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COSTAM Project

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ABBREVIATIONS

COSTAM	COmparative performance assessment of STAtcom technologies based on Modular multilevel converters architectures
DSCC :	Double Star Chopper-Cells
HV:	High Voltage
LV:	Low Voltage
MSC:	Mechanically Switched Capacitor
MSR:	Mechanically Switched Reactor
MV:	Medium Voltage
NPC :	Neutral-Point Clamped
PWM :	Pulse Width Modulation
RES :	Renewable Energy Sources
SDBC :	Single Delta Bridge-Cells
IGBT:	Insulated Gate Bipolar Transistor
SSBC :	Single Star Bridge-Cells
STATCOM :	STAtic synchronous COMpensator
TSC:	Thyristor Switched Capacitors
TSR:	Thyristor Switched Reactors

1 INTRODUCTION

This report D1.3 is the third part of COSTAM project's deliverable D1. The aim of this report is to make a review of main STATCOM technologies available on the market nowadays. Then these technologies are compared based on the following criteria:

- Converter topology (architecture and power modules);
- Voltage level MV, LV or HV;
- Power range;
- Cooling system;
- Fooprint;
- Cost.

Cost is a sensitive information that only project partners can have access. This is the reason why costs are mentioned as confidential for this report which can be freely published. A separate report will be sent only to the partners of the project, containing this information.

In this report, section 2 summarizes the STATCOM products and their main features in tables for each manufacturer. Section 3 and section 4 compare the products of section 2 according to the criteria above mentioned. Finally, section 5 provides a list of the possible STATCOMs that could fit the SIL case study of this project.

To begin this study, trusted companies supplying STATCOM products were identified. The methodology to select the manufacturers is presented in Figure 1-1.

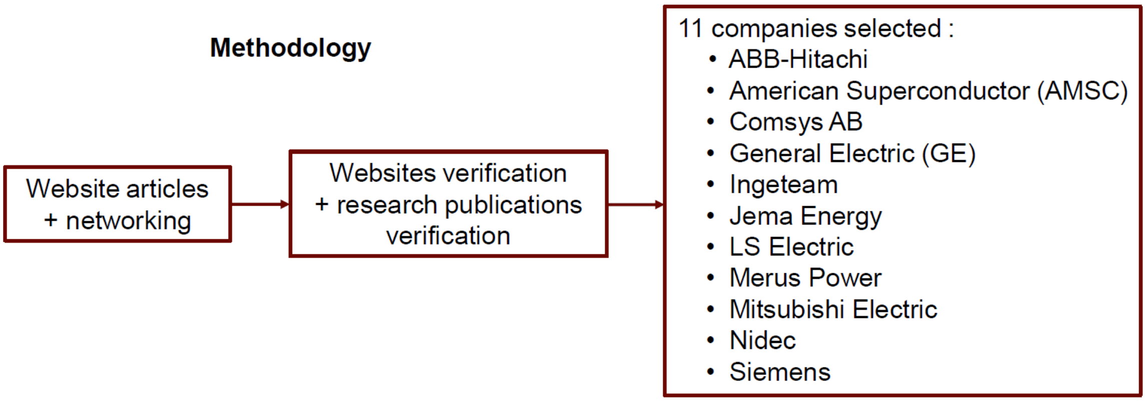

Figure 1-1: Manufacturers selection methodology

Websites [1] and [2], the document [3] as well as networking were used first. Then some verifications on companies' website and IEEE Xplore were made to definitely select suppliers to study, presented in Figure 1-1.

2 REVIEW OF STATCOM PRODUCTS BY MANUFACTURER

In each sub sections, a table summary of the products for each manufacturer with their criteria above mentioned is proposed. No commentary is necessary because next sections already go in details. For better clarity, references have colours and are exposed once in the STATCOM name cell of the table.

2.1 ABB-HITACHI

	PCS100 [4]	**VARPRO** [5], [6], [7]	**PCS 6000** **Low power** [8], [9]	**SVC LIGHT** **Medium power** [8], [10], [11]	**SVC LIGHT** **High power** [8], [10], [11]
Topology	2-level inverter IGBT modules	2-level inverter IGBT modules	3-level NPC IGCT modules	SDBC IGCT modules	SDBC IGBT modules
Voltage level	LV 480 V without transformer or MV with transformer	BT 480 V without transformer or MV with transformer	MV → 10 kV without transformer or MT → HT 345 kV with transformer	MV → 69 kV without transformer or MT → HT 345 kV with transformer	MT → 69 kV without transformer or MT → HT 345 kV with transformer
Power range	100 kvar → 10 Mvar	50 kvar → 32 Mvar	15 Mvar → 40 Mvar	40 Mvar → 120 Mvar	75 Mvar → 440 Mvar
Type of cooling	Forced air	Forced air or Liquid with forced air heat exchanger	Water with forced air heat exchanger	Liquid with forced air heat exchanger	Liquid with forced air heat exchanger
Converter footprint **(height x length x depth)**	Armoire 2 Mvar 2.2 x 4.082 x 0.703 m Ou Container 2 Mvar ~ 3 x 6 x 3 m	Armoire 3 Mvar ~ 3 x 5 x 1.5 m Ou Container 12 Mvar ~ 3 x 14 x 3 m	Container 20 Mvar ~ 3 x 12 x 3 m	Typically for 95 Mvar application, ground floor building ~ 10 x 15 m	
Cost	No information	No information	***CONFIDENTIAL***		

Some pictures of ABB-HITACHI STATCOMs are presented below.

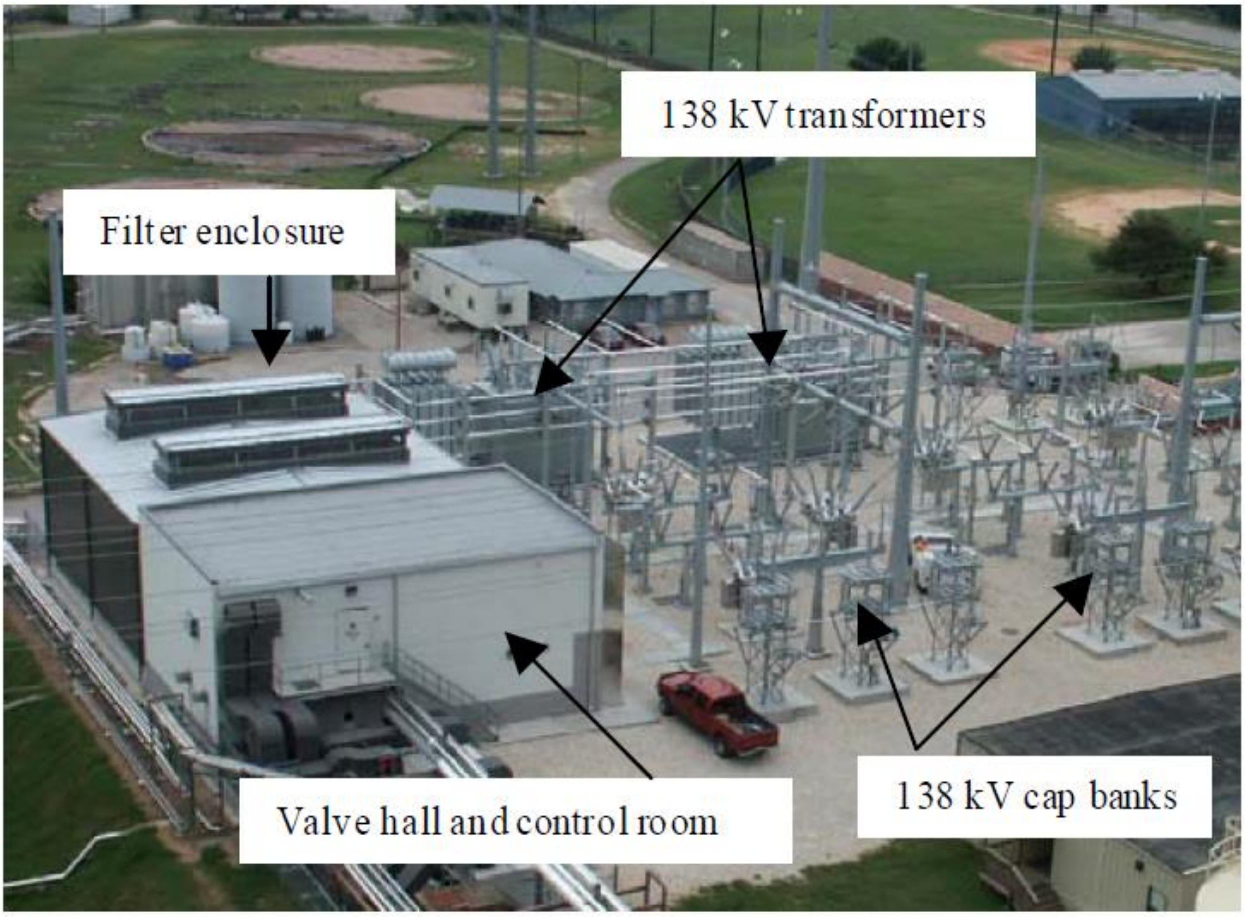

Figure 2-1: Holly STATCOM plant, taken from [11]

Modular H-bridge units,
2 stacks of 4 modules each

Figure 2-2 : Photo of 2 stacks of 4 modules of the SVC LIGHT STATCOM, taken from [12]

Figure 2-3: SVC LIGHT "Stakpak" IGBT modules, taken from [8]

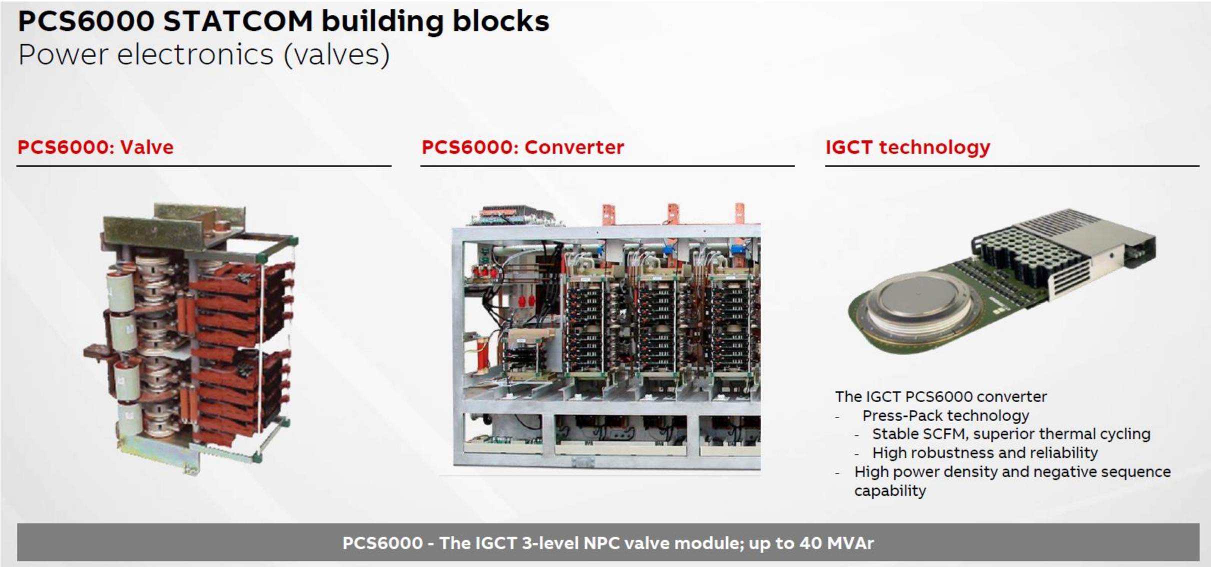

Figure 2-4 : PSC6000, valve module on the left, in the middle a part of the converter, on the right IGCT power module, taken from [8]

Figure 2-5: 3 Mvar ABB VarPro STATCOM cupboard with converters in the middle, taken from [13]

2.2 AMSC

	D-VAR [14], [15]	**D-VAR VVO** [16], [17], [18], [19], [20], [21]
Topology	2-level inverter IGBT modules	SSBC IGBT modules
Voltage level	LV without transformer or MV → 46 kV with transformer	MV 10 kV → 15 kV without transformer or MV 19 kV → 35 kV with transformer
Power range	2 Mvar (4 Mvar standard) → 96 Mvar (= 24 * 4 Mvar)	500 kvar → 1 Mvar (3 ph, 1 x convertisseur) → 4 Mvar 167 kvar → 333 kvar (1 ph, 1 x convertisseur)
Type of cooling	Forced air	Oil (internal) / air (external) heat exchanger (both natural convection)
Converter footprint **(height x length x depth)**	4 Mvar outdoor cabinet 2.44 x 2.44 x 2.44 m	Outdoor cabinet with 1 Mvar 3 phases and integrated cooler 1.52 x 1.52 x 3.25 m
Cost	CONFIDENTIAL	CONFIDENTIAL

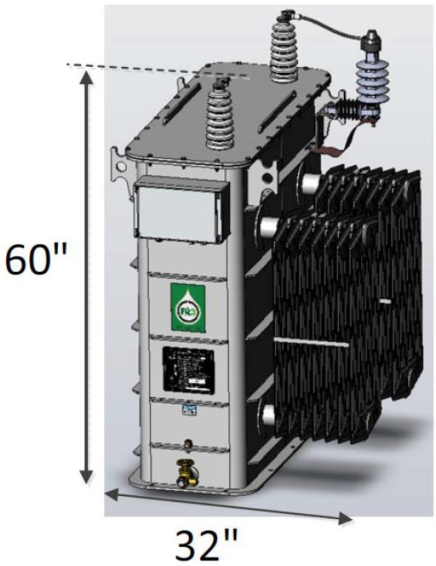

Figure 6: +/- 343 kvar one phase inverter D-VAR VVO, taken from [22]

2.3 COMSYS

	ADF-P300 [23], [24], [25]	ADF PPM300 [23], [25], [26],	ADF P700 [23], [25], [27], [28]
Topology	2-level Modules IGBT	2-level Modules IGBT	2-level Modules IGBT
Voltage level	LV 480 or 600 or 690 V Without transformer or MV possible with transformer	LV 480 or 690 V Without transformer or MV possible with transformer	LV 480 or 600 or 690 V Without transformer or MV 6 -> 36 kV with transformer
Power range	83 kvar -> 3.735 Mvar	34 kvar -> 9 270 kvar	1 Mvar -> 20 Mvar
Type of cooling	Forced air	Forced air	Liquid with forced air heat exchanger
Converter footprint **(height x length x depth)**	Indoor cupboard for 249 kvar model 2.168 x 0.805 x 0.636 m	Indoor cupboard for 103 kvar model 1.443 x 0.227 x 0.471 m	Container 20 ft: 8'6'' x 20' x 8' 2.6 x 6.1 x 2.44 m Ou For 6 Mvar, container 40 ft: 8'6'' x 40' x 8' 2.6 x 12.19 x 2.44 m
Cost	No information	No information	CONFIDENTIAL

2.4 General Electric

	General Electric STATCOM [29], [30], [31]
Topology	SDBC Module IGBT
Voltage level	MT -> around 70 kV without transformer or HV -> 345 kV with transformer
Power range	1 Mvar -> 975 Mvar
Type of cooling	Liquid : Water/Glycol mix with forced air heat exchanger
Converter footprint **(height x length x depth)**	No information
Cost	CONFIDENTIAL

2.5 INGETEAM

	Ingegrid STATCOM [32], [33]
Topology	3-level NPC IGBT modules
Voltage level	MV 3.3 kV -> 4.16 kV without transformer MV 13.8 kV -> HV 230 kV with transformer
Power range	10 Mvar -> 4*20 = 80 Mvar
Type of cooling	Forced air or Water + antifreeze with forced air heat exchanger
Converter footprint **(height x length x depth)**	Cupboard : 17 à 20 Mvar 2.3 x 5.2 x 1.4 m Container : 14 Mvar (40 foot) *8’6’’ x 40’ x 8’* *2.6 x 12.19 x 2.44 m*
Cost	No information

2.6 JEMA ENERGY

	LV STATCOM [34]	MV STATCOM [34]
Topology	2-level IGBT modules	MMC, but no more information IGBT modules
Voltage level	LV without transformer	MV -> 33 kV
Power range	500 kvar -> 3 Mvar	10 Mvar -> 40 Mvar
Type of cooling	Forced air	Water with forced air heat exchanger
Converter footprint **(height x length x depth)**	No information	(10 Mvar ou 20 Mvar) Container 20 foots: 8’6’’ x 20’ x 8’ 2.6 x 6.1 x 2.44 m or (30 Mvar ou 40 Mvar) Container 40 foots : 8’6’’ x 40’ x 8’ 2.6 x 12.19 x 2.44 m
Cost	No information	No information

2.7 LS ELECTRIC

	Panel STATCOM [35], [36], [37]	MMC STATCOM [35], [36]
Topology	3-level NPC	SDBC Modules IGBT
Voltage level	LV : 380 or 440 V without transformer MV -> 12 kV with transformer	MV -> 345 kV
Power range	90 kvar -> 24 Mvar	-> 300 Mvar
Type of cooling	Forced air	Water with forced air heat exchanger
Converter footprint **(height x length x depth)**	2 Mvar cupboard: 2.205 x 3.83 x 0.88 m	Container 45 ft until 50 Mvar (including cooling system, control and heat exchanger on the roof) 8ft 6ins x 45 ft x 8 ft 2.59 x 13.72 x 2.44 m or Custom building for high power
Cost	No information	No information

2.8 Merus Power

	M-STATCOM [38], [39], [40]
Topology	Probably 3-level NPC Modules IGBT
Voltage level	MV: 0.96 kV (M1000) or 2 kV (M2000) without transformer >2 kV -> 38.5 kV Avec transformateur
Power range	1.36 Mvar (M1000) ou 2 MVAR (2000) -> hundreds of Mvar (at least 150 Mvar)
Type of cooling	Water with forced air heat exchanger
Converter footprint **(height x length x depth)**	Container 40 ft for 8 Mvar (including cooling system, control and heat exchanger on the roof) 12.78 ft x 40 ft x 8 ft 3.895 x 12.19 x 2.44 m Building installation for converter 144 Mvar: 4 x 22 x 18 m
Cost	No information

2.9 Mitsubishi Electric

	SVC-Diamond [41], [42]
Topology	SDBC Modules IGBT
Voltage level	69 kV -> 765 kV
Power range	50 Mvar -> 800 Mvar
Type of cooling	Water mixed with propylene glycol and forced air heat exchanger
Converter footprint **(height x length x depth)**	No information
Cost	No information

2.10 NIDEC

	Silcovar D [43], [44]	Silcovar H [43], [44], [45], [46],
Topology	3-level NPC Modules IGBT	On demand: SDBC or SSBC Modules IGBT
Voltage level	LV <= 700 V Without transformer 0.7 kV < MV <= 24 kV With transformer	MV: 6 kV, 6.6 kV, 10 kV, 11 kV (SSBC) or 13.8 kV until 35 kV (SDBC) Without transformer Until 35 kV (for SSBC) With transformer
Power range	0.5 Mvar -> 10 Mvar	2.598 Mvar -> 170 Mvar
Type of cooling	Forced air Or Water with forced air heat exchanger	Forced air Or Water with forced air heat exchanger
Converter footprint **(height x length x depth)**	30 ft container for 10 Mvar water cooled: 2.59 x 9.14 x 2.44 m (8.5 x 30 x 8 ft)	Only indoor cabinet for air cooled, for 12 Mvar: 3 x 6.5 x 1.4 m Indoor cabinet for water cooled (within a container possible), for 30.117 Mvar: 2.6 x 11.3 x 1.6 m 40 ft container for water cooled 40 Mvar: 8.5 ft x 40 ft x 8 ft 2.59 x 12.19 x 2.44 m Building installation above 125 Mvar
Cost	No information	No information

2.11 SIEMENS

	Easy STATCOM [47]	SVC PLUS [47], [48], [49], [50], [51]
Topology	3-Level NPC IGBT modules	SDBC IGBT modules
Voltage level	LV without transformer or Any MV until 69 kV with transformer	MV 8 kV → 36 kV without transformer or MV → HV 800 kV with transformer
Power range	2.5 Mvar → 20 Mvar	25 MVAR → 500 MVAR
Type of cooling	Forced air and air-to-air heat exchanger	Liquid with forced air heat exchanger
Converter footprint **(height x length x depth)**	Outdoor cabinet for 5 Mvar: 3.76 x 3.69 x 1.17 m	Container 50 MVAR ~ 3 x 12 x 3 m Or Building application above 75 Mvar
Cost	CONFIDENTIAL	No information

3 STATCOMs COMPARISON BETWEEN EACH MANUFACTURER

Each of the manufacturer studied in previous section are compared to analyse the differences between their STATCOM products. In this section, voltage range, power range, cooling system, footprint and costs between manufacturers are compared.

3.1 Topologies distribution by manufacturer

Table 3-1 shows a summary of the different topologies proposed by each manufacturer.

Topologies distribution by manufacturer				
Manufacturer	**2-level**	**3-level NPC**	**SSBC**	**SDBC**
ABB-Hitachi	Yes	Yes	No	Yes
AMSC	Yes	No	Yes	No
COMSYS	Yes	No	No	No
General Electric	No	No	No	Yes
Ingeteam	No	Yes	No	No
Jema Energy	Yes	?	?	?
LS Electric	No	Yes	No	Yes
Merus Power	?	?	?	?
Mitsubishi Electric	No	No	No	Yes
Nidec	No	Yes	Yes	Yes
Siemens	No	Yes	No	Yes
Percentage of manufacturers using this topology	36%	45%	18%	55%

Table 3-1 : Topologies distribution by manufacturer

As it can be seen, concerning modular multilevel topologies, none of the manufacturers uses MMC Double Star topologies (DSCC or DSBC) for STATCOM applications. However, SSBC and SDBC topologies are proposed by 7 manufacturers on 11 studied (64 %).

It shows that conventional topologies (2-level and 3-level NPC) are often proposed with 8 manufacturers on 11 (73 %) too. Indeed, they are the first and simpler topologies used. However, figures show that modular topologies are well established in the STATCOM market.

5/11 manufacturers (45%) propose both conventional and modular topologies to adapt to all kind of applications and needs.

The most spread topology is the SDBC followed by 3-level NPC and 2-level. The last one is SSBC.

3.2 Voltage range comparison between manufacturers

Table 3-2 shows the voltage range available at the output of the STATCOMs without transformer for MV application (> 1kV) per manufacturer.

Voltage range without transformer by manufacturer for MV application		
Manufacturer	**MV min [kV]**	**MV max [kV]**
ABB-Hitachi	At least 10 kV	69
AMSC	10	15
COMSYS	x	x
General Electric	No information	Around 70
Ingeteam	3.3	4.16
Jema Energy	No information	No information
LS Electric	No information	No information
Merus Power	2	2
Mitsubishi Electric	No information	No information
Nidec	6	35
Siemens	8	36

Table 3-2: Voltage range without transformer by manufacturer for MV application

Figure 3-1 shows the table values in a bar chart.

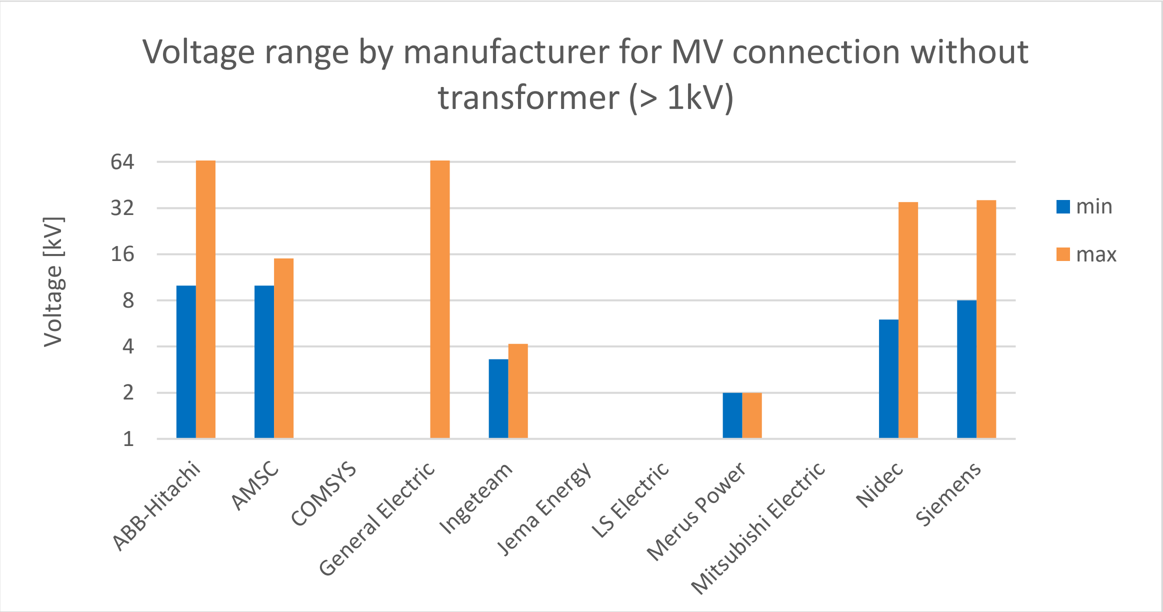

Figure 3-1 : Voltage range by manufacturer for MV connection without transformer (> 1kV)

Bar chart in Figure 3-1 is displayed with base 2 logarithmic graduation to better see the low voltage values.

Considering all manufacturers, we can see possible MV connections without the use of transformer going from 2 kV to around 70 kV. It is not possible to fit the entire range of voltage. There are only some discrete steps available between the minimum and maximum voltage values.

Table 3-3 shows the voltage range accessible for application > 1kV using a transformer per manufacturer.

Voltage range with transformer by manufacturer		
Manufacturer	**min [kV]**	**max [kV]**
ABB-Hitachi	No information	345
AMSC	At least 12	46
COMSYS	6	36
General Electric	No information	345
Ingeteam	13.8	230
Jema Energy	No information	No information
LS Electric	At least 12	345
Merus Power	2	38.5
Mitsubishi Electric	No information	765
Nidec	1	35
Siemens	1	800

Table 3-3 : Voltage range with transformer by manufacturer

Figure 3-2, shows the table values in a bar chart.

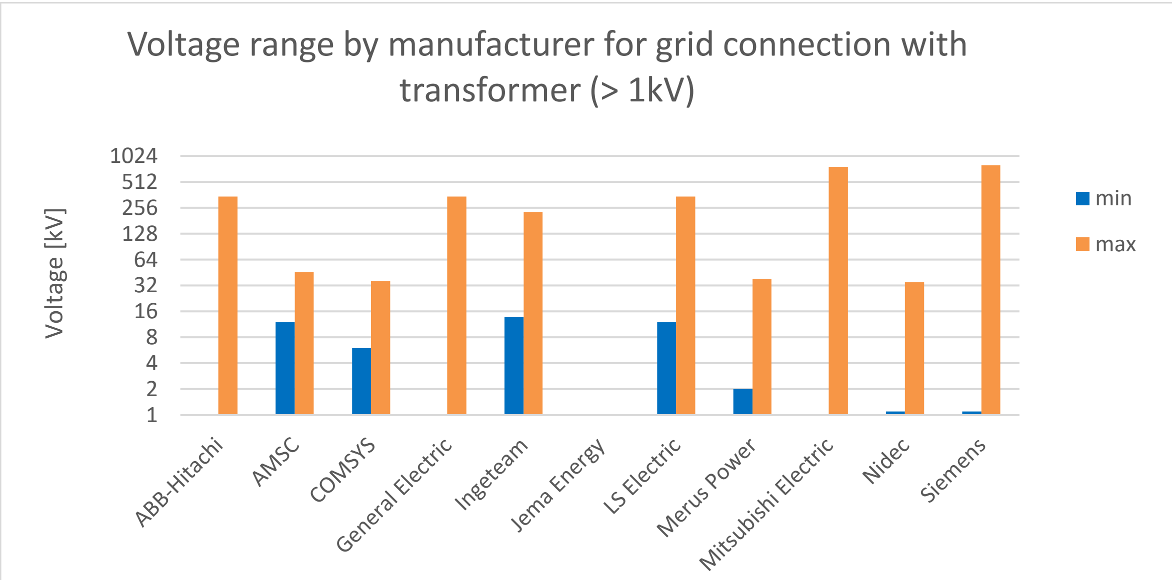

Figure 3-2: Voltage range by manufacturer for grid connection with transformer (> 1kV)

This bar chart is also displayed with base 2 logarithmic graduation to better see the low voltage values.

It can be seen that a lot of manufacturers only give information about maximum voltage connection with transformers. This is due to the fact that there is a wide variety of voltage levels depending on the application. Transformers are generally customized for the application.

Considering all manufacturers, we can see voltage connections going from 1kV to 800 kV with transformer.

The maximum voltage available with transformer gives a good estimation of the companies able to work directly in the transmission network with very high power and the ones which provide solutions to integrate in the distribution network with of course less important power.

3.3 POWER RANGE COMPARISON BETWEEN MANUFACTURERS

Table 3-4 summaries the STATCOM power range available for each manufacturer.

Power range by manufacturer		
Manufacturer	**min [Mvar]**	**max [Mvar]**
ABB-Hitachi	0.05	440
AMSC	0.5	96
COMSYS	0.034	20
General Electric	1	975
Ingeteam	10	80
Jema Energy	0.5	40
LS Electric	0.09	300
Merus Power	1.36	150
Mitsubishi Electric	50	800
Nidec	0.5	170
Siemens	2.5	500

Table 3-4 : Power range by manufacturer

In Figure 3-3, power range are distributed in an ascending order according to their minimum power available.

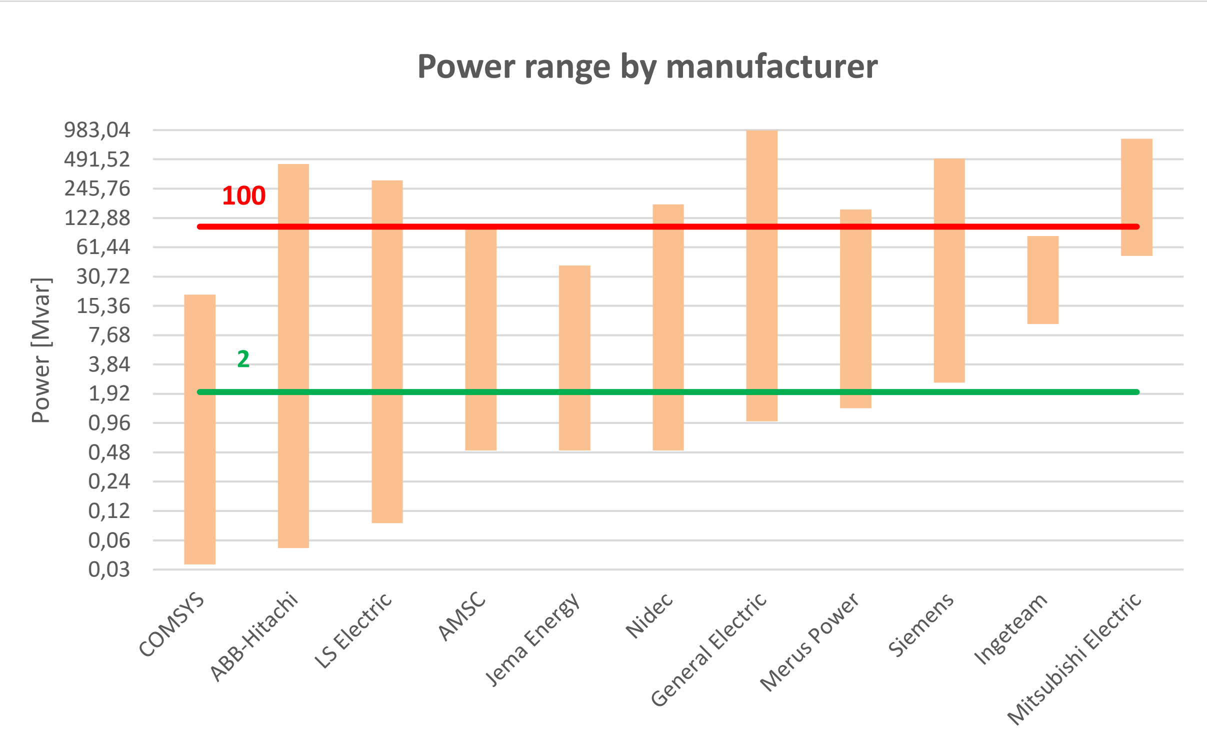

Figure 3-3 : Power range by manufacturer

Power information is well documented by manufacturers. This leads to a comparison possible between each manufacturer. It only shows minimum and maximum possible values for each manufacturer according to their proper documentation.

Manufacturers has standard converters with a specified nominal power. It does not allow to provide all powers included in the range displayed. However, by paralleling converters, manufacturers can provide some intermediate values between minimum and maximum power range.

It is also possible to use hybrid solutions adding Mechanically Switched Capacitors (MSC), Mechanically Switched Reactors (MSR), Thyristor Switched Capacitors (TSC) or Thyristor Switched Reactors (TSR) to reach the desired range of power.

There is an important difference between the lowest and the biggest power going from 0.034 Mvar to 975 Mvar. There is a huge factor of 28’676.5 between them.

8 manufacturers on 11 (73% of the 11 manufacturers studied) provide power solutions from 34 kvar to 2 Mvar in this study. This means many applications needs power quality help in relatively small range of reactive power.

However, 7 on 11 manufacturers (64% of the 11 manufacturers studied) provide power solutions more than 100 Mvar in this study. These important powers are generally used to improve power quality in high power transmission grid applications.

All manufacturers studied except Mitsubishi Electric, provide at least one solution in the range of 1 to 10 Mvar. It seems that this range of power satisfies a lot of customers. It is interesting because the study made by HEIA-FR team [52] on Lausanne MV grid made leaded to a STATCOM power in the range of 1 to 10 Mvar.

3.4 Cooling system comparison between manufacturers

Table 3-5 summaries the STATCOM cooling systems used by each manufacturer.

Cooling systems by manufacturer			
Manufacturer	**Forced air**	**Liquid with forced air heat exchanger**	**Liquid to air heat exchanger both with natural convection**
ABB-Hitachi	Yes	Yes	No
AMSC	Yes	No	Yes
COMSYS	Yes	Yes	No
General Electric	No	Yes	No
Ingeteam	Yes	Yes	No
Jema Energy	Yes	Yes	No
LS Electric	Yes	Yes	No
Merus Power	No	Yes	No
Mitsubishi Electric	No	Yes	No
Nidec	Yes	Yes	No
Siemens	Yes	Yes	No

Table 3-5: Cooling systems by manufacturer

It is interesting to see that all manufacturers uses liquid cooling system. All companies use heat exchanger with liquid/forced air operation except AMSC company which designed their D-VAR VVO STATCOM to avoid the use of forced air. It only uses oil/air heat exchanger both with natural convection.

8 on 11 manufacturer (73% of the 11 manufacturers studied) propose direct forced air cooling too. They propose it only for the lower power applications while liquid cooling is used for higher power applications.

3.5 Converter footprint comparison between manufacturers

Table 3-6 summaries footprints, surface power densities and volume power densities of all STATCOM converters studied.

Converter footprint by manufacturer *(surfaces and volumes rounded at 0.5 m^2 and 0.5 m^3 except for ADF P300 et ADF PPM300 at 0.05 m^2 and 0.05 m^3)*						
Manufacturer	**Converter surface** $[m^2]$	**Converter volume** $[m^3]$	**Power [Mvar]**	**Surface power density [Mvar/m^2]**	**Volume power density [Mvar/m^3]**	**STATCOM name**
ABB-Hitachi	3	6.5	2	0.67	0.31	PCS100
ABB-Hitachi	36	108	20	0.56	0.19	PCS6000
ABB-Hitachi	150	No info	95	0.63	No info	SVC LIGHT
ABB-Hitachi	7.5	22.5	3	0.40	0.13	VAR PRO
AMSC	6	14.5	4	0.67	0.28	D-VAR
AMSC	5	7.5	1	0.20	0.13	D-VAR VVO 3 phases
COMSYS	0.5	1.1	0.249	0.50	0.23	ADF P300
COMSYS	30	77	6	0.20	0.08	ADF P700
COMSYS	0.1	0.15	0.103	1.03	0.69	ADF PPM300
General Electric	No info	No info	No info	No info	No info	GE STATCOM
Ingeteam	30	77	14	0.47	0.18	STATCOM INGEGRID
Jema Energy	15	39	20	1.33	0.51	JEMA MV STATCOM
LS Electric	33.5	87	50	1.49	0.57	LS MMC STATCOM
LS Electric	3.5	7.5	2	0.57	0.27	LS Panel STATCOM
Merus Power	396	1584	144	0.36	0.09	M-STATCOM building
Merus Power	30	77	8	0.27	0.10	M-STATCOM container
Mitsubishi Electric	No info	No info	No info	No info	No info	SVC-Diamond
Nidec	22.5	58	10	0.44	0.17	SILCOVAR D
Nidec	30	77	40	1.33	0.52	SILCOVAR H
Siemens	4.5	16	5	1.11	0.31	Easy STATCOM
Siemens	36	108	50	1.39	0.46	SVC PLUS

Table 3-6: Converter footprint by manufacturer

Figure 3-4 shows a bar chart of the surface power density of all STATCOM converters studied, organised in an ascending order.

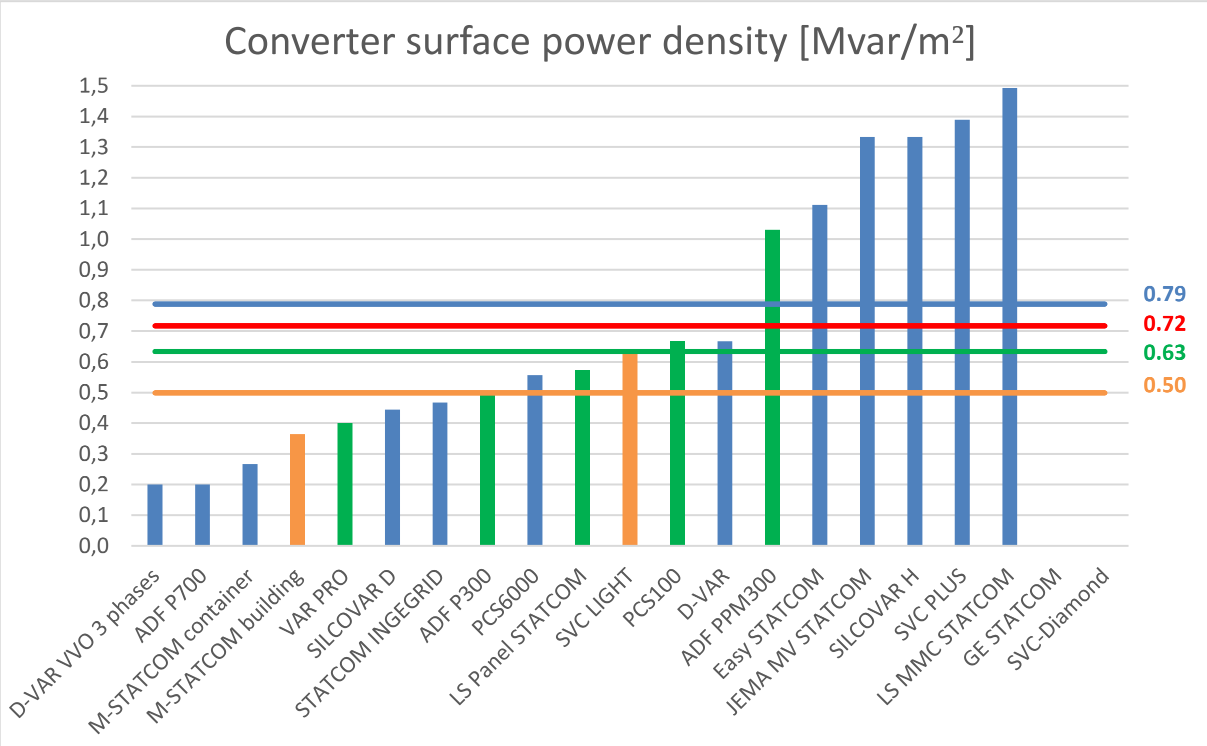

Figure 3-4: Converter surface power density [Mvar/m²]

The different colours correspond to different operational environments. Green colour corresponds to indoor cabinet products. Blue colour corresponds to outdoor products (outdoor cabinet or container solution). Orange colour corresponds to on site building construction. Horizontal lines correspond to the mean of each category of products. The red line corresponds to the mean of all the products together.

For all the products together, it can be seen that minimum converter surface power density is around 0.2 [Mvar/m^2] while the maximum is around 1.5 [Mvar/m^2]. There is a factor 7.5 between these two values. Even if information for some manufacturers is missing, it is enough to consider this comparison as a good representation of the global trend.

The overall mean of all of these surface power densities is 0.72 [Mvar/m^2].

The overall distribution seems relatively linear.

Between the different categories, we can see globally that they are uniformly distributed. The best and the worst surface power densities correspond to outdoor solutions (outdoor cabinet or container).

Considering the mean of the categories, outdoor solutions offer the best surface power densities (better than overall mean). In second, under the overall mean, there is the indoor cabinets. Building solutions have the lowest mean of all the categories.

The two following figures are bar charts of respectively indoor cabinet converter volume power density [Mvar/m^3] and container or outdoor cabinet volume power density [Mvar/m^3]. Bar charts are distributed in ascending order of their surface power density.

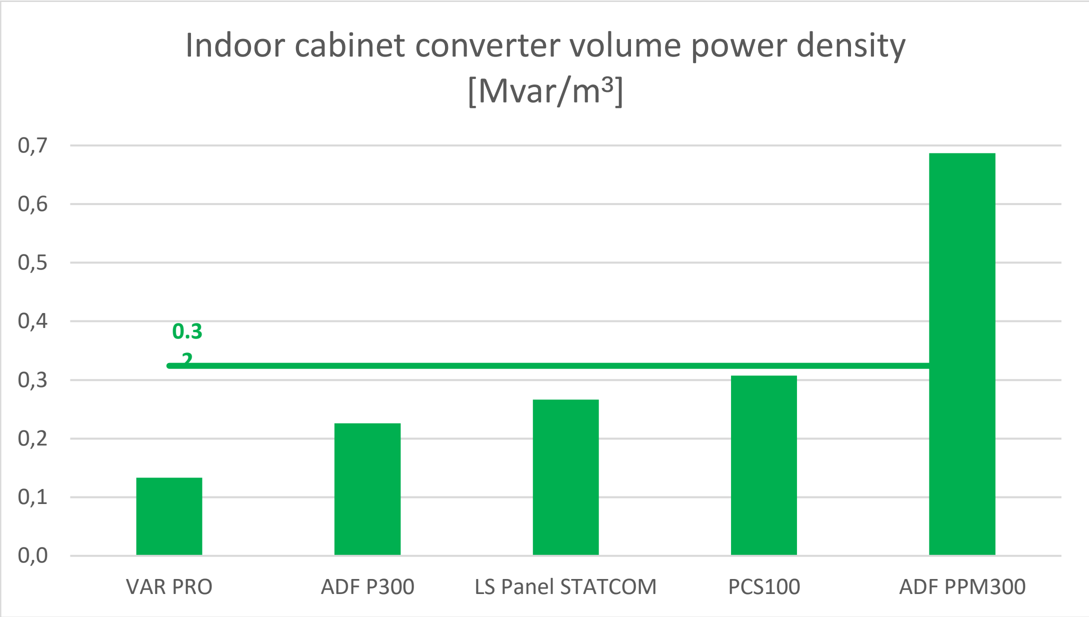

Figure 3-5: Indoor cabinet converter volume power density [Mvar/m³]

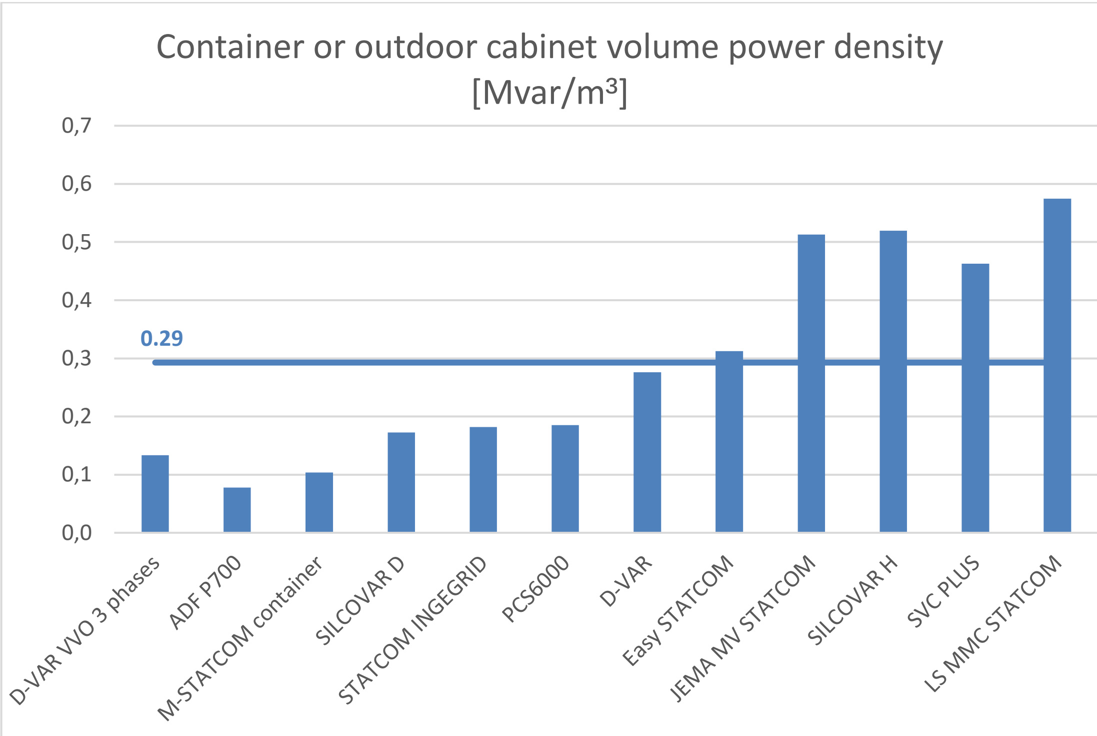

Figure 3-6: Container or outdoor cabinet volume power density [Mvar/m³]

We can see that volume power density ranking is nearly the same as surface power density ranking. This is due to the fact that all converter cabinets and containers are ground floor sized for human dimensions. Generally more than 1 meter height, it leads to lower volume power density compared to surface power density. In this study, surface power density is a good indicator of volume power density. Furthermore, it allows to compare also footprints given only in 2 dimensions (length x width).

It can be seen that volume power density mean is slightly higher for indoor products. This is due to the fact that outdoor solutions are generally higher than indoor cabinets. Indeed, sometimes indoor cabinets are stored inside container for outdoor applications.

3.6 Cost comparison between manufacturers

This section is not presented because of confidentiality issues.

Cost estimation by manufacturer				
Manufacturer	**Model name**	**Converter [kUSD/Mvar]**	**Complete installation [kUSD/Mvar]**	**Information linearly extrapolated from**
ABB-Hitachi	PCS 6000, SVC LIGHT	**CONFIDENTIAL**	No information	**CONFIDENTIAL**
AMSC	D-VAR	No information	**CONFIDENTIAL**	**CONFIDENTIAL**
AMSC	D-VAR VVO	200	**CONFIDENTIAL**	**CONFIDENTIAL**
COMSYS	ADF P700	180	**CONFIDENTIAL**	**CONFIDENTIAL**
General Electric	GE STATCOM	No information	**CONFIDENTIAL**	**CONFIDENTIAL**
Ingeteam		No information	No information	
Jema Energy		No information	No information	
LS Electric		No information	No information	
Merus Power		No information	No information	
Mitsubishi Electric		No information	No information	
Nidec		No information	No information	
Siemens	Easy STATCOM	No information	**CONFIDENTIAL**	**CONFIDENTIAL**

Table 3-7: Cost estimation by manufacturer

4 TOPOLOGIES COMPARISON

In this section, STATCOMs on the market are compared on their topologies according to voltage range and footprint.

4.1 LOW VOLTAGE TOPOLOGIES

Table 4-1 shows a summary of all the STATCOM converter topologies with their semiconductors type for output voltage < 1 kV (LV). It gives the number of models by topologies for each manufacturer studied as well as semiconductor type.

STATCOM topologies with LV output (< 1kV)			
Manufacturer	**Topologies**	**Number of models**	**Semiconductors**
ABB-Hitachi	2-level inverter	2	IGBT
AMSC	2-level inverter	1	IGBT
COMSYS	2-level inverter	2	IGBT
General Electric	x	0	x
Ingeteam	x	0	x
Jema Energy	2-level inverter	1	IGBT
LS Electric	3-level NPC	1	IGBT
Merus Power	No information	1	IGBT
Mitsubishi Electric	x	0	x
Nidec	3-level NPC	1	IGBT
Siemens	3-level NPC	1	IGBT

Table 4-1: STATCOM topologies with LV output (< 1kV)

It can be seen that on the 11 manufacturers, there are 9 LV STATCOM models proposed. Furthermore, semiconductors used are always IGBTs.

It can be seen that 60 % of the STATCOMs with output voltage < 1kV are 2-level inverters. 30 % are 3-level NPC and 10 % are not defined in manufacturers documentation. The low cost, simple design and control of 2-level inverters are probably the reason why this topology is the most used. However, for LV applications, 3-level NPC topologies provide less signal distortion compared to 2-level converters. This is why they are used by some companies.

4.2 MEDIUM VOLTAGE TOPOLOGIES

Table 4-2 shows a summary of all the STATCOM converter topologies with their semiconductors type for output voltage > 1 kV (MV). It gives the number of models by topologies for each manufacturer studied as well as semiconductor type.

STATCOM topologies with MV output (> 1kV)			
Manufacturer	**Topologies**	**Number of models**	**Semiconductors**
ABB-Hitachi	3-level NPC	1	IGCT
	SDBC	1	IGCT
	SDBC	1	IGBT
AMSC	SSBC	1	IGBT
COMSYS	x	0	x
General Electric	SDBC	1	IGBT
Ingeteam	3-level NPC	1	IGBT
Jema Energy	No information	1	IGBT
LS Electric	SDBC	1	IGBT
Merus Power	No information	1	IGBT
Mitsubishi Electric	SDBC	1	IGBT
Nidec	SSBC	1	IGBT
	SDBC	1	IGBT
Siemens	SDBC	1	IGBT

Table 4-2: STATCOM topologies with MV output (> 1kV)

It can be seen that on 11 manufacturers, there are 14 MV STATCOM models proposed. Furthermore, semiconductors used are always IGBTs except for ABB-Hitachi which also uses its own semiconductor technology IGCT (Integrated Gate Commutated Thyristor).

Figure 4-1 shows MV STATCOMs distribution by topology for the 11 manufacturers studied.

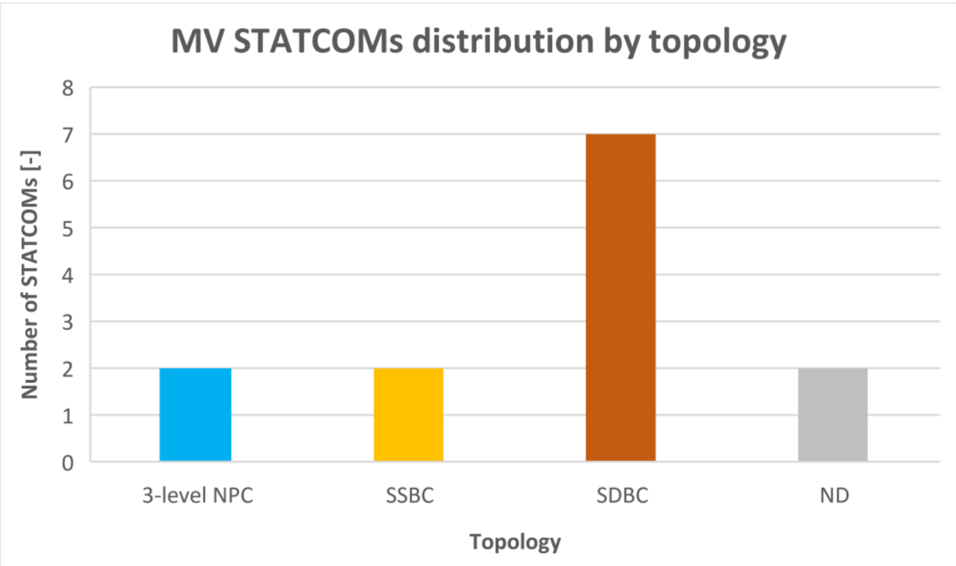

Figure 4-1: MV STATCOMs distribution by topology

It can be seen that 54 % of the STATCOMs with output voltage > 1kV uses SDBC topology. 15 % are 3-level NPC or SSBC or not defined in manufacturers documentation.

This result indicates industry mainly uses modular multilevel converters for MV and HV applications. It reinforces the relevance of this project. Furthermore, MMC topologies available on the market are SSBC and SDBC which were chosen during topologies assessment in this project. However, MMC DSCC is never used by these manufacturers. Simulations will give information on the effectiveness of this topology as STATCOM.

4.3 Topologies depending on converter output voltage range

Table 4-3 and Figure 4-2 show STATCOMs output voltage range depending on their topology for the 11 manufacturers studied.

Voltage range at STATCOM output without transformer		
	Minimum value [kV]	Maximum value [kV]
2-level	0.480	0.690
3-level NPC	0.380	10
SSBC	6	15
SDBC	6.6	70

Table 4-3: Voltage range at STATCOM output without transformer

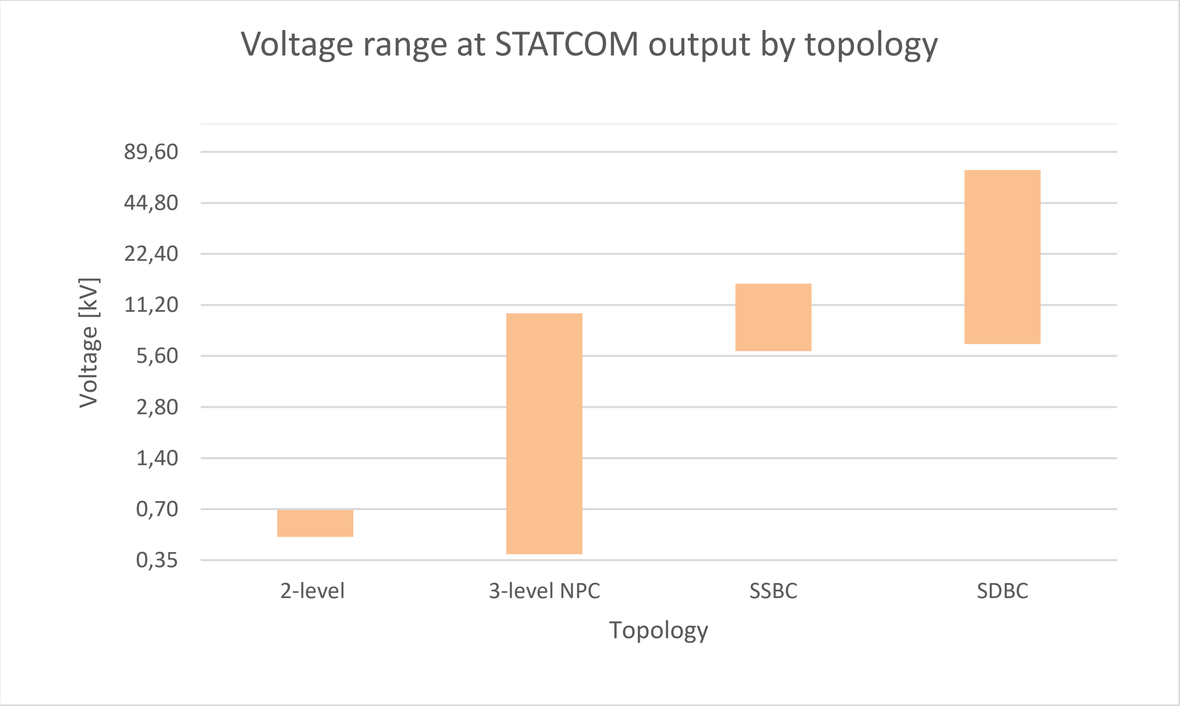

Figure 4-2: Voltage range at STATCOM output by topology

It can be seen that 2-level inverters studied only provide LV outputs. This is due to semiconductors voltage limits and costs. As above, 2-level inverters studied are all made by IGBTs.

3-level NPC topology STATCOM allows connection without transformer until 10 kV according to the manufacturers studied. There are some MV grid at 10 kV or lower but a lot of MV grids need a step-up transformer to connect.

Modular technologies (SSBC and SDBC) are the only one permitting to connect until 70 kV without transformer in this study. They allow to connect to a wide variety of MV grid. Furthermore, they permit to realize one converter with important power capacity. It allows the exportation of enough reactive power to improve HV transmission grid via the use of a MV/HV transformer.

4.4 Converter topologies depending on power density

Figure 4-3, Figure 4-4 and Table 4-4 show STATCOM models power density depending on their topology for the 11 manufacturers studied.

Converter power density by topology sorted by surface power density in ascending order (rounded at 0.5 m^2 or 0.5 m^3 except ADF P300 et ADF PPM300 at 0.05)				
STATCOM model	Surface power density [Mvar/m^2]	Volume power density [Mvar/m^3]	Environment	Topology
D-VAR VVO 3 phases	0.20	0.13	outdoor	SSBC
ADF P700	0.20	0.08	outdoor	2-level
M-STATCOM container	0.27	0.10	outdoor	No information
M-STATCOM building	0.36	0.09	outdoor	No information
VAR PRO	0.40	0.13	indoor	2-level
SILCOVAR D	0.44	0.17	outdoor	3-level NPC
STATCOM INGEGRID	0.47	0.18	outdoor	3-level NPC
ADF P300	0.50	0.23	indoor	2-level
PCS6000	0.56	0.19	outdoor	3-level NPC
LS Panel STATCOM	0.57	0.27	indoor	3-level NPC
SVC LIGHT	0.63	No information	outdoor	SDBC
PCS100	0.67	0.31	indoor	2-level
D-VAR	0.67	0.28	outdoor	2-level
ADF PPM300	1.03	0.69	indoor	2-level
Easy STATCOM	1.11	0.31	outdoor	3-level NPC
SILCOVAR H	1.33	0.52	outdoor	SSBC or SDBC
JEMA MV STATCOM	1.33	0.51	outdoor	No information
SVC PLUS	1.39	0.46	outdoor	SDBC
LS MMC STATCOM	1.49	0.57	outdoor	SDBC
GE STATCOM	No information	No information	No information	SDBC
SVC-Diamond	No information	No information	No information	SDBC

Table 4-4: Converter power density by topology sorted by surface power density in ascending order

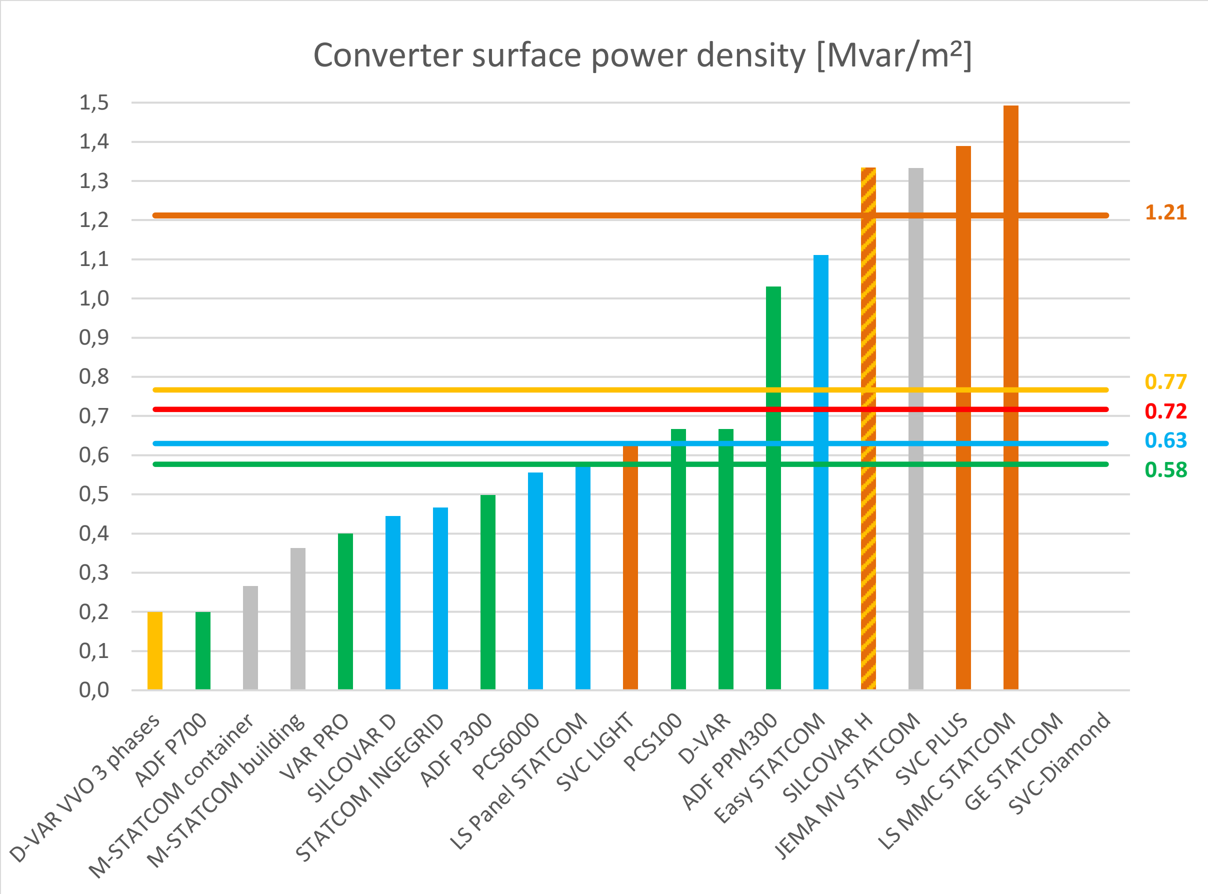

Figure 4-3 : Converter surface power density [Mvar/m²] by topology

It can be seen that 2-level topology in green is well distributed according to their surface power density. Their surface power density mean of 0.58 [Mvar/m^2] is in last position.

It can be seen that 3-level NPC topology in blue is in the middle according to their surface power density. Their surface power density mean of 0.63 [Mvar/m^2] is in third position below the overall mean of 0.72 [Mvar/m^2] in red.

It can be seen that SSBC topology in yellow has a surface power density mean of 0.77 [Mvar/m^2]. This mean is in second position but above the overall mean.

It can be seen that SDBC topology in orange has a surface power density mean of 1.21 [Mvar/m^2]. This mean is in first position and well above the overall mean.

According to the 11 manufacturers studied, SDBC topology proposes the best surface power density well above the other topologies. The second one is SSBC which is still a modular multilevel converter. Then, there are 3-level NPC inverters and the last one are 2-level topologies. It is important to note that the footprints mentioned in this section are only for converter. Modular topologies are better than conventional 2-level and 3 level topologies in term of surface power density of the converter.

Furthermore, 2-level and 3-level converters probably need a step up transformer to connect to the grid. It means that the overall surface power density is even worse.

When important power is needed, 2-level and 3-level converters need complete units in parallel whereas modular multilevel converters just need more valves, leading to better power density.

Figure 4-4 show converter volume power density depending on topologies and sorted by surface power density in ascending order.

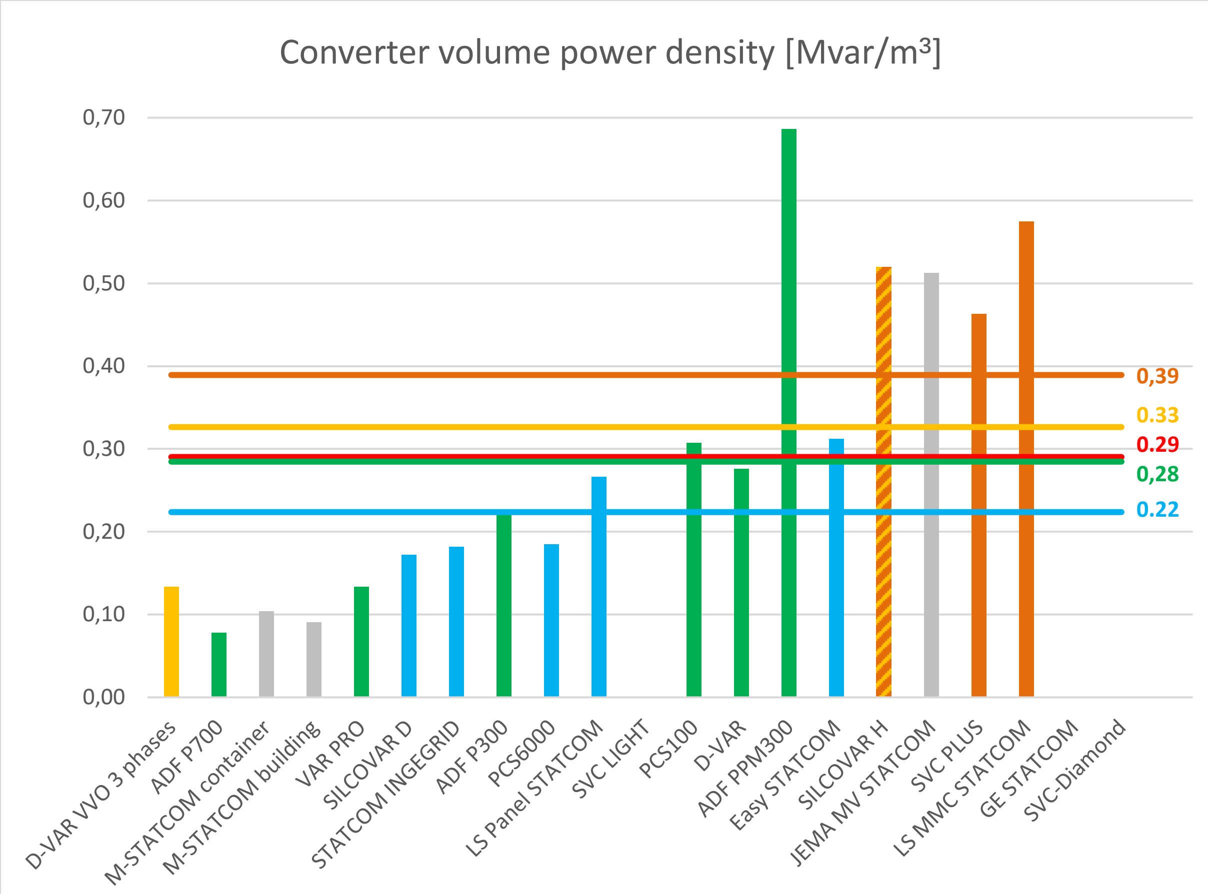

Figure 4-4: Converter volume power density [Mvar/m³] by topology

As it can be seen in figure xxx, the trend for volume power density looks like the one for surface power density for the same reasons mentioned in section xxxx. Some converters are voluntary higher than larger (like D-VAR VVO or ADF PPM300) but generally the height is standard for human dimensions.

The means of 3-level NPC, 2-level, SSBC and SDBC are respectively 0.22, 0.28, 0.33 and 0.39 [Mvar/m^3]. The overall mean is 0.29 [Mvar/m^3].

SDBC topology volume power density mean is respectively 1.74, 1.37 and 1.19 times higher than 3-level NPC, 2-level and SSBC means. As a comparison SDBC topology surface power density mean is respectively 1.92, 2.10 and 1.58 times higher than 3-level NPC, 2-level and SSBC means. The gap between each volume power density mean is lower than for surface power density. It is mainly due to the fact that D-VAR VVO has high design for cooling purpose and COMSYS basic products (ADF P300 and ADF PPM300) are designed for relatively small power which leads to a small product voluntary designed slender which is generally more convenient in these dimensions.

5 List of STATCOMs adapted to SIL case study

In this section, possible models of STATCOM which could suit to this particular case of SIL MV grid are proposed. Several solutions are proposed because the SIL needs are not known. This is just an indication on which solutions could fit with this application.

In this case, the study made in WP2 and WP3 [52] leaded to STATCOM power in the range of 1 to 10 [Mvar]. The distribution grid voltage is 11.5 [kV].

As already mentioned, manufacturers do not give all possible voltages available to connect to a grid given that solution is often custom made. However, thanks to this market analysis of technologies, it possible to select possible models fitting with the 11.5 [kV] grid voltage connection point. Furthermore, models chosen has to provide at least one value of power in the range of 1 up to 10 [Mvar]. Table 5-1 summarizes possible models among the 11 manufacturers studied which could potentially fit with this application. Models with very few information are excluded.

This table is tool based on the sources found during this study. To know if other models can fit as well or to have more details, it is better to contact manufacturers directly. Given that this project is a pre-study and the specifications are not defined for the moment, it is impossible to select one solution among all of them. However, DSOs can use this table as a tool.

Model name	Manufacturer	11 kV voltage fitting	Power range available [Mvar]	Topology	Cost estimation [kUSD]
PCS100	ABB-Hitachi	Possible if transformer adapted	1.076 and 10	2-level	no information
VAR PRO	ABB-Hitachi	Possible if transformer adapted	1 and 10	2-level	no information
D-VAR	AMSC	Possible if transformer adapted	2 to 10	2-level	**CONFIDENTIAL**
D-VAR VVO	AMSC	OK without transformer	1 to 4	SSBC	**CONFIDENTIAL**
ADF P700	COMSYS	OK with transformer	1 to 10	2-level	**CONFIDENTIAL**
General Electric STATCOM	General Electric	no information	no information	SDBC	no information
JEMA LV STATCOM	Jema Energy	Possible if transformer adapted	1 to 3	2-level	no information
JEMA MV STATCOM	Jema Energy	Possible if transformer adapted	10	no information	no information
Panel STATCOM	LS Electric	Possible if transformer adapted	2 to 10	3-level NPC	no information
M-STATCOM	Merus Power	Possible if transformer adapted	1.36 to 10	no information	no information
SILCOVAR D	Nidec	Possible if transformer adapted	0.5 to 10	3-level NPC	no information
SILCOVAR H	Nidec	OK without transformer	4.763 to 7.621	SSBC	no information
EASY STATCOM	Siemens	OK with transformer	2.5 to 10	3-level NPC	**CONFIDENTIAL**

Table 5-1: List of STATCOMs adapted to SIL case study

It is interesting to see that most of the solutions use conventional topologies for LV application with an additional transformer. More precisely, 61.5 % of possible models are 2-level and 3-level topologies. Only 23% are modular topologies SSBC or SDBC. For other models, no information was found on the topology. It seems that for relatively small power (considering utility applications) conventional topologies are preferred by the manufacturers on the market.

However, modular topologies are interesting solutions when space saving is needed. Indeed, conventional topologies need filters and transformers which have the nearly same dimensions that the converter. They are not necessary in modular converters leading to space saving.

6 Conclusion

This report gives an overview of main STATCOM product available on the market. Furthermore, comparison studies are realized to analyse more in detail the difference between manufacturers and topology based on basic criteria mentioned in introduction. We can see that, STATCOM are power systems used generally for high power application. A wide variety of products are available and cover a lot of applications. It can be seen that modular structure STATCOM are increasingly used nowadays, especially for high power applications. To finish, this report proposes a tool table for SIL partner of possible STATCOM products that could fit to their MV grid application.

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