Schweizerische Eidgenossenschaft
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Federal Department of the Environment, Transport, Energy and Communications DETEC

Deliverable 2 dated 22/04/2021

COSTAM Project

D2 – Report on preliminary analysis (WP2) and test case simulations (WP3) results

Location: Fribourg

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SFOE contract number: SI/502069~01

Résumé

Les STATCOM (static Var compensator) sont des dispositifs bien établis dans les systèmes de transport et distribution suprarégionale, en particulier dans les réseaux ayant de longues lignes de transport ou des réseaux de distribution peu robustes. Les STATCOM sont également un élément prometteur dans les systèmes de distribution locale et régionale, soumis à l'impact croissant des productions décentralisées. Les STATCOM peuvent contrôler la tension en régime permanent, par exemple dans les réseaux MT, et ainsi éviter des variations de tension indésirables en fonction de la charge ou de la situation de production. Les STATCOM devraient aussi contribuer au soutien dynamique de la tension, par exemple lors du rétablissement après un défaut.

Les travaux présentés dans ce rapport se concentrent sur la contribution des STATCOM en régime permanent. Le rôle de l'emplacement, du mode de réglage ainsi que de la puissance assignée des STATCOM sont étudiés à partir du modèle de réseau MT des SIL (Lausanne). Un modèle d'un réseau MT (B) avec des charges et de la production PV a été construit avec les données fournies par SIL et météosuisse. Sur la base des simulations annuelles (avec une résolution de 1h), les effets des différents emplacements et modes de réglage ont été comparés. Les résultats montrent que la puissance des STATCOM requise pour un fonctionnement optimal peut être relativement élevée, jusqu'à 5MVAr. Dans ce cas, il est préférable de placer les STATCOM à proximité de la sous-station de départ HT/MT, ou à des nœuds bien interconnectés. Si la puissance disponible au STATCOM est limitée (en raison de contraintes d'espace ou financières), le meilleur emplacement est un nœud bien interconnecté, au « milieu » d'un feeder MT.

Pour conclure, l'efficacité d'exportation de la puissance réactive depuis le système de distribution vers le système de transport a été analysée, pour deux cas de figures relativement simples. Les résultats démontrent que les interconnexions complexes entre les deux systèmes de distribution et transport de Suisse occidentale limitent le potentiel d'un tel concept, donc le STATCOM devrait être considéré principalement pour ses avantages locaux dans la suite de ce projet, y compris lors des tests prévus dans le laboratoire ReIne.

Summary

STATCOMs (static VAr compensators) are well-established devices in transmission and subtransmission systems, especially in large power systems with long transmission lines or weak subtransmission structures. STATCOMs are also a promising building block of distribution systems subjected to the increasing impact of distributed generators. STATCOMs can control the stady-state voltage, e.g. in MV networks and thus avoid unwanted variations of the voltage depending on the load or generation situation. STATCOMs are also expected to contribute to dynamic voltage support, e.g. for post-fault recovery.

The work presented in this report focuses on the steady-state contribution of STATCOMs. The role of the location, control mode and size of STATCOMs is investigated based on the example of the SIL (Lausanne) MV network. A model of an MV network (B) with loads and PV generation has been built with data provided by SIL and meteosuisse. Based on annual simulations (with 1h time steps), the effect of different locations and control modes of STATCOMs was compared. The results show that the required rating of STATCOMs for optimal operation could be relatively high, i.e. 5 MVAr. In such a case, STATCOMs would best be placed close to the HV/MV primary substation of at well interconnected nodes. If the available STATCOM rating is limited (due to space and financial constraints), the best location is at a well-connected node in the "middle" of an MV feeder.

Finally, the effectiveness of exporting reactive power from the distribution to the transmission system was analysed on two simple examples. The result is that the complex interlinks between the transmission and subtransmission systems of western Switzerland are a limit to the attractiveness of such a scheme, hence the STATCOM should primarily be considered for its local benefits in the further course of this project, including the tests planned in the ReIne laboratory network.

Acronyms

CPP	Common Connection Point (between STATCOM and network)
DMS	Distribution management system
DSO	Distribution System Operator
DG	Distributed generation
GIS	Geographic information system
HV	High Voltage
LV	Low Voltage
MV	Medium Voltage
OPF	Optimal Power Flow
PV	Photovoltaic
RES	Renewable energy sources
SIL	Services Industriels de Lausanne
WP	Work package

Contents

1 Introduction

1.1 COSTAM project introduction

The aim of the COSTAM project is to establish a comparative performance assessment of STATCOM technologies based on Modular multilevel converters architectures. The comparative performance assessment will be focused on the future Swiss energy system scenarios with massive integration of RES at the distribution grid level. Under these scenario, utilities and customers may be confronted with voltage sags, poor power factor and voltage instability. Dynamic reactive power control by STATCOM can solve these issues. A simulation-based part based on study cases proposed by SIL (Lausanne) and an experimental part on the ReIne laboratory (HEIG-VD) are planned. The main outcomes will be the technology assessment and the knowledge of the impact of the increasing number of renewable energies production on the flow of reactive energy.

1.2 WP2 description

In work package 2 the options to place a STATCOM into the SIL MV grid will be analysed: two network areas (MV grids fed by a chosen HV/MV transformer) have been selected, and all the useful information to study and simulate the site/s have been gathered. The network areas envisaged are the MV grids fed by the B and A HV/MV substations. The A site has the advantage of being a substation connected to the EHV network of Swissgrid and also of having a high number of solar generation systems connected to the LV network supplied by this substation while the B site is planned to eventually host a wind farm with a power generation up to 30MW. A set of quantitative performance indices used to assess the benefits of STATCOM for grid operation has been defined.

1.3 WP3 description

In work package 3, network simulations for the network areas selected in WP2 have been performed in order to evaluate the benefits of the STATCOM insertion. A preliminary benefits analysis of different STATCOM locations, sizes and control objectives has also been carried out by comparing these options against each other and to other approaches for (distributed) voltage control. This will contribute to specifying the control and ratings of a STATCOM for different use-cases in MV networks. Similarly, this work will be taken into account in the requirements for the ReIne Laboratory set-up (see WP5). WP3 also includes the development of load/generation scenarios for the present and future situation of the network considered.

1.4 Work plan for WP2 and WP3

A table of the planned tasks can be found in Annex A and Figure 1 shows a Gantt diagram of the related tasks in WP2, 3 and 8 (as far as work related to this deliverable is involved). The main steps in the work plan were as follows:

- Selection of realistic network areas and use-cases for the STATCOM.
- Creation of network models based on available network data, historic weather data, estimates of future PV generation installation and representative load profiles.
- Generation of several variants (size, location, type of control) for networks with and without STATCOMs.
- Comparison of variants, analysis and recommendations for the next project stages.

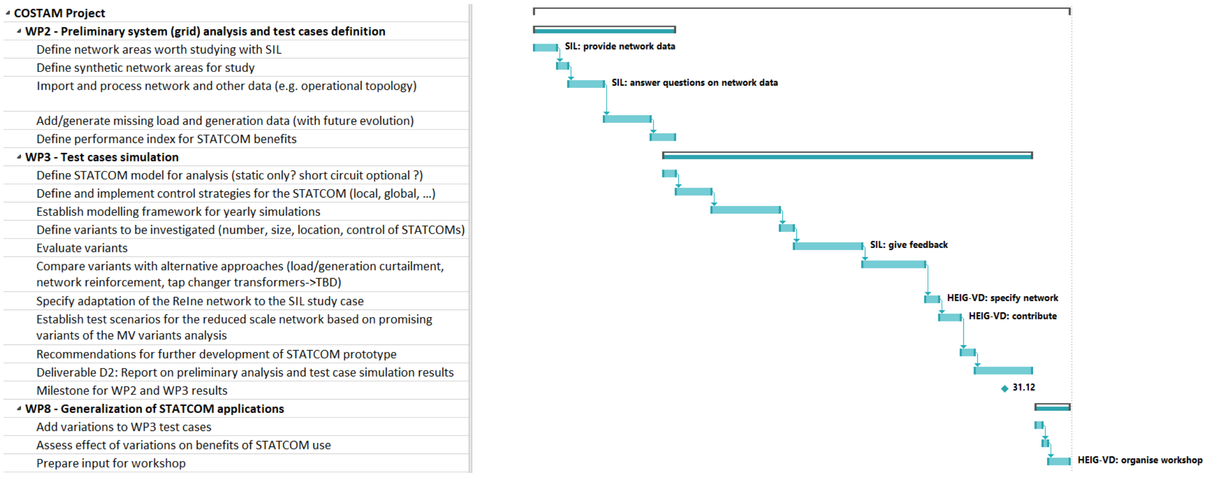

Figure 1: GANTT diagram for WP2/3 (and 8)

1.5 Deliverable's scope

This deliverable covers all aspects related to the network models, load/generation scenarios and STATCOM use-cases. The data and methods used to create network models of portions of the SIL HV/MV grids are presented, as well as the adjustments and assumptions made where no adequate data was available. Load profiles at MV/LV substation level is not measured directly, hence the allocation method of measurements performed at HV level is presented. Generation profiles are based on past irradiance data and assumptions regarding the development of solar generation in SIL's network. Finally, the set-up of several STATCOM use-cases and the comparison of different options is discussed. The aim is to identify favourable locations, sizes and control objectives in MV networks with increased penetration of renewable energy. The SIL use-cases are the basis for this discussion.

2 WP2 - Preliminary system (grid) analysis and test case definition

2.1 State of the art and literature review

2.1.1 STATCOM control in distribution networks

At the beginning of WP3, the literature has been briefly reviewed with respect to the control and placement of STATCOM, specifically in distribution systems. A large share of the literature is directly related to the local control principle of the STATCOM itself. Converter control schemes are e.g. discussed in [1], [2] and [3]. The relevance of these sources to the studies presented in this deliverable is low, since the work performed in WP2 and WP3 is mostly based on (static) load flows. This topic is dealt with in WP1. Nevertheless, the lessons learnt and general remarks on modelling have been considered where appropriate.

Optimal placement of STATCOM:

A second topic of interest is the placement STATCOMs. Several criteria for placing STATCOMs are discussed in the literature, e.g.:

- Placement based on a "Power Loss Index", aimed at reducing line losses and improving the voltage profile [4], [5]. This approach appears to be the most relevant in the context of adding DG to a medium voltage network, since the DG units precisely deteriorate the voltage profile. Line losses within the considered MV network might be of lower importance than those in the HV/MV transformer and in the upstream network.
- Placement based on a "Reactive Power Stability Index", aimed at increasing voltage stability margins [6] or "Voltage stability index" also with the objective to improve voltage profile [7], [8], [5]. Voltage stability (long-term) is unlikely to become the most frequent issue in distribution systems with increasing shares of distributed generation. Therefore, such criteria are less relevant to the scope of the COSTAM project.

For these reasons, a placement based on voltage profile improvement and losses (also in transformers) has been chosen for the studies performed in WP2 and WP3.

2.1.2 Performance improvement quantification

Beyond the benefits and performance improvements related to the STATCOM itself, the system-oriented contribution of a STATCOM is also of high interest, although less frequently discussed in the literature. In [9] e.g., the contribution of a STATCOM to system stability in the case of rapidly fluctuating RES infeed. Similarly, [10] discusses the reduction of fast voltage fluctuations (within a half-cycle of the system voltage) by use of STATCOMs. [11] introduces the use of STATCOMs in relation to power systems oscillations: adequate control of the STATCOM increases damping and can support voltage during post-fault recovery.

For an initial decision regarding the placement of a STATCOM system in a distribution system, considering the static behaviour of the system is however necessary as well. In a different context, the authors of this report have assessed the effectiveness of a soft-open point for mitigating the adverse consequences of integrating renewable energy generators into the LV network. A ranking system based on voltage, line loading, transformer loading and network losses was established [12]. This system will be used in the COSTAM project, with adjustments based on the literature review.

2.2 Definition of network areas to study

As the city-owned multi-utility, SIL among others operates the electricity distribution system in the city of Lausanne. This includes high voltage networks at 50 and 125 kV, which are essentially cable networks within the boundaries of the city. MV networks are operated at 6 and 11 kV, whereas overhead lines are in use essentially at the northern end of the city. Figure 2 shows a non-geographical representation the MV network of SIL (in different colours) with a partial representation of the interlinking HV cables (in black). The colours indicate the HV/MV transformer feeding each secondary substation. The secondary substations are represented by circles and contain at least one MV/LV transformer. Figure 2 is a representation of the substations and the direct links among these, hence some objects are omitted in the representation, but indeed used in the simulations performed in WP3.

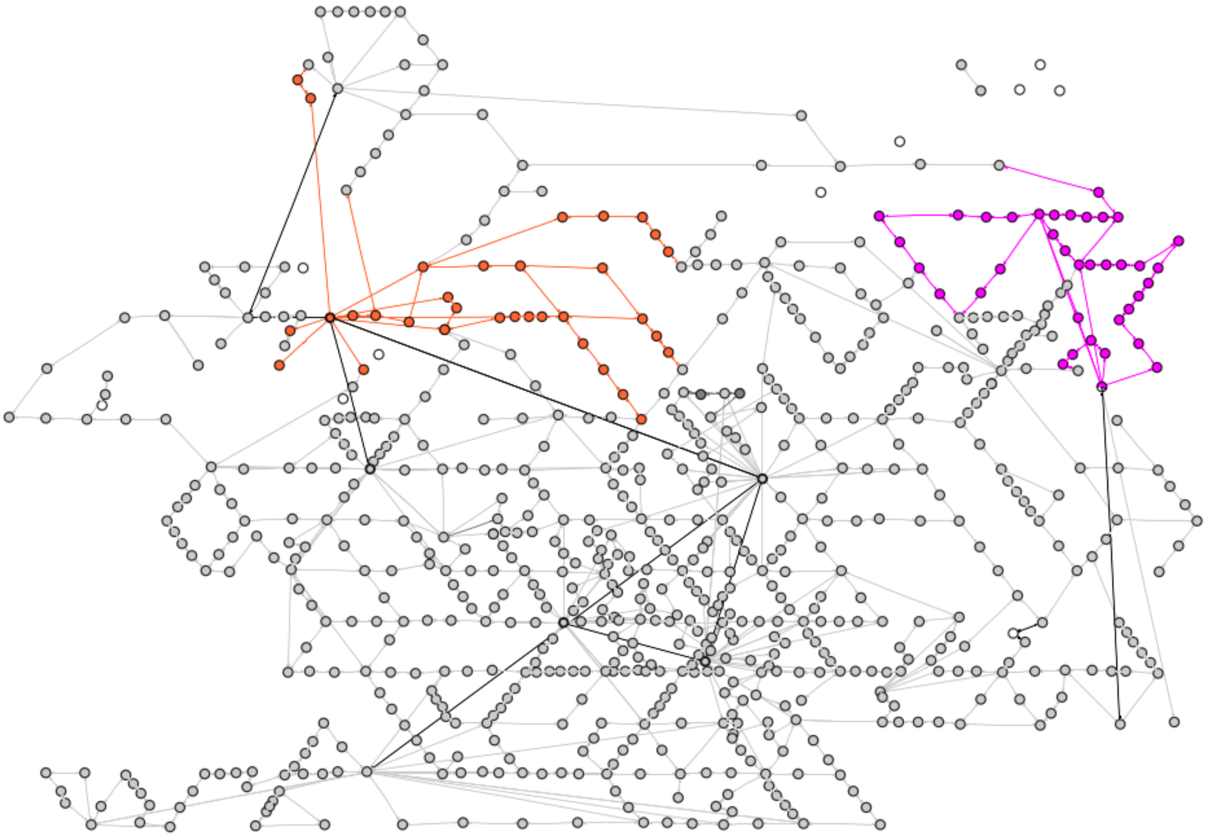

Figure 2: SIL MV network (with selected HV links in black), topological coloring (purple: B; orange: A).

A qualitative review of the challenges related to hosting additional renewable energy in SIL's network, revealed two situations of particular interest:

- MV networks with high amounts of DG planned for installation and relatively long connections to EHV/HV substations. In such cases, maintaining voltages within operational limits and reducing reactive power flows will be more challenging in the future. The MV network area fed by the B substation has been selected as representative illustration of this situation.
- As a secondary interest, the export of reactive power to the transmission network from MV grids close to EHV/HV substations might be of interest for SIL. The MV network area fed by the A substation has been selected as a secondary and more generic study case.

Figure 3 shows the MV network of B. The network is fed by a 50/11.5 kV transformer. Several normally open sectioning points ensure a radial operational topology. The sectioning points are either located at the boundary to neighbouring HV/MV substations or within loops of the B MV network. The second network area, A, is shown in Figure 4. The structure of the MV network is similar to B, but the 10 kV system is fed directly via a 125/10 kV transformer and a 220/125 kV transformer located within the same substation. Hence the distance to the transmission network interconnection point is extremely short.

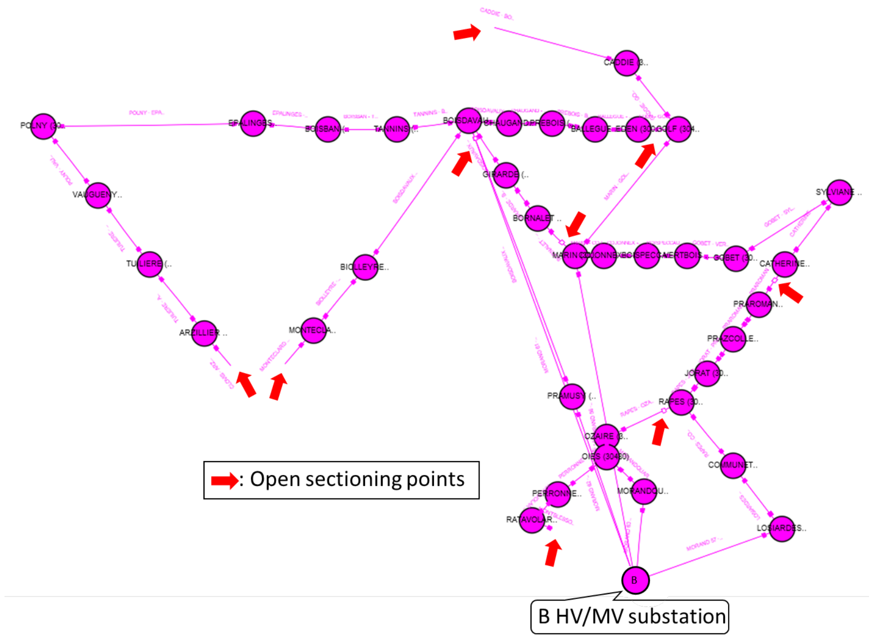

Figure 3: B MV network with normally open sectionning points.

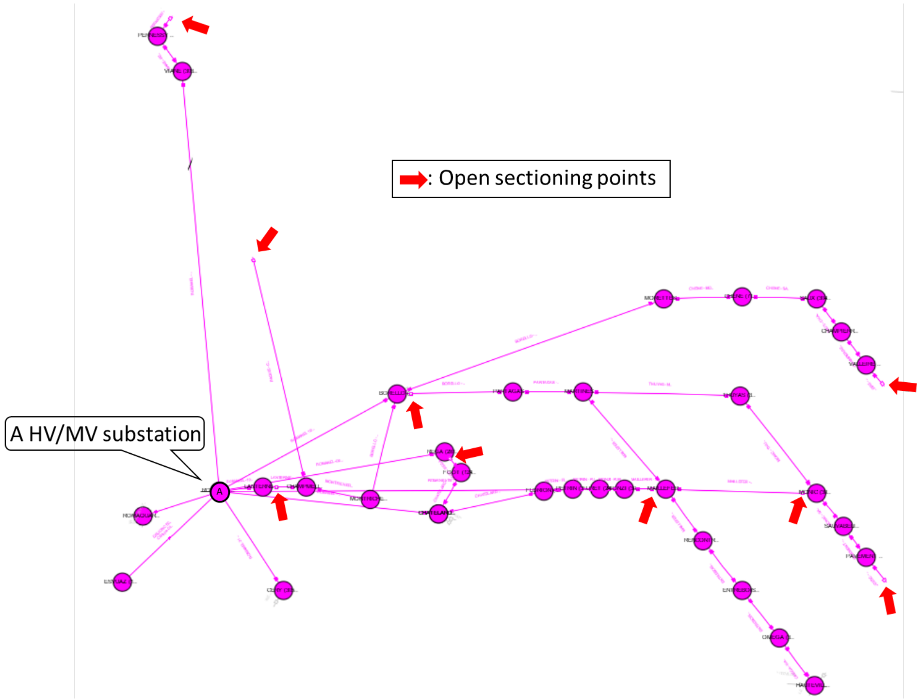

Figure 4: A MV network.

2.3 Preliminary tests on a synthetic network

In addition to the network areas selected within SIL's network, a reduced-scale and simplified synthetic MV system was also used for initial investigations. The main goal of the synthetic network was to validate the operation of the control algorithm, as well as the calculation of the indices. Figure 5 shows the topology of this test system. The test system was used in order to perform the following tests:

- Validate the scripts used to control the STATCOM
- Validate the correct operation of the STATCOM model (based on the built-in model in PowerFactory)
- Validate the method and script used for the computation of the performance indices (described in section 2.6).

Figure 6 shows an example illustrating the use of the scripts and the synthetic model: a STATCOM with a rating exceeding the maximum needed reactive power (in this sense "unlimited") was placed at four locations within the network in four different simulation runs (snapshots). The control method of the STATCOM for this simulation was to control the voltage at the STATCOM connection point to 1 p.u. A score comparing the STATCOM's effect on voltage variations, line loading, HV/MV transformer loading and network losses is assigned to each location and compared. The scores shown in Figure 6 are based on the performance index described in section 2.6 and Appendix 7.4 of this report. In essence, a low index means that the margins (for voltage variation and component loading) is higher, and thus is a more desirable situation. In this initial test, the situation is first assessed without a STATCOM and then a STATCOM is alternatively connected at node A, B, C or D according to Figure 5. In this particular case, the best location is A (lowest score), whereas locations B and C would also bring benefits compared to the situation without a STATCOM. Placing the STATCOM at location D would however not improve (and even decrease) the network's performance in terms of the criteria chosen in this study. For this particular case, the results confirm that controlling the voltage at the end of an MV feeder with a STATCOM is unlikely to be attractive. The main objective of this initial test was to set up the tooling and performance evaluation. Performing these preliminary tests permitted the scripts to be applied to the larger network without any major problems. Furthermore, the example discussed here is based on a single snapshot whereas the work performed on the SIL network is done on annual load / generation profiles with 60 minutes time intervals.

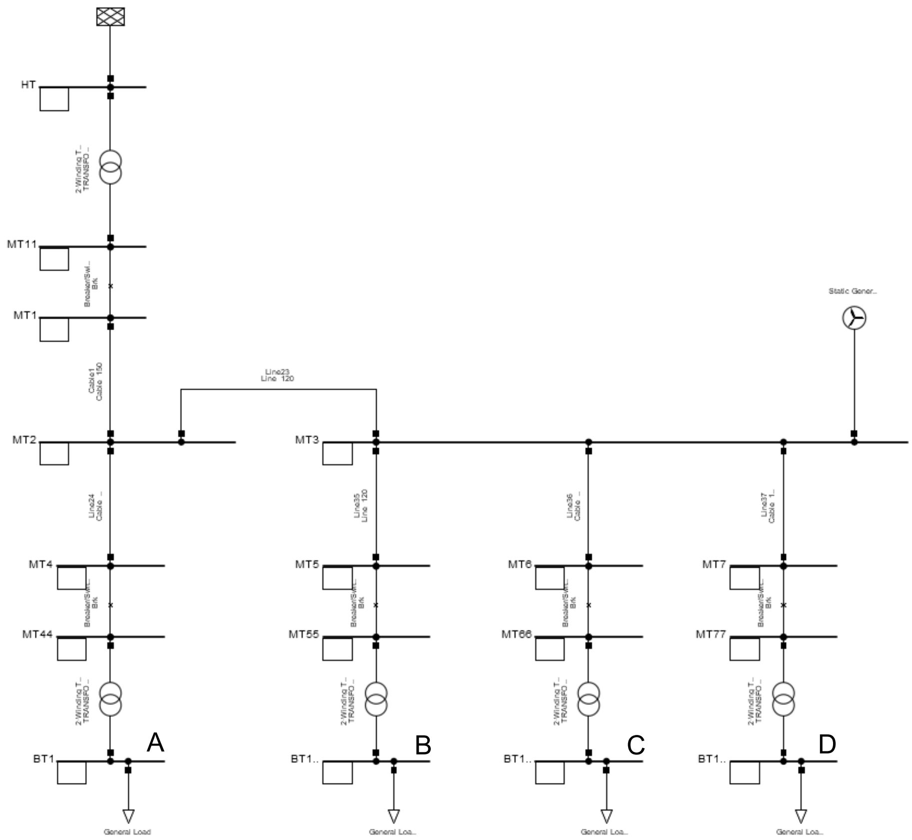

Figure 5: Synthetic network

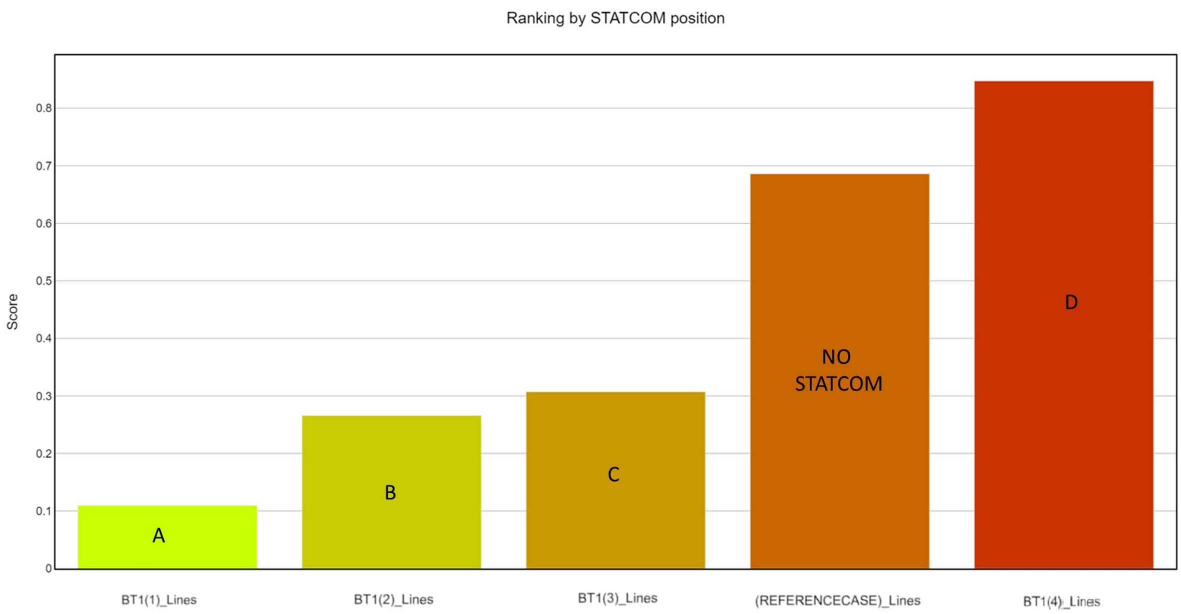

Figure 6: Synthetic network ranking example. The lowest score is the most desirable one.

2.4 Network data import and model creation

The tasks planned in this work package require performing network simulations, calculating setpoints for the STATCOM and running the STATCOM in controlled mode simultaneously. Therefore, it was necessary to establish a model in a comprehensive network simulation package (in this case, PowerFactory). The basis for the creation of network models, load data and generation data were the following:

- The network topology was extracted from the Lynx DMS of SIL. This included the topology of lines/cables, nodes, switchgear and transformers in EHV, HV, MV and LV grids in Lausanne. Information regarding boundaries to other systems is included. Some adjustments were made based on plausibility checks in order to obtain a valid topology.
- The characteristics of network elements (such as impedances, etc.) have been selected mostly based on typical component data and where possible, based on available information from the DMS.
- Controller information and the characteristics of tap-changers for those transformers with OLTC was used as available in the information extracted from the DMS and guessed based on a discussion with SIL for all other transformers.
- Consumption data is based on current measurements in the bays of HV/MV substations. These measurements are available with an hourly interval for one year. The allocation to secondary substations was done using the estimated annual energy for each MV/LV transformer, recovered from aggregated billing data.
- Generation data is based on historic solar irradiance data from meteosuisse and the nominal power of PV systems extracted from the DMS. A future scenario with additional PV systems is also considered.

In practice, a number of additional details and effects had to be accounted for and resolved in order to obtain a consistent behaviour of the network model. Figure 2 discussed before was created using the data described above. The consumption and generation data permit to perform annual load flow simulations with hourly intervals. The annual data used corresponds to the year 2019.

As an illustration, Figure 7 shows the load profile for the HV/MV transformer in B, based on current measurements and assuming nominal voltage. This was used in combination with the annual energy consumption of each MV/LV substation as well as the nominal powers of the transformers. Figure 8 shows the result of the load allocation process for a time period of roughly one months. The curve represents the total load without generation which is modelled directly on the LV side of the distribution transformer. Figure 9 shows the annual solar irradiance profile which has been obtained from a measurement station close to Lausanne. This data is used to create the generation profile of each secondary substation. The total PV generation in each LV grid is aggregated into a single generation unit connected to the LV side of the distribution transformer. PV generators directly connected to the MV grid are modelled individually.

The data discussed in this section permits to determine the loading of each component in the network, the voltage profile at each bus and the network losses (in the considered MV network) for a yearly simulation period. These are the values used in order to determine the scores of each variant of STATCOM insertion into the network.

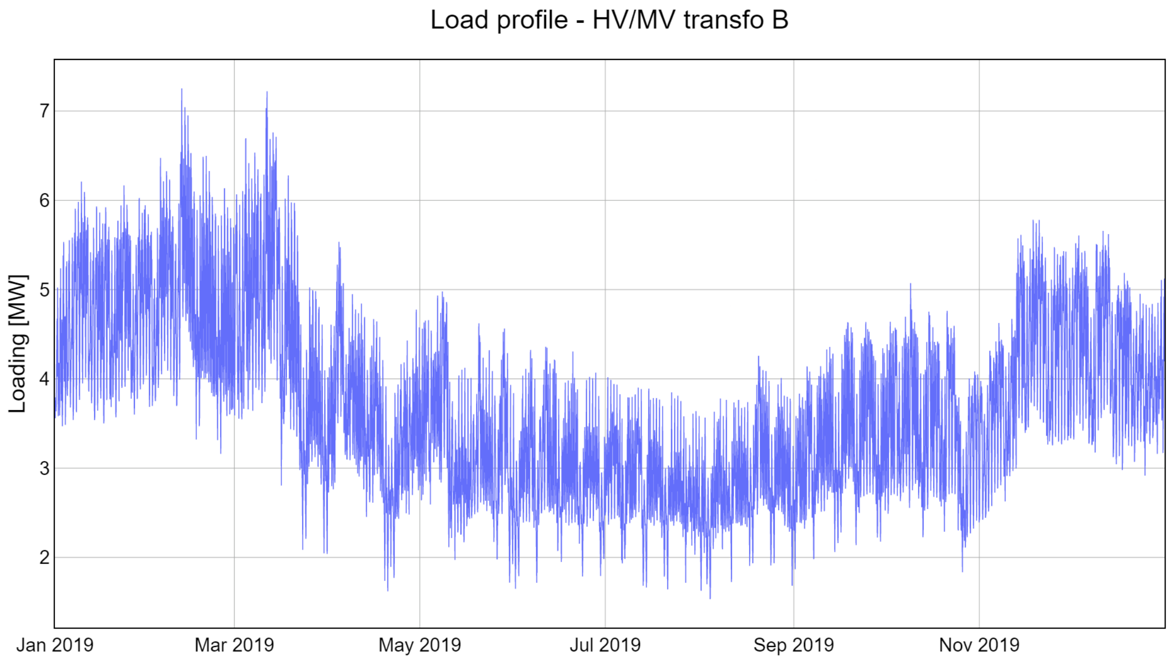

Figure 7: Annual load profile of HV/MV transformer B – measurement

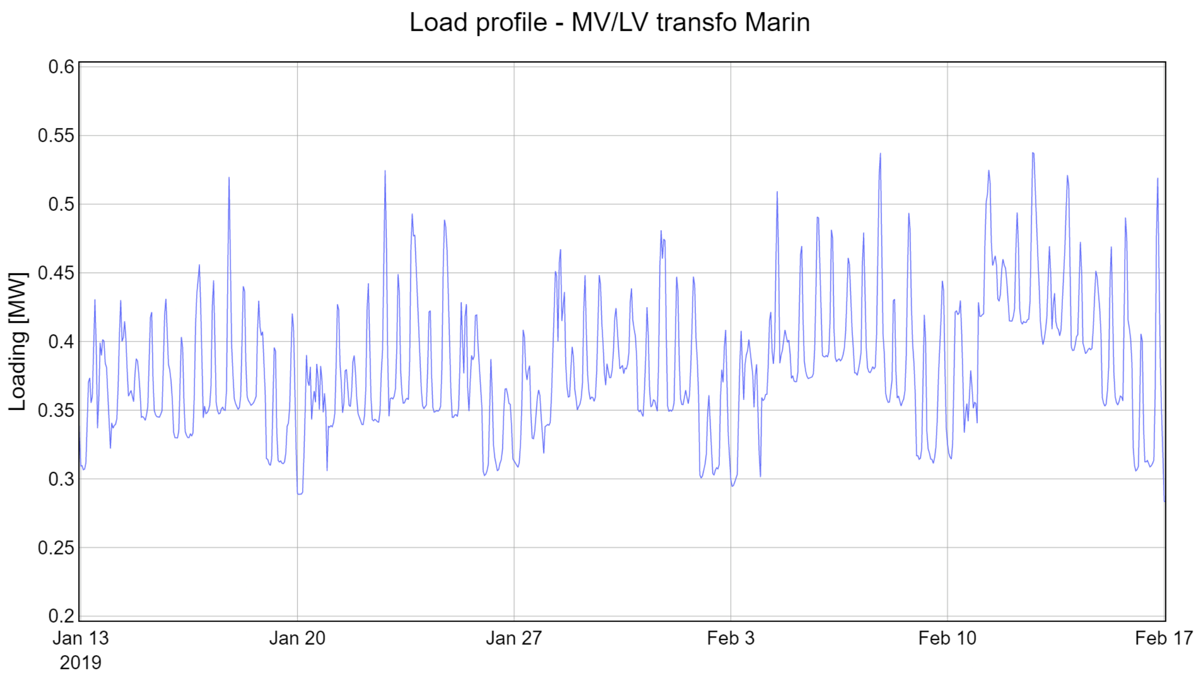

Figure 8: Close-up of the load profile of Marin's 0.63MVA transformer - allocated

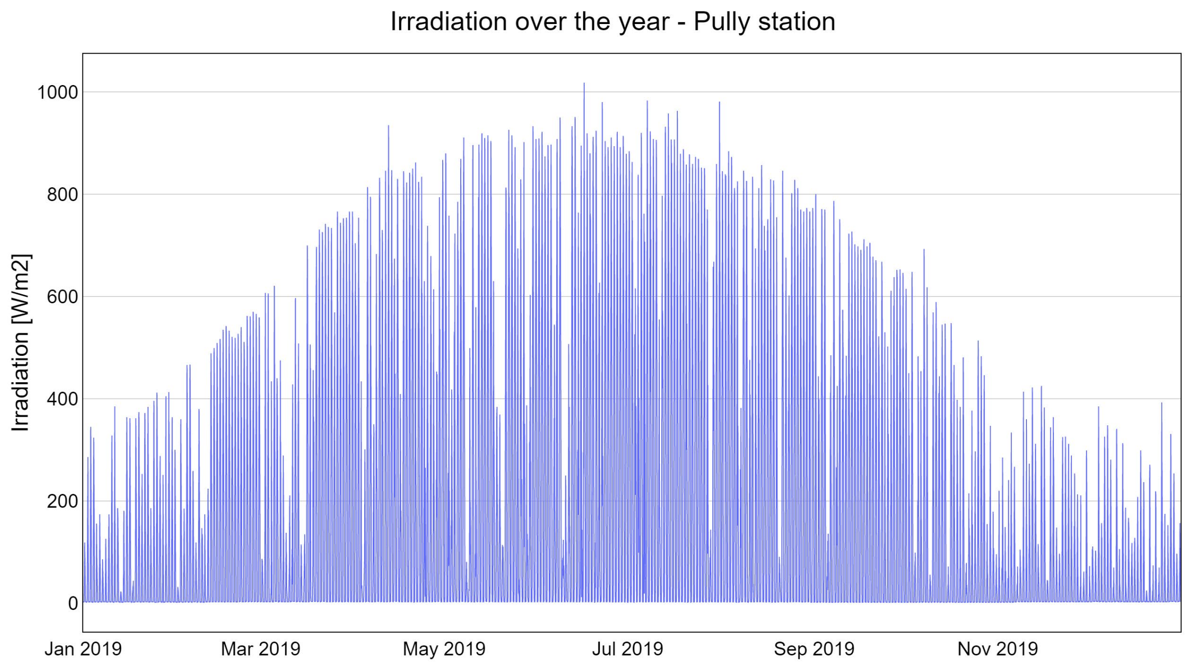

Figure 9: Solar irradiance profile over the year used to simulate PV production – nearest measurement station.

2.5 Future generation scenarios

Figure 10 shows the evolution of the total installed PV power in Switzerland. An extrapolation of this data until 2050 is also included using two sets of data: firstly the blue curve is based on an extrapolation of the installed PV capacity based on SFoE statistics, secondly the green curve is based on the 2050+ energy perspectives [13]. After discussion with SIL, it appears that it is unlikely that the installed PV in the city of Lausanne will be proportional to the national target, since obviously space availability is constrained. Therefore the installed PV scenario represented by the blue curve will be used. Appendix 7.3.13 contains an example for a simulation using the Energy 2050+ perspectives. The ranking does not change fundamentally, but it is obvious that for such high changes in the installed power, the STATCOM cannot solve all capacity issues. Therefore, its addition does not provide an advantage compared to the situation without STATCOM. For the needs of this project, the assumption is made that PV installations within the B MV network as a whole will follow the same trend as Switzerland as a whole. As an initial verification, the installed power for 2019 (which is meanwhile known) has been compared to the extrapolation result in Table 1. Projections shown in Figure 10 are based on data from [14] and [15].

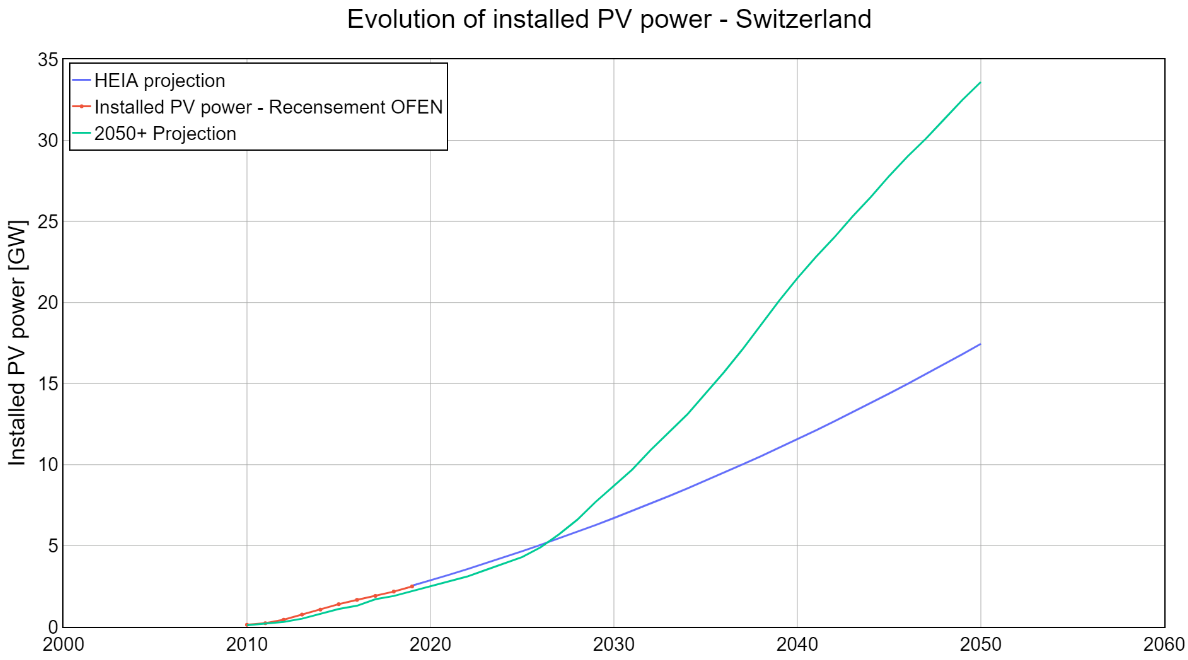

Figure 10: Evolution of installed PV power - Future projection

Installed power [MW]	2498
Extrapolated power [MW]	2536

Table 1: Comparison between current and projected power - year 2019

In order to compute the increment for each MV/LV substation, a ratio between the current installed PV power in B (1.55MW, in 2019) and the rating power of each station transformer is made. Table 2 shows the projection of PV power for a given MV/LV substation (the complete table showing all the projection made for each substation can be found at Appendix 7.2). As shown in Table 2, if the substation already has PV installed, for the first projection (year 2030) the current installed value is kept. Next projections (2040 and 2050) will then increase the power even more. This choice has been made in order to maximise the unexploited PV potential.

Substation name	Substation transformer [MVA]	Installed DG [kW]	IPE 2030 [kW]	IPE 2040 [kW]	IPE 2050 [kW]
MARIN (30419)	0.63	34.00	34.00	117.83	220.02

Table 2: Example of PV evolution for Marin's substation

2.6 Definition of performance indexes for STATCOM evaluation

The comparison of different STATCOM locations, control schemes and sizes requires a (relative) quantification of the STATCOM's effect on the considered network. Several effects need to be considered: component loading, voltage variations and network losses. An index, adapted from the development of a soft-open point demonstrator, will be used in this study. The details of the index calculation are presented in Appendix 7.4. The index is a combined score of several criteria:

- The voltage index takes into account the maximum deviation of the voltage magnitude for each bus connected to a load among all scenarios.
- The current index introduces a penalty for lines that are loaded more than 50%.
- The transformer loading index indicates the peak load of the HV/MV transformer.
- The network losses index takes the mean value of total losses among all scenarios into account.

These indices are combined into a score, where lower scores are more desirable. Hence, e.g. the location with the lowest score would be the most interesting one with respect the criteria explained above. These scores will be used to rank the investigated variants in the analysis part of this report.

3 WP3 - Test cases for benefits of STATCOMs in the distribution network

3.1 STATCOM model for network simulations

The STATCOM model used for network simulation is a template integrated into PowerFactory, depicted in Figure 11. It is a complete model with the ability to perform static as well as short-circuit analyses. For the simulations used in this project, the possibility to independently control the reactive power was used: the control modes discussed in section 3.2 were implemented in Python scripts and/or external controllers depending on the criterion used.

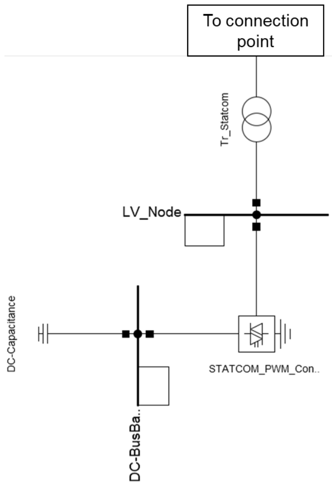

Figure 11: STATCOM model

3.2 Definition and implementation of control strategies

The effect of the STATCOM on the network performance indicators will largely depend on the specific control to be applied. For the purpose of comparing the variants, the following control strategies have been added to the models:

1. Control the busbar at which the STATCOM is installed to 1 p.u.: in the specific case of the SIL network, the 50/11.5 kV transformers are not continuously regulated using on-load tap changers. Instead, the 50 kV voltage is controlled. The result is that the 11.5 kV network voltage will vary slightly more in this case. This will be exacerbated in case of an increase in installed PV. In general, this kind of control would rather help to reduce the number of control actions on on-load tap changers (which is a real concern due to maintenance involved with these systems) and to reduce the amount of reactive power exchanged with the higher network levels.
2. Control the MV busbar with the highest voltage deviation with respect to B to the same level as the B MV busbar: with this control objective, the variation of voltages during the day due to load and generation will decrease as the voltage difference between the extreme values in the MV network will be reduced by the STATCOM.
3. Control the reactive power exchange with the HV network to zero: this will reduce the adverse influence of the loaded MV cable network on the HV network.
4. PowerFactory OPF with the objective to minimise the MV network losses: this control mode is a comparison basis with the other defined modes. Since the OPF requires the values of all state variables in the network, this solution can hardly be implemented in practice since only few measurements will be available to the STATCOM control system. The comparison will however be a good indication of the performance of the above simplified control modes.

Each of these control modes will be assessed either with a STATCOM large enough to inject any required reactive power and also with a STATCOM that will limit its output at a reasonable rating.

3.3 Optimal STATCOM placement

To begin with, all simulations were performed with a resolution of 1 value per day: this was done in order to reduce the simulation time while testing several hypotheses and validating the models. In the main evaluation step, this resolution was brought to 1 value per hour, with the simulation time increasing to up to 16h (for each type of control according to section 3.2). Two assumptions have been made regarding the size of the STATCOM: initially, no restriction was made to the STATCOM's size, which allows to determine the size of the STATCOM ideally needed at a given location for a selected control mode. In a second step, a set of realistic ratings (in MVA) was defined and used in each scenario, i.e. if a power exceeding the STATCOM's rating was required by the control scheme, the output of the STATCOM was limited to its rating. In summary, the following simulation series were carried out:

1. Quasi-dynamic simulation (QDS) over one year, 1d data resample, unlimited STATCOM power, all substations tested as candidates for locating the STATCOM
2. QDS over one year, 1h data resolution, unlimited STATCOM power, all substations
3. QDS over one year, 1h data resolution, limited STATCOM power, all substations. Two ratings have been considered: 1 MVAr and 3 MVAr (i.e. rating exceeding the maximum MVAr demand).

Table 3 shows the results of the annual simulations with unlimited STATCOM power. For each of the four control modes introduced in section 3.2, the achieved performance index and the maximum required reactive power from the STATCOM are given. A so-called "final index" is obtained by multiplying the two values: a lower score indicates better network performance and a lower STATCOM rating implies a lower technical and financial effort to achieve this performance improvement. A low final score thus indicates a combination of low effort and high impact. For example, the first three columns of Table 3 contain the scores for simulations where the STATCOM is used to control its connection point voltage to 1 p.u. If placed at the Xavier or Morandquar stations, the STATCOM leads to the best improvement of the network performance. The STATCOMs required in order to reach this effect are almost the same size. As another example, placing the STATCOM at Tannins will improve the network more than at Oies, which is remarkable since the rating of the STATCOM for the better solution is even smaller. In order to achieve more robustness in the placement recommendation for the STATCOM, the same procedure is repeated for the three other control modes and an overall score is used in order to determine which location of the STATCOM will lead to favourable results for several choices of the control scheme. The overall score is the sum of the partial scores for each control scheme. This overall score has been used for sorting the lines of Table 3. The best location is thus Xavier.

	Local busbar @ 1pu			**Busbar with max deviation as B**			**Q flow @ B fixed at 0VAr**			**OPF: minimisation of losses in B**			
Substation name	**In-dex**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
(A) XAVIER	0.137	5.50	0.753	0.198	6.87	1.36	0.167	2.63	0.546	0.114	4.96	0.564	3.12
(B) MORANDQUAR	0.144	5.46	0.786	0.209	6.82	1.42	0.169	2.63	0.551	0.120	4.93	0.591	3.25
(C) PRAMUSY	0.201	5.12	1.03	0.262	6.39	1.67	0.185	2.64	0.602	0.169	4.62	0.781	3.97
(D) BOISDAVAUX	0.210	5.65	1.19	0.242	6.74	1.63	0.0915	2.63	0.298	0.206	5.30	1.09	4.15
(E) TANNINS	0.239	5.36	1.28	0.253	6.22	1.57	0.0785	2.64	0.255	0.240	5.05	1.21	4.22
(F) OIES	0.224	5.00	1.12	0.280	6.22	1.74	0.192	2.63	0.624	0.189	4.52	0.854	4.27
(G) MARIN	0.245	5.12	1.25	0.315	6.23	1.96	0.191	2.64	0.622	0.202	4.69	0.946	4.67
(H) OZAIRE	0.291	4.55	1.32	0.346	5.59	1.93	0.218	2.64	0.709	0.245	4.11	1.01	4.84
(I) PERRONNE	0.309	4.41	1.36	0.363	5.41	1.96	0.227	2.64	0.738	0.263	3.99	1.05	4.97
(J) GOLF	0.297	4.83	1.43	0.361	5.85	2.12	0.206	2.64	0.670	0.254	4.45	1.13	5.22
REFERENCE CASE		**0.506**			**0.504**			**0.513**			**0.507**		

Table 3: Performance index and required STATCOM rating for different control modes and locations. The locations shown are the 10 locations with the best (i.e. lowest) score.

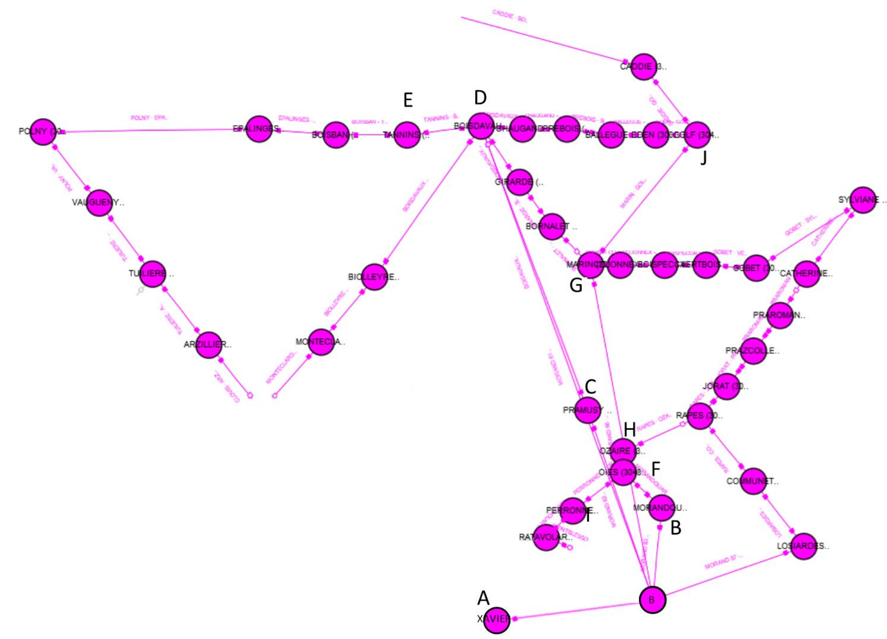

Figure 12: Overall best locations. Line lengths: (E-D)=1.9km / (F-I)=1.1km / (F-H)=0.5km / (F-B)=0.7km / (G-J)=0.6km / (D-C)=1.8km.

Figure 12 shows the 10 best locations for the STATCOM according to Table 3. It appears that the locations where the STATCOM is most useful are grouped in three clusters. Within these clusters, the line lengths are relatively short. The clusters correspond to nodes with several connections, i.e. well-interconnected nodes. Any control of the voltage at such nodes would extend its positive effect on more nodes and more importantly, the reactive power injected by the STATCOM within these clusters does not need to be transmitted far in order to reach a suitable number of consumers and/or producers. The required STATCOM size appears to be a combination of the distance to the B primary substation and the degree of meshing of the node chosen for the STATCOM connection.

The optimal STATCOM placement shown in Figure 12 requires a STATCOM with a rating determined by the location and the control scheme. The ranking assumes that the reactive power needed to fulfil the control condition can be injected without any limitation. The limitation of a STATCOM's rating to a value smaller than the required maximum apparent power resulting from an ideal setting is a realistic use-case: it is unlikely that a STATCOM will be chosen with a rating corresponding to a maximum output used only a few hours per year. The placement and control mode comparison was therefore also carried out for STATCOMs with reduced ratings. Table 4 and Figure 13 show the results for a rating of 1 MVAr. The limited rating influences the trade-off between the positive influence of the voltage support and the negative influence of the increased line loading. The best locations for this size of STATCOM are shown in Figure 13. It appears the best suited locations are situated relatively close to Boisdavaux. With a limited rating, locations with a higher level of interconnection remain attractive, but locations closer to the HV/MV transformer loose in attractiveness. Hence it can be qualitatively that the best suited locations are slightly more distant to the HV/MV substation, as can be seen from Figure 13. The results for limited STATCOM ratings can be better for control modes other than OPF, which is due to the formulation of the problem, i.e. minimisation of losses. It is worth mentioning that the area around Boisdavaux consists of relatively short cable and line sections, hence the concentration of several of the best locations around this particular substation. Appendix 7.3 contains the detailed results and information for each of the simulations used in this section. The difference between the individual control strategies also tends to vanish, since the STATCOM with a reduced size is more likely to be at its maximum output regardless of the actually chosen control strategy.

	Local busbar @ 1pu			Busbar with max deviation as B			Q flow @ B fixed at 0VAr			OPF: minimisation of losses in B			
Substation name	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
(A) VAUGUENY	0.0761	1.00	0.0762	0.0528	1.00	0.0529	0.0546	1.00	0.0546	0.327	1.00	0.327	0.511
(B) POLNY	0.0829	1.00	0.0830	0.0589	1.00	0.0589	0.0600	1.00	0.0601	0.324	1.00	0.324	0.526
(C) ARZILLIER	0.0695	1.00	0.0696	0.0454	1.00	0.0454	0.0477	1.00	0.0477	0.366	1.00	0.366	0.529
(D) TUILIERE	0.0713	1.00	0.0714	0.0480	1.00	0.0481	0.0500	1.00	0.0500	0.361	1.00	0.362	0.531
(E) EPALINGES	0.0994	1.00	0.0994	0.0718	1.00	0.0719	0.0724	1.00	0.0725	0.316	1.00	0.316	0.560
(F) BOISBAN	0.122	1.00	0.122	0.0911	1.00	0.0912	0.0852	1.00	0.0853	0.302	1.00	0.302	0.601
(G) TANNINS	0.158	1.00	0.159	0.124	1.00	0.124	0.0966	1.00	0.0967	0.290	1.00	0.290	0.669
(H) BOISDAVAUX	0.216	1.00	0.216	0.168	1.00	0.169	0.144	1.00	0.144	0.185	1.00	0.185	0.714
(I) CHAUGAN	0.220	1.00	0.220	0.180	1.00	0.180	0.156	1.00	0.156	0.242	1.00	0.242	0.798
(J) BIOLLEYRE	0.222	1.00	0.223	0.180	1.00	0.180	0.155	1.00	0.155	0.271	1.00	0.271	0.829
REFERENCE CASE		**0.725**			**0.749**			**0.691**			**0.504**		

Table 4: Performance index and required STATCOM rating for different control modes and locations. The STATCOM power was limited as indicated.

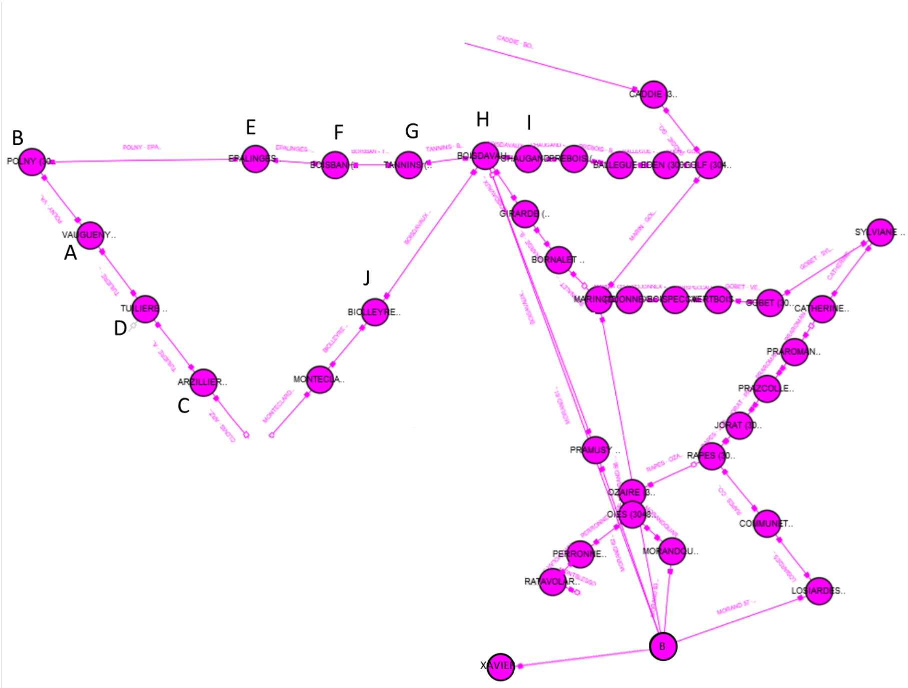

Figure 13: Overall best locations for a limited power of 1MVA.

A third realistic rating of 3 MVAr for the STATCOM has been selected as in intermediate case between the two previously discussed ones. Figure 14 and Table 5 show the simulation results for the placement of the 3 MVAr STATCOM. These results show a continuity in the distribution of the best-suited locations: the locations at meshed nodes remain attractive, and in addition, the locations closer to the HV/MV substation gain in attractiveness compared to the smallest STATCOM rating of 1 MVAr.

	Local busbar @ 1pu			Busbar with max deviation as B			Q flow @ B fixed at 0VAr			OPF: minimisation of losses in B			
Substation name	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
(A) BOISDAVAUX	0.233	3.00	0.698	0.107	3.00	0.322	0.109	2.62	0.285	0.185	3.00	0.556	1.86
(B) TANNINS	0.239	3.00	0.716	0.151	3.00	0.453	0.081	2.62	0.213	0.290	3.00	0.870	2.25
(C) MORANDQUAR	0.275	3.00	0.826	0.206	2.78	0.573	0.215	2.62	0.564	0.119	3.00	0.357	2.32
(D) BIOLLEYRE	0.276	3.00	0.827	0.163	3.00	0.488	0.134	2.62	0.351	0.271	3.00	0.814	2.48
(E) XAVIER	0.271	3.00	0.814	0.203	2.80	0.567	0.214	2.62	0.560	0.113	3.00	0.339	2.28
(F) CHAUGAND	0.289	3.00	0.866	0.180	3.00	0.542	0.145	2.62	0.380	0.242	3.00	0.726	2.51
(G) BOISBAN	0.264	3.00	0.791	0.194	3.00	0.582	0.094	2.62	0.247	0.302	3.00	0.907	2.53
(H) EPALINGES	0.269	3.00	0.806	0.220	3.00	0.659	0.089	2.62	0.234	0.316	3.00	0.947	2.65
(I) PRAMUSY	0.308	3.00	0.923	0.240	2.62	0.628	0.230	2.63	0.605	0.168	3.00	0.504	2.66
(J) POLNY	0.272	3.00	0.816	0.244	3.00	0.733	0.082	2.63	0.215	0.324	3.00	0.971	2.74
REFERENCE CASE	**0.506**			**0.515**			**0.528**			**0.504**			

Table 5: Performance index and required STATCOM rating for different control modes and locations. The STATCOM power was limited as indicated.

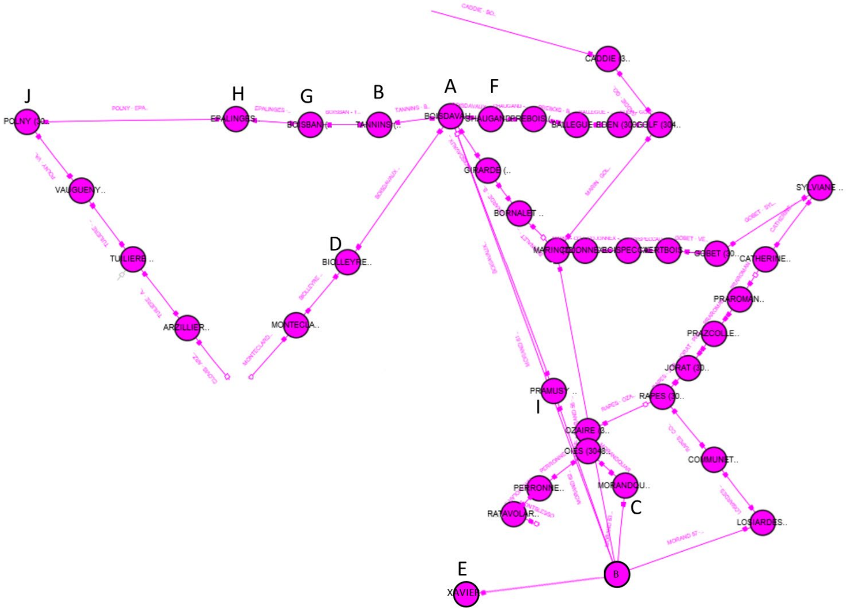

Figure 14: Overall best locations for a limited power of 3MVA

3.4 Comparison with alternative approaches

Although the topic of this project is the use of STATCOMs, the effectiveness of placing a STATCOM into a distribution network will be briefly compared to other reinforcement measures that might achieve similar effect. The following types of measures have been included in the comparison: adding parallel lines/cables to existing ones, replacing existing cables by cables with increased cross-section, increasing the rating of selected MV/LV transformers and increasing the rating of the HV/MV transformer. This investigation was carried out using the example of a 1 MVA STATCOM placed at the Arzillier station, using the voltage control mode (Q flow at B fixed at 0). Arzillier is the station that provided the best possible STATCOM location for this control. The alternative network reinforcement measures considered in this case were the following (each of these being considered separately):

- Addition of parallel lines: for the three 3 lines (or cable) with highest load over the year, a parallel line is added:
    - B-BOISDAVAUX (74.8%, 2.3km)
    - B-MARIN (48.7%, 1.14km)
    - TANNINS-BOISDAVAUX (43.4%, 1.19km)

  Each of the following alternatives is considered:
    - Situation A: Addition of a parallel line to line B-BOISDAVAUX
    - Situation B: Addition of a parallel line to lines B-BOISDAVAUX and B-MARIN
    - Situation C: Addition of a parallel line to lines B-BOISDAVAUX, B-MARIN and TANNINS-BOISDAVAUX

- Increase lines section: for the three 3 lines (or cable) with highest load over the year, the cross-section is changed from 150 mm^2 Alu to 300 mm^2 Cu. Each of the following alternatives is considered:
    - Situation A: Improved characteristics on line B-BOISDAVAUX
    - Situation B: Improved characteristics on lines B-BOISDAVAUX and B-MARIN
    - Situation C: Improved characteristics on lines B-BOISDAVAUX, B-MARIN and TANNINS-BOISDAVAUX
- Increase B HV/MV transformer power: the rating of the B HV/MV transformer is increased from 15 to 25 MVA. The characteristics of the original and the replacement transformer are given in Table 4.

		Original transformer	Upgraded transformer
	Rated Power	15 MVA	25 MVA
	Transforming ratio	53/11.5 kV	53/11.5 kV
	Vector group	YN-D	YN-D
	Short-circuit Voltage	7.93 %	8.11 %
	Copper losses	49.3 kW	65.26 kW
TAP CHANGER	Additional Voltage per Tap	2%	2%
	Maximum position	3	3
	Minimum position	-3	-3
	Neutral position	0	0

Table 6: Transformers parameters

- Increase MV/LV transformer ratings: the 3 transformers with highest load over the year are replaced by transformer with a rating equal to twice the currently installed power of each one of those 3 transformers:
    - Arzillier (0.4MVA→0.8MVA)
    - Prazcollet (0.4MVA→0.8MVA)
    - Marin (0.63MVA→1.26MVA)

Table 7 shows the results of the comparison between the classical reinforcement approaches and the STATCOM. All measures are assessed using the same scoring system that can be compared to the initial situation (without STATCOM and without reinforcement), i.e. the "reference case". The best control mode for the STATCOM (i.e. minimisation of the reactive power exchange with the HV network) is given in the second column. The results show that the STATCOM is the most competitive option for improving the voltage profile whereas the improvement to component loadings is less attractive. In practise, the type of issue to be resolved will therefore decide on the attractiveness of using a STATCOM.

		STATCOM	PARALLEL LINES			INCREASE LINE SECTION			INCREASE TRANSFO POWER
	REFERENCECASE	ARZILLIER *(Q flow at B fixed at 0l)*	A	B	C	A	B	C	Transfo HV/MV B 15MVA→25MVA
U index	0.641	0.186	0.429	0.423	0.383	0.462	0.461	0.421	0.462
I index	0.8825	0.857	0.349	0.346	0.346	0.737	0.734	0.733	0.737
L index	0.013	0.014	0.013	0.012	0.012	0.012	0.012	0.012	0.012
T index %	177.89	173.41	176.59	176.57	176.21	176.9	176.9	176.6	176.47
Index	0.894	0.488	0.456	0.307	0.264	0.529	0.527	0.488	0.728

Table 7: Comparison with alternative approaches

3.5 Analysis and results

3.5.1 Future STATCOM role in distribution networks

In general, STATCOMs will contribute to the development of distribution networks by contributing to voltage control, reactive power control, oscillations damping, increase of voltage stability margins and power quality. Specifically, the results shown in Table 3 and Table 4 help to identify possible contributions of STATCOMs to MV networks with a diverse mix of consumer types, short cable/line lengths and increasing PV (similar to the example of SIL in Lausanne, chosen in this project). The contribution of STATCOMs is most relevant in the case of voltage related issues. The comparison with alternative network reinforcement measures in Table 7 shows that a STATCOM in the 1 MVA class would have a contribution to the network performance that is comparable to a cable with a length of 1…2 km. Surely this is not yet a sufficient justification for the installation of a STATCOM and the consideration of more services, e.g. dynamic voltage recovery would increase the attractiveness of such installations. The placement of STATCOMs in networks with well distributed loads and generator is most useful if a node with a high number of connections is chosen as the STATCOM location.

3.5.2 STATCOM in the ReIne network

In analogy with the results obtained for the SIL distribution network, the following rules are suggested for the deployment of a STATCOM to the ReIne laboratory:

- Select a location with several branches, midway between the primary substation and the edge of the network.
- Select a rating in the range of 10…20% of the primary substation's transformer.
- Use a control strategy to minimize the reactive power exchange at the primary substation.

Figure 15 shows the suggested topology for the tests to ben run in the ReIne laboratory, based on the criteria mentioned above. The objective is to have two branches, with the STATCOM located at the junction of these branches. In order to best exploit the available elements of the laboratory, the addition of two disconnectors is recommended.

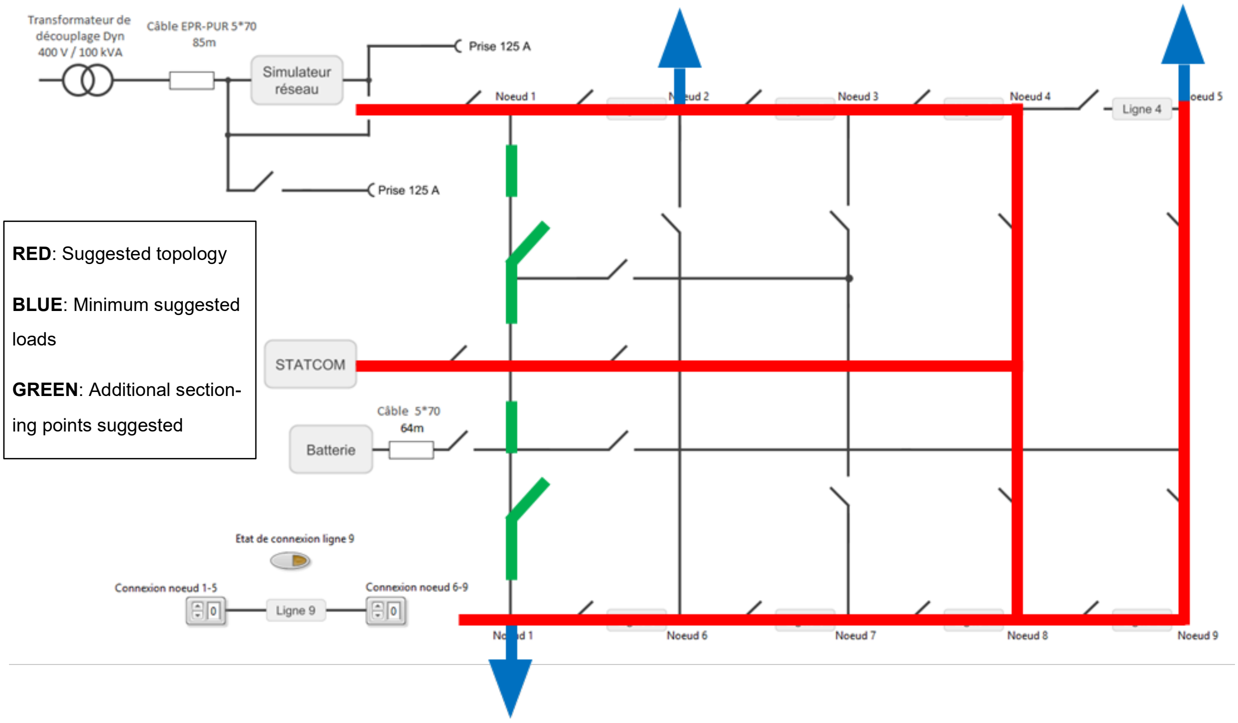

Figure 15: Suggested topology for the tests to ben run in the Relne laboratory.

3.6 Future improvements

As previously mentioned, STATCOMs are anticipated to deliver further benefits with respect to the network's dynamic behaviour. With an adequate control, STATCOMs could contribute to reducing flickers and improve post-fault recovery of the voltage. Such simulations however require EMT models of the grid and the power electronic converter. Initial investigations have been carried out with the available data and these have shown that further work is required in order to adequately understand higher frequency phenomena that become relevant in the MV system for such analyses which are beyond the scope of the work presented in this report.

4 WP3 – Test case for benefits to the HV network: export of reactive power

In order to briefly discuss the benefits of adding a STATCOM to the distribution network in order to export reactive power towards the transmission system, two cases will be investigated here: exporting from an MV network relatively far from the interconnection point with the 220/380 kV transmission system (B) and injecting from within an MV network adjacent to the EHV system (A). For this analysis, a reactive power of 10MVAr is injected at 5 different locations: The four different injection points in A have the following characteristics, and can be seen in Figure 16:

- Hauteville (A): Many substations to A, total cable length of 4.5 km
- Pavement (B): Many substations to A, total cable length of 5.2 km
- Romandquart (C): Direct connection with A, cable length of 0.12 km
- Borello (D): Direct connection with A, cable length of 2.4 km

The objective of these simulations was to assess whether the export of reactive power from the MV system to the HV system was a realistic scenario. Table 8 and Table 9 contain the summary of the effect of the reactive power injection on one of the exchange points (with two transformers) with the 220/380 kV system in A. The difference between Table 8 and Table 9 is the load situation: in Table 8 the load at B corresponds to a measured load whereas the remainder of the distribution system has no load (no data was available for this and the effort related to integrating the load of B into the model is not negligible). Table 9 shows the situation with no load in the distribution network. The reference corresponds to the situation with no STATCOM installed.

The results show that the particular situation of the 125 kV network running in parallel with the 220/380 kV system of western Switzerland largely affects the effectiveness of the export from the distribution system towards the transmission system. Almost regardless of the distance between the connection point of the STATCOM and the interconnection point with the transmission system, the effectiveness of the transfer of reactive power is around 50%, which is a low share of the reactive power. The comparison of Table 8 and Table 9 shows that the loading of the distribution system only slightly affects the situation. With even higher loads, the effect of the well-known P-U relation which has the consequence that a network will react with more sensitivity to variations of the injected reactive power if its loading is higher would be expected. In practice, the value of injecting reactive power into the MV network with the objective of adjusting the exchange with the transmission network will depend on the costs and/or remuneration, but the low effectiveness would rather be in favour of connecting a VAr compensation system to the transmission system directly.

				P[1] [MW]	Q [MVAr]	S [MVA]	Losses [MW]	Increase of losses [%]	Percentage of Q [%]
		REFERENCE		**0.44**	**24.00**	**24.00**	**0.0806**		
Injecting 10MVAr into MV	**B**	-10MVAr at B		0.32	27.75	27.75	0.0813	-0.89	37.5
			Δ from ref	0.112	-3.750	-3.748	-0.00072		
	A	-10MVAr at HAUTEVILLE (A)		0.08	28.45	28.45	0.0815	-1.07	44.5
			Δ from ref	0.359	-4.45	-4.45	-0.00087		
		-10MVAr at ROMAQUARD (C)		0.30	28.61	28.62	0.0815	-1.12	46.2
			Δ from ref	0.1393	-4.62	-4.61	-0.00090		
		-10MVAr at BORELLO (D)		0.17	28.53	28.53	0.0815	-1.09	45.3
			Δ from ref	0.263	-4.53	-4.52	-0.00088		
		-10MVAr at PAVEMENT (B)		0.04	28.43	28.43	0.0815	-1.07	44.3
			Δ from ref	0.394	4.43	-4.42	-0.00086		
Drawing 10MVAr from MV	**B**	10MVAr at B		0.52	19.40	19.40	0.0799	0.93	46.0
			Δ from ref	-0.0799	4.6037	4.6008	0.00075		
	A	10MVAr at HAUTEVILLE (A)		0.29	18.06	18.06	0.0797	1.17	59.4
			Δ from ref	0.1505	5.9438	5.9455	0.00094		
		10MVAr at ROMAQUARD (C)		0.54	18.27	18.28	0.0797	1.13	57.3
			Δ from ref	-0.1011	5.7300	5.7260	0.00091		
		10MVAr at BORELLO (D)		0.40	18.16	18.17	0.0797	1.15	58.4
			Δ from ref	0.0326	5.8376	5.8371	0.00093		
		10MVAr at PAVEMENT (B)		0.24	18.02	18.02	0.0797	1.18	59.8
			Δ from ref	0.1985	5.9839	5.9863	0.00095		

Table 8: Different injections points and their influence on HV/MV transformer in A – 01.10.18, 10h00

[1] Positive values correspond to transfers from the HV to the LV side. In the present case, no active load is simulated in the distribution grid outside B. Therefore, and because of other interconnections of the distribution grid with the 125 kV and 220 kV systems, the transformer at A might see a negative power.

				P [MW]	Q [MVAr]	S [MVA]	Losses [MW]		
		REFERENCE		1.22	24.25	24.28	0.0807	**Increase of losses [%]**	**Percentage of Q [%]**
Injecting 10MVAr into MV	**B**	-10MVAr at B	1.11	28.00	28.02	0.0814	1.11	-0.90	37.5
			0.113	-3.745	-3.736	-0.00072	0.113		
	A	-10MVAr at HAUTEVILLE	0.86	28.70	28.71	0.0815	0.86	-1.08	44.5
			0.359	-4.45	-4.43	-0.00087	0.359		
		-10MVAr at ROMAQUARD	1.08	28.86	28.88	0.0816	1.08	-1.12	46.1
			0.1402	-4.61	-4.60	-0.00091	0.1402		
		-10MVAr at BORELLO	0.96	28.77	28.79	0.0815	0.96	-1.10	45.2
			0.264	-4.52	-4.51	-0.00089	0.264		
		-10MVAr at PAVEMENT	0.83	28.67	28.69	0.0815	0.83	-1.07	44.2
			0.395	4.42	-4.40	-0.00086	0.395		
Drawing 10MVAr from MV	**B**	10MVAr at B	1.30	19.65	19.69	0.0799	1.30	0.94	46.0
			-0.0818	4.5983	4.5859	0.00076	-0.0818		
	A	10MVAr at HAUTEVILLE	1.09	19.07	19.10	0.0798	1.09	1.05	51.8
			0.1285	5.1809	5.1804	0.00084	0.1285		
		10MVAr at ROMAQUARD	1.34	19.28	19.33	0.0798	1.34	1.01	49.7
			-0.1230	4.9672	4.9511	0.00081	-0.1230		
		10MVAr at BORELLO	1.21	19.18	19.21	0.0798	1.21	1.03	50.7
			0.0107	5.0748	5.0674	0.00083	0.0107		
		10MVAr at PAVEMENT	1.04	19.03	19.06	0.0798	1.04	1.06	52.2
			0.1765	5.2210	5.2231	0.00085	0.1765		

Table 9: Different injections points and their influence on HV/MV transformer in A – No loads in B Feeder

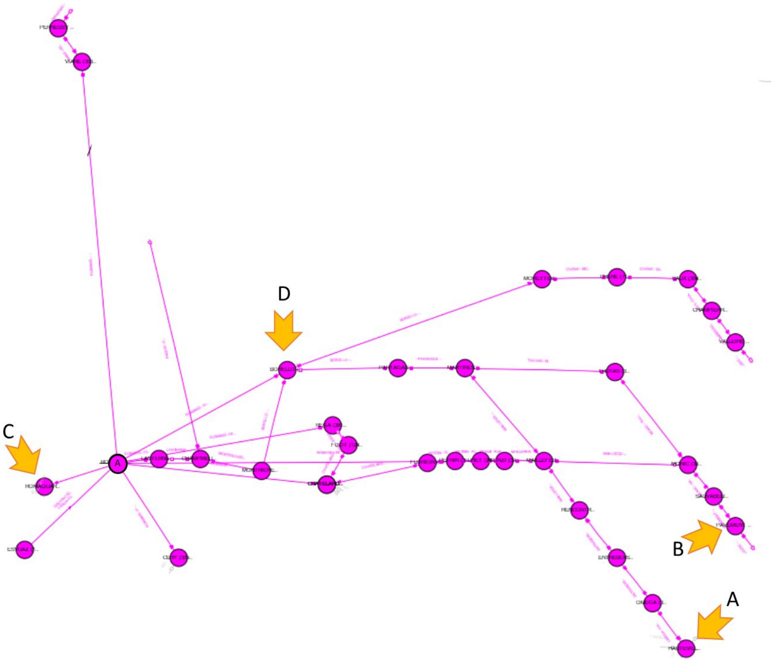

Figure 16: Injections points in A

5 Results summary

Table 10 and Figure 17 show the ten best-suited STATCOM locations overall, in dependence of the STATCOM's rated power. Interestingly, the substation of Boisdavaux appears to be a robust candidate location, since it ranks high regardless of the size limitation. The Tannins substation is also present in all lists of best-suited stations, which is due to its vicinity to the Boisdavaux station. If a unique candidate for the placement of a STATCOM should be identified, this would be Boisdavaux.

	10 BEST OVERALL SUBSTATION		
	UNLIMITED	1MVA	3MVA
1	XAVIER	VAUGUENY	BOISDAVAUX
2	MORANDQUAR	POLNY	TANNINS
3	PRAMUSY	ARZILLIER	MORANDQUAR
4	BOISDAVAUX	TUILIERE	BIOLLEYRE
5	OIES	EPALINGES	XAVIER
6	TANNINS	BOISBAN	CHAUGAND
7	MARIN	TANNINS	BOISBAN
8	OZAIRE	BOISDAVAUX	EPALINGES
9	PERRONNE	CHAUGAND	PRAMUSY
10	GOLF	BIOLLEYRE	POLNY

Table 10: Overall best-suited substations

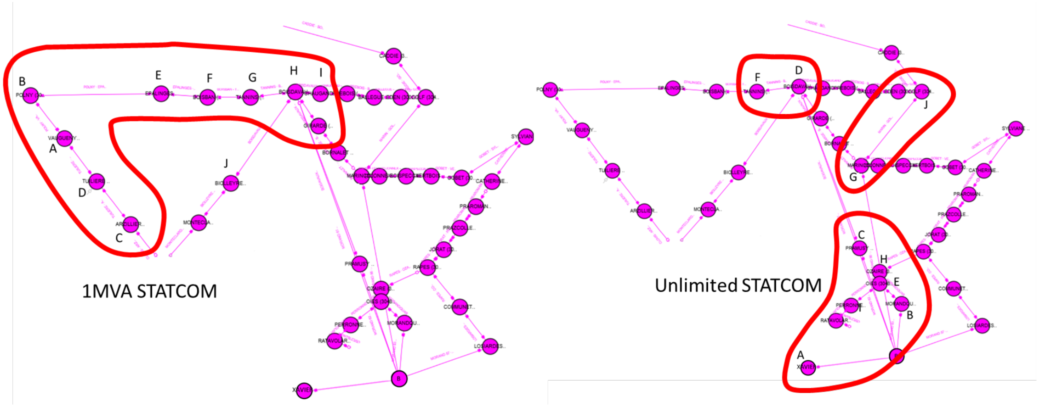

Figure 17: Best suited location depending on the STATCOM rating.

Figure 18 shows the comparison of the STATCOM's and alternative solutions' performance. As discussed in Table 7, the STATCOM is effective at resolving voltage related issues. For other criteria, the picture is more differentiated. This can be seen in the overall scores, where alternative approaches can lead to even higher improvements. Indeed adding parallel lines is likely to be more expensive and complex to implement. At this project stage, such an economic comparison would however be hazardous.

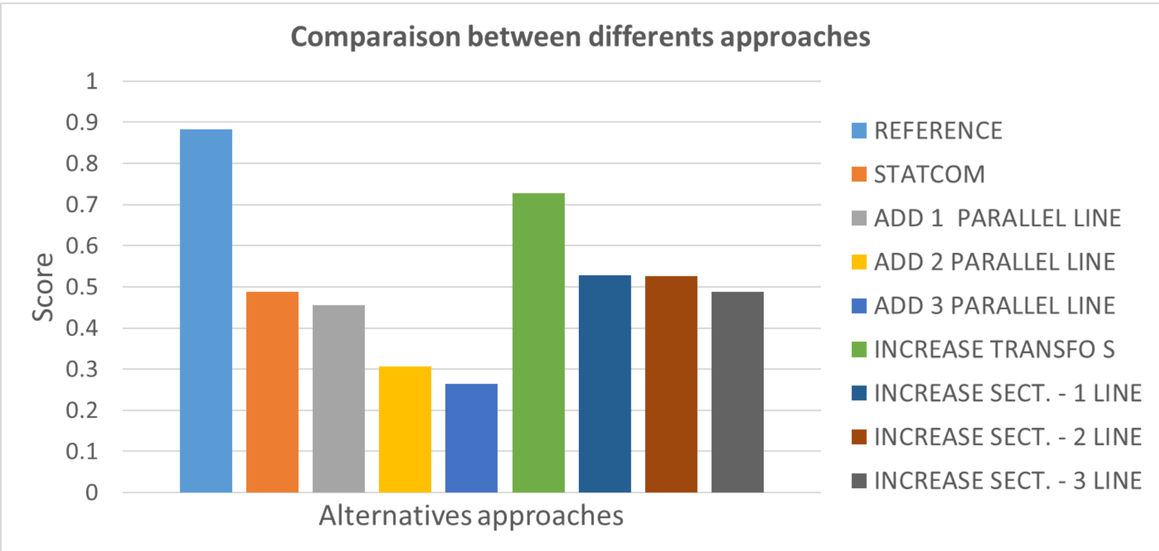

Figure 18: Comparison between different approaches

6 Bibliography

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7 Appendix

7.1 WP planning

COSTAM Project		630 h
WP2 - Preliminary system (grid) analysis and test cases definition		**160 h**
Define network areas worth studying with SIL	SIL: provide network data	20 h
Define synthetic network areas for study		20 h
Import and process network and other data (e.g. operational topology)	SIL: answer questions on network data	40 h
Add/generate missing load and generation data (with future evolution)		60 h
Define performance index for STATCOM benefits		20 h
WP3 - Test cases simulation		**430 h**
Define STATCOM model for analysis (static only? short circuit optional ?)		20 h
Define and implement control strategies for the STATCOM (local, global, …)		40 h
Establish modelling framework for yearly simulations		80 h
Define variants to be investigated (number, size, location, control of STATCOMs)		20 h
Evaluate variants	SIL: give feedback	80 h
Compare variants with alternative approaches (load/generation curtailment, network reinforcement, tap changer transformers)		70 h
Specify adaptation of the ReIne network to the SIL study case	HEIG-VD: specify network	20 h
Establish test scenarios for the reduced scale network based on promising variants of the MV variants analysis	HEIG-VD: contribute	20 h
Recommendations for further development of STATCOM prototype		20 h
Deliverable D2: Report on preliminary analysis and test case simulation results		60 h
Milestone for WP2 and WP3 results		0 h
WP8 - Generalization of STATCOM applications		**40 h**
Add variations to WP3 test cases		10 h
Assess effect of variations on benefits of STATCOM use		10 h
Prepare input for workshop	HEIG-VD: organise workshop	20 h

7.2 List of PV forecast for each substation

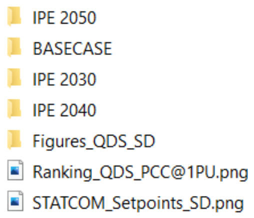
Substation name	Transfo power [MVA]	PV power for each scenario [kW]			
		Actual IPE	IPE 2030	IPE 2040	IPE 2050
ARZILLIER (30015)	0.4	9.00	*9.00*	62.23	127.11
BALLEGUE (30026)	0.4	95.80	*95.80*	149.03	213.91
BIOLLEYRE (30006)	0.4	27.92	*27.92*	81.15	146.03
BOISBAN (30019)	0.63		46.294087	130.13	232.32
BOISDAVAUX (30010)	0.4		29.3930711	82.62	147.50
BOISPECCAU (110979)	1	302.9	*151.5*	284.57	446.77
BOISPECCAU (110979)	1		*151.5*	284.57	446.77
BORNALET (30008)	0.4	9.00	*9*	62.23	127.11
CADDIE (30421)	0.1		7.34826779	20.65	36.88
CATHERINE (30635)	0.16		11.7572285	33.05	59.00
CHAUGAND (30645)	0.63	63.30	*63.3000002*	147.13	249.32
COJONNEX (116542)	1	247.4	*94.07*	227.14	389.34
COJONNEX (116542)	1		*94.07*	227.14	389.34
COJONNEX (116542)	0.63		*59.26*	143.09	245.28
COMMUNET (30483)	0.25		18.3706695	51.64	92.19
EDEN (30011)	0.4		29.3930711	82.62	147.50
EPALINGES (30023)	0.63	3.00	*3*	86.83	189.02
GIRARDE (53480)	0.63	13.46	*13.46*	97.29	199.48
GOBET (30003)	0.63	9.00	*9*	92.83	195.02
GOLF (30422)	0.25	28.00	*28*	61.27	101.82
JORAT (30670)	0.25	200.34	*200.34*	233.61	274.16
LOSIARDES (30484)	0.25		18.3706695	51.64	92.19
MARIN (30419)	0.63	34.00	*34.00*	117.83	220.02
MONTECLARD (30009)	0.4	15.80	*15.80*	69.03	133.91
MORANDQUAR (30481)	0.4		29.3930711	82.62	147.50
OIES (30480)	0.63	*27.85*	*27.85*	111.68	213.87
OZAIRE (30494)	0.4		29.3930711	82.62	147.50
PERRONNE (30424)	0.25		18.3706695	51.64	92.19
POLNY (30022)	0.4	53.55	*53.55*	106.78	171.66
PRAMUSY (40424)	0.63	0	46.294087	130.13	232.32
PRAROMAN (30482)	0.4	175.00	*175.00*	228.23	293.11
PRAZCOLLET (30485)	0.4		29.3930711	82.62	147.50
PRAZCOLLET (30485)	0.4		29.3930711	82.62	147.50
PREBOIS (30025)	0.4		29.3930711	82.62	147.50
RAPES (30486)	0.25		18.3706695	51.64	92.19
RATAVOLAR (15051)	0.4	35.70	*35.70*	88.93	153.81
SYLVIANE (25097)	0.25		18.3706695	51.64	92.19
TANNINS (30016)	0.4		29.3930711	82.62	147.50
TUILIERE (30012)	0.4		29.3930711	82.62	147.50
TUILIERE (30012)	0.4		29.3930711	82.62	147.50
VAUGUENY (30688)	0.4	13.00	*13.00*	66.23	131.11
VERTBOIS (30002)	0.4		29.3930711	82.62	147.50
XAVIER		185.60	*185.60*	185.60	185.60

7.3 Simulation results

More results are available as files, organised in different folder.

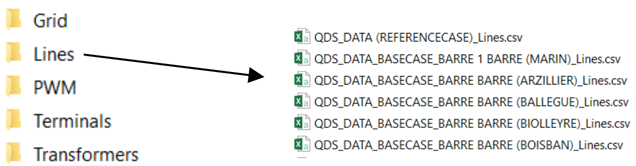
Each simulation folder is organised as follows:

- **BASECASE**
- **IPE_2030**
- **IPE_2040**
- **IPE_2050**
- **Figures_QDS_SD**
- *RankingQDS_"control-mode-name-here".png*
- *STATCOM_Setpoint_SD.png*



The 4 folders highlighted in red have the same internal organisation, as shown below :

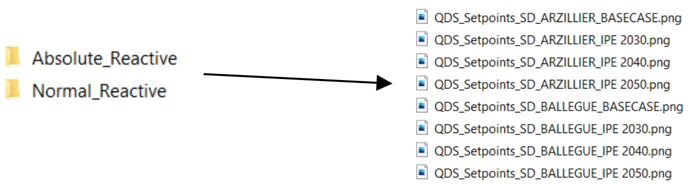
- **Grid**
- **Lines**
- **PWM**
- **Terminals**
- **Transformers**



Each of these folders in turn contains the *.csv* files containing the raw data from the simulations, for each substation.

The **Figures_QDS_SD** folder contains 2 more folders, each one with a series of *.png* files containing the standard deviation of the reactive power, used by the STATCOM, for each location and each scenario:

- **Normal_Reactive**
- **Absolute_Reactive**



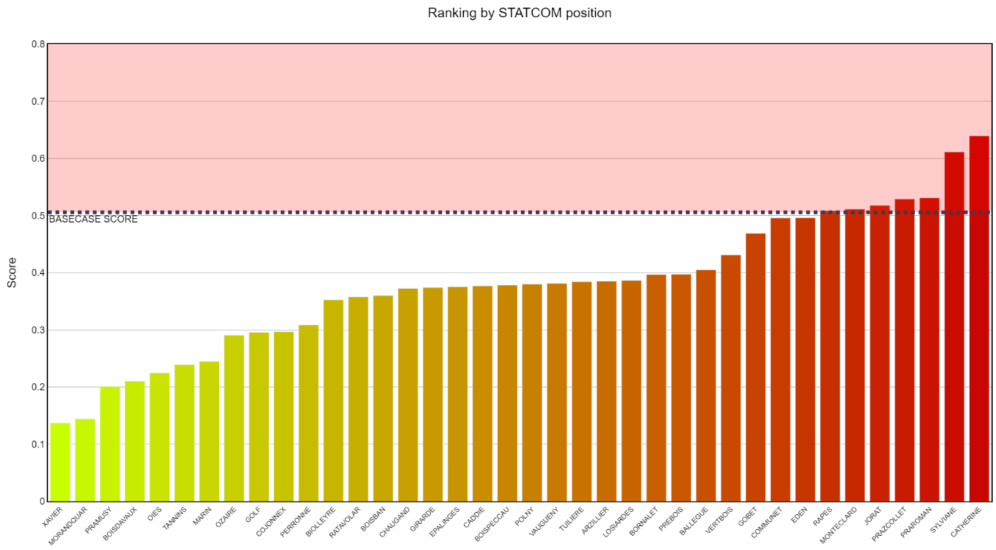
The "Normal_Reactive" contains the standard deviation for the used powers, and the "Absolute_Reactive" the standard deviation of the absolute value of the reactive power.

7.3.1 Local busbar at 1pu

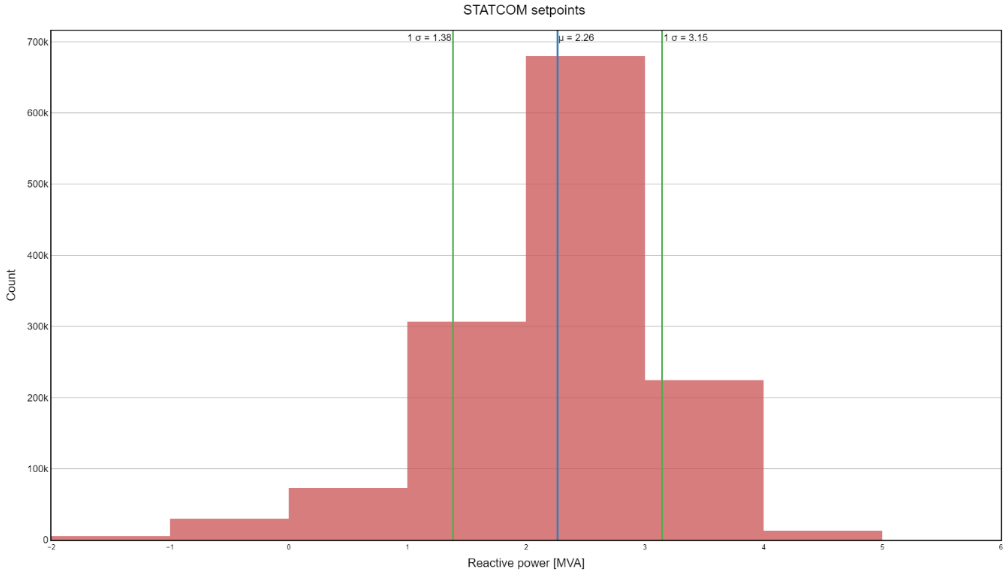
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	Infinite
Substations considered as STATCOM locations	All

Ranking



Setpoints

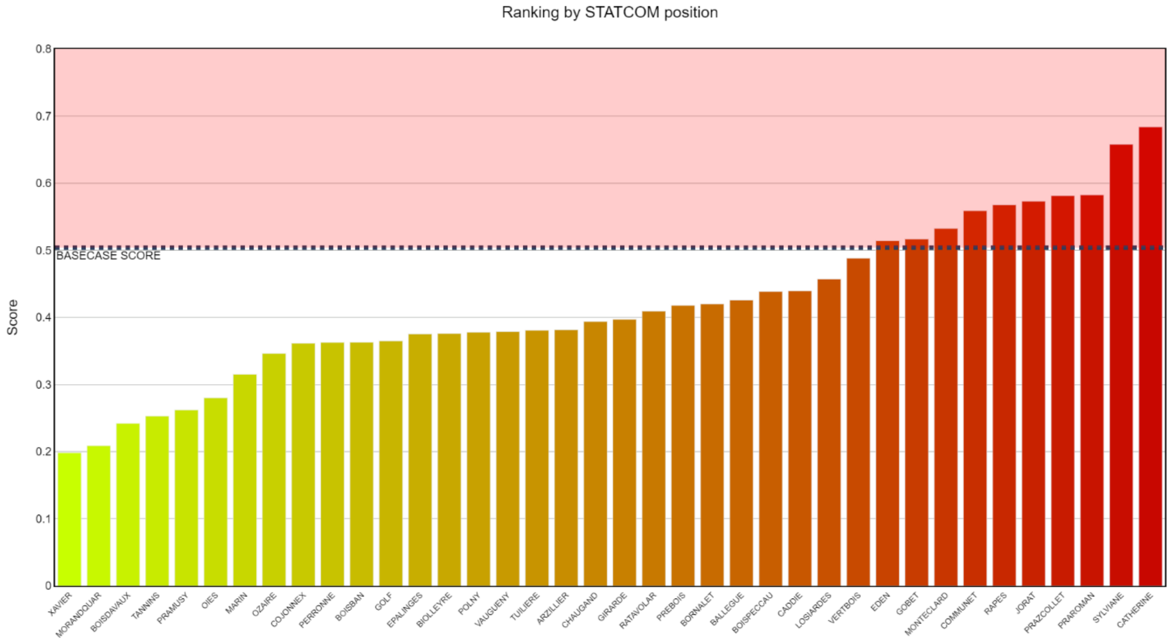


7.3.2 Busbar with max deviation as B

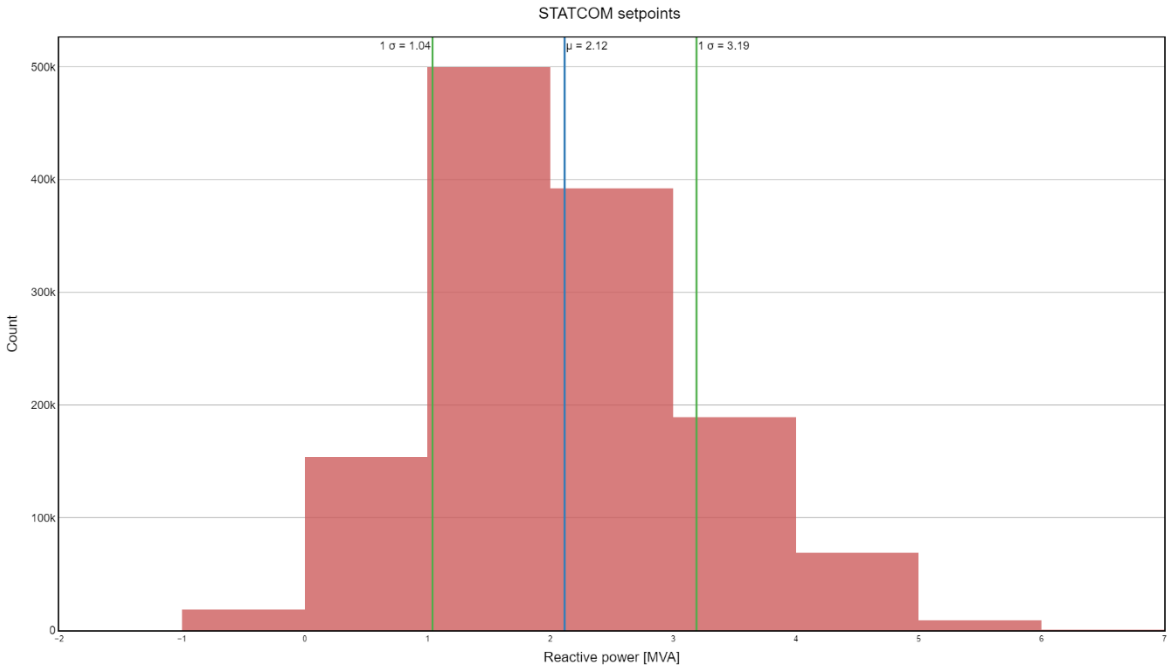
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	Infinite
SUBSTATIONS	All

Ranking



Setpoints

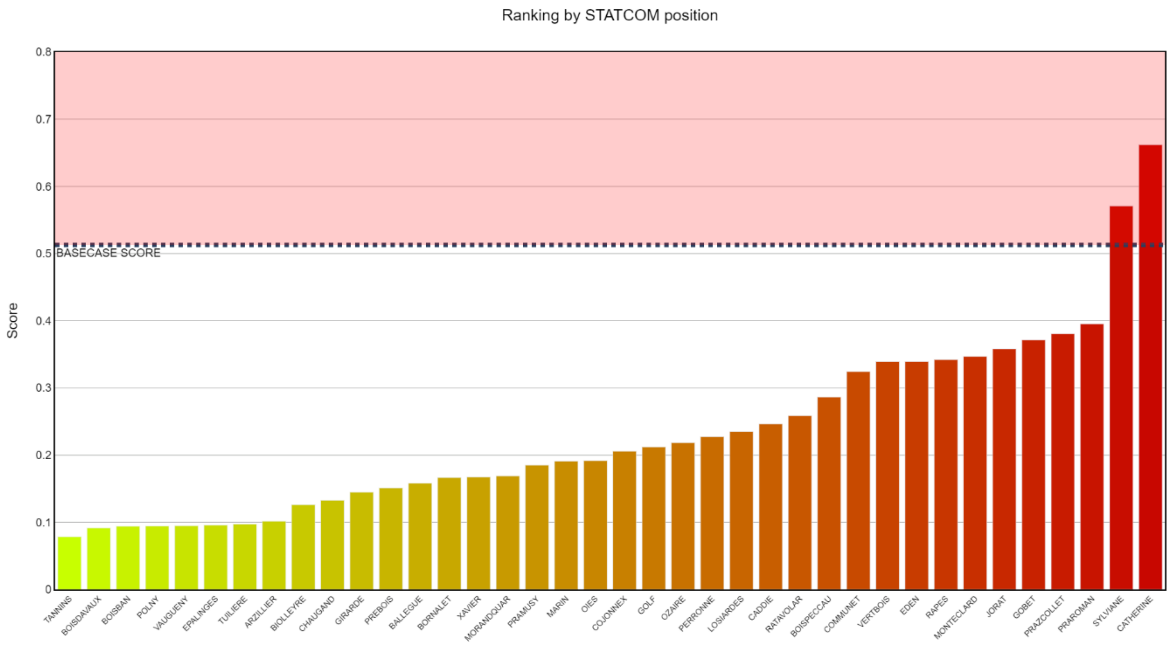


7.3.3 Q flow @ B fixed at 0MVAr

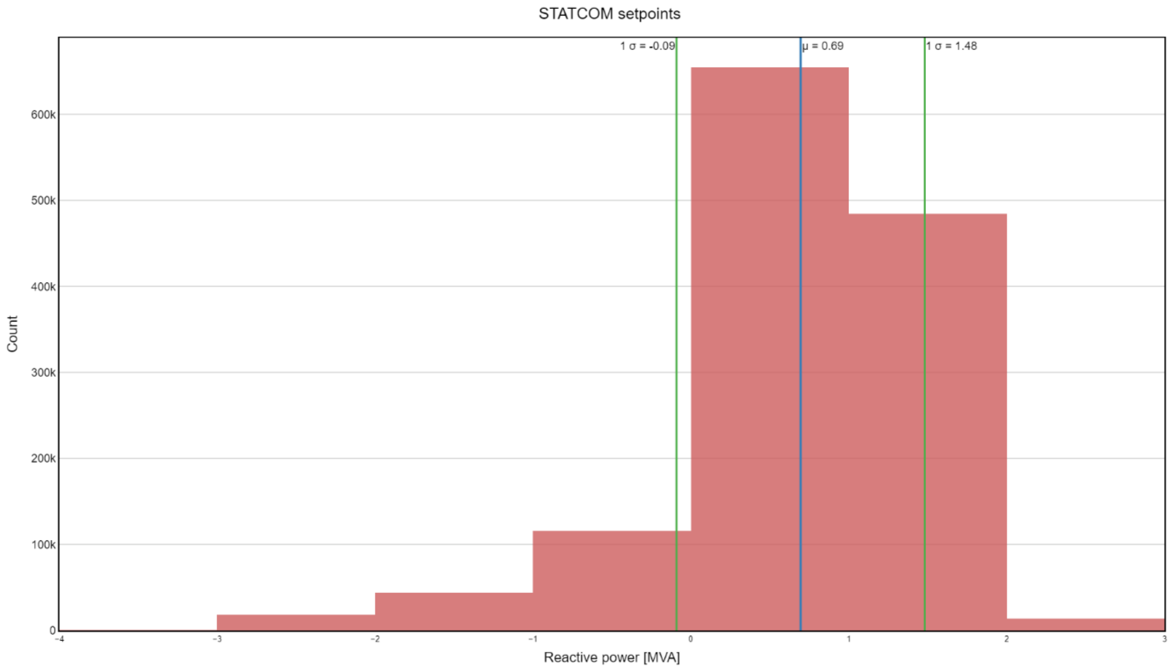
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	Infinite
SUBSTATIONS	All

Ranking



Setpoints

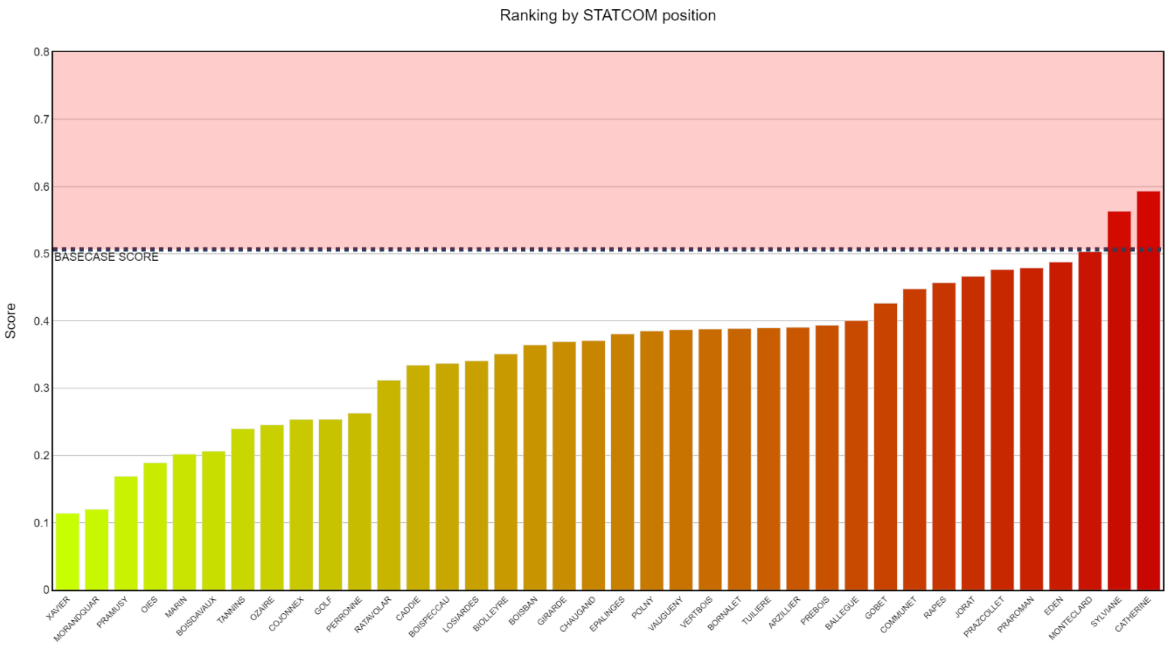


7.3.4 OPF control: minimisation of losses in B feeder

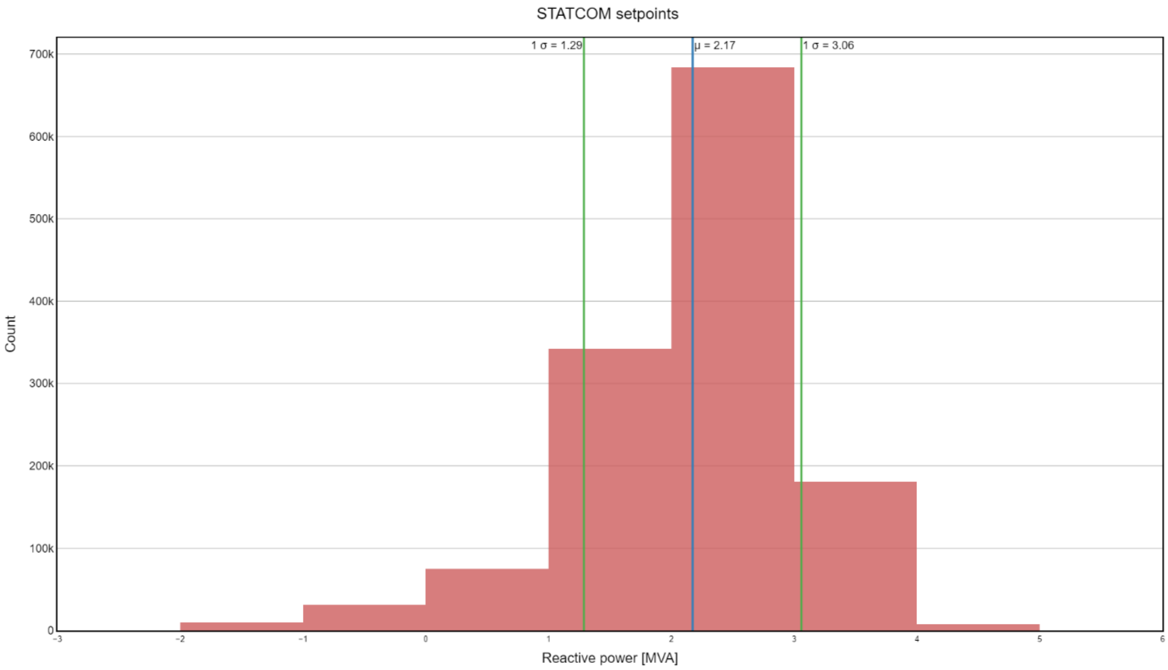
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	Infinite
SUBSTATIONS	All

Ranking



Setpoints

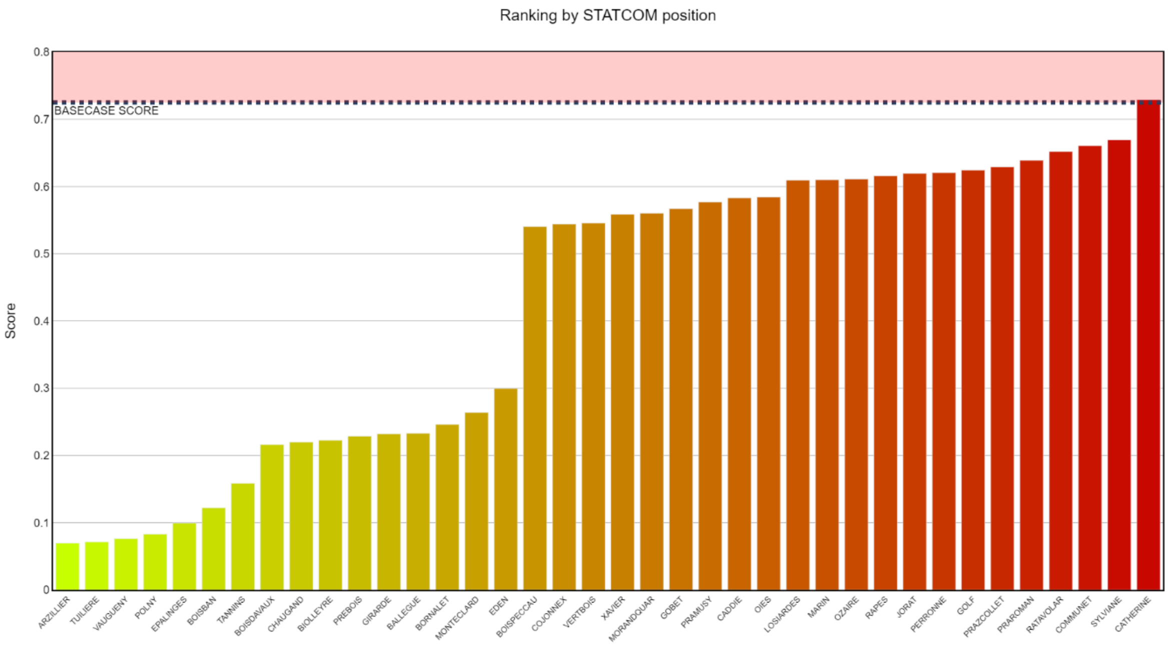


7.3.5 Local busbar at 1pu

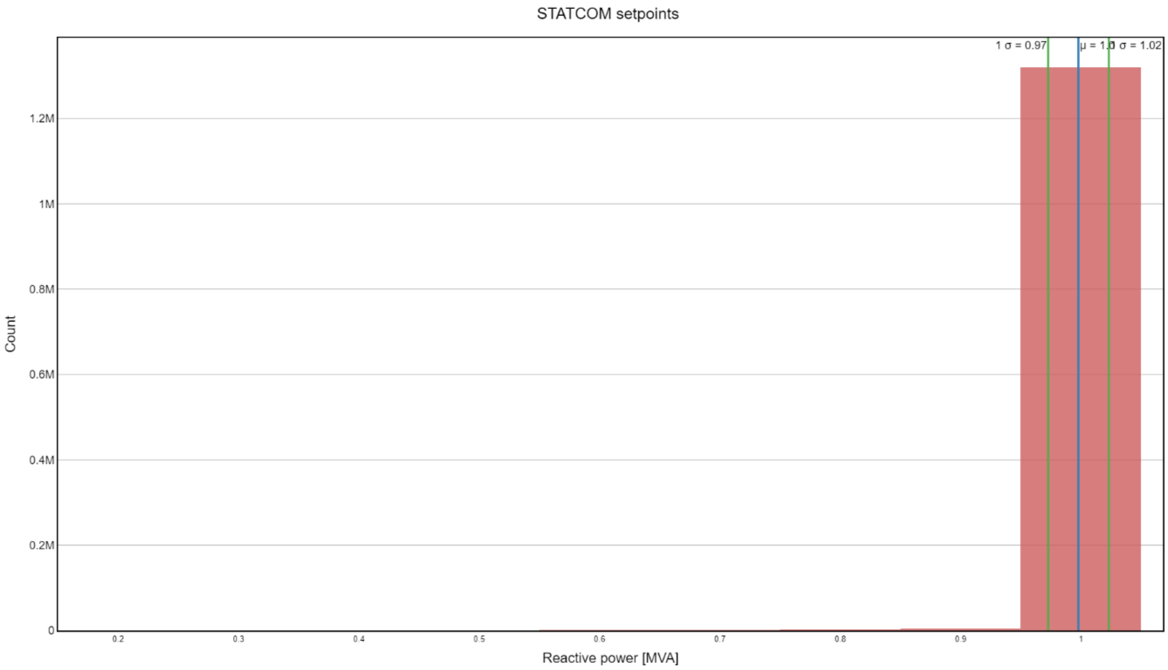
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	1MVA
SUBSTATIONS	All

Ranking



Setpoints

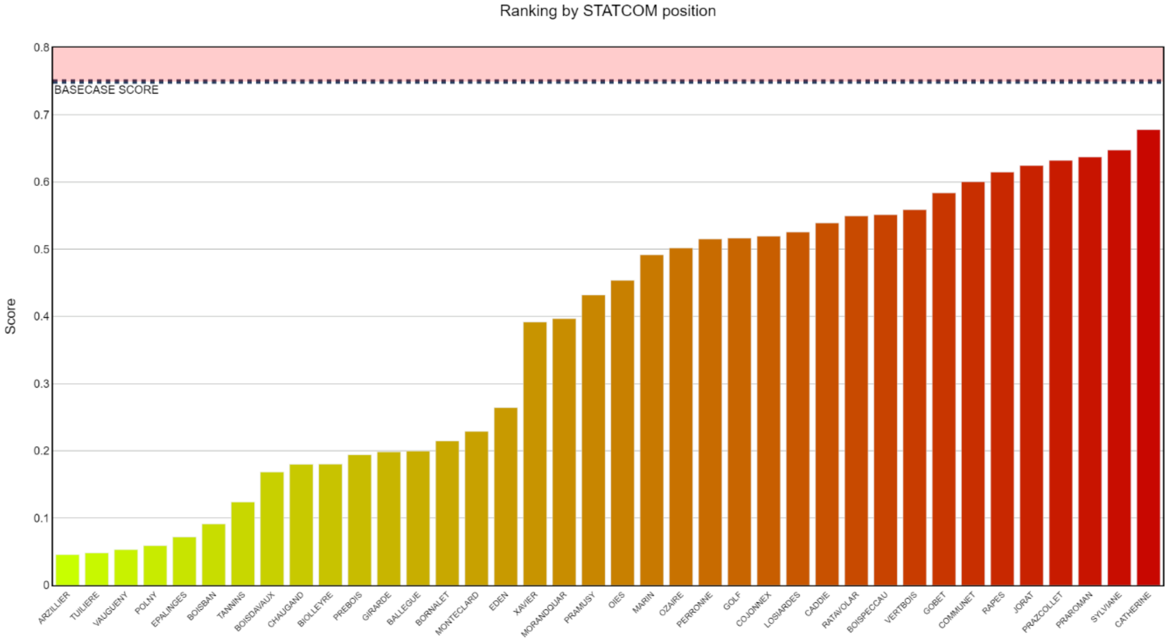


7.3.6 Busbar with max deviation as B

Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	1MVA
SUBSTATIONS	All

Ranking



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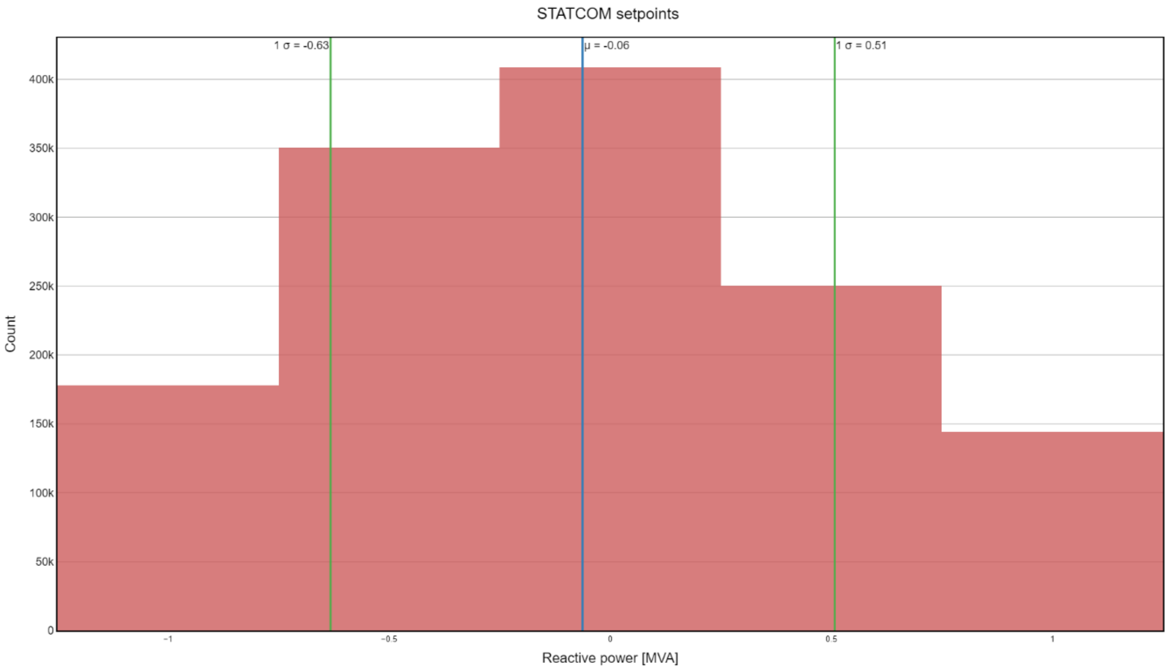
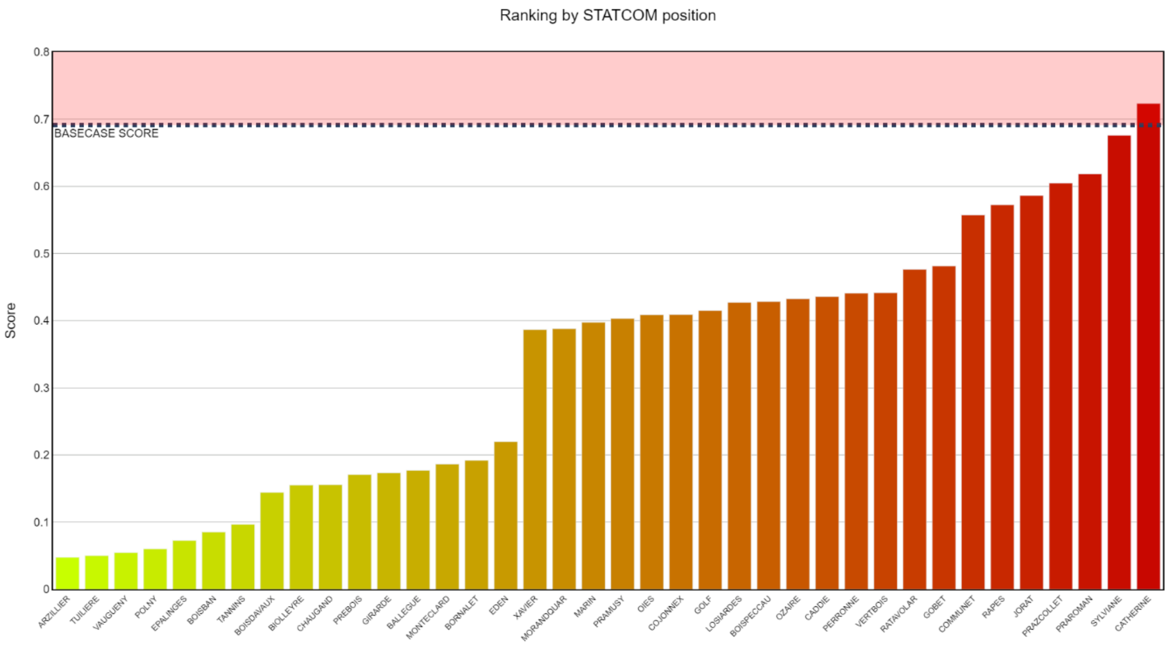


7.3.7 Q flow @ B fixed at 0MVAr

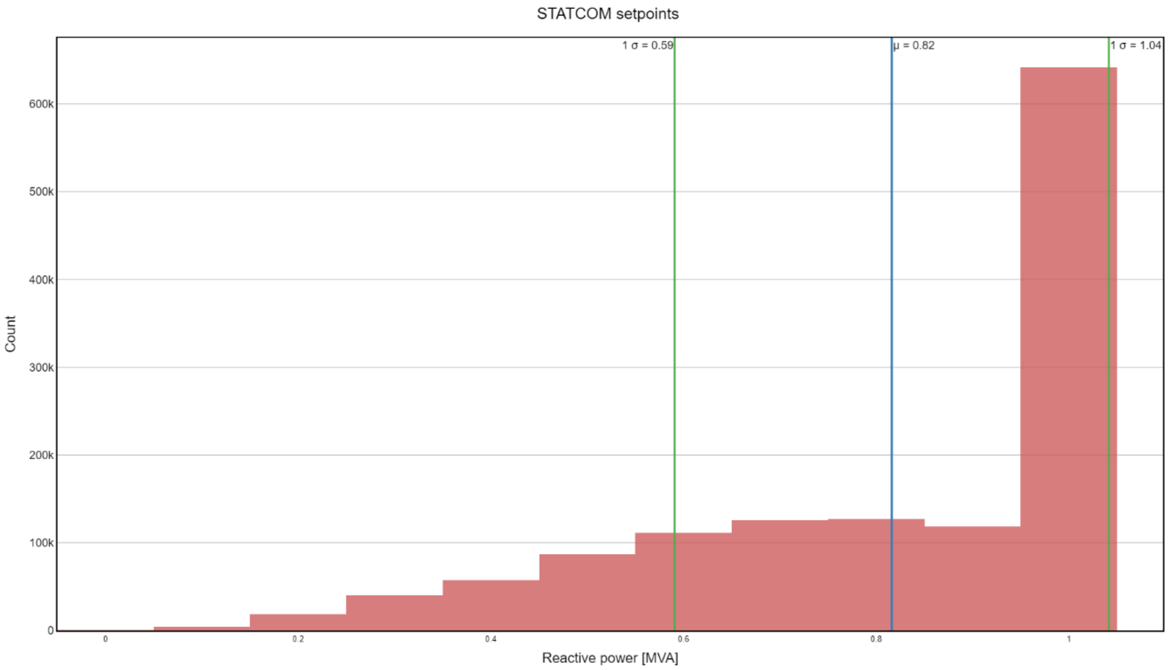
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	1MVA
SUBSTATIONS	All

Ranking



Setpoints

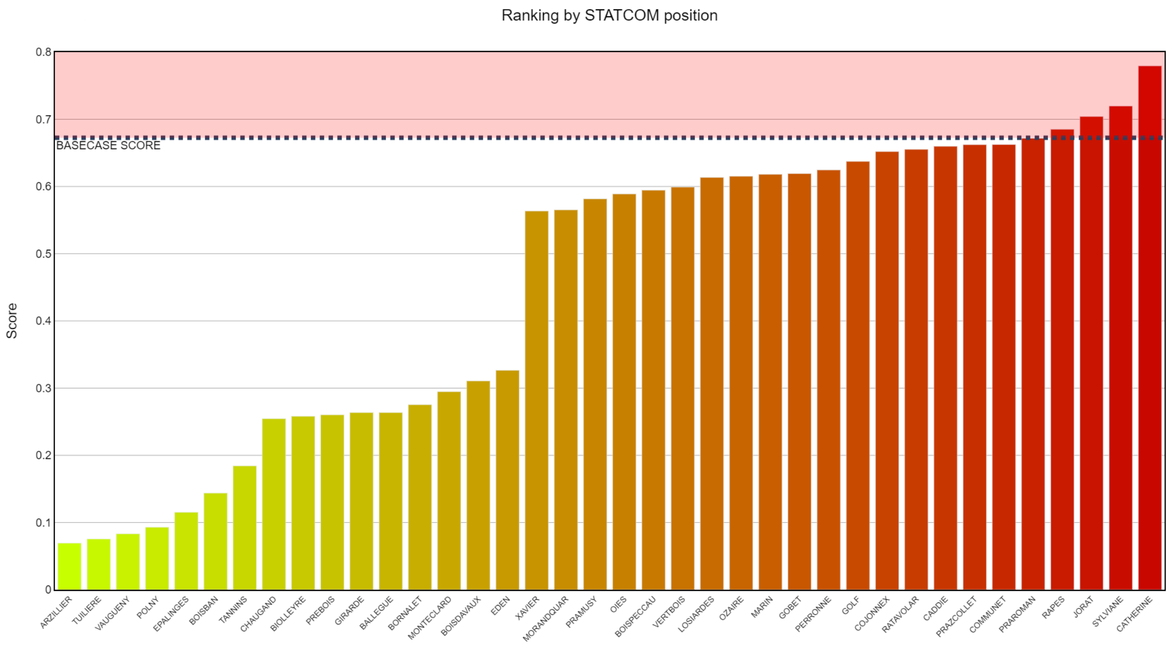


7.3.8 OPF control: minimisation of losses in B feeder

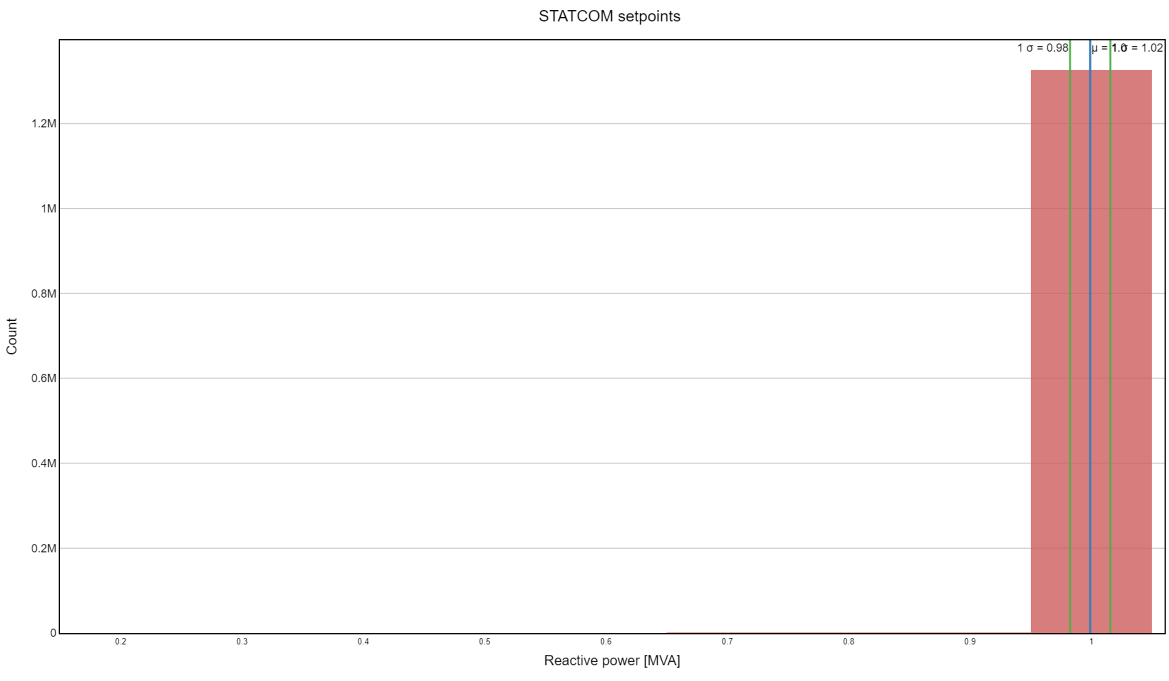
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	1MVA
SUBSTATIONS	All

Ranking



Setpoints

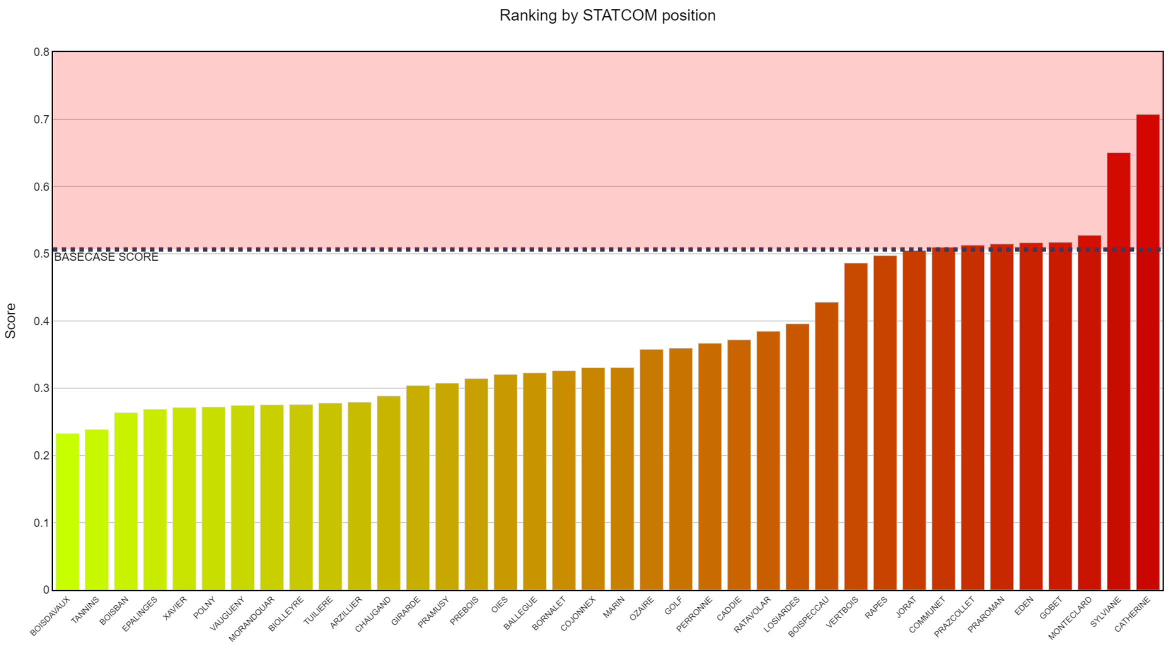


7.3.9 Local busbar at 1pu

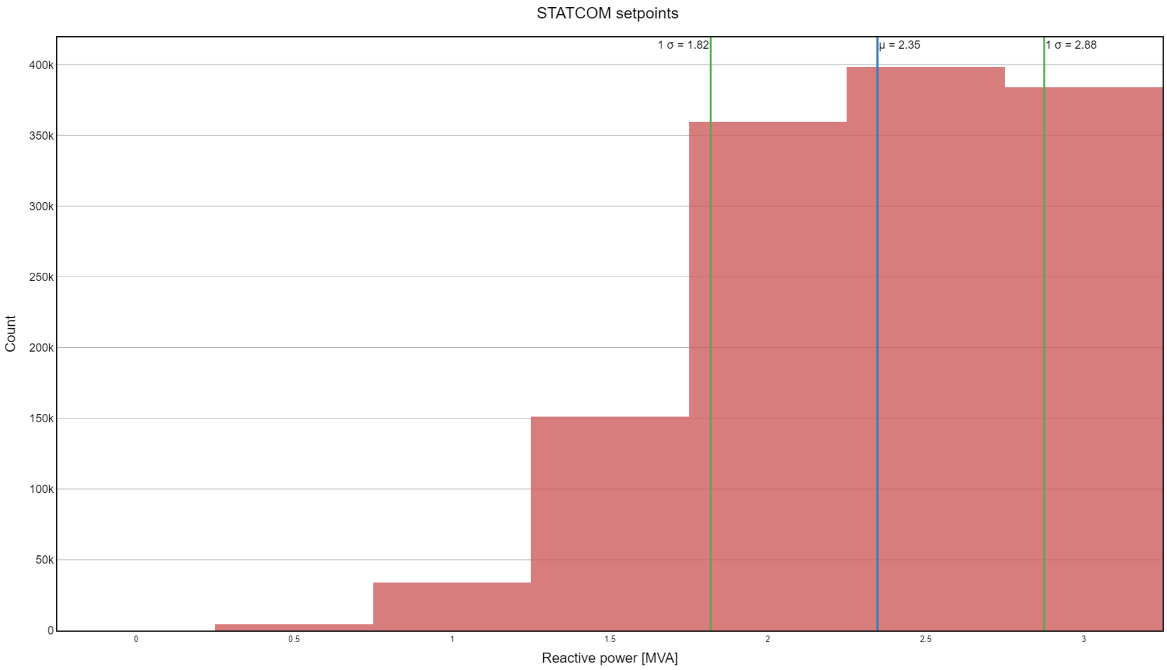
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	3MVA
SUBSTATIONS	All

Ranking



Setpoints

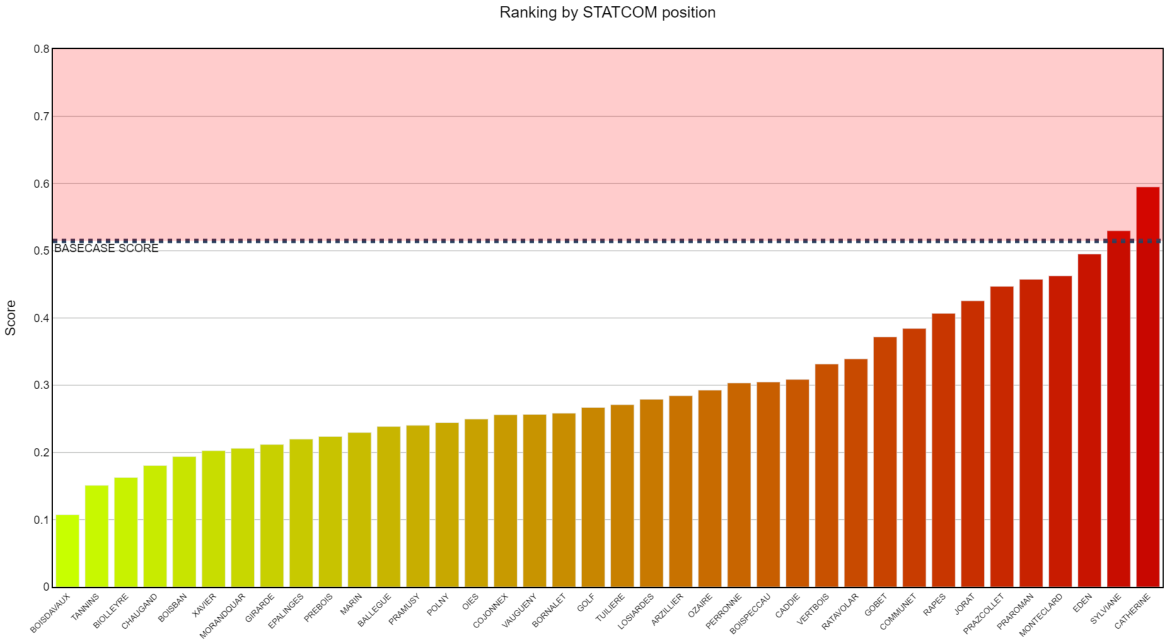


7.3.10 Busbar with max deviation as B

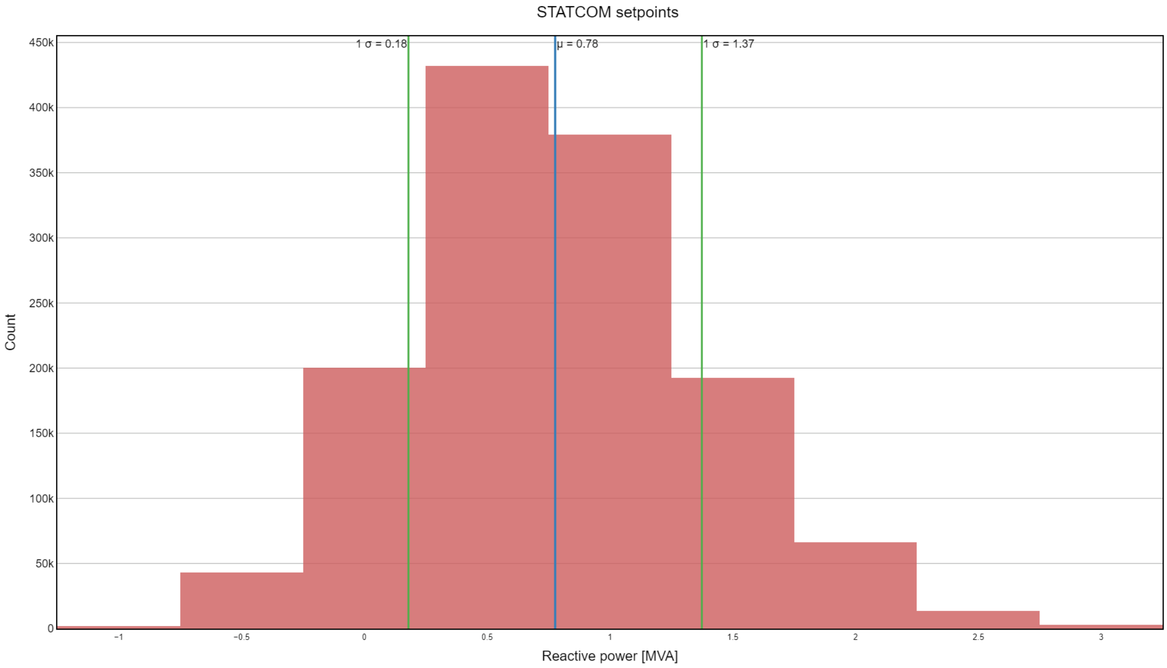
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	3MVA
SUBSTATIONS	All

Ranking



Setpoints

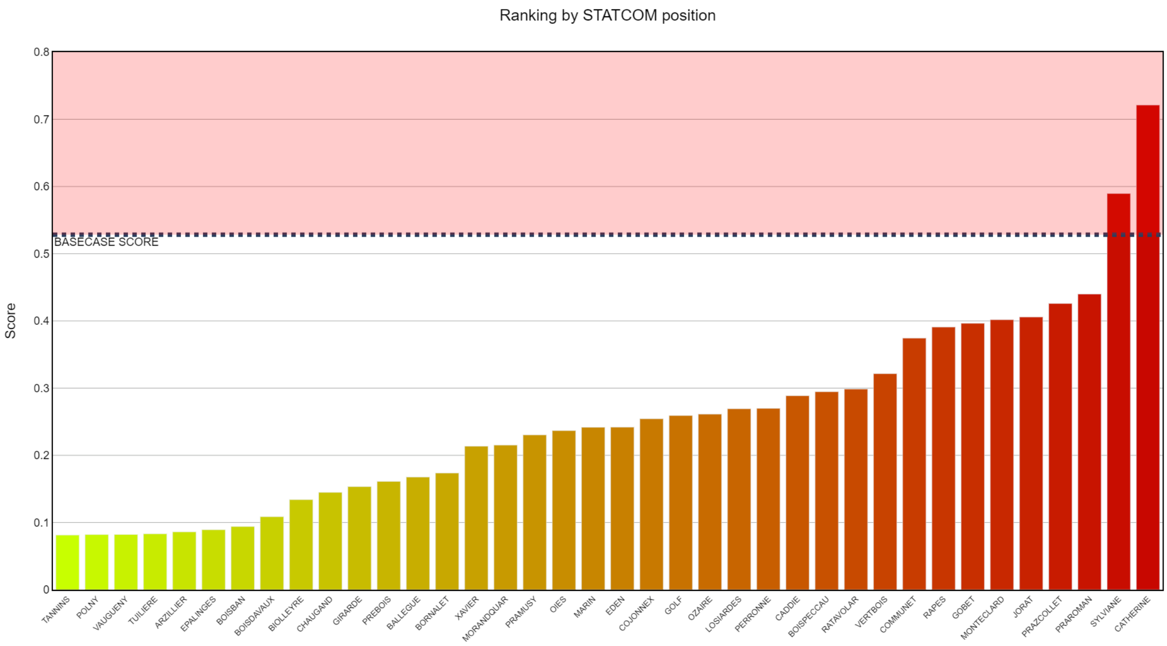


7.3.11 Q flow @ B fixed at 0MVAr

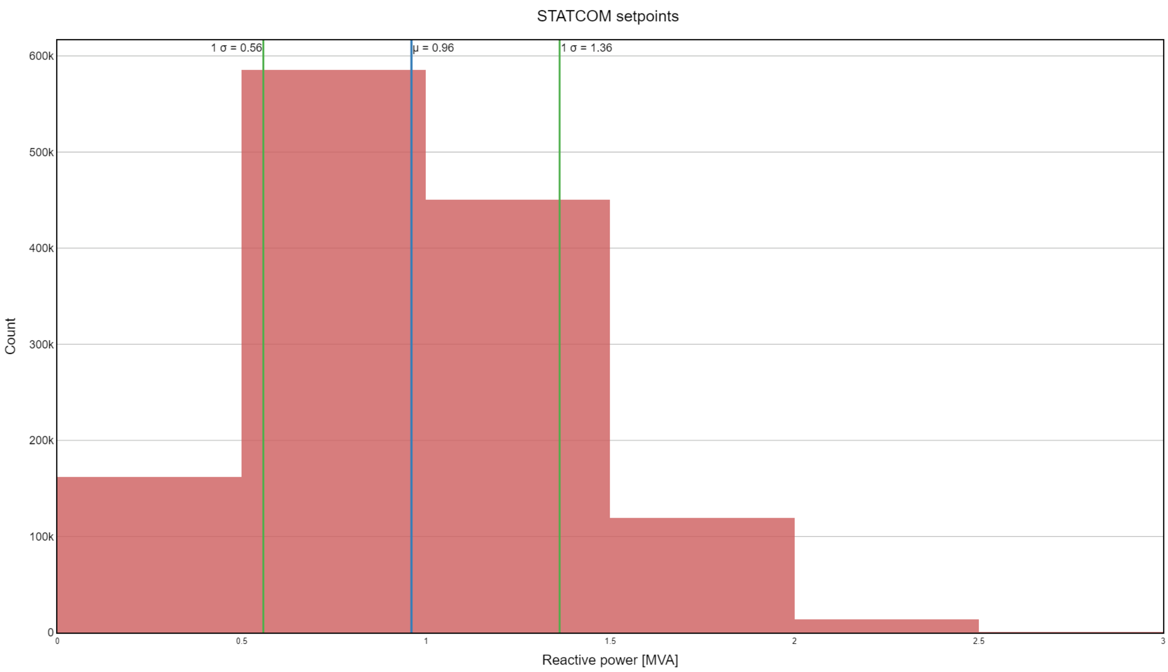
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	3MVA
SUBSTATIONS	All

Ranking



Setpoints

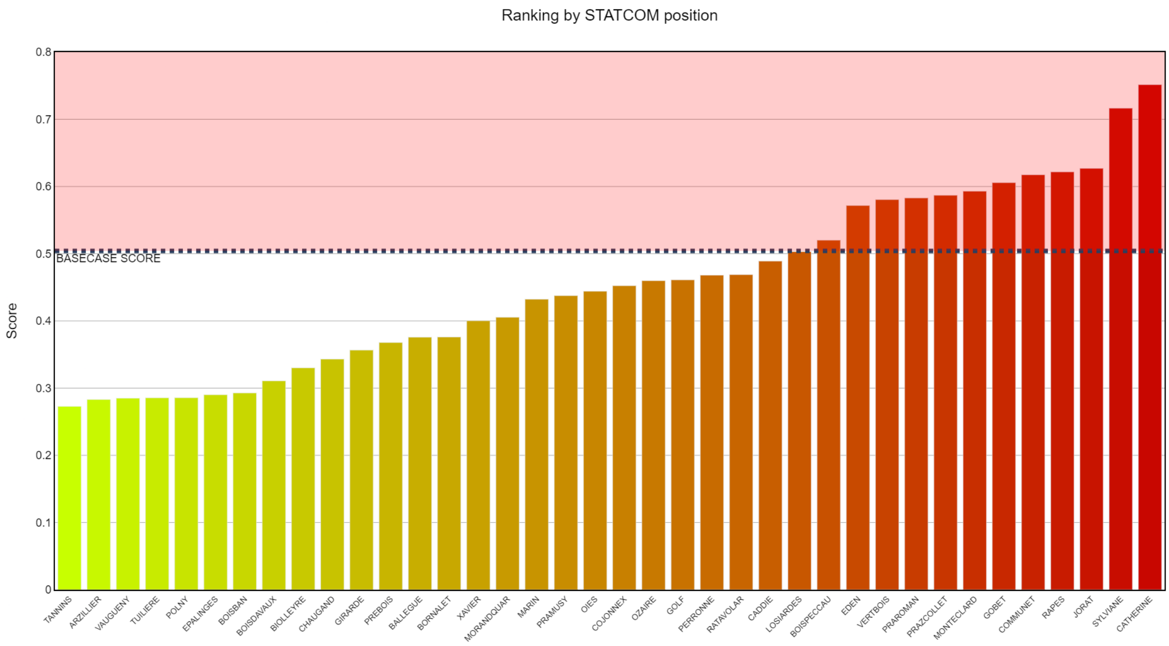


7.3.12 OPF control: minimisation of losses in B feeder

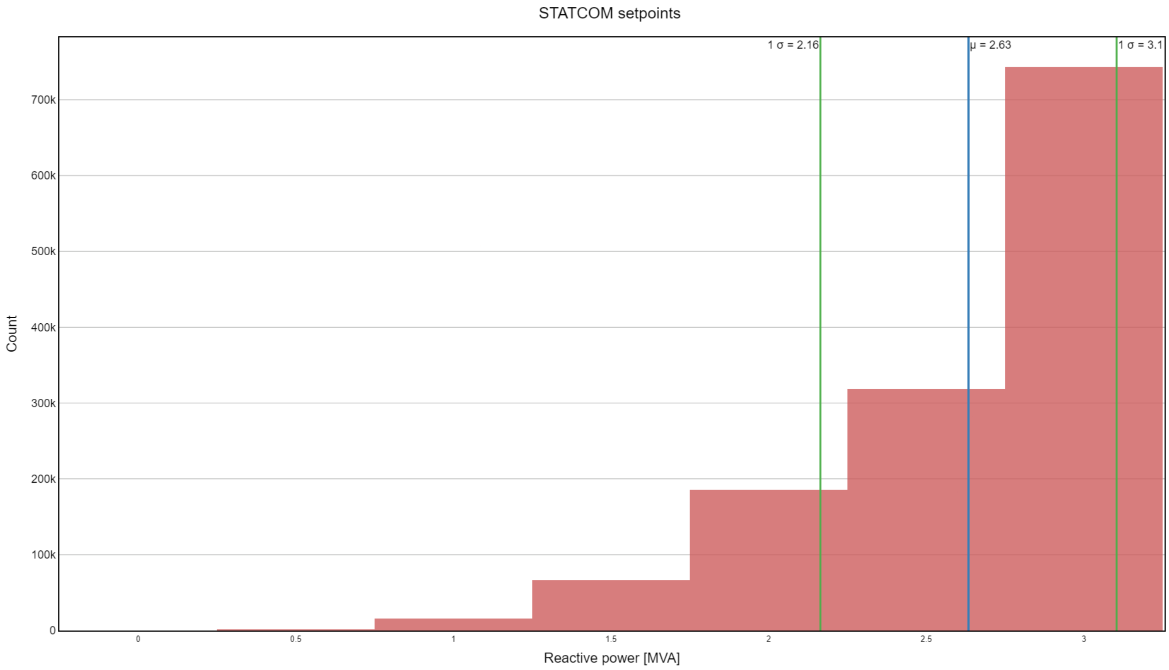
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	3MVA
SUBSTATIONS	All

Ranking



Setpoints

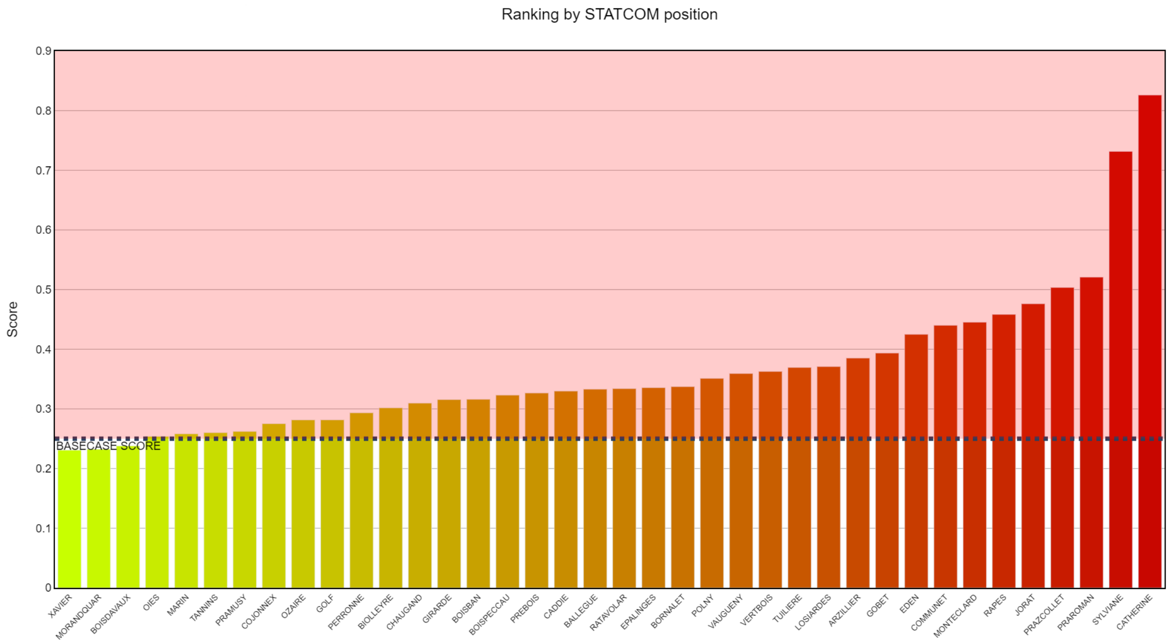


7.3.13 Q flow @ B fixed at 0MVAr – with 2050+ projections

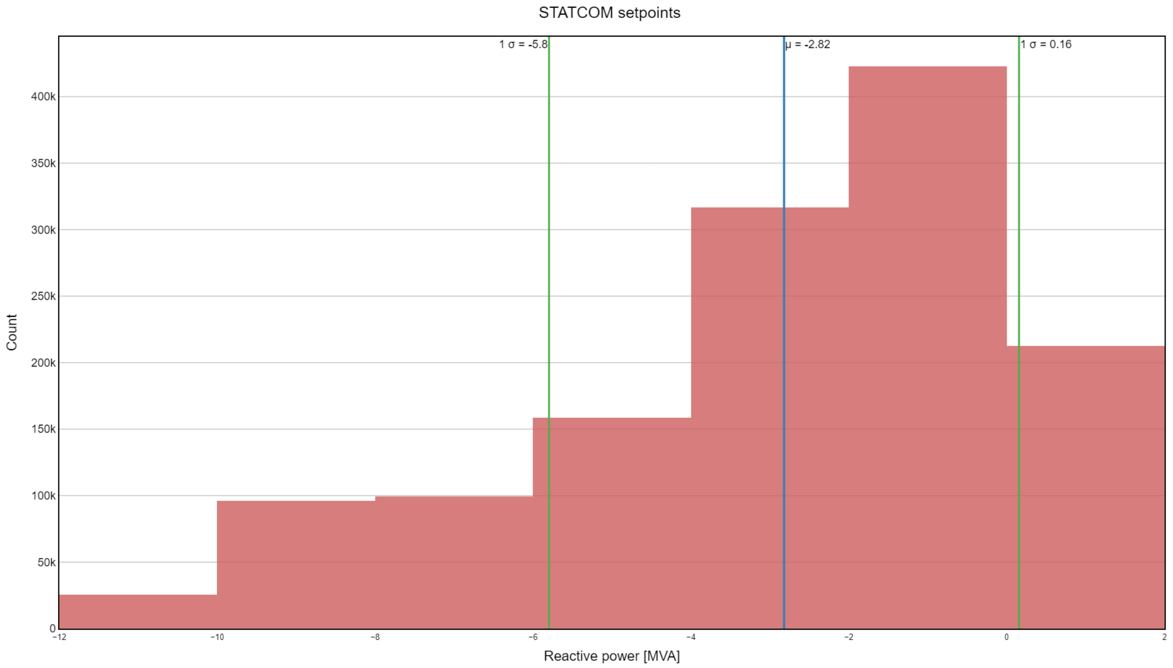
Simulation Data

Simulation	Quasi Dynamic Simulation – One year
Data definition	1-hour data resolution
STATCOM power	Unlimited
SUBSTATIONS	All

Ranking



Setpoints



7.4 Performance index description

In order to give a unique score for each grid topology and for each grid control mode when using the SOP, we combine the effect of four indexes:

7.4.1 Voltage index:

$$index_{\Delta u} = \frac{1}{n}\sum_{i=1}^{N}\left(\frac{\max_{k}\{u_{i,k}\} - \min_{k}\{u_{i,k}\}}{d_{\{max\}}}\right)^2 \quad (eq.1)$$

Where:

$\boldsymbol{N}$	Total number of buses with loads connected
$\max_{i}\{u_{k,i}\}$ $\min_{i}\{u_{k,i}\}$	Represent respectively the maximum and minimum voltage magnitudes for each "i" node among the "k" scenarios, among all STATCOM location
$\boldsymbol{d_{\{max\}}}$	The maximum voltage magnitude deviation margin.

This index takes into account the maximum deviation of the voltage magnitude for each bus connected to a load among all scenarios.

7.4.2 Current index:

$$index_{\Delta i_{\{cable\}}} = \frac{1}{M}\sum_{j=1}^{M}\Delta i_{\{cable\},j} \quad (eq.2)$$

$$\Delta i_{\{cable\},j} = \begin{cases} \dfrac{\dfrac{\max_{k}\{I_{(m,j),k}\}}{I_{n,j}}}{2}, & \dfrac{\max_{k}\{I_{(m,j),k}\}}{I_{n,j}} \geq 0.5 \\ \dfrac{\max_{k}\{I_{(m,j),k}\}}{I_{n,j}}, & \dfrac{I_{m,j}}{I_{n,j}} < 0.5 \end{cases} \quad (eq.3)$$

Where:

$\boldsymbol{M}$	Total number of line connections
$\max_{k}\{I_{(m,j),k}\}$	The maximum value of the measured current "m" for line "j" among the "k" scenarios, among all STATCOM location
$\boldsymbol{I_{n,j}}$	The nominal current "n" for line "j"

For this index, we choose to penalize lines that are loaded more than 50%. The current index gives an approach to translate the maximum loading of different lines in the network.

7.4.3 Maximum transformer loading:

$$index_{i_{TR\{max\}}} = \max_{i,k}\{i_{TR_{i,k}}\} \quad (eq.4)$$

Where:

$\boldsymbol{i_{TR_{i,k}}}$	Loading in [p.u] of transformer "i" during scenario "k", among all STATCOM location

This index returns the value of a current in [p.u] for the transformer with the highest loading among all scenarios.

7.4.4 Losses index:

$$index_{losses} = \frac{1}{K}\sum_{k=1}^{K}\left(\gamma_k * \frac{P_{loss,tot,k}}{P_{load,tot,k}}\right) \quad (eq.5)$$

Where:

$\boldsymbol{K}$	Total number of scenarios
$\boldsymbol{P_{loss,tot,k}}$	Total grid losses in [kW] for scenario "k", among all STATCOM location
$\boldsymbol{P_{load,tot,k}}$	Total load in [kW] for scenario "k", among all STATCOM location
$\boldsymbol{\gamma_k}$	Weighting factor for each scenario "k", where $\sum_k \gamma_k = 1$

The losses index is in [p.u] and it computes the mean value of total losses among all scenarios. In this simulation studies, we assumed that total losses in each scenario include cables, transformers and converter losses (if STATCOM is connected) and the total load divides them in order to have losses in [p.u].

7.4.5 Normalization

After collecting all indexes mentioned above, we can compute the score of each case study by using the following equation:

$$score = \sum_{j=1}^{J}(\alpha_j * idx_j) \quad (eq.6)$$

Where:

$\boldsymbol{J}$	Total number of involved indexes
$\boldsymbol{idx_j}$	The normalized index
$\boldsymbol{\alpha_j}$	Weighting factor for each index "j", where $\sum_j \alpha_j = 1$

The score value ranges between zero and one because indexes are normalised before the score computation. The best score is the lowest one because an index with a high value means that the electrical grid is approaching its limits by indicating for example a high deviation in voltage magnitudes or a high loading of cables and transformers or as well a lot of losses, depending on the computed index. In order to compare the score between different study cases, we normalise each category of indexes by following these steps:

- We classify in a descending order the corresponding indices among all case studies
- We compute the maximum deviation, i.e. the difference between the first and last index
- We compute the normalised index by using this equation:

$$idx = 1 - \left(\frac{index_{max} - index_{initial}}{\Delta max}\right) \quad (eq.7)$$

Where:

$\boldsymbol{index_{max}}$	Index with the highest value (classified in the first position)
$\boldsymbol{index_{initial}}$	Initial value of the index
$\boldsymbol{\Delta max}$	The maximum deviation, i.e. the difference between the first and last index

7.5 Index results for each simulation

7.5.1 Infinite STATCOM power

	Local busbar @ 1pu			Busbar with max deviation as B			Q flow @ B fixed at 0VAr			OPF: minimisation of losses in B			
Substation name	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
ARZILLIER	0.385	4.65	1.791	0.382	5.35	2.039	0.101	2.64	0.268	0.390	4.42	1.727	5.83
BALLEGUE	0.405	5.03	2.040	0.426	5.89	2.506	0.158	2.64	0.417	0.400	4.74	1.897	6.86
BIOLLEYRE	0.352	5.44	1.917	0.376	6.37	2.395	0.126	2.63	0.332	0.351	5.10	1.791	6.43
BOISBAN	0.360	5.26	1.893	0.363	6.09	2.210	0.094	2.63	0.247	0.364	4.97	1.809	6.16
BOISDAVAUX	0.210	5.65	1.187	0.242	6.74	1.631	0.091	2.63	0.241	0.206	5.30	1.092	4.15
BOISPECCAU	0.378	4.58	1.733	0.439	5.53	2.425	0.286	2.64	0.756	0.337	4.22	1.423	6.34
BORNALET	0.397	4.80	1.905	0.420	5.62	2.360	0.167	2.64	0.440	0.389	4.53	1.762	6.47
CADDIE	0.377	4.44	1.674	0.439	5.40	2.373	0.246	2.64	0.651	0.334	4.06	1.358	6.06
CATHERINE	0.639	3.20	2.049	0.684	3.86	2.641	0.662	2.67	1.766	0.593	2.97	1.762	8.22
CHAUGAND	0.372	5.39	2.007	0.394	6.31	2.485	0.133	2.63	0.349	0.371	5.06	1.877	6.72
COJONNEX	0.297	4.83	1.434	0.361	5.85	2.115	0.206	2.64	0.542	0.254	4.45	1.127	5.22
COMMUNET	0.496	4.76	2.362	0.559	5.77	3.223	0.324	2.64	0.857	0.448	4.35	1.947	8.39
EDEN	0.496	4.52	2.242	0.514	5.28	2.715	0.339	2.64	0.897	0.488	4.26	2.075	7.93
EPALINGES	0.375	5.13	1.926	0.375	5.93	2.224	0.096	2.63	0.252	0.381	4.85	1.847	6.25
GIRARDE	0.374	5.09	1.906	0.397	5.96	2.368	0.145	2.63	0.381	0.369	4.80	1.772	6.43
GOBET	0.469	4.18	1.958	0.517	5.04	2.602	0.371	2.65	0.983	0.426	3.86	1.645	7.19
GOLF	0.296	4.80	1.417	0.365	5.83	2.127	0.212	2.64	0.559	0.254	4.39	1.113	5.22
JORAT	0.518	4.33	2.240	0.573	5.20	2.981	0.358	2.65	0.948	0.466	3.97	1.851	8.02
LOSIARDES	0.387	4.94	1.910	0.457	6.02	2.751	0.235	2.64	0.620	0.341	4.50	1.532	6.81
MARIN	0.245	5.12	1.254	0.315	6.23	1.964	0.191	2.64	0.503	0.202	4.69	0.946	4.67
MONTECLARD	0.511	4.94	2.527	0.533	5.79	3.081	0.347	2.64	0.915	0.503	4.64	2.336	8.86
MORANDQUAR	0.144	5.46	0.786	0.209	6.82	1.424	0.169	2.63	0.445	0.120	4.93	0.591	3.25
OIES	0.224	5.00	1.122	0.280	6.22	1.743	0.192	2.64	0.505	0.189	4.52	0.854	4.22
OZAIRE	0.291	4.55	1.322	0.346	5.59	1.935	0.218	2.64	0.577	0.245	4.11	1.008	4.84
PERRONNE	0.309	4.41	1.360	0.363	5.41	1.963	0.227	2.64	0.601	0.263	3.99	1.049	4.97
POLNY	0.380	4.96	1.883	0.378	5.71	2.158	0.094	2.64	0.249	0.385	4.70	1.810	6.10
PRAMUSY	0.201	5.12	1.029	0.262	6.39	1.675	0.185	2.64	0.487	0.169	4.62	0.781	3.97
PRAROMAN	0.531	3.94	2.094	0.582	4.73	2.753	0.395	2.65	1.049	0.479	3.63	1.737	7.63
PRAZCOLLET	0.529	4.10	2.168	0.581	4.91	2.856	0.381	2.65	1.009	0.476	3.77	1.795	7.83
PREBOIS	0.397	5.13	2.038	0.418	6.00	2.507	0.151	2.63	0.398	0.394	4.82	1.899	6.84
RAPES	0.509	4.52	2.300	0.568	5.45	3.095	0.342	2.64	0.905	0.457	4.14	1.890	8.19
RATAVOLAR	0.358	3.98	1.423	0.409	4.88	1.998	0.259	2.65	0.685	0.312	3.60	1.124	5.23
SYLVIANE	0.611	3.43	2.095	0.658	4.13	2.718	0.571	2.66	1.520	0.563	3.18	1.790	8.12
TANNINS	0.239	5.36	1.281	0.253	6.22	1.573	0.079	2.63	0.207	0.240	5.05	1.210	4.27
TUILIERE	0.384	4.78	1.837	0.381	5.50	2.094	0.097	2.64	0.256	0.390	4.54	1.771	5.96
VAUGUENY	0.381	4.87	1.857	0.379	5.61	2.123	0.095	2.64	0.250	0.387	4.62	1.789	6.02
VERTBOIS	0.431	4.46	1.921	0.488	5.38	2.625	0.339	2.64	0.896	0.388	4.11	1.596	7.04
XAVIER	0.137	5.50	0.753	0.198	6.87	1.362	0.167	2.63	0.440	0.114	4.96	0.564	3.12

7.5.2 STATCOM power limited at 1MVA

	Local busbar @ 1pu			Busbar with max deviation as B			Q flow @ B fixed at 0VAr			OPF: minimisation of losses in B			
Substation name	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
ARZILLIER	0.070	1.00	0.070	0.045	1.00	0.045	0.048	1.00	0.048	0.366	1.00	0.366	0.53
BALLEGUE	0.233	1.00	0.233	0.200	1.00	0.200	0.177	1.00	0.177	0.316	1.00	0.316	0.93
BIOLLEYRE	0.222	1.00	0.223	0.180	1.00	0.180	0.155	1.00	0.155	0.271	1.00	0.271	0.83
BOISBAN	0.122	1.00	0.122	0.091	1.00	0.091	0.085	1.00	0.085	0.302	1.00	0.302	0.60
BOISDAVAUX	0.216	1.00	0.216	0.168	1.00	0.169	0.144	1.00	0.144	0.185	1.00	0.185	0.71
BOISPECCAU	0.540	1.00	0.541	0.551	1.00	0.552	0.428	1.00	0.429	0.266	1.00	0.267	1.79
BORNALET	0.246	1.00	0.246	0.214	1.00	0.215	0.192	1.00	0.192	0.344	1.00	0.344	1.00
CADDIE	0.583	1.00	0.583	0.539	1.00	0.539	0.436	1.00	0.436	0.331	1.00	0.331	1.89
CATHERINE	0.729	1.00	0.730	0.678	1.00	0.679	0.723	1.00	0.724	0.611	1.00	0.612	2.74
CHAUGAND	0.220	1.00	0.220	0.180	1.00	0.180	0.156	1.00	0.156	0.242	1.00	0.242	0.80
COJONNEX	0.544	1.00	0.545	0.519	1.00	0.520	0.409	1.00	0.409	0.235	1.00	0.235	1.71
COMMUNET	0.661	1.00	0.661	0.600	1.00	0.601	0.557	1.00	0.558	0.551	1.00	0.551	2.37
EDEN	0.299	1.00	0.300	0.264	1.00	0.264	0.220	1.00	0.220	0.371	1.00	0.372	1.16
EPALINGES	0.099	1.00	0.099	0.072	1.00	0.072	0.072	1.00	0.073	0.316	1.00	0.316	0.56
GIRARDE	0.232	1.00	0.232	0.198	1.00	0.199	0.173	1.00	0.174	0.265	1.00	0.266	0.87
GOBET	0.567	1.00	0.568	0.584	1.00	0.584	0.481	1.00	0.482	0.319	1.00	0.319	1.95
GOLF	0.624	1.00	0.625	0.516	1.00	0.517	0.415	1.00	0.416	0.299	1.00	0.299	1.86
JORAT	0.619	1.00	0.620	0.624	1.00	0.625	0.586	1.00	0.587	0.564	1.00	0.565	2.40
LOSIARDES	0.609	1.00	0.609	0.526	1.00	0.526	0.427	1.00	0.427	0.265	1.00	0.265	1.83
MARIN	0.610	1.00	0.611	0.492	1.00	0.492	0.398	1.00	0.398	0.188	1.00	0.188	1.69
MONTECLARD	0.264	1.00	0.264	0.229	1.00	0.229	0.186	1.00	0.187	0.367	1.00	0.367	1.05
MORANDQUAR	0.560	1.00	0.560	0.397	1.00	0.397	0.388	1.00	0.388	0.119	1.00	0.119	1.46
OIES	0.584	1.00	0.584	0.454	1.00	0.454	0.409	1.00	0.409	0.206	1.00	0.206	1.65
OZAIRE	0.611	1.00	0.611	0.502	1.00	0.502	0.433	1.00	0.433	0.272	1.00	0.272	1.82
PERRONNE	0.621	1.00	0.621	0.515	1.00	0.516	0.441	1.00	0.441	0.279	1.00	0.279	1.86
POLNY	0.083	1.00	0.083	0.059	1.00	0.059	0.060	1.00	0.060	0.324	1.00	0.324	0.53
PRAMUSY	0.577	1.00	0.577	0.432	1.00	0.432	0.403	1.00	0.403	0.168	1.00	0.168	1.58
PRAROMAN	0.639	1.00	0.639	0.637	1.00	0.638	0.618	1.00	0.619	0.571	1.00	0.572	2.47
PRAZCOLLET	0.629	1.00	0.630	0.632	1.00	0.633	0.605	1.00	0.605	0.571	1.00	0.571	2.44
PREBOIS	0.229	1.00	0.229	0.194	1.00	0.194	0.171	1.00	0.171	0.307	1.00	0.307	0.90
RAPES	0.616	1.00	0.616	0.615	1.00	0.615	0.572	1.00	0.573	0.557	1.00	0.557	2.36
RATAVOLAR	0.652	1.00	0.652	0.549	1.00	0.550	0.476	1.00	0.477	0.323	1.00	0.323	2.00
SYLVIANE	0.669	1.00	0.670	0.648	1.00	0.648	0.676	1.00	0.677	0.601	1.00	0.601	2.60
TANNINS	0.158	1.00	0.159	0.124	1.00	0.124	0.097	1.00	0.097	0.290	1.00	0.290	0.67
TUILIERE	0.071	1.00	0.071	0.048	1.00	0.048	0.050	1.00	0.050	0.361	1.00	0.362	0.53
VAUGUENY	0.076	1.00	0.076	0.053	1.00	0.053	0.055	1.00	0.055	0.327	1.00	0.327	0.51
VERTBOIS	0.546	1.00	0.546	0.559	1.00	0.559	0.442	1.00	0.442	0.280	1.00	0.280	1.83
XAVIER	0.559	1.00	0.559	0.392	1.00	0.392	0.387	1.00	0.387	0.113	1.00	0.113	1.45

7.5.3 STATCOM power limited at 3MVA

	Local busbar @ 1pu			Busbar with max deviation as B			Q flow @ B fixed at 0VAr			OPF: minimisation of losses in B			
Substation name	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	**Index**	***max STATCOM Q***	***Final Index***	***Overall***
ARZILLIER	0.279	3.00	0.838	0.284	3.00	0.853	0.086	2.63	0.227	0.366	3.00	1.098	3.02
BALLEGUE	0.323	3.00	0.969	0.239	3.00	0.716	0.168	2.63	0.440	0.316	3.00	0.948	3.07
BIOLLEYRE	0.276	3.00	0.827	0.163	3.00	0.488	0.134	2.62	0.351	0.271	3.00	0.814	2.48
BOISBAN	0.264	3.00	0.791	0.194	3.00	0.582	0.094	2.62	0.247	0.302	3.00	0.907	2.53
BOISDAVAUX	0.233	3.00	0.698	0.107	3.00	0.322	0.109	2.62	0.285	0.185	3.00	0.556	1.86
BOISPECCAU	0.428	3.00	1.284	0.305	2.63	0.802	0.295	2.63	0.775	0.266	3.00	0.799	3.66
BORNALET	0.326	3.00	0.979	0.258	3.00	0.775	0.174	2.63	0.457	0.344	3.00	1.033	3.24
CADDIE	0.372	3.00	1.117	0.309	2.46	0.758	0.289	2.63	0.760	0.331	2.92	0.965	3.60
CATHERINE	0.707	3.00	2.122	0.595	1.87	1.110	0.721	2.66	1.917	0.611	3.00	1.835	6.98
CHAUGAND	0.289	3.00	0.866	0.180	3.00	0.542	0.145	2.62	0.380	0.242	3.00	0.726	2.51
COJONNEX	0.331	3.00	0.992	0.256	2.74	0.701	0.254	2.63	0.669	0.235	3.00	0.706	3.07
COMMUNET	0.510	3.00	1.529	0.384	2.67	1.025	0.374	2.63	0.985	0.551	3.00	1.653	5.19
EDEN	0.516	3.00	1.550	0.495	2.98	1.474	0.242	2.63	0.637	0.371	3.00	1.114	4.78
EPALINGES	0.269	3.00	0.806	0.220	3.00	0.659	0.089	2.62	0.234	0.316	3.00	0.947	2.65
GIRARDE	0.304	3.00	0.912	0.212	3.00	0.636	0.153	2.62	0.403	0.265	3.00	0.797	2.75
GOBET	0.517	3.00	1.551	0.372	2.41	0.897	0.396	2.64	1.046	0.319	3.00	0.957	4.45
GOLF	0.359	3.00	1.079	0.267	2.65	0.707	0.259	2.63	0.681	0.299	3.00	0.898	3.37
JORAT	0.505	3.00	1.515	0.426	2.50	1.064	0.406	2.64	1.070	0.564	3.00	1.694	5.34
LOSIARDES	0.396	3.00	1.188	0.279	2.69	0.751	0.269	2.63	0.708	0.265	3.00	0.795	3.44
MARIN	0.331	3.00	0.992	0.230	2.82	0.649	0.242	2.63	0.635	0.188	3.00	0.565	2.84
MONTECLARD	0.527	3.00	1.583	0.463	3.00	1.388	0.402	2.63	1.056	0.367	3.00	1.100	5.13
MORANDQUAR	0.275	3.00	0.826	0.206	2.78	0.573	0.215	2.62	0.564	0.119	3.00	0.357	2.32
OIES	0.321	3.00	0.962	0.250	2.58	0.645	0.237	2.63	0.622	0.206	3.00	0.619	2.85
OZAIRE	0.358	3.00	1.074	0.293	2.36	0.690	0.261	2.63	0.687	0.272	3.00	0.816	3.27
PERRONNE	0.367	3.00	1.101	0.303	2.30	0.698	0.270	2.63	0.710	0.279	3.00	0.837	3.35
POLNY	0.272	3.00	0.816	0.244	3.00	0.733	0.082	2.63	0.215	0.324	3.00	0.971	2.74
PRAMUSY	0.308	3.00	0.923	0.240	2.62	0.628	0.230	2.63	0.605	0.168	3.00	0.504	2.66
PRAROMAN	0.515	3.00	1.544	0.457	2.31	1.058	0.440	2.64	1.163	0.571	3.00	1.715	5.48
PRAZCOLLET	0.513	3.00	1.539	0.447	2.40	1.072	0.426	2.64	1.125	0.571	3.00	1.713	5.45
PREBOIS	0.314	3.00	0.943	0.224	3.00	0.671	0.161	2.62	0.423	0.307	3.00	0.920	2.96
RAPES	0.497	3.00	1.492	0.407	2.58	1.049	0.391	2.63	1.029	0.557	3.00	1.673	5.24
RATAVOLAR	0.385	3.00	1.154	0.339	2.08	0.706	0.299	2.64	0.788	0.323	3.00	0.970	3.62
SYLVIANE	0.650	3.00	1.951	0.530	2.00	1.057	0.590	2.65	1.563	0.601	3.00	1.803	6.37
TANNINS	0.239	3.00	0.716	0.151	3.00	0.453	0.081	2.62	0.213	0.290	3.00	0.870	2.25
TUILIERE	0.278	3.00	0.834	0.271	3.00	0.813	0.083	2.63	0.219	0.361	3.00	1.084	2.95
VAUGUENY	0.274	3.00	0.824	0.257	3.00	0.770	0.082	2.63	0.216	0.327	3.00	0.981	2.79
VERTBOIS	0.486	3.00	1.459	0.331	2.57	0.851	0.321	2.63	0.847	0.280	3.00	0.840	4.00
XAVIER	0.271	3.00	0.814	0.203	2.80	0.567	0.214	2.62	0.560	0.113	3.00	0.339	2.28