COST BENEFIT ANALYSIS (CBA) APPROACH OF NON-CONVENTIONAL STATCOM APPLICATIONS

Mark FRIESE
TNEI – Scotland
mark.friese@tneigroup.com

Stephanie HAY
TNEI – Scotland
stephanie.hay@tneigroup.com

David NEILSON
SPEN - Scotland
David.Neilson@spenergynetworks.co.uk

Albert SANTANDREU
SPEN - Scotland
asantandreu@spenergynetworks.co.uk

Emanuel MUGWANDA
SPEN - Scotland
emanuel.mugwanda@spenergynetworks.co.uk

ABSTRACT

This paper evaluates non-conventional reinforcement options in four areas of the Scottish Power Energy Networks distribution network that are, or are expected to be, experiencing voltage issues. STATCOMs and mechanically switched capacitors have been assessed qualitatively against traditional forms of reinforcement. Cost-benefit analyses have shown that the net present value saving on STATCOM installation can be significant, in comparison to a conventional reinforcement solution, but is highly dependent on the scale, and therefore cost, of the conventional solution.

INTRODUCTION

Static Synchronous Compensators (STATCOM) are a class of flexible alternating current transmission systems (FACTS) that are characterised by their ability to rapidly control the system voltage with the import and export of reactive power. STATCOMs rely on solid state electronic technology and can swiftly regulate the flow of reactive power. This speed of response has meant that STATCOMs are ideally suited to provide voltage control for renewable generation projects to achieve grid compliance, as well as rectifying power quality issues caused by unbalanced loads in industrial plant [1]. Over the past decade, the increasing implementation of STATCOMs to support renewable energy projects has led to improvements in capability and reliability. STATCOMs are now an established technology with a proven track record. It is therefore now possible to consider the use of STATCOMs as an alternative to traditional upgrades in alleviating voltage issues on the distribution network.

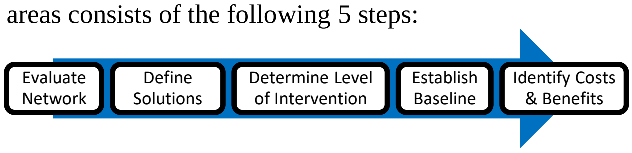
This paper evaluates STATCOM intervention on four areas of the Scottish Power Energy Networks (SPEN) distribution network that are, or are expected to be, experiencing voltage issues. These issues mainly arise due to long circuit lengths, network load changes and continuing connection of distributed generation. A STATCOM sizing study highlighted voltage violations, thermal overloading conditions and the appropriate STATCOM placement and size to alleviate the issues. The studies highlighted that all four network areas would benefit from STATCOM intervention, with units placed at six locations to eliminate all voltage violations.

Costs and benefits of STATCOM interventions have been assessed qualitatively through a series of cost-benefit analyses (CBA), benchmarking the interventions against traditional reinforcements. The Ofgem CBA template, used by DNOs in the UK in their RIIO-ED1 business plan submissions, has been utilised for these analyses. The Net Present Value (NPV) of each intervention has been calculated to determine which are the most cost-effective. CBAs were then carried out for three typical STATCOM interventions representing small, medium and large sizes.

From the results of the CBA presented in this paper, and from the STATCOM sizing studies, it is evident that STATCOMs can be a technically feasible and cost-effective way of providing support and reinforcement to an area of network experiencing voltage issues. The research has also shown that although feasible, the best choice of reinforcement solution is highly site-specific and dependent on scale. The paper explores these dependencies, evaluating their impact on the choice of conventional or non-conventional solutions, with the overall aim of providing guidance for informed and prudent network planning.

APPROACH TO COST-BENEFIT ANALYSIS

The method applied in each of the evaluated network areas consists of the following 5 steps:



Evaluate network for voltage violations

Identify areas of the network that are, or are expected to be, experiencing voltage issues. Perform load flow studies to assess if voltage violations occur for an intact system, in addition to any likely N-1 outage scenarios.

Define alternate solutions

Define non-conventional solutions for network reinforcement based on the specific issue identified. Three non-conventional solutions were identified to mitigate the voltage issues in the network areas evaluated for this paper: STATCOMs; Mechanically Switched Capacitors (MSC) and a Hybrid solution containing both STATCOMs and MSC's.

Determine level of non-conventional intervention

Determine the level of reactive compensation required to remove voltage violations. Repeat this exercise to discover the location with the smallest level of mitigation to maintain system voltage compliance.

Establish a baseline scenario

Establishing the baseline scenario will be highly site-specific and represent the conventional reinforcement solution. Solutions established for this paper included circuit upgrades, new switching stations and new grid supply points.

Identify costs and benefits

Identify the costs and benefits for the baseline scenario in addition to each of the previously defined non-conventional scenarios. A list of financial and technical indicators for the study cases in this paper has been established for comparison.

APPLICATION OF CBA METHODOLOGY

Evaluation of network for voltage violations

Four areas of the SPEN distribution network were analysed in order to determine if any voltage violations or thermal overloading conditions could occur under network normal (N-0) and contingency (N-1) configurations. The chosen contingency configurations represent scenarios that are known to cause voltage issues at the relevant primary substations/busbars. Simulations were carried out using PowerFactory power system analysis software using steady-state models. The results of the constraint analysis studies are summarised in the table below.

Table 0-1: Summary of Constraint Analyses Studies

Network Area	Network Constraint	
	N-0	N-1
1	No Violations	Under Voltages observed
2	Under Voltages observed	Under & Over Voltages observed
3	Under Voltages observed	Under Voltages observed
4	No Violations	Over Voltages observed

Definition of non-conventional solutions

Fluctuating demand profiles; predicted uptake in electric vehicles (EV); the move to electrified heat and the evolution of the power system towards a low carbon future requires the power systems industry to consider novel ways to reinforce the network quickly, efficiently and cost-effectively. This paper proposes that FACTS devices at EHV can be used to address local issues with improvements in voltage control, removal of thermal constraints on the network, cost reductions and enhanced stability.

Static Synchronous Compensator

Since the load often varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage variations, voltage depression, or even voltage collapse. STATCOMs can provide instantaneous and continuously variable reactive power in response to grid voltage fluctuations, enhancing the grid voltage stability [1]. Because of the high-speed operation and dynamic response, it can also be dedicated to active harmonic filtering and voltage flicker mitigation.

Installing a STATCOM at suitable points in the network will increase the grid transfer capability by providing enhanced voltage stability while maintaining a smooth voltage profile under varying network conditions. The STATCOM also provides additional versatility in terms of power quality improvement capabilities. A STATCOM is capable of yielding a high reactive input to the grid more or less unimpeded by possible low grid voltages and weakened network conditions while still providing a high degree of dynamic response. This is useful, for instance, for support of weak grids and to improve the availability of renewable generation under varying network conditions.

Mechanically Switched Capacitor

MSCs are an inexpensive, economical and an easy resolution to voltage problems, which have been a growing concern for networks over the last 10-15 years. However, the issue of fitting an MSC as a shunt reactive power compensation device has two issues. The first pertains to unwanted harmonics due to the capacitor banks, which may result in unwanted resonances [2]. The other concern is the magnitude of transients that occur across the various elements of the MSC at the moment of energisation. The insulation is therefore exposed to transient overvoltage in addition to inrush current which can either completely or partially fail due to thermal as well as electrical stresses.

Hybrid System

An alternative option for provision of additional reactive power compensation would be through a combination of STATCOM with MSC. Under the hybrid compensation option, 50% of the required compensation will be through a STATCOM and balance 50% through MSC. Hybrid compensation will be cost effective as compared to the full STATCOM consideration; however, the MSC related issues as highlighted in the section above would remain a significant drawback for consideration of this option

Determine level of non-conventional intervention

In Table 0-1, worst case thermal overloading and voltage violations were identified and documented for the N-0 and N-1 scenarios analysed. As expected, N-1 scenario studies are the worst case from a low and high voltage perspective, so these were used for the STATCOM sizing studies. The worst-case scenarios were analysed with a STATCOM deployed in the model to identify the required reactive compensation that will mitigate the voltage violation/s. Where multiple voltage violations were observed, single and multi-point implementation solutions were studied.

Table 0-2 summarises the results of the studies, providing the minimum level of reactive compensation required to remove all violations in each network area. The table shows that network area 2 and 3 require a multi-point implementation to remove all violations.

Table 0-2:Summary of Reactive Compensation Studies

Network Area	Statcom Size	Location
1	11.3 Mvar Export	Site 1
2	17.5 Mvar Export	Site 2
	4.78 Mvar Export 2.43 Mvar Import	Site 3
3	10.0 Mvar Export	Site 4
	4.00 Mvar Export	Site 5
4	3.70 Mvar Import	Site 6

Before further research is conducted, three of the six areas identified have been selected as case studies for analyses. The areas were chosen to represent three typical STATCOM interventions: small (Q<5MVar), medium (5<Q<10MVar) and large (Q>10MVar) sizes. The selected areas have been highlighted light blue in Table 0-2.

Establishment of a baseline scenario

The baseline scenario is site specific and represents the conventional reinforcement solution to the network issues identified in the constraint analyses. The subsections below summarise each of the traditional reinforcement solutions for the small, medium and large sites.

Small (Site 5)
The existing network arrangement in this area has primary substations banked onto the same circuits. The traditional reinforcement solution would be to un-bank the primary substations and install new circuits back to the grid supply point (GSP) substation. The existing switchboard at the GSP for this site can no longer be extended. Therefore, a new switchboard would also be required to accommodate the additional circuits.

Medium (Site 4)
A conventional solution to the issues at Site 4 would be to reduce the impedance between load and source. This is achieved by installing a circuit with a larger cross-sectional area. Due to the arrangements at the site, it is also necessary to install a 33-kV switching station to enable the connection of the new circuits.

Large (Site 2)
Evaluation of assets in the Site 2 network area identified existing assets that can be utilised to enable the construction of a high-value traditional reinforcement option that would usually require a more substantial investment. Using the identified assets, SPEN would establish a new GSP close to the locale of the existing primary substations. The new location would allow the transfer of Primary substations with long circuit lengths to the new GSP. The shorter circuit lengths, due to the reconfiguration of the network, reduce the impedance between load and source and hence improve the voltage profile in the network area 2.

Identify costs and benefits

To identify the costs and benefits of non-conventional reinforcement, the previously defined FACT devices are first considered separately. Table 0-3 shows the resulting comparison of the respective non-conventional technologies.

Table 0-3: Comparison of voltage control technologies

Characteristic	MSC	STATCOM
Response to transient events	Permanently on or off	Fast (50 ms)
Continuously variable Q output	No	Yes
Robust response to severe voltage dips	No	Yes
Robust response to moderate voltage dips	No	Yes
Inherent Transient overload rating	No	Yes (3 times for 2 seconds)
Discretely controlled output	No	Yes
Harmonic generation and filtering	No	Yes
Output dependant on bus voltage	Yes	No
Installation and commissioning	Medium	Easy
Losses	Electrical losses	Electronic & electrical
Cost	Low	High
Expected ease of regulatory approval	Easy	Medium

Further to the technical comparison, a detailed cost comparison was conducted. The results highlighted that capital cost and spread of the voltage problem throughout the network are significant factors in the cost of both conventional and non-conventional reinforcement. The results of the cost-benefit analyses are shown in Figure 0-1.

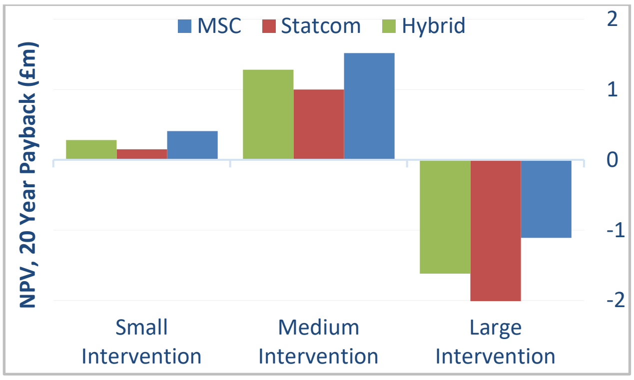


Figure 0-1: NPV savings of avoided conventional reinforcement using FACTs

It is important to notice that the shown cost and benefits topics are entirely focused on the technical and economic aspects of the non-conventional solution. Further indications based on additional processual or organisational changes are not included in this CBA.

DISCUSSION & EVALUATION OF RESULTS

Costs and benefits of successful STATCOM interventions have been assessed qualitatively through a series of cost-benefit analyses, benchmarking the interventions against traditional reinforcements. The Net Present Value of each intervention has been calculated to determine which are cost effective. The three areas evaluated were chosen by SPEN based on the size of intervention, choice of alternatives and business priorities. The recommendation for each site is detailed below.

Small STATCOM Intervention

From the STATCOM sizing study, it was concluded that network area 3 will experience under voltage issues during normal and contingency operating conditions.

The small site selection requires 4MVAr of reactive compensation. The conventional reinforcement solution in network area 3 would be to un-bank existing primaries, then build two additional circuits back to the grid substation. The switchboard at the GSP cannot be extended and would therefore also need to be replaced to accommodate the connection of the additional two circuits. The switchgear at the GSP has a health index of 1, this is, therefore, an unlikely solution and STATCOM intervention is recommended.

In terms of cost, the conventional solution also has a high Capex when compared to non-conventional intervention. The variance in Capex between conventional and non-conventional reinforcement results in an NPV of £0.15m to £0.41m.

In this scenario, the non-conventional solution provides the best value solution to SPEN and its customers. Additionally, when compared to the other smart solutions (MSC and Hybrid), STATCOMs also provide the best technical solution, providing better power quality and greater voltage control. It is therefore recommended that STATCOMs are the intervention solution for Site 5.

Medium STATCOM Intervention

From the STATCOM sizing study, it was concluded that the network area 3 will experience voltage issues during normal and contingency operating conditions, specifically with the 33 kV busbars at Site 4 experiencing voltage violations.

The medium site selection requires 10MVAr of reactive compensation. The conventional reinforcement solution at Site 4 would be to construct a new switching station and upgrade the circuit between Site 4 and network area 3 grid substation. This solution has a high Capex when compared to non-conventional intervention. The variance in Capex between conventional and non-conventional reinforcement results in an NPV of £1.00m to £1.52m.

Results of the CBA show that for medium interventions, MSC's provide the lowest cost solution, but due to the technical drawbacks of MSC's, STATCOMs can provide the best value for money to SPEN and their customers (£1.00m NPV of avoided reinforcement). Additionally, when compared to the other smart solutions (MSC and Hybrid), STATCOMs also provide the best technical solution, providing better power quality and greater voltage control. It is therefore recommended that STATCOMs are the intervention solution at Site 4.

Large STATCOM Intervention

From the STATCOM sizing study, it was concluded that network area 2 would experience voltage violations during normal operating conditions & contingency configurations. Voltage violations are seen at Site 2, 33kV busbars, as well as an additional 33 kV site.

Site 2 within network area 2 requires the most substantial STATCOM intervention at 17.5MVAr. The conventional reinforcement solution would be the construction of a new grid supply point (GSP). Due to the existing assets available in this area, the solution has a low Capex when compared to non-conventional intervention. The variance in Capex between reinforcement types results in an NPV saving of £1.11m to £2.01m using traditional reinforcement.

Results of the CBA show that for large interventions, the conventional solution provides the best return on investment to SPEN and their customers. It is therefore recommended that a new GSP is the intervention solution for network area 2.

CONCLUSIONS

From the results of the CBA presented in this article, and from the STATCOM Sizing Study report, it is evident that STATCOMs can be a technically feasible and cost-effective way of providing support and reinforcement to an area of network experiencing voltage issues.

The net saving on a STATCOM installation, in comparison to a conventional reinforcement solution, is highly dependent on the scale, and therefore cost, of the conventional solution. As seen with Site 2, the cost calculations favoured the installation of a new GSP, which would also offer improved network flexibility in the area. In each of the other cases, the conventional reinforcement required was more extensive, and so the STATCOM was the most cost-effective option. The implementation of a STATCOM solution, therefore, is highly case dependent.

There are many areas in the SPD network that are similar to those studied and could be subject to voltage issues in the future, with increasing penetrations of renewable generation and overall changes in load patterns. There are also large areas of radially configured network in SPM which could experience these same problems. This study has shown that a STATCOM should be considered as a feasible solution to be proposed alongside business as usual options.

It is recommended that the installation of STATCOMs be carried out such that their effectiveness as a solution to voltage problems can be quantified, alongside other potential benefits such as reducing losses in the surrounding areas. Together with lessons learned through the whole process, STATCOMs could eventually become integrated as business as usual solutions both within SPEN and potentially other DNOs.

REFERENCES

[1] J. Diaz De Leon II, B. Lieblick, E. Wilie, "How Facts on the distribution system are being used to improve power quality", *Proceedings CIRED Workshop 2017,* paper 101

[2] R. Bose, K. Samanta, S.Chatterjee, "Transient analysis of mechanically switched capacitors with and without damping network connected to A.C grid", *2nd International Conference on Control, Instrumentation, Energy & Communication (CIEC),* Jan 2016