include:

- DSOs should only use functional specifications in tenders, permitting the widest inclusion of grid innovation technologies.
- The Cost Benefit Analysis should be a net present value calculation with a true reflection of the costs and benefits. This should include the actual annual phased spending for building the project, and for fast deploying innovative grid technologies the added benefit from early construction, or delayed spending on constructing the project. The Cost Benefit Analysis should also consider the relative construction costs associated with one technology against another.
- The Cost Benefit Analysis shall be adapted to the national regulatory regime applicable to the Distribution System Operator.
- The list of equivalent technical international standards where provided are recommended to be used.
- It is advantageous not to wait to use grid-optimizing technologies, but start the evaluation through to deployment process to avail of the benefits early. This paper has shown these benefits to the distribution network and its operators to be faster, lower cost, more flexible, beneficial and seamlessly integrated solutions.
- A Distribution Technopedia to provide DSOs with a list of commercial ready technologies to minimize the effort in identifying and learning how to appraise (often new) alternative technologies. A transparent national or European Technopedia simplifies DSOs tasks of identifying technologies, sharing with stakeholders what they are and will consider, and sharing knowledge internally.
- That DSOs customize their due diligence innovation process based on factual and not perceived risk of each new technology. The grid-optimizing technologies in this paper actually all have a method of application that provides significant benefits that do not jeopardize the network security.

## Recommendations for DSO project deployments

- The use of trial projects, or limited use first deployments, are eliminated in favour or first deployment[s] into full active use in the network. As DSOs who perform the recommended review of the impact will find the needs and benefits of introducing the technology far outweigh any risk of stranding assets.
- That bespoke technical assurance work completed by a DSO is made available to peers to support their own technical assurance, through either CurrENT, or a relevant DSO association.
- Wherever possible technical assurance should be minimized to only the areas of a new technology where the technology performance is truly essential. The suppliers have at their disposal past investigations (or selection and proof of international standards) compliance for other customers that are equivalent or often more onerous than the local conditions.
- DSOs to work collaboratively with the grid optimized technology supplier[s] to ensure the technical assurance process can make best use of these materials to eliminate the need for repeat works and streamline the DSO commitment.
- That the technologies in this paper are considered in combination. The suppliers of these technologies can offer guidance on the possible combinations to address individual cases or needs, and there are other published examples included in the references of this paper.
- The application of any new technology requires consideration on how it is to be introduced into widespread operation. Existing technological introductory processes have been built around the prolonged timelines, high resources and very high capital expense of a project investment. The risk of a costly stranded asset is high.
- That regulatory bodies and policy makers both nationally and European, put incentives in place to support the introduction of these technologies [1]. As mentioned in many places in this paper the introduction of new technology can be highly effective for DSOs, but requires initially time and resources to be diverted to the task.
- That DSOs select from these known issues on their network and aligned these with the use cases presented in the paper to apply these technologies as alternatives.

## Introduction

This guide document provides a series of recommendations to Distribution System Operators to support the deployment of a range of mature, commercially available, innovative grid technologies that optimise and maximise the use of the existing electricity grid, that are still not standardised for most companies.

Introducing new innovative technologies has been universally recognised by DSOs and their industry bodies [2] [3] [4] as a necessity to meet the expected pace of development.

> *'The European Union's goals to reduce greenhouse gas emissions by increasing the share of renewables and to place customers at the centre of the energy system cannot be achieved without smart forward-looking electricity grids', E.DSO*

However, one of the greatest challenges to introducing these new technologies is the time of limited DSO expert resources to consider the specifics of the technology and its deployment.

CurrENT has recognised this barrier to the timely development of the innovative technologies that it represents, and so has used its unique technology experts and experience of working with DSOs to assist and inform DSOs to reduce this burden.

At present, the deployment of many of the range of technologies in this guide is limited in the Distribution network. As a result, international standardisation through IEC, IEEE, ANSI, CIRED, CIGRE, ASTM and other international standardisation bodies has not been completed in some cases. In the absence of these, DSOs must encounter a more complex and involved process in specifying the equipment they want to meet their needs. CurrENT recognises this challenge and its members have contributed their expert knowledge of the technologies and best practice in their application by DSOs in order to provide the recommendations in this guide.

In addition, many DSOs and their regulatory bodies will need to have a regulatory [5] and procurement system in place to manage these innovative technologies through to deployment. This guide provides recommendations on how this might be achieved based on past experience and the combined knowledge of the association. This covers initial analysis, to procurement of technologies (typically term or bulk buying), and finally through to infield deployment.

This guide first seeks to identify the issues that have arisen in deployment of innovative distribution grid technologies, and then discusses a series of recommendations to address these issues. The recommendations are broken into two main categories, those that are generic to all technologies and recommendations that apply to specific technology[s].

We have found that collaboration with our customers is at the core of successful delivery of projects that work as needed. We hope that this guide is illuminating and would welcome your feedback on what is missing or could be improved. CurrENT and its members would be pleased to offer further support in your needs. Please feel free to contact us at Info@CurrENTeurope.eu.

# Known Deployment Issues for DSOs of Smart Grid technologies

Both through published sources [2] and CurrENT members' first-hand experience working with DSOs the past years, a number of issues in understanding and the development of innovative grid technologies come up repeatedly. These are briefly outlined and described below, and will help frame the content of this paper, which will try to address and provide direction or solutions on the management of these issues.

Clearly, as the distribution network and its users develop over time, new issues emerge, and it is CurrENT's intention for this paper to be a living document that will be periodically updated to capture new issues.

## DSO company skills and resources

In a time of intense growth in the industry, with new customers, service providers and sectors opening up the pressure on existing internal resources and the ability to replace or bolster these has become acute for most DSOs. The ability of DSOs to maintain their core business and examine vitally needed new innovations is a major challenge. Growth in network replacements, extensions and/or adaptions in the future is predicted by all. Hence, this situation needs to be mitigated to enable decarbonisation and to meet targets and expectations.

Unlike many TSOs, DSOs often lack the engineering headcount to deliver the required CBA and engineering. To enable faster deployment, DSOs require easy access and well explained guides to new technologies, their benefits and applications, and from a verifiable or certified source.

In tandem, the support from experts in the field of these innovations from academia and suppliers will be an increasing necessity to quick test promising technologies, without extensive ranges of tests, or labour-intensive internal expert reviews.

## Standards and Specifications

Traditionally DSOs have placed greater reliance on international general standards and specifications, than bespoke investigation and customisation. There are simply too many projects and maintenance activities at the DSO level to practically support the same approach and specialization as that used in the transmission network. This means that new technologies and innovations that may not be fully standardised or specified by the international bodies (IEC, IEEE, ANSI, BS, CIRED, CIGRE TB, etc.) present a real challenge, requiring more internal time and energy.

Like the DSOs, the standards bodies have a certain bandwidth, which by their own admission at present cannot keep pace with the speed of innovation. As cited by nearly every stakeholder in the industry, innovation must intensify and therefore this problem will continue to grow and must be resolved. Like the rest of the industry, there is insufficient experienced resources and too much interaction between existing and new standards to simply increase the size of the standards bodies in response.

To enable faster deployment, DSOs require an alternative equivalent method of providing the necessary type testing evidence of equipment suitability to DSOs for use. Acceptance of testing data, and reliance of peers' evaluations will be one mechanism. The support from experts in the field of these innovations from academia and suppliers will be another. Suppliers will undoubtedly be expected to provide equivalent standards and specifications, with reasonable justification and/or assurances to mitigate this issue.

### Regulation and Business models

At present regulatory recovery of investments are based on the capital invested [6], which is independent of the technology being used. The perception that new technology performance presents a risk of the unknown means that often the known is selected over the unknown, resulting in inefficiency. This is compounded by the fact that deployment of a new technology may require the education of design, operation and fields teams into how to deploy and use

Whilst some funds are made available from regulators and the EC to support new technology in favour of conventional approaches, it is often necessity because of a lack of an alternative that drives innovations and new technology use.

The level of uncertainty of future needs and predictions also make justification of a project more difficult with regulators, permitting authorities and wider society.

The use of new business models such as leasing, software as a service or public private financing, can offer some support but only where flexible regulatory processes and procedures can be supportive rather than obstructive.

### Roles and Responsibilities

The deployment of technology as part of a wider project has been traditionally been the responsibility of the DSO and their contractors. This has meant that a significant burden is placed on the DSO to be efficient in their plan of deployment, timely sourcing of material, commissioning tests, and provide sufficiently trained and skilled personnel for the work. To avoid simply repeating project deployments with known technology requires a step change in cost, reliability or scope of works.

Scope of works, costs and reliability can be greatly impacted with a change in roles and responsibilities, with suppliers either reducing the complexity of size of the scope of works and/or managing some deployment themselves. Alternatively, ancillary issues in the preparation and risk management of a project such as method statements being supplied with equipment can be a major labour saving.

One major issue is the commissioning of the deployment, where experienced resources are very limited and inclusion of new technologies may be challenging. Traditionally witness testing has been a common approach to manage this, but can be resource expensive and complex. Limiting on-site commissioning would be desirable, as well as provision of supplier developed commissioning plans, ideally certifiable and globally reusable.

Technology that serves multiple purposes [7] [8] [9] can also be issued and a source of improvement, reducing the number of projects or components needed.

## Innovative Grid Technologies: General Deployment Recommendations

CurrENT has reviewed and documented the specific deployment requirements for its members in the following chapters. These provide guidance and recommendations of the more specific requirements that DSO are likely to encounter in deploying the innovative grid technologies that its members provide.

### DSO network studies

The DSO network study general recommendations make very little change to the normal network study principles used by DSOs to identify the distribution network development needs. In order to consider the viability and value of the use of most of the technologies presented in this report, network studies, use classical evaluation techniques. Normally a representative network and/or market model of the system operators is used, in conjunction with a proprietary software tool, to represent the current and future network.

Using this, the existing network can be assessed to see whether it complies with the planning and operational standards applied by the system operator and asset owner. A failing to meet these standards is a clearly identified need to consider mitigation. In addition, whilst these standards may be met, they may only be by using high-cost and often inefficient measures (e.g. high cost generation or demand response, or demand disconnection). This might also trigger the need to do a mitigating development to reduce these costs.

These network studies usually start with market or load flow analysis, as these are simpler and quicker to do, capturing many of the needs that arise. However, more uncommon studies are becoming increasingly important as higher levels of renewables develop in the distribution system with fault level analysis, dynamic, power quality and EMT also being periodically required. These presently uncommon studies are primarily driven not by the technologies in this report, but by the condition of the network and hence the needs that arise. For example, power quality studies are becoming commonly needed due to the rising background harmonic levels of the network, as renewable energy use grows and the use of larger scale fossil fuel power plants that suppressed harmonics reduces. CurrENT recognizes the growing commonality of these studies and provides models to support these[1].

Once the need has been established, it is recommended to install the technology being considered (based on the network needs the technology is typically used to mitigate) into the same model and repeat the process. The viability and sizing of the solution to address the issue can then checked and confirmed, either resolving the uncompliant network standards issue or providing sufficient economic benefit to deploy. It is imperative to a good investment decision to consider a range of technologies that is diverse enough to identify most efficient solution, but that represents a commercially available and mature solution. CurrENT recommends that a

[1] 'Innovative grid technologies Standardized Modelling of Static Synchronous Series Compensator (SSSC) and High Capacity Superconductor DC cables' Griddigit report commissioned by CurrENT

technology toolbox either developed by the DSO independently or from a centralized recognized European DSO body (EUDSO, E.DSO, etc.) is used to perform this role. This approach is transparent and yet resource efficient to manage.

The specifics of how to conduct the network modelling before a solution, selecting and sizing a solution and how to confirm its viability as a solution, is explained in more detail in the relevant technology sections below.

## Procurement and Functional Tender Specification

Tender specification is a complex and often challenging process with the need to be specific to ensure that a solution will work and to an acceptable standard, but not unwittingly reduce the ability of viable solution providers to be bid and therefore the competitive process.

The primary recommendation from CurrENT is to only use functional specifications in tenders. For example, that the components connected into a circuit and operating at line voltage must be able to withstand the operating voltage range of the circuit into which they are to be installed, or will directly control or manage. However, care must be taken to not assume how a technology will work for instance a device controlling a circuit may not have any component at line voltage, therefore requiring components to be able to withstand the line voltage may unwittingly force some viable solutions to be non-compliant to the tender.

Tender specifications that present the environment into which the technology will be placed and must perform i.e. voltage range, current range, frequency range, etc. are less prone to unintentional bias. That being said, it is advisable to qualify the requirement, e.g. 'If the devices will be installed and operate at line voltage then they must be able to…'. Tender specifications that define the performance/physical characteristics such as availability of a solution, its construction, or the specifics of how it should operate are areas where commonly bias between technologies can more easily occur.

CurrENT recommends simple adjustments to tendering processes can benefit the process with no material time taken to manage tender specifications.

As a first adjustment, the inclusion of 'or equivalent' for performance/physical characteristics, provides suppliers with the opportunity to still submit to a tender where their offering would be unintentionally not able to meet the specification. This change places the emphasis on the supplier/contractor to explain to the DSO satisfaction how it can still perform as well or better than the tender specifies, with them doing most of the work.

The second adjustment would be the use of a Pre-Qualification Questionnaire (PQQ) or even a Request for Information (RFI) as a first step in a tender process. This first step allows the DSO tendering to collect responses to their specification, or information to inform it, as well as expressions of interest with either a RFI or PQQ. For example, the necessary information can be collected from potential suppliers that can be used to ensure no unintentional biases, e.g. suppliers own equipment specification sheets. In addition, this process can be used to draw together the international standards (e.g. IEC, ANSI, IEEE, ASTM) that innovative solution suppliers use to ensure that the functional capabilities have been tested, but that equipment standards that only apply to a subset of technologies are not required to be completed to meet the tender specification. Using the previous voltage example, specifying a standard that provides a supplier with internationally recognized method to prove equipment can operate at line voltages, only makes sense for solutions that will come in contact with the energized line.

It should be noted that the categories of the innovative grid technology in this report are very varied in the purpose, use and application, but share a common attribute of being essentially modular in their nature. This practically eliminates the risk of complete failure of a solution, and consequently means that network compliance to design standards is rarely jeopardized from a forced outage. It is recommended that this attribute is considered and reflected in tenders, for example when placing any expected availability of a solution in a tender.

It is expected that most tenders will be for term contracts, given the rapidity of DSO projects, as oppose to bespoke per unit specification. It is recommended that any type testing requirements be flexible as possible to the tenderer to provide the burden of proof of meeting requirements, with the use of 'or equivalent' to the greatest extent possible. The reason for this is twofold, firstly in many cases such term contracts will be for a range of unit sizes and/or capabilities, and secondarily suppliers have a wealth of past type testing to relevant standards or more onerous conditions to draw on, reducing time and cost to technical assurance for the customer. Given the rapidity of grid optimisation technology projects, it is often better to make a first deployment the type test.

## Cost Benefit Analysis

The need for Cost Benefit Analysis will be governed by the regulatory regime applicable to the Distribution System Operator, which varies around Europe and therefore these recommendations must be considered in conjunction with the local regulatory requirements.

Cost Benefit Analysis can fall into two steps in the deployment of a project, the assessment of the need to do something and the selection between alternative solutions. The need to reinforce the network may not be required if the network is non-compliant with national planning standards, which can form this first step cost benefit analysis.

For either step, it is recommended that Cost Benefit Analysis for distribution deployments use the industry standard [7] of using net present value calculations. Whether projects are sufficiently large as to justify bespoke Cost Benefit Analysis, or are grouped it is recommended that the same benefits and costs be considered.

The main difference in the cost benefit analysis is the method that is used to provide the inputs to the net present value calculation. For bespoke assessment, the specific network need is identified and the specific solution are used. For grouped analysis a once off Cost Benefit Analysis will be made using typical network issues and solutions to identify a solution to apply where a need of that type arises anywhere on the network.

The central general recommendation for all technologies with regard to cost benefit analysis is how the net present value calculation is formulated. A true reflection of the costs and benefits as they arise must be included.

This means that the cost of a solution should be included in the years as they arise, e.g. for solution options that take multiple years to develop costs should be included for each year rather than as a single capital cost in the year of commissioning. Similarly, as most technologies in this document are modular solutions, so where needs are developing so can the solution. This is unlike conventional solutions, which require the entire solution for the life of the equipment (typically 40 years) to be built at time of commissioning. Therefore, modular solutions should be included in the net present value calculation in phased steps over a number of years, compared to a single step at the time of commissioning for conventional solutions. Also, the grid optimising technologies are much faster than conventional solutions, so they can either be built earlier, accruing additional years of benefit as a result to alternatives, or can be commenced later (e.g. the year before) than a conventional solution (many years before) saving the cost of earlier spend.

For grouped Cost Benefit Analysis, an additional consideration arises in that decisions are not individually made, but rather based on a single indicative calculation. There is an additional benefit that the technologies in this paper can provide that needs to be reflected in the avoidance of stranded assets. Many of the technologies are almost entirely re-deployable if a need changes, meaning that the residual value of these assets should be included if this aspect is considered in a term contract Cost Benefit Analysis

## Installation and Testing

The grid optimising technologies in this paper are all markedly different in their deployment to most conventional technologies presenting reduced risk. They will be explained in greater detail in the following section. Each is considered commercially available, with field deployments and a growing operating record of accomplishment.

Each supplier can provide method statements for deployment, and recommendations on how to install quickly and easily based on past experience.

For technologies that include hardware they are modular in nature and should be installed allowing for future possible developments.

# Innovative Grid Technologies: Specific Deployment Recommendations

In additional to the general deployment recommendations in the preceding chapter each technology has a number of unique and specific capabilities and deployment needs. This chapter outlines for a range of innovative technologies a general understanding of the technology and specific recommendations for these.

## Advanced Conductors

### High-level Description

Advanced Conductors are a symbiotic technology to others listed in this document and permit the Distribution System Operator to double the transmission capacity on a given line route whilst ensuring minimal conductor sag. They fall under the general classification of HTLS (High Temperature Low Sag) but yield significant advantages over their traditional steel-cored HTLS equivalents.

Advanced Conductors comprise either a Polymer Matrix Core (PMC) such as ACCC® or Metal Matrix Core (MMC), such as 3M ACCR. Compared to steel, PMC and MMC designs offer greater strength, lighter weight and a lower coefficient of thermal expansion – which mitigates excessive sag under high electrical load conditions. The core's lighter weight allows the incorporation of approximately 30 percent more aluminum – without a diameter or weight penalty. The added aluminum content and enhanced electrical properties reduces the conductor's resistance and associated IR power losses[2]. Reduced line losses have profound benefits as pointed out in recent studies[2] which reveal that 2/3 of T&D (Transmission & Distribution)-associated losses lie in the wires and not the substation.


*Figure 1. Advanced conductors by CTC Global*

[2] "Electricity Distribution Systems Losses", Sohn Associates/Ofgem

## Recommendations for DSO project deployments

The inherent attributes of the PMC and MMC cores generally permit installation of these conductors on existing towers with little or no foundation or strengthening work required. This can dramatically lower project costs, simplify permitting, and expedite project completion – which are all very significant factors in Europe. The conductors share many fittings with their steel-core equivalents, now also including wedge-clamps.

### Technical Readiness

At the time of writing, approximately 20,000km of Advanced Conductors have been installed throughout Europe over the last 20 years and nearly 200,000km worldwide. This solution is readily available and well proven, therefore TRL 9 would be applicable (depending on the individual manufacturer's development path).

### Applicable Standards

The following are the applicable standards relating specifically to PMC cores:

| Standard | Comment |
|---|---|
| ASTM B987-20 | ASTM B987 is a long-standing standard for evaluation of the composite core. The-20 variant includes a requirement for a more robust galvanic protection between the core itself and the aluminium strands that surround it. |
| IEC 62818 | This standard will be effective early 2024. It adds to the ASTM standard by including longevity prediction using the Arrhenius method and certain thermographic tests relating to the matrix |

### Risk Mitigation - Inspection Systems

If seriously mishandled through excessive bending during installation, Advanced Conductors carry the risk of compressive failure. In response to this, certain manufacturers have developed inspection systems to monitor the condition of the core before, during and after installation. Recent innovations permit inspection of the core at any time throughout the conductor's life; of significant importance following unforeseen impact events such as tree-strikes. Enhanced inspection systems also add to Asset Management security in the event that line-carts are used during routine MRO. Such inspection systems are already being widely deployed in Europe, a recent example being Elia[3].

### CBA

CBA naturally varies from project to project, considering the following factors:

- If existing, what conductor is to be replaced?
- Tower/foundation strengthening requirements (if any), comparing Advanced Conductors with other technologies.
- Carbon emissions associated with the line-losses, or reduced generation requirements resulting from conductor efficiency.

[3] J-F Goffinet "Elia Tackles Grid Reliability Through New Technologies" (T&D World, August 2022)

Typically, Advanced Conductors yield a project payback within a very short time. The greatly increased capacity reserve also future-proofs the line to cater for redispatching, future RES generation and foreseen increases in line-loading.
A recent report[4] by the Energy Institute at Haas states that Advanced Conductors effectively enhance the viability of RES projects from the outset.

## Digital Twin platform

### High Level Description of technology

Digital Twin Platforms are an innovative part of the modernisation of the grid technologies, using data analytics and modelling, delivering monitoring of the assets, dynamic line ratings, topology optimisation and power flow control.

Digital twin technologies are creating an "image – twin" of a real asset by its physical-mathematical modelling by advanced analytics and algorithms. By feeding the algorithms by real time data, the model will create results describing the operational behaviour of the modelled asset
The results represent the reality, the model behaves like reality. The digital twin model is a single holistic multi-directional system, connecting into the real behaviour and capturing history, present and future.

### Benefits of a digital twin platform

- A platform provides all distributed data of an asset to enable collaboration of all involved stakeholders to solve common problems and needs
- Development and implementation to solve specific problems and needs over internal or even international organisational gaps
- Support of daily operations by the digital model of reality - rebuilding the "whole picture" for being able to make decisions based on updated new information and for solving complex challenging problems. In case of advanced AI technologies and machine learning features daily and future operation can be predicted
- Due to the nature of the digital grid technology, the usage of additional sensors or measuring hardware can be minimized in many areas.
- AI analytics of the Platform are creating measures to foster grid stability and security and adapt system operation to the new mix of resources, considering the EU's regulations and tariff policies
- Realization of an integrated European digital grid, able to unleash the Energy Transition

[4] E. Chojkewicz,U. Paliwal, N. Abyankar, C. Baker, R. O'Connell, D. Callaway, A. Phadke "Accelerating Transmission Expansion by Using Advanced Conductors in Existing Right-of-Way"

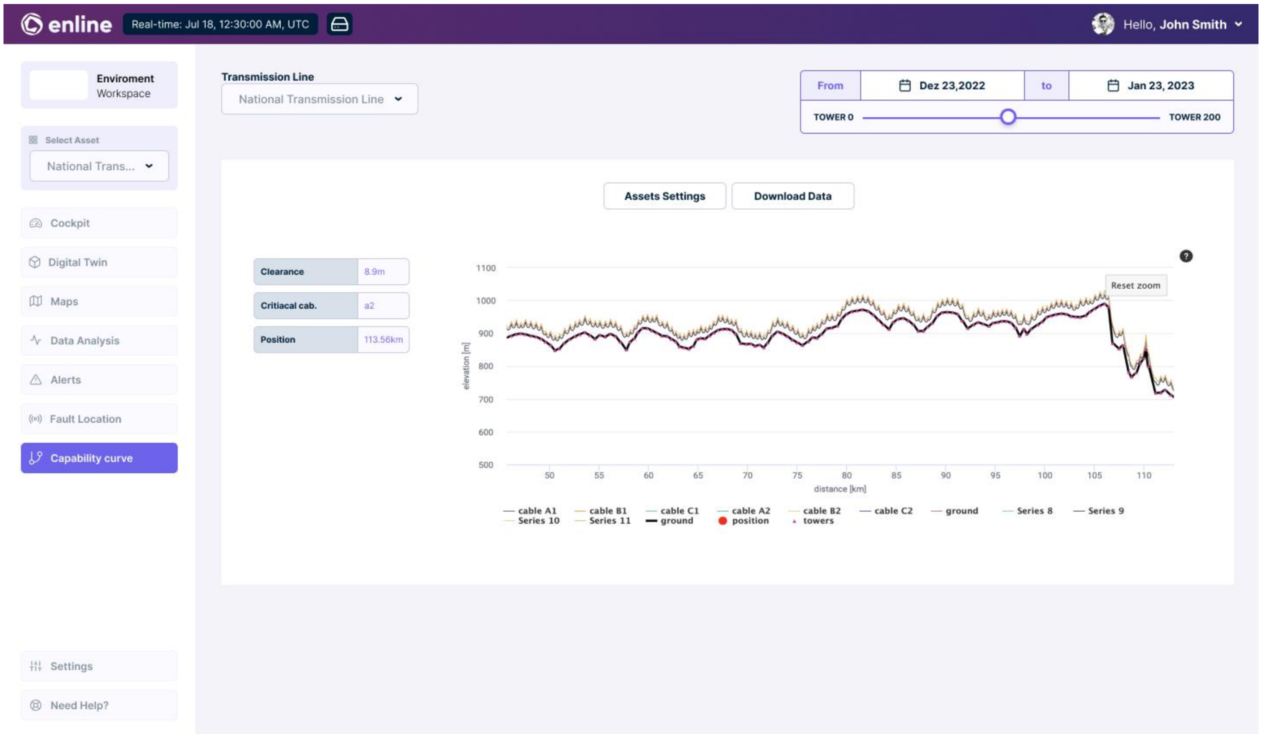


*Figure 2: Presentation of the electrical line in the platform*

With the Digital Twin platform any line can be modelled, showing all parameters at each point along the line, be it electrical values, sag per span, clearances or cable temperature values etc.

## Recommended technology risk management

Important for digital twin platform operation is maximum accuracy, the potential deviations between the real asset parameters and the parameters resulting on the twin platform.
To manage that risk, it must be secured that:

- the analytical algorithms are considering the international standards (DIN, IEC, IEEE etc.) for any asset modelling and operational calculation,
- the physical asset data and parameters for the modelling of an asset are available and updated or approximated within acceptable tolerances
- The necessary real time input data for daily operational simulation are provided precisely and without time delay in defined tolerance bandwidth.
- Solutions must be capable of tackling challenges for big data, providing all cyber security measures necessary for protecting critical national infrastructure assets

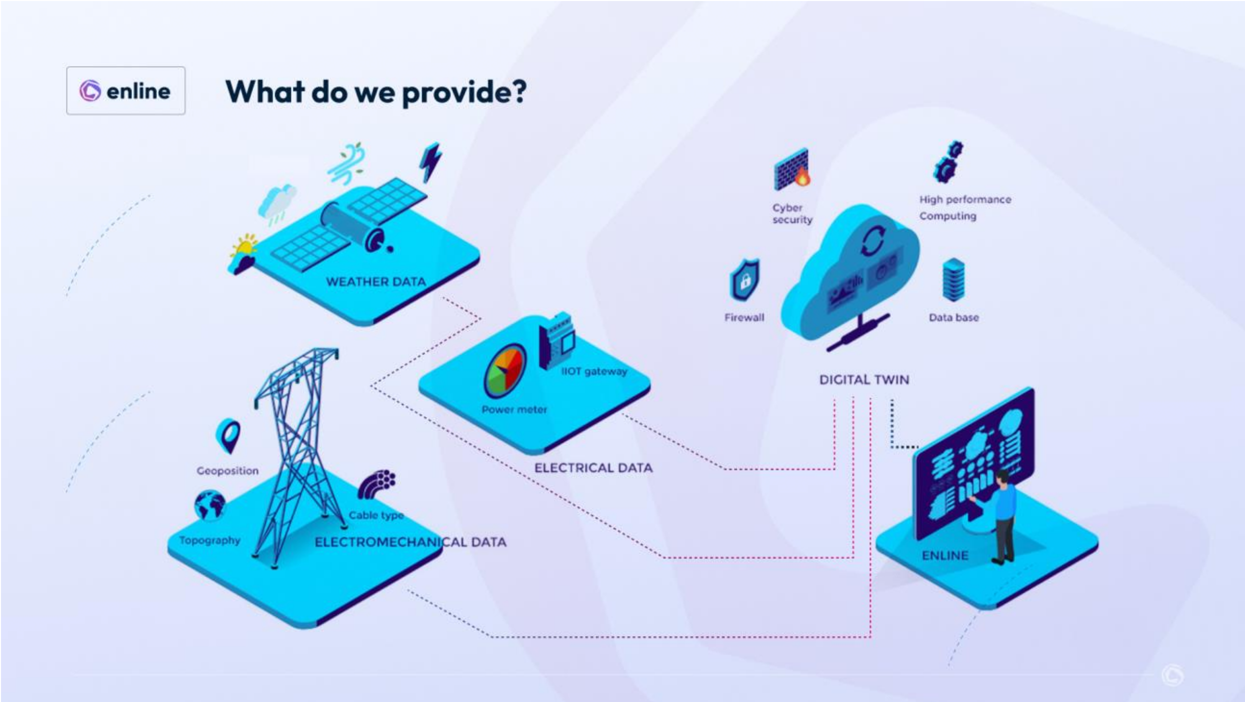


*Figure 3: Schematic illustration on how and where the platform obtains its data*

After start-up of the digital platform, Pilot/type test measurements in the field may be carried out in order to compare the measured field values with the resulting data on the platform

### Distribution Grid Operations

A Digital Twin platform for DSOs should take into consideration all available electromagnetic and physical project parameters of the electrical elements, such as switchgear, transformers, lines and towers, topography and geometric data.

The platform usually is modelling the installation in a cloud application, either on or off premises.

For the operation of the digital twin platform and generating the results, the following data are usually necessary: comprehensive weather data on a high granularity level, satellite data and relevant real time electrical data from the grid operators.
The results of all required parameters, predictions, alerts and warnings will be presented on the digital platform on operators' premises by acknowledging all electrical and thermal parameters in real-time and predicting mode providing GET functionalities like dynamic line ratings, topology optimization and power flow control.

### Deployment Process Stages

As Digital Twin Platforms are an innovative part of the modernisation of the grid technologies, more and more operators are developing their own models or are using platforms of innovative company developments.
The EU is requesting from utility level to the goal of an EU pan-national digitisation of the grids, harmonisation of necessities, standards, adherence to regulations – or adapting regulations to

enable to harvest the new technologies contributions - need to be defined in process steps with realistic/ambitious time horizons.

Typical solutions of Digital twin platform providers could be technically harmonised by EU funded HORIZON programs or by any DSO council related working group.

### Recommended CBA methodology

CBA of the implementation of digital twin platforms is under way by some DSO/utilities for their asset portfolio, showing advantages for a smart way of grid monitoring and operation, like recognizing upcoming critical grid situations, real-time and predictive congestion identification, proposals for countermeasures, optimization of the power flow control incl. forecasts of the next day's etc.

It is important to gain a holistic picture by defining common evaluation criteria. Such activities to be supported by e.g. DSO council related working groups.

As AI based algorithms are part of the digital twin platform, one of the benefits is not only the permanent monitoring of the grid but also the analytics that will recognize any changes in the normal behaviour and will alert the operator of any fault coming up. Therefore, a digital twin platform enables the operator to take action even before a fault or risk will appear, thus saving considerable OPEX costs by usage of the digital twin platform.

## Dynamic Line Rating

### High Level Description of technology

DLR is an operational improvement technology otherwise known as a Grid-Enhancing Technology (GET) that adjusts a line's thermal rating based on actual and predictive weather conditions including ambient air temperature, wind speed and direction, humidity, direct and diffuse solar irradiance, and precipitation. By doing so, DLR can give crucial insights to systems' operators on how much energy they can or cannot transmit in a given period. As a matter of numbers, DLR can increase, on average, 30% of a line's transmission capacity over a year, while increasing a day's transmission capacity by over 200% respectively. This is confirmed in the ENTSO-E Technopedia [15] "An increase of ampacity can be achieved up to 200% depending on the weather conditions and required confidence intervals. The highest potential is observed in areas of high wind RES, as convective cooling and loading of overhead lines are strongly coupled."

An increase in ampacity supports grid operators in making more efficient use of existing grid assets and avoiding congestion restrictions."

By utilising mathematical, statistical, physical, electromagnetic, mechanical and thermal models standardized by international entities such as CIGRE, EPRI and IEEE, it is possible to create a highly precise digital twin of a power asset to monitor all variables of interest. DLR requires line-specific data, such as conductors' specifications, towers' locations and silhouettes, combined with real-time and predictive monitoring to provide forecasts for operation planning. Real-time monitoring may include the use of field-deployed sensors, but it is optional for a software or digital twin-based technology.

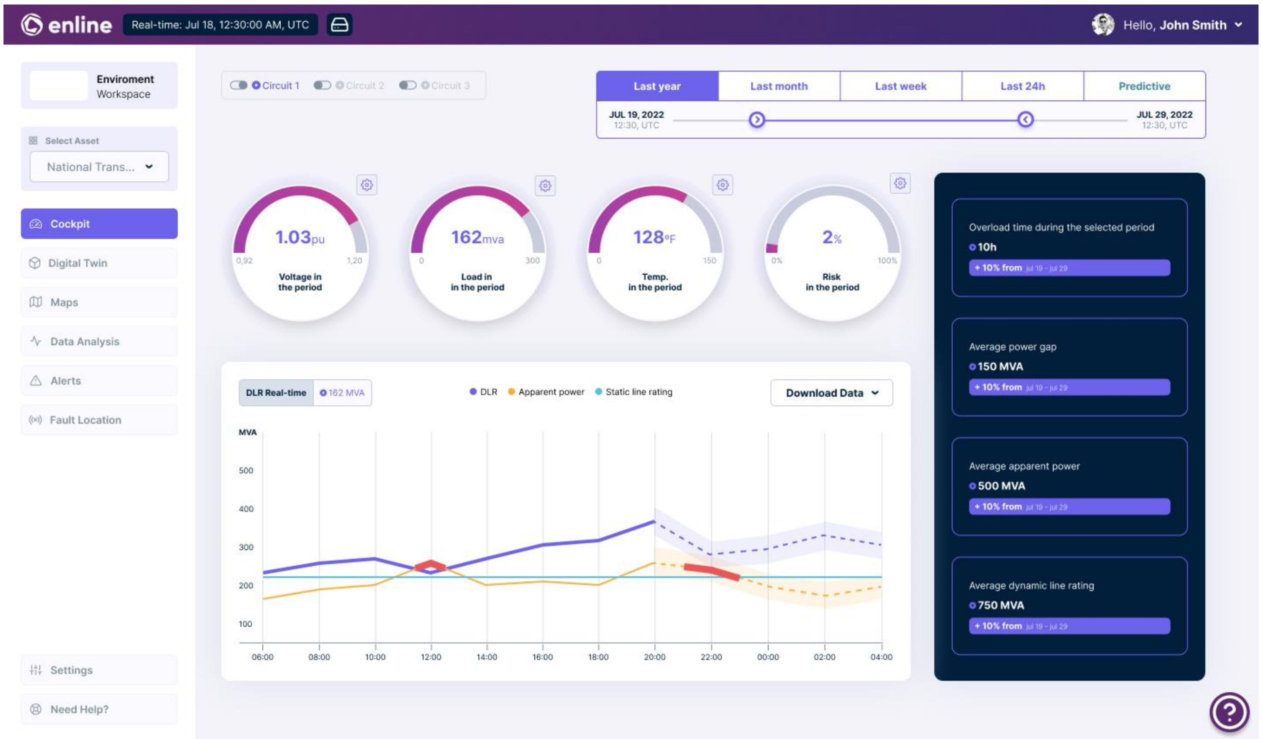


*Figure 4: Interface of the software with values about the monitored line*

## Recommended technology risk management

There are two types of risk involving DLR for DSOs: granularity and accuracy of forecast up to e.g. 7 days. The first is related to the technology applied for the distribution grid. By not knowing precisely which spans are the limiting ones, DSOs can wrongly identify a curtailed span and waste resources and work-hours trying if they ever need to go to the field. In the case of sensorless solutions, DLR can perform with high granularity, as weather providers give a 90-meter spatial resolution for needed variables. DLR can even be performed on multiple subdivisions within one single span for higher accuracy. The second one is society-based, as people damage line posts and their equipment, such as insulators, switches, reclosers and conductor-mounted sensors. For the second risk - accuracy of forecast - having a forecast for the maximum admissible ampacity on a line, the forecast will have reduced accuracy as longer the forecast is predicted. However, by permanent revision of the weather data the forecast will become more and more accurate by each update of weather data.

### System and Equipment Modelling

For sensorless solutions, there is the need to model the conductor cables and the towers/posts geometry to precisely evaluate the DLR of a distribution grid. By providing cable and insulator datasheets and GIS location of towers/posts, it is possible to perform the DLR for the customer. It is interesting to have the single line diagram of the grid, as the platform can alert overcurrent's and curtailment on equipment, such as switches, circuit breakers, etc.

### Procurement

#### Tendering Specification Recommendations

In the case of Software as a Service (SaaS) solutions, the price is based on some factors, but mainly on total grid length. For bulk purchasing, it is only necessary to inform which grids are of interest and how long they are. Sections of a grid can be delivered in parts as their models are finished, optimizing delivery for the client.

As a disruptive solution, it is important to notice the following:

- **In the case of a sensorless technology:** it's not necessary to utilize sensors, solutions are fast deployable and cheap for the client. This allows the digitalization of any power grid, anywhere in the world at any time, with a total of 0 hours of downtime. There is no need for on-field personnel, nor waiting for equipment to be delivered on site. We are not impacted by logistics nor safety restrictions as seen during the COVID-19 pandemic.
- **Even though it does not utilize sensors, it's accuracy is around 98%, proven by operators**: in special cases, some customers went on to the field to take real measures of some of the calculated values and upon comparison they got the same numbers as the software in over 98% of the times;

This type of solution **can be in the same pool of competitors that perform DLR.**

#### Type tests

Type tests are not necessary, but for results' validation, the client can go *in-loco* and measure the desired variables with adequate and calibrated equipment.

For DLR, references are as below:

| Product | Voltage Level | Contract | Country |
|---|---|---|---|
| EDLR / EMS | 380kV | Since April 2022 | Germany |
| EDLR / EMS | 220kV | Since January 2022 | Austria |
| EMS / EPO / EDLR / EFL | 230kV | Since April 2021 | USA |

| | | | |
|---|---|---|---|
| EDLR / EPO | 60/220 kV | Since October 2022 | Portugal |
| EMS / EDLR / EFL | 220kV | Since April 2022 | Canada |
| EMS / EDLR | 500kV | From Dec/2020 to Jun/22 | Argentina |
| EDLR | 400 kV | Since July 2022 | Portugal |
| EDLR | 66/220/400 kV | Since December 2019 | Spain |
| EMS / EDLR | 500kV | Since May 2022 | Chile |
| EDLR / EMS | 150kV | Since March 2021 | Uruguay |

*Table 1: Reference Dynamic Line Rating Projects*

## Deployment Process Stages

| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 |
|---|---|---|---|---|---|
| **Receiving cable, insulator, tower and GIS data** | | | | | |
| **Software parametrization** | | | | | |
| **Personnel training (Platform)** | | | | | |
| Note: The timeline is an approximation for a hypothetical grid. For an accurate timeline, the single line diagram should be shared with Enline | | | | | |

*Table 2: Development timeline and stages*

## CBA methods for this technology

The CBA method utilized for the DLR is the total benefits vs. total costs for the client per month [14]. As an example of a European client, the monthly benefit for a 400 kV transmission line is 18.1 M euros, while the costs are 11.3 k euros, creating a CBA of 160.

## Modular Power Flow Control

### High Level Description of technology

Modular Power Flow Control is a device that is designed from its inception to be modular in nature, combining a variable number of the units together in operation to operate as one to control the flow of power.

At present, the commercially available modular power flow control devices are Static Synchronous Series Compensators (m-SSSC). They are part of the FACTS family, injecting a leading or lagging voltage in quadrature (aka shifted 90 degrees) with the line current as shown in Figure 4, using power electronics. This reactive voltage injection makes the effective impedance of a circuit increase or decrease, which increases or decreases the loading on the circuit respectively.

Modular Power Flow Controllers can inject the voltage independently of the line current. This allows the devices to provide a linear not stepped response and to modify the effective reactance of the circuit immediately whilst injecting and at any point in time up to its rated value. An example, of the Modular Power Flow controller operating range is shown in Figure 4.

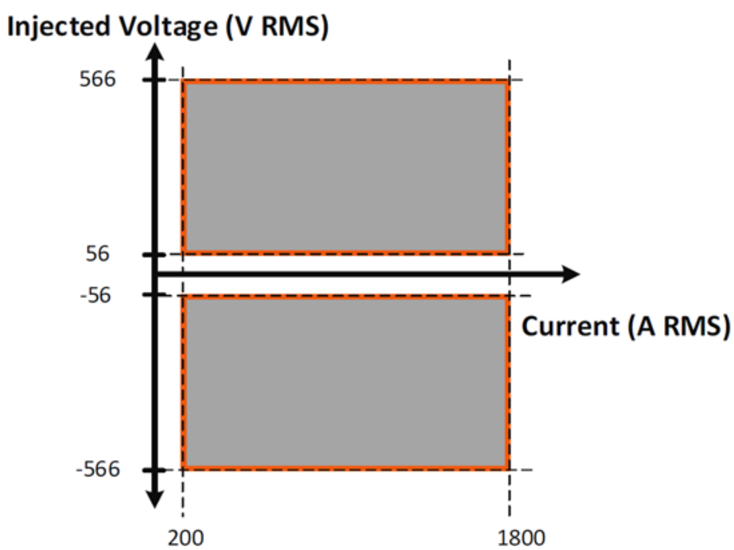


*Figure 5: SmartValve 1-1800 Voltage Operating Range*

They do this by harvesting energy from the line current directly and using this to generate the necessary reactive voltage. Consequently, as they are self-powered series connected devices their optimal design is as a 'live tank' device, operating at the line voltage and isolated from the ground. Either this can be done by insulated support structures, line deployment or rapid insulated trailer mounted mobile deployment, explained in more detailed in the Installation section below. The 'live tank' design means that the same device can be used at any voltage level, limited only by the ability to physically site the device where it is needed and the economic performance (cost benefit analysis) of the device compared to that of the need.

## Recommendations for DSO project deployments

The size of commercially available Modular Power Flow Control devices vary based on their ampacity, with typically 1800A and 3600A devices currently available. They also vary in size with 1MVAr and 10MVAr units available. It should be noted that the relative size of the units e.g. 1MVAr is a combination of the maximum rating 1800A and the maximum voltage they can inject 566V. As a result, the MVAr rating of the devices cannot be directly compared to that of other Power Flow Control devices, e.g. series capacitors, reactors, phase shifting transformers, etc.

To limit the images and descriptions in this guide, the devices shown will focus on an 1800A, 1MVAr units that are considered the most suitable for wide spread DSO network use.

The typical operational reactive range of an 1800A 1MVAr device is shown in Figure 5, with the device being operational between 200A and 1800 A. The device also have a short-term overload capability. The time an overload may be endured reduces as the size of the overload is increased, for example, a 120% overload can be withstood for 2 hours, but a higher overload would be less than 2 hours.

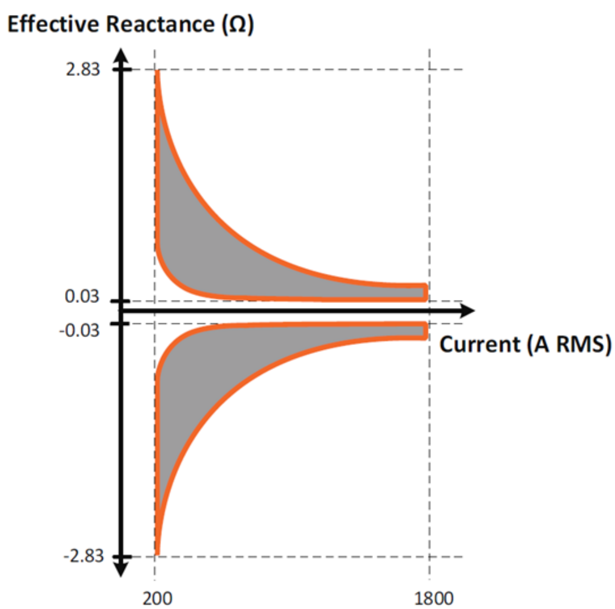

*Figure 6: SmartValve 1-1800 Reactance Operating Range*

As can be seen from the diagram in Figure 5, the higher the current the lower effective impedance that each device will contribute. Therefore, often a smaller level of impedance is required when the devices are deployed on the overloaded circuit that power flow needs to be reduced. However, this can result in a number of devices being required due to the lower effective impedance at high current. Therefore, a more effective solution can be to use the devices in pull mode, requiring a higher level of impedance, but potentially a smaller number of devices. To optimize the effectiveness of the solution against its cost, this relationship must be considered when assessing the network needs.

Modular Power Flow Control can be controlled in number of ways. They can be programmed to turn on when a certain level of current is seen on the line. The control arrangements can be integrated into the Energy Management System ('EMS') of the utility deploying them allowing direct control through the EMS.

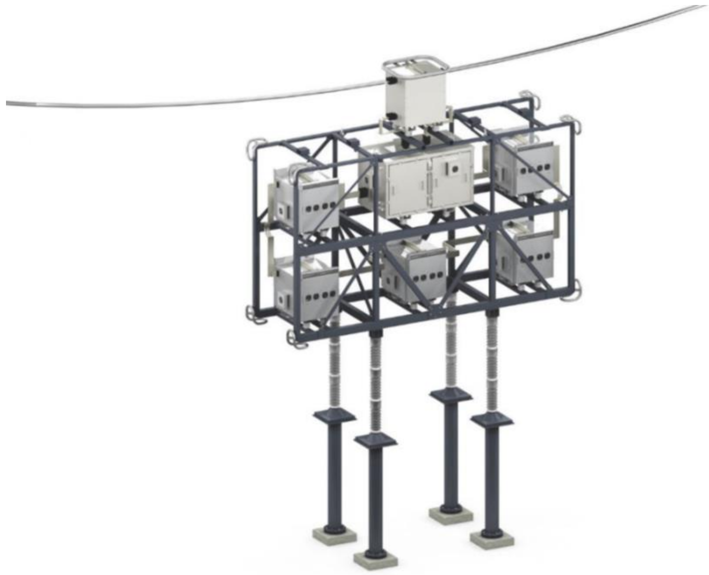

*Figure 7: Layout of ground based 1-1800 SmartValves*

### Communications

Communications between the MPFC can either be through encrypted ISM (Industrial, Scientific, Medical) radio signals or fibre optics.

The ISM frequencies are radio bands reserved for the use of radio frequency energy for industrial, scientific and medical purposes other than telecommunications.

The ISM signals are collected by a radio antenna connected to a device that manages the secure wireless link between the MPFC and the gateway communications module, which provides for operation and management of the devices and supports multiple communications approaches.

Figure 7 is a schematic of the communications arrangements.

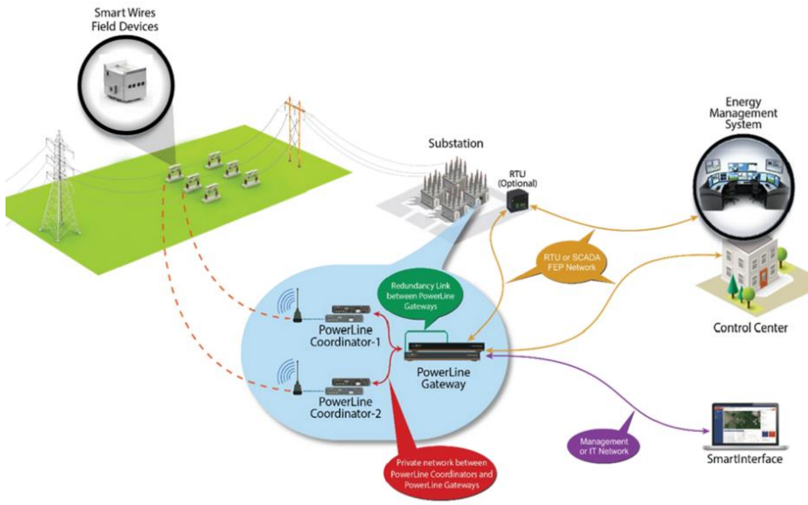


*Figure 8: Schematic of Communications Arrangements for the Project*

## Recommended technology risk management

Modular Power Flow Control technology is an extremely low risk technology in comparison to many existing conventional power flow control technologies for the following key reasons.

It is typical for Modular Power flow Control devices to be designed with an internal bypass. This switch is a 'normally closed' switch which means that in a failure of power to the devices, its circuits boards, controls, wiring, etc. the device defaults to closed the device is bypassed and the circuit will remain in service. In comparison, failure of nearly every other asset on the system will require it to be isolated by the opening of the circuit. This means that the failure of any one unit does not present the same scale of risk as conventional technologies where as a single unit the entire capability would be lost.

The speed of isolation (typically 1ms or less) in the event of a fault also means that the impact on system protection is eliminated as the devices will be faster than the protection to operate, resulting in the protection experiencing the same fault conditions as before the devices are deployed. This removes the risk of failure in design or modification to protection, or the inability to apply new settings. It is recommended that the need for amendments to protection be considered as part of the initial evaluation of the technology, ideally based on existing third party deployment experience and evaluations, to confirm the negligible impact of the devices on protection. Thereafter this generic due diligence of the technology, deployments need not reconsider protection implications.

Unlike other items of plant and equipment the Modular Power Flow Control are centred on modularity and the ability to combine units together seamlessly to scale their capability, or to offer a wider range of services [12] [13]. Consequently, they are also designed to be quick to assemble, move and replace. This means that there is virtually no risk of asset stranding if the system needs change or move.

## Recommendations for DSO project deployments

It is recommended therefore that Modular Power Flow Control be deployed to address the immediate need and not over dimensioned to account for a range of possible future needs over the 40-year lifetime of the devices. It also recommended that a periodic reassessment on the performance and need for the devices is performed. Typically, this would be done as part of the normal modelling studies of network's needs. This can identify whether to resize and/or move devices to more pressing needs.

Remaining risk from ancillary items such as the communication devices is typically also minimized through the standard duplication of these devices, their power boards and fibre-optic connections, so that they are effectively N-1 compliant. However, in the unlikely event of a double failure of the devices or where used the customers SCADA communication, there is an ability for the devices to be either locked in their present position, revert to their own on-board controls working independently or to isolate themselves. It is recommended that for each deployment that the optimum approach between these options is considered and identified in the design specification.

### Recommended Technical Assurance Process

It is recommended that the technical assurance is completed using a type test approach. This means that the technology has a more detailed assessment initially by the system operator and their experts, generally as part of a first deployment, which is not repeated for subsequent deployments.

It is also recommended to use the wide range of published test results of the devices, by previous research centres and bodies. Many of these will have assessed the same or more onerous system conditions than would be experienced on the system operator's network. As a result the bespoke work that is required to assess the technology is reduced for best practice due diligence. Equivalent network standards that exist and that have been applied to Modular Power Flow Control Devices are also a key method of reducing technical assurance, a table showing typical standards that have been applied is shown in table 1 to 3.

| Requirement | Applicable Standard | Title |
|---|---|---|
| Fault current | IEEE C37.32 – 2002 | High Voltage Switches, Bus Supports, and Accessories Schedules of Preferred Ratings, Construction Guidelines, and Specifications |
| EMC Compatibility | IEC TR 61000 – 4-1:2016 series<br><br>IEC 62271-1 | Electromagnetic compatibility (EMC) – Part 4 – 1: Testing and measurement techniques – Overview of IEC 61000 – 4 series |
| Lightning/Surge | IEEE Std. 4 – 1995 | IEEE Standard Techniques for High – Voltage Testing |

| | | |
|---|---|---|
| Maximum Operating Voltage (Corona and RIV) | IEEE C37.32 – 2002 | High-Voltage Switches, Bus Supports and Accessories Schedule of Preferred Ratings, Construction Guidelines and Specifications |
| Harmonic Content | IEEE 519 – 2014 | IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems |
| | IEEE 1547 | IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems |
| | IEC/TR3 61000 – 3 – 6:2008 | Electromagnetic compatibility (EMC) – Part 3 – 6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems |
| Insulation Coordination | IEEE 1313.2 – 1999 | IEEE Guide for the Application of Insulation Coordination |
| | IEC 60071 - 2 | |
| Electrical Safety | NESC C2 – 2012 | National Electric Safety Code(R) (NESC(R)) |

*Table 3: Electrical Standards*

| Applicable Standard | Titles |
|---|---|
| IEEE 1815 – 2012 | IEEE Standard for Electric Power Systems Communications – Distributed Network Protocol (DNP3) |
| IEC 62351 series | Power systems management and associated information exchange – Data and communications security |
| IEC 61850:2016 Series | Communication networks and systems for power utility automation |
| IEC 60870 – 5:2016 Series | Telecontrol equipment and systems – Part 5: Transmission protocols |
| IEEE 802 | Local and Metropolitan Area Network Standards |

*Table 4: Cybersecurity Standards*

| **Requirement** | **Applicable Standard** | **Title** |
|---|---|---|
| Intrusion Protection (Water and Dust) | IEC 60529 – 2004 | Degrees of Protection Provided by Enclosures |
| Thermal Cycling | IEC 61284 | Overhead lines – Requirements and tests for fittings – Clause 12 and 13 |
| Electrical Connections | ANSI C119.4 | American National Standard for Electric Connectors–Connectors for Use Between Aluminum-to-Aluminum and Aluminum-to-Copper Conductors Designed for Normal Operation at or Below 93°C and Copper-to-Copper |

| | | |
|---|---|---|
| Corrosion Resistance | ASTM B117 – 11 | Standard Practice for Operating Salt Spray (Fog) Apparatus |
| | IEC 60068 – 2 – 52:1996 | Environmental testing – Part 2: Tests – Test Kb: Salt mist, cyclic (sodium, chloride solution) |
| Seismic | IEEE 693 | Recommended Practice for Seismic Design of Substations – Section 8: Seismic Performance Criteria for Electrical Substation Equipment |

*Table 5: Mechanical and Other Standards*

## System and Equipment Modelling

The services provided by the Modular Power Flow Control is very varied and consequently the ranges of studies and models are also varied to permit these services to be evaluated. A high level of summary and guidance for the more frequent applications is provided in this section.

In order to perform these studies Modular Power Flow Control providers generally provide both steady state, dynamic and EMT models.

The historical main use of Power Flow Control Devices is to direct power flow to avoid overloading of network equipment ratings, whether they be overhead lines, cables, transformers or other substation equipment. This could be pre or post contingency. This type of network modelling study is a steady state analysis. The application of Modular Power Flow Control device is to change the relative impedance of the circuit or transformers to alleviate an overload by redirecting power into other pathways.

For a single issue, this can be done simply done manually or through automated routines directly changing the circuit impedances until the problem is resolved or adding in additional impedance in the form of a capacitor or reactor in series with the circuit, (or alternatively a more sophisticated Modular Power Flow Control model). The equivalent impedance calculated can then be used to define the number of modular units required.

For multiple issues the same approach can be used, but it is often more efficient to use more automated operational optimization techniques[1]. These techniques use the interacting capabilities of the devices to alleviate local and regional overloading problems at a number of points in a grid and by doing minimize the overall number of devices that must be deployed.

[1] For example, see Appendix 6.3 of RWTH Aachen University paper 'Modular Power Flow Control Enhancing German Transmission Grid Capacity'

## Procurement

The following should be read in conjunction with those general recommendations already provided.

## Tendering Specification Recommendations

Modular Power Flow Control is a rapidly developing technological space, with new customers experiencing the technology generally for the first time. This has been a cause for delay in many instances, as customer technical specifications typically are developed with use and experience.

The key technical specifications for Modular Power Flow Control selection are relatively simplistic. The operating conditions normally required for tendering of other plant and equipment operating as part of the main grid are a primary requirement to be specified. These include the connecting voltage, maximum continuous current, maximum short overload current, maximum fault current (single and three phase). In addition to this are power quality, EMC and noise requirements, and the standards and parameters that the customer uses for these.

In addition, functional requirements should be provided. These include the overall availability of the devices (as there are many options to achieve this), the impedance that deployment should be able to able to provide, and the space constraints that exist in the station[s] or route corridor[s] that the devices will be installed. Many of these functional requirements would be best discussed or worked on collaboratively and typically, suppliers would work with system operators to guide and inform these choices.

The use of appropriate standards is standard procurement requirement and can be a cause of difficulty in tenders due to the natural delay in technology specific standards recommendations from the industry standard organizations like of IEC, ANSI or IEEE. In the preceding technical assurance chapter above a list of equivalent standards are provided and are recommended to be used.

## Typical Lead-time for Deployment

In advance of carrying out the deployment of Modular Power Flow Control (MPFC) devices, the deployment layout and design should be completed and approved by the relevant parties. This takes roughly 6 months.

There are many technical details and records of activities preformed as part of the construction and installation process. The construction process can be summarized as:

- Shipment of equipment to site
- Pre-installation on site evaluation and equipment check
- Preparation of foundations
- Preparation of connection into network (overhead line/busbar) configuration
- Assembly of steel support structures
- Assembly of Modular Power Flow Control devices into their support structures
- Assembly and connection of cabling and busbars between Modular Power Flow Control Devices

- Assembly and connection of Communication equipment
- Installation

### Recommended CBA methodology

Modular Power Flow Control should follow the generic CBA methodology in the general requirements in the preceding chapter, but with the following additional elements as applicable.

Modular power flow control has the potential for a number of uses e.g. overloading of network elements, voltage management, oscillation damping, etc. As well as the primary need driving the initial investment, the current or future network needs from added benefits should be considered by the system operator and their annualized benefit included into the CBA

### Example cases

### UKPN 'Loadshare' project5

The DNO is committed to facilitate the connection of renewable generators in an economic and reliable manner to enable the transition to a low carbon future. A constraint was identified on the 132 kV network in Essex between two substations (Lawford Grid and Bramford) which was delaying the connection of renewable generators on the local network. Traditional solutions to add additional network capacity include increasing operating temperature with infringement clearance works, reconductoring existing lines or building new circuits. These approaches are often quite costly and require significant time and resources to engage appropriate stakeholders, plan, secure requisite system outages and construct. They are also intrusive to local communities and environmentally protected areas. Given that the 132 kV network between Lawford and Bramford is a meshed network, with three circuits of varying impedance operating in parallel, the DNO investigated a power flow control solution as an alternative option. Analyzing historical line flows and today's constraints, it was identified that there was potential to utilize power flow controllers to solve the constraint and release capacity for future generators. Upon investigation, it was determined that the impedance of the three parallel circuits was not evenly balanced. An adjustment of the impedance - through change in Reactance (X), or phase Angle (δ) - on one circuit changes the ratio of impedance between the three circuits, resulting in power flow changes on the individual circuits as described in the equation below.

$$P = V1V2 \sin\delta/X$$

Where:
P = Active power transmitted
V1 = Line-to-line voltage at sending end
V2 = Line-to-line voltage at receiving end
X = Reactance of circuit
δ = Angle of V1 with respect to V2

[5] https://innovation.ukpowernetworks.co.uk/projects/load-share/

The DNO assessed all forms of power flow control as possible solutions. In order to deliver the optimal level of constraint relief and load sharing on the three circuits, it was determined that a fine-tuned power flow controller was required on two of the three parallel circuits. Traditional power flow controllers such as phase shift transformers and series reactors were considered, but costs, spatial constraints, timing and lack of discrete, real-time controllability meant that a more modular and discrete option was required. The exact network configuration is shown in Figure 8 for reference.

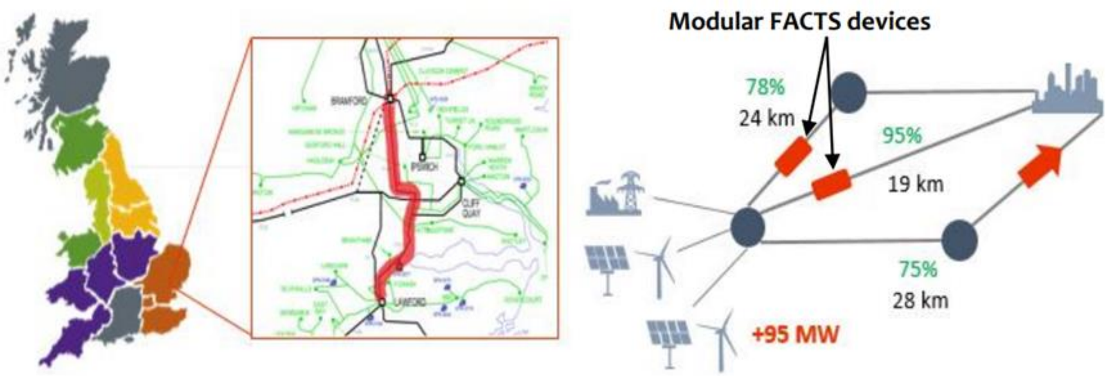


*Figure 9: Modular Power Flow Control in UK on two 132 kV circuits delivering 95MW of additional capacity*

## Horizon Europe Project - Farcross

The Farcross project considered the ability of Modular Power Flow Control to improve interconnection capacities.

After considering four lines situated in Northern Greece chosen in order to observe the impact on the interconnection line between Greece and Bulgaria, and Nea Santa substation was selected. The studies that were completed in this process followed the type of load flow modelling described in the equipment and system modelling approach, to find the lines most restricted due to their limited line rated capacity (MW rating). These lines represent the weak links in the network that would constrain the amount of power that can flow through the network before it becomes overloaded. The Nea Santa-Lasmos transmission line, offered the second highest level of impact from a Modular Power Flow Controller deployment, and the station was ideally suited to locate the equipment.


*Figure 10: Top view of the Nea Santa Substation*

It showed that its remote location would allow for easy transportation of the required large equipment and offer sufficient installation space with no social acceptance issues. Following IPTO's impact analysis, the installation in Nea Santa substation was determined to have positive impact on nearby renewable energy integration and the cross-border capacity between Greece – Bulgaria and Greece – Turkey.

Consequently, the Nea Santa substation is an ideal installation location, as shown in Figure 9.


*Figure 11: Nea Santa – Lasmos line on map and its loading*

## Monitoring Sensors

### Description of technology

For a correctly monitored, controlled, and regulated power grid, a balance between generation and consumption of active and reactive power is needed. According to the power equation, this means measuring voltage and current as well as frequency.

Since medium and high voltage as well as current levels cannot be directly connected to measurement devices a transducer is needed. This transducer can be realized with different measurement principles. Conventional voltage and current transformers use many resources, have heavy and bulky dimensions and are expansive.

However, with a smart grid, many substations, especially on medium-voltage level, should be digitalized. As a rule of thumb for every 100 households there is one substation or ring-main unit. With over 2 billion households worldwide this results in 20 million ring-main units. To digitalize one ring-main unit, around 15 sensors or conventional products are needed. Now with a needed share of 20 to 50 percent this results in 60 to 150 million devices. In detail, this means that during production all resources for this number of products must be available and that the power grid must produce the needed power to supply those measurement points.

This calls for so called non-conventional instrument transformer, also named sensors, which use up to 80 percent less resources, cost 30 percent less and are super small as well as easy in installation. They also need around 70 percent less power and are thus energy efficient.

### Non-conventional low power voltage measurement (LPVT):

LVPTs for example utilize an ohmic-capacitive voltage divider with the principle of a normal voltage divider. By splitting up the primary voltage with several resistors and capacitances, the secondary voltage is generated. Here secondary voltages of almost every value can be achieved by using the ratio between resistors and capacitances. In standards, the general output voltage of 3.25V/√3 is stated but can be easily changed to customer specifications.

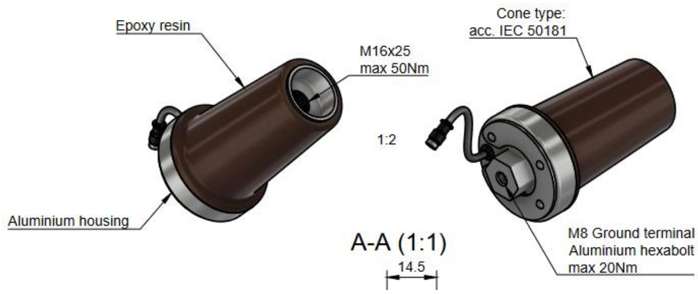


*Figure 12: Voltage sensor by Greenwood-Power*

### Non-conventional low power current transformers (LPCT):

In the case of LPCTs, also called current sensors, inductive current generation is applied; however, this current is further transformed into an output voltage. Here with the usage of a shunt-resistor at the output of the product a completely different output value, namely a voltage instead of a current, is achieved.
The integration of the shunt-resistor allows a smaller number of turns, which are transformed with the value of the shunt resistor to the output voltage required by the customer.

*Figure 13: Current sensor with split-core by Greenwood-Power*

### Recommended technology risk management

Since LPVTs and LPCTs transform the voltage and current into values that are way smaller than their conventional counterparts, the product itself is very safe during installation. Here, no field engineer can be hurt if a short circuit of the current measurement is forgotten. They are also easy to deploy due to their small and lightweight design. When designing the measurement chain, however, the right measurement or protection devices should be utilized. As the secondary outputs of the products are different, still many devices on the market have not adapted to those input signals. With a wrong measurement device, the LPVT or LPCT is not compatible to, the complete measurement or protection chain is useless and must be redesigned. For this reason reading technical datasheets and getting in contact with the companies supplying the measurement equipment and sensors is a prerequisite.

## Procurement

### Tendering Specification Recommendations

All non-conventional products only include passive components in their design, so once they are ordered their lifespan is decreasing even when only in storage before deployment. In addition, they do not need any updates or an additional power supply, making them a plug-and-play product for system operators. With passive components, the lifespan once employed in the power grid is around 30 years, in line with the standard devices in the power grid.

As already mentioned the output voltages of the devices are quite different when compared to conventional products. This means if non-conventional products should be applied in a tender, also the measurement device after the transducer will have to fit accordingly. From technical perspective the input burden and voltage level as well as connecting cable length must be made known to the transducer manufacturer since the product is adjusted for every measurement device and application case specifically.

### Specific type test

As many electric products, sensors have to be tested according to standards. For non-conventional voltage and current transformers applies IEC 61869-1, -6, -10, -11. Accordingly, lightning-impulse tests as well as partial discharge tests are the most important test of the product. Provided the product passes this test, it is technically safe and can withstand overvoltages in the systems without any problems. It makes no sense to apply the cable test standard in which sensors are tested in boiling water above 100 degrees, as this is not a condition that occurs in reality.

### Typical process stages and timelines for deployment

The type and process of product deployment depends strongly on the application. Sensor can be designed for use in air-insulated switchgear as well as air-insulated switchgear or pole mounted solutions. Normally once the equipment is chosen and paid for, delivery times for the sensor equipment are around 2 month and can then be directly installed.

### Example Cases

#### Already installed equipment

In these cases, sensors must be able to be added as retrofit solution. Since the dimensions of switchgear or poles are already in operation, changing those to adapt to additional measurement gear is not feasible. Here the customer looks for the smallest products on the market that can be added without cutting open cable connections.

#### Switchgear application

For switchgears, normally the customer already has a manufacturer for it and wants to add the measurement gear. In cooperation with the sensor manufacturer, the customer can choose a measurement device and sensor for his voltage level. Depending on the sensor manufacturer, special installations are possible, but generally, in gas-insulated switchgear the voltage sensor is of cone type for installation inside a tee connector. Here C-shape as well as shapes for asymmetrical tee connectors are standard. For current sensors a ring type sensor with a full or split-able core are utilized, which are installed directly around the cables. For air-insulated switchgear, voltage measurements can be combined with supporting insulators, where the voltage sensor is manufactured as supporting insulator making it a 2-for-1 product. For current sensors, a measurement on an uninsulated busbar is not possible.

#### Pole applications

## Recommendations for DSO project deployments

Here the main application is an insulator put either directly on the overhead line or on a supporting beam. New generation products can measure voltage and current in one product can transmit those signal values to the measurement device. From there the analog signals are converted into digital ones and then further processed to SCADA systems or cloud based solutions. In addition, here the system operator has an initial concept and based on it the sensor is integrated, certified with pilot installations and then rolled out into series installation.

### CBA methods for this technology

The easiest way to evaluate this technology is not by strictly comparing conventional technologies to non-conventional technologies but by looking at the complete measurement chain. As the measurement or protection device plays an important role and has to fulfill certain criteria not only the sensor has to fit the application but also the measurement device and then the sensor to the measurement device. When comparing the two technologies directly to each other non-conventional products are often more than 30 percent less expansive and do not require additional space in applications. Since space is also an important factor there are now more variables to consider, as well as when thinking about the energy-efficiency the power consumption of the product. Here non-conventional technologies also beat conventional technology.

### Example cases

As market adoption always includes a mindset or political change and conventional products are well known and used in the energy sector, the adaption of sensors is still slow compared to the need of digitalization.

#### Saudi Arabia

One of the countries with the most installed sensors is Saudi Arabia. Between 2019 and 2023, more than 150 000 sensors were installed in different kind of switchgears. Here the main use case is measurement for active and reactive power calculation as well as harmonic detection.

#### Europe

Energy transition in Europe is picking up speed and the market change in the sensor market is visible. With most measurement and protection device manufacturers, including sensor inputs in their devices also sales in all over Europe is steadily increasing. Now over 100 000 sensors are installed in different switchgears as well as on pole installations.

## Concluding recommendations

This paper has made and supported a number of key recommendations for the deployment of grid optimizing technologies in the distribution network. Whilst effort have been made to make these recommendations self-explanatory and standalone, their application would benefit from close co-operation with representatives of the relevant members of the CurrENT association.

### Efficiency first

This paper has sought to show the benefit of the application of grid optimising technologies to the distribution network and its operators can ensure faster, lower cost, more flexible, beneficial and seamlessly integrated solutions. Digitalization of the energy system is targeted, and essential, with universally recognized major benefits to stakeholders and network operators alike. It is advantageous not to wait, but start the evaluation through to deployment process to avail of these benefits early.

To demonstrate this, it is recommended that the reader look at the use cases presented in the paper, and select from these known issues on their network to apply these technologies as alternatives.

### Distribution Technopedia

In addition, CurrENT is at present advocating for a Distribution Technopedia to provide DSOs with a list of commercial ready technologies to minimize the effort in identifying and learning how to appraise (often new) alternative technologies. It can provide industry best practice with regard to the range of technologies for solutions that will be considered. A transparent national or European Technopedia simplifies a DSOs task of identifying technologies, sharing with stakeholders what they are and will consider, and sharing knowledge internally. It is for these reasons that it is recommended that DSOs consider a national Technopedia. This deployment paper can be seen as an addendum to a future national/European Technopedia.

### Technical assurance

Technical assurance of a new technology for DSOs can be challenging due to the resource commitment it requires from technical experts that often have limited availability. However paradoxically the need for new technology is increasing to keep pace with the changing role of DSOs and the move to decarbonisation.

Therefore, it is recommended that wherever possible technical assurance should be minimized to only the areas of a new technology where the technology performance is truly essential. The suppliers of the technologies in this paper have a broad range of technical assurance experience with other system operators. They have at their disposal past investigations (or selection and proof of international standards) compliance for other customers that are equivalent or often more onerous than the local conditions. It is also recommended to work collaboratively with the supplier[s] to ensure the technical assurance process can make best use of these materials to eliminate the need for repeat works and streamline the DSO commitment.

For the same reasons it is also recommended that bespoke technical assurance work completed by a DSO is made available to peers to support their own technical assurance either bilaterally, through CurrENT or a relevant DSO association.

## Application of symbiotic technologies

All of the DSO grid optimizing technologies in this paper cannot only be applied standalone, but in combination, often in a much more powerful application.

It is recommended that the technologies in this paper be considered in combination. The suppliers of these technologies can offer guidance on the possible combinations to address individual cases or needs, and there are other published examples included in the references of this paper.

It is expected that if the Technopedia concept that forms one of the earlier recommendations of this paper is developed either national or Europe wide, that this will also be another reference source of symbiotic technologies and their unique applications.

## Innovation Incentives

CurrENT has recognized and been actively supporting the need for incentives to support DSOs and their introduction of grid optimizing innovative technologies.

It has and continues to recommend that regulatory bodies and policy makers both nationally and European, put incentives in place to support the introduction of these technologies. As mentioned in many places in this paper the introduction of new technology can be highly effective for DSOs, but initially requires time and resources to be diverted to the task. This places financial costs and short-term resource management impacts on DSOs that need to be acknowledged and supported by industry.

Incentives from policy makers, regulators, EC and other sources also has a second almost equally important role in combating perceived risk from new technologies. DSOs are often questioned on their need to use, or perceived risk in applying a new technology. Incentives show that wider industry stakeholders recognize the importance of the technologies and there is universal agreement on the risks of failure to use technology to address network needs more efficiently outweighs any perceived risks from the technology itself.

## Trialing what matters

As discussed previously, the application of any new technology requires consideration on how it is to be introduced into widespread operation. Existing technological introductory processes have been built around the prolonged timelines, high resources, and very high capital expense of a project investment. The risk of a costly stranded asset is high.

This supports a slow introduction of a technology. Pilot projects followed by a period of assessment, often in less vital areas of a network are a common approach. First deployments often small then follow with another period of assessment. If successful, further projects then follow growing in size and complexity. This whole process may take a decade or more before widespread use is considered. This process is fit for purpose for a high-cost project, that uses bespoke equipment with fixed or limited capability to be reused, and whose failure or poor performance jeopardizes security of supply. The grid optimizing technologies in this paper are none of these things.

CurrENT recommends that the existing process for the introduction of new technology be reviewed and the impact that grid-optimizing technologies actually represents is considered first, and that a much more streamlined process to trial these technologies is used. All of the technologies have a method of application that provides benefits but does not jeopardize the network security, by being able to be removed from service, or failing safe, that does not impact on the continuity of the network. All of these technologies are comparatively low-cost investments, with near complete ability to be redeployed in full for a range of needs or locations across the network.

CurrENT recommends that the use of trial projects, or limited use in first deployments, be avoided in favour of first deployment[s] into full active use in the network. It expects that DSOs who perform the recommended review of the impact of these technologies will reach the same conclusion. This being that the needs and benefits of introducing the technology this way far outweigh the limited risk of stranding of any assets. In addition, that on balance that there is a negative impact on security of supply, comparing to the improvements they provide, to any risk of failure they might introduce.

Every effort has been made to make these recommendations concurrent, however innovation is perpetual, and CurrENT is committed for this paper to be a living paper and will release further updates as required.

CurrENT and its member welcome your feedback. We find have found that a collaboration approach with stakeholders and customers to be the most effective form of developing knowledge, buy in and application of new technologies.

Consequently, if you require further information, wish to pursue further investigation into one or more of the technologies in this paper we commit and would be happy to work with you.

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