

REPORT



# Cost difference between single busbar and double busbar

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Doc. no. 1494360  
Ver. no. 1494360A  
Case no. 120550-02-02

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14 March 2013  
Doc. no. 1494360  
(ver. no. 1494360A)

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## 1. Introduction

This document is made for the purpose of investigating difference between single and double busbar and show that single busbar is the optimal solution for the onshore substation design for offshore wind farm connections. This paper is attached to an amendment proposal to change the GB SQSS.

## 2. Scenario

For the investigation an illustrative 220kV switchgear layout considered typical for offshore wind connections has been used.

The illustrative project consists of two offshore substation and one onshore substation. Each of the offshore substations is connected to the onshore substation with a single export cable. In the onshore substation there will be two transformers. The transformers will transform the voltage to 400kV and will each be connected to a National Grid substation in separated connections. It is common practice to build two separate GIS sections connected in between by an section coupler. The design also considers harmonic filters connected directly to the 220kV busbars, and reactors connected via an extended bay to the offshore cable circuits. This results in the following designs:

Each of the GIS setup will have an common of

- Two (2) transformer bays
- Two (2) combined cable and reactor bays
- Two (2) harmonic filter bays
- Two (2) single busbar sections equipped with earthing switches
- One (1) section coupler

For the double busbar there will be further

- Two (2) bus couplers

To see SLDs please refer to appendix A.

Please note that in the case of the double busbar layout each of the bays will be equipped with a second disconnector (DS) to connect to the second busbar and the sections coupler is equipped with further an DS.

### 3. Cost

#### 3.1 GIS and installation

The following switchgear costs have been assumed, which have been made as an combination of several supplier's indications.

Bay type	Cost pr. Bay	
	Single busbar	Double busbar
Normal bay	£425,000	£500,000
Extended bay	£467,500	£550,000
Section coupler	£382,500	£450,000
Bus coupler		£400,000

#### 3.2 Table 1: Component costs for 220kV switchgearProtection

The increase in protection cost for the double busbar relative to a single busbar due to the need for more complex busbar protection, is estimated to be about £125,000 per section. This estimation is based on previous projects. The busbar protection for a double busbar substation is also complex system to install, commission and test.

As it have been shown earlier the GIS need two sections, therefore will the increase in protection cost be £250,000 for the double busbar (see table below).

#### 3.3 Delays in commissioning

The installation and commissioning of the protection for double busbar is a very complex task, which have been identified as an risk for delay of commissioning the onshore substation, and thereby delay of commissioning the offshore substation and the wind turbines. The costs associated with this is included in the table below.

#### 3.4 Total Costs

Based upon the aforementioned costs, and the single line diagrams in the appendices and associated switchgear numbers, the total estimated cost of switchgear, protection and potential delay risk in the scenarios are shown in the Table below.

	Single busbar	Double busbar
GIS equipment cost	£3,017,500	£4,350,000
Extra protection		£250,000
Possible delay risk due to busbar protection		£900,000
Total cost(without risk)	£3,017,500	£4,600,000

**Table 2: Total switchgear cost for the proposed configurations**

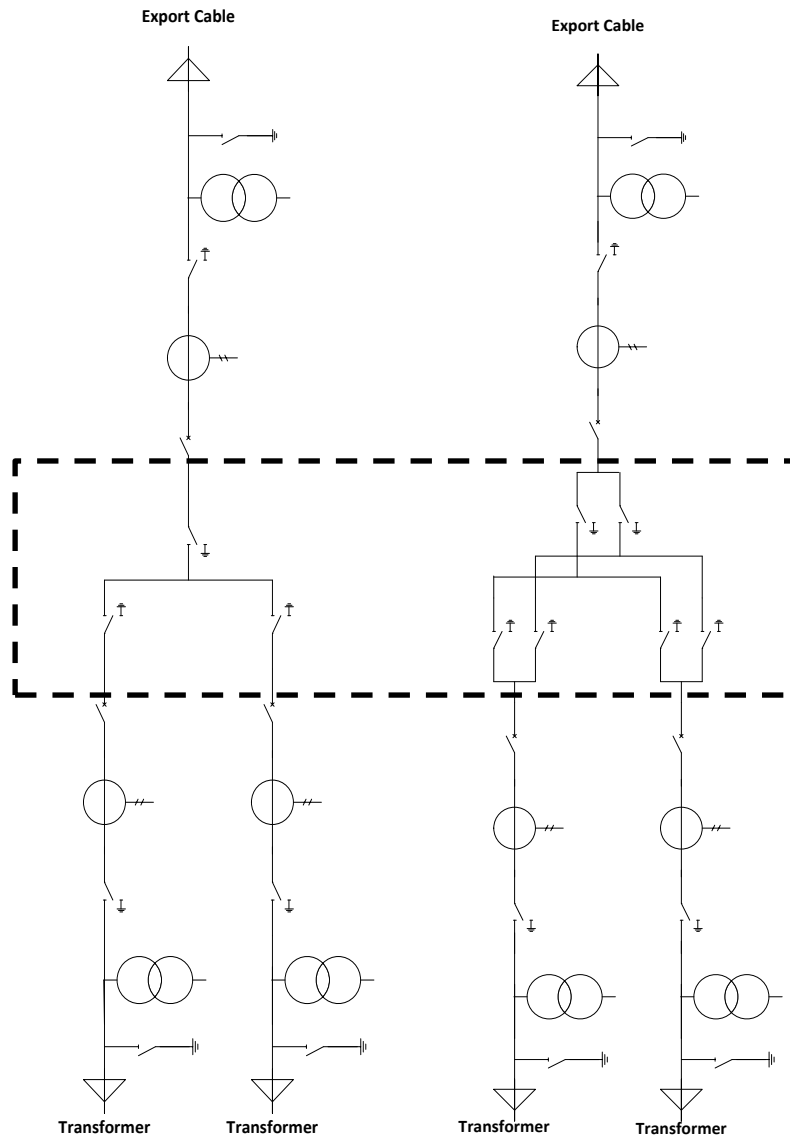
### 4. Savings in case of failures and outage

When installing double busbar there are potential savings due to redundancy in certain systems. This is explored in following section.

Working Group A3.06 of the CIGRÉ has issued a report on the reliability of GIS equipment called '*Final Report of the 2004 - 2007 International Enquiry on Reliability of High Voltage Equipment*'(CIGRÉ 513) which is the source used in this section.

## 4.1 Comparison of systems

In order to compare the pros and cons between the single and double busbar, it is necessary to define which differences will have a key influence on the evaluation.



As each bay consists of the same number of components from the CB and beyond, seen from the busbars, they will not be influenced by the presence of a single or double busbar. Therefore, the failure rate of these components will not influence the comparison of a single or double busbar and will not be taken into account in this analysis.

The difference between a single or a double busbar is confined to the number of DS's connected to a busbar and the busbars themselves. As the amount of components is doubled, the risk of a failure is also doubled. The actual risk of failure will be investigated further in the coming sections.

## 4.2 Planned Outage

### 4.2.1 Single busbar

The busbar is not subject to planned maintenance. Maintenance will only be done on occasions when the rest of the switchgear is disconnected.

If one of the DS's is in need of planned maintenance, it is necessary to have a planned outage of the busbar and consequently the complete switchgear. It is common practice to maintain the complete set of DS's at the same outage.

Typical DS's demand inspections every eight (8) years during which a visual inspection and function test are performed. In order to perform inspection, no busbar outage is needed.

Typical DS's will need maintenance after 5000 switch operations in which busbar outage is needed. In normal use, the DS will not switch more than a few times a year and therefore according to manufacturer guidelines it may not be necessary to maintain the DS within its operational lifetime. However in the event maintenance is required, DS maintenance will be planned alongside the rest of the switchgear and transformers attached to a bus-section, therefore no additional maintenance outage time is expected.

#### 4.2.2 Double busbar

In the case of the double busbar maintenance of the DS's, will include a planned outage of a single busbar section. This will not cause loss of power infeed as the connection will continue on the other busbar. Please note that the bay in which the DS is placed will not be able to feed power during maintenance as the DS cannot be isolated without outage of the parallel DS. During maintenance of any DS in the export cable/NGET connection, there will be no power infeed due to the need of outage of the parallel DS and the CB. However once again, DS maintenance will be planned alongside the rest of the switchgear and transformers attached to a bus-section, therefore no additional maintenance outage time is expected.

#### 4.3 GIS failure component distribution

The CIGRÉ report divides faults into four groups of components. Table 4 shows how the major failures are divided between the four groups.

CB	Circuit breaker
DS/ES	DS's and earthing switches
IT	Instrument transformers
GI	Busbars, bus ducts, surge arrestors, joints, bushings, cable boxes

**Table 3. GIS components is divided into four groups**

Major failure risk according to CIGRÉ 513 (Table 5-38)				
Voltage level	CB	DS/ES	IT	GI
200-300kV	25%	46.4%	10.7%	17.9%

**Table 4. Distribution of major (MaF) failures for the four basic GIS CB -bay components.**

##### 4.3.1 Busbar

As shown in Table 4, the major failures (MaF) is due to GI 17.9% for 220kV. Table 3 shows that GI includes more than the busbar. The breakdown of the major failures in GI component is shown in Figure 1 **Error! Reference source not found.**, which shows that MaF in GI is due to busbar and busducts being 40% for 220kV. MaF in GIS due to busbar and bus ducts being 7.16% for 220kV (40% of 17.9%).

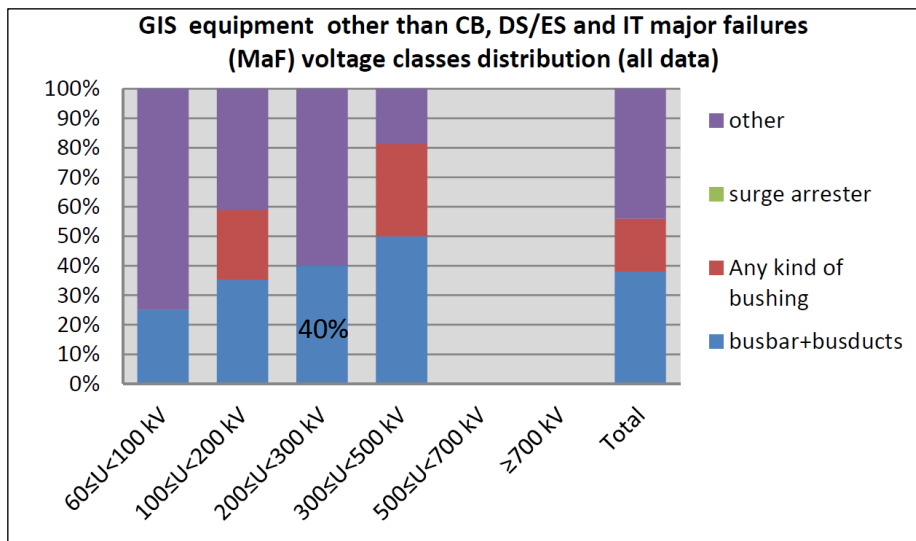


Figure 1: Major failures in GI components

#### 4.4 GIS major failure frequency

Stating the number of MaFs per 100 CB-bay-years is a normal method to state the reliability of a GIS. It simply defines the number of failures on 100 CB bays in a year. The unit does not define where the failure will occur in the CB bays. The MaF/100 CB-bay-years can be found in Table 5.

MaF/100 CB-bay-years according to CIGRÉ 513 (Table 5-57)	
200-300kV	0.67

Table 5. Distribution of major failure frequency for GIS-CB-bay

#### 4.5 Failure rate

When combining the knowledge of 4.3 and 4.4, it is possible to calculate the MaF/100 CB-bay-years for a single busbar section or a single DS.

The calculation for a single busbar section at 220kV:

$$7.16\% * 0.67 \frac{MaF}{100CB \text{ bay years}} = 0.05 \frac{MaF}{100CB \text{ bay years}}$$

From this calculation, it is then possible to deduce that there will be a failure on one busbar per 2000 busbars every year at 220kV.

The MaF/100 CB-bay-years for all the components can be seen in Table 6.

MaF/100 CB-bay-years calculated				
Item	CB	DS/ES	IT	Busbar
200-300kV	0.17	0.31	0.07	0.05

Table 6. MaF/100 CB-bay-years for all components in a CB bay

As shown in Table 6, the risk of failure in a DS will be 0.31MaF/100 CB-bay-years for 220kV For a busbar, the risk will be 0.05 MaF/100 CB-bay-years for 220kV.

The numbers in Table 6 show how often a fault occurs in the specific components in a CB bay. It is presumed that by increasing the number of components, it will also increase the number of failed components. In a double busbar versus a single busbar, this means a double risk that a fault will occur in the busbar and in the DSs.

It should be noted that the CIGRÉ failure statistics refer to complete bays, which also contain line DS's not just the busbar DS's, and as such the failure rates quoted will overstate the failure rate of busbar DS's and represent a pessimistic failure rate when comparing a single to a double busbar.

## **4.6 Consequence of a failure**

### **4.6.1 Single busbar**

A fault in the busbar will cause the switchgear to be unusable and cause total loss of power infeed of the section where the fault is located. The other section will not be influenced by the failure.

Faults in one of the DS's can cause total loss of power infeed, but will most likely only limit the loss of power infeed to the bay in question. If the failed DS is placed in a transformer bay, it has been assumed that half of the power infeed from the offshore wind farm will be lost. If a fault occurs in the export cable/NGET bay, again half the total power will be lost. It has also been assumed that in the event of a harmonic filter outage half of the exported energy will be lost due to a forced disconnection due to harmonic non-compliance.

In actuality, these assumptions are somewhat conservative, as transformers are often dimensioned above 50% of wind farm rating, and the ability to close the section breaker will limit the loss of production to the rating of a single transformer (which is not the same as 50% of the possible energy) in the event of transformer feeder outage. Furthermore, it may be possible to continue to operate, by agreement, during harmonic filter outages.

### **4.6.2 Double busbar**

A fault in one of the busbars will cause total loss of power infeed for a short period of time. However, will this quickly be restored, as the transmission will continue on the other busbar with full capacity.

Faults in a DS can cause total loss of power infeed for a short period of time, but will soon be restored. As there is twice as many DSs in each bay, the first fault in a DS may not cause permanent loss of power infeed, unless the connection to the other DS forces outage. During repair work, the need for outage is as for single busbar.

## **4.7 Repair**

Repair in a GIS creates a series of challenges that need to be addressed and will influence the availabilities of the GIS. This section is based on IEC 62271-203.

### **4.7.1 Gas compartments**

Safety rules dictate that no one must apply stress on a pressurised gas barrier. Therefore, work in a gas compartment requires the adjacent compartments to be depressurised. Depending on how the GIS is constructed, the depressurising of adjacent compartments can cause loss of power infeed in the appurtenant feeder. However, most GISs are constructed to avoid the loss of adjacent feeder during repair or maintenance inside a gas compartment.

#### 4.7.2 Repair time

Repair time will of course depend on which kind of repair is needed, but in order to investigate the unavailability of the GIS during repair, the term Mean-Time-To-Repair (MTTR) is often used. It is a simple way of stating the average repair time.

Number of units X		X	AVG
Voltage class		200≤kV≤300	
Average repair time GIS	Man-hours	109	201
	Hours of outage	125	81

Table 7 MTTR for GIS. 'Report on the second international survey on high voltage GIS service experience' [CIGRÉ 150, appendix 8]

In Table 7, it is possible to see that the average repair time for GIS is 81 hours. These numbers are not specific for DS or busbars. The survey done by CIGRÉ showed that there is a big difference in the repair time depending on whether it is a major dismantling or replacement of an enclosure, which can easily double the average repair time, whereas repairs which do not include these types of operation can be done in half the time.

Delivery time is not included in the repair time. However, the majority of the participants in the survey expected that spare parts were made available by the manufacturer immediately when needed.

#### 4.8 Outage times due to failure

Based on the numbers identified in this section, it is possible to calculate the possible loss of revenue for the wind farm.

##### 4.8.1 Busbar

It is clear that 7.16% of all faults in the GIS happens in the busbar and busduct, and that the rate of occurrence is 0.67 MaF/100CB bay years. Calculated above to 0.05 MaF per 100 bay years due to busbar. With the number of bays and a lifetime of 20 years:

	Single busbar	Double busbar
MaF in scenario	0.08	0.21

Table 8: Busbar failure frequency for scenarios

This translates to the following failure time during the life time of 20 years.

	Single busbar	Double busbar
Failure time[h, lifetime]	5.44	13.99
Failure time [h, per annum]	0.27	0.70

Table 9: Busbar failure time for scenarios

This shows that the failure time of the system with double busbar is actually higher than for one busbar but because of the double busbar there will be no loss of power due to failure.

##### 4.8.2 Disconnecter

The disconnecter (DS) is the cause of 46.6% of the faults in the GIS. Doing the same calculations for the DS as for the busbar the following numbers can be deduced.

	Single busbar	Double busbar
MaF in scenario	0.31	0.62
Failure time[h, lifetime]	30.22	60.43
Failure time [h, per annum]	1.51	3.02

**Table 10: DS failure rate and outage time for scenarios**

For the double busbar calculation it is presupposed that the failure only causes an outage of the DS and not the surrounding gas chambers and equipment. If the failure is of a type that demands outage of surrounding gas chambers, this will cause a power loss of the bay where the DS is located and thereby 50 % of the revenue.

## 5. Cost/Benefit Analysis

A cost benefit analysis has been conducted, considering expected equipment outage times discussed in this report, according to the Spackman method for valuing private investment for public benefit. the following parameters have been assumed:

- Weighted Average Cost of Capital (WACC) of 6.5%
- Social Time Preference Rate (STPR) of 3.5%
- Power Price of £150/MWh
- Inflation 2%
- Lifetime of 20 years
- Illustrative OWF production curve
- Offshore Wind Farm Size between 400 - 800MW (200 - 400MW per offshore platform; assumed range using selected switchgear configuration)

	400MW	600MW	800MW
CAPEX Difference (Double Vs Single Bus)	-£1,582,500	-£1,582,500	-£1,582,500
Lost Energy (MWh/Year)	186.61	279.92	373.22
NPV of Investment	-£1,568,687.39	-£1,332,424.22	-£1,096,161.05

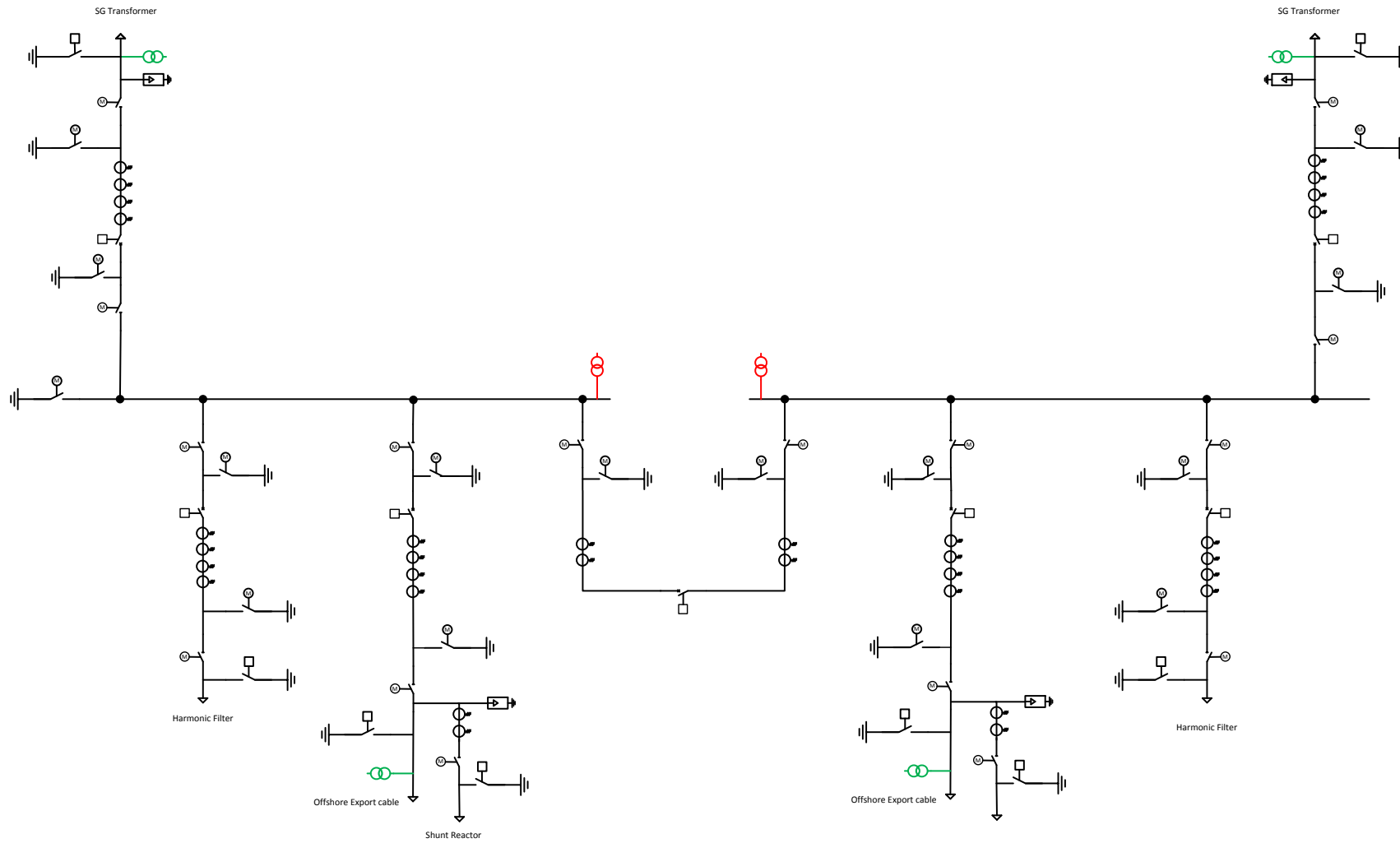
In all cases installing a double bus configuration results in a considerable net present cost increase; i.e. the increase in availability is not sufficient to offset the increased capital cost of the investment.

## 6. Conclusion

Based on cost of GIS equipment, protection cost and average loss alone there is no case for having a double busbar in offshore wind farms with similar switchgear configurations and MW outputs to those discussed in this report .

Furthermore there is an increased risk of delay of commissioning the substation and therefore a risk of delaying the commissioning the offshore substation and thereby the commissioning schedule of the wind turbines. The capitalisation of the risk in this document only covers lost revenue from equipment failure, and not consequential loss due to delays in production.

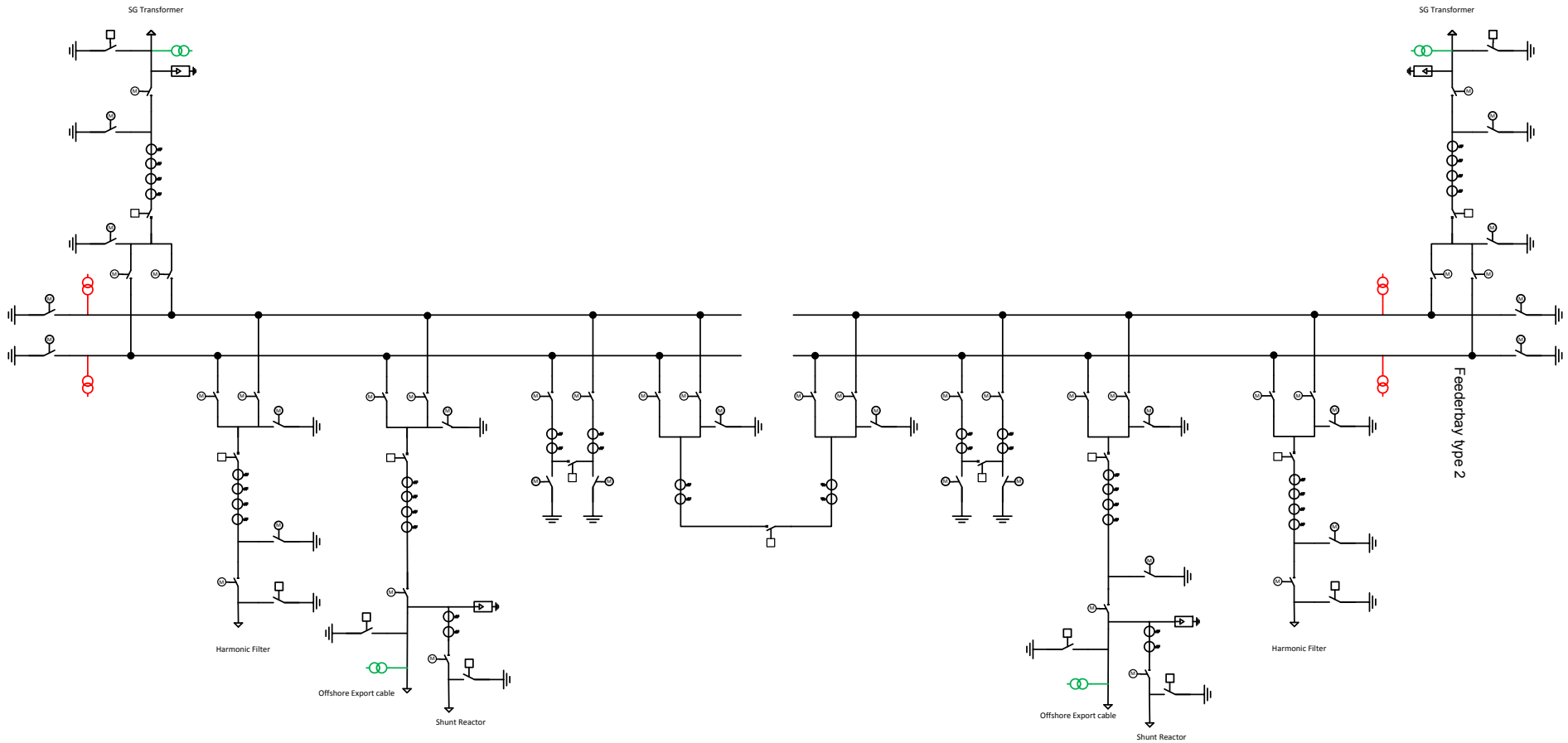
## 7. Appendix A



Single busbar setup

Single or double busbar

Doc. no. 1494360  
(ver. no. 1494360A)



Double busbar setup