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EQUIPMENT LAYOUT OF THE  
GENERATOR SET SECTION IN THE  
ENGINE HALL

School of Technology  
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## TIIVISTELMÄ

|                    |  |
|--------------------|--|
| Tekijä             | Tarvo Tuomisto                                     |
| Opinnäytetyön nimi | Generaattorin alueen laitteet ja niiden sijoittelu |
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Tämä opinnäytetyön päätehtävänä oli luoda Wärtsilälle suunnitelma siitä, miten generaattorin läheisyydessä olevat laitteet voitaisiin sijoitella mahdollisimman järkevästi. Laitteisiin kuuluu generaattorin magnetointijärjestelmä, nolapistemaadoitus, sekä ylijännitesuojaus. Toisena tehtävänä oli luoda suunnittelutiimille ideoita konehallin generaattoripuolen päätyseinän johdotuksista. Wärtsilä tulee hyödyntämään näitä suunnitelmia, kun sijoittamiselle ja johdottamiselle luodaan standardit.

Työ aloitettiin selvittämällä aiemmista projekteista yllämainittujen laitteiden sijainnit, koot, sekä valmistajat. Tutkittuja voimalaitosprojekteja oli noin 70 ympäri maailmaa, joiden tehot vaihtelivat 30 megawattista 500 megawattiin. Saaduista tiedoista luotiin punainen lanka laitteiden sijoittamiselle, joita hyödyntäen uudet ehdotukset luotiin. Lähdeaineistona käytettiin yrityksen omaa tietokantaa ja opetusmateriaaleja, sekä myös muuta julkaistua kirjallisuutta. Tutkimusosuutta varten käytettiin vain yrityksen sisäisiä lähteitä.

## ABSTRACT

|                    |  |
|--------------------|--|
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The main task of this thesis was to create ideas for Wärtsilä about how the equipment near the end of the generator set could be arranged in the best possible way. The equipment includes the excitation system control panel, the generator neutral grounding cubicle as well as the generator surge arrester cubicle. The secondary task was to develop a guide for the design team regarding the auxiliary electrification of the generator end wall in the engine hall. These ideas and guides will be used as a potential basis when Wärtsilä develops a standard for the layout and the electrification.

The thesis began by finding out the locations, sizes and manufacturers of the above-mentioned equipment from previous projects. This included about 70 different power plant projects from all over the world since 2013 with a power output ranging from 30MW to 500MW. The statistics from these projects were compared and used to create a common thread between the equipment arrangement. This information gained from this research was then used to derive ideas for arranging the equipment. The source materials used for the general information included external sources as well as internal sources from Wärtsilä database. Only internal sources were used for the research portion of the thesis.

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## 1 INTRODUCTION

The main objective of this thesis was to develop a concept for the layout of various equipment found near the end of the engine-generator in the engine hall, more specifically from the generator area to the end wall of the engine hall. This includes equipment, such as the generating unit control panel, the neutral point cubicle and the surge arrester cubicle.

Previously the equipment has been placed according to the guidelines, but the final location has been decided by the project team. This has led to the equipment being located in such ways that leave insufficient room for personnel creating tight spaces between two engine-generators. The purpose for this thesis is therefore to develop a concept that can be used by the project team regarding where the equipment should be located in all situations. There are variables that can make it hard to choose proper locations for the equipment, such as the size and model of the engine and generator, any stairways near the engine-generator, the size of the equipment which vary from project to project and the need of additional equipment.

The first step was to find out where the equipment have been installed in previous power plant projects and a total of 65 projects were investigated for this purpose. This information was gained by checking the 3D models made for these projects to find out the exact locations and dimensions of the equipment used. In addition to the locations of the equipment, also the dimensions and manufacturers were found out. With the information gained a common thread could be determined and used for the eventual concept.

The secondary objective of this thesis was to determine if the electrification of the auxiliary equipment installed on the end of wall of the engine hall could be planned beforehand. The auxiliary equipment includes items such as lighting, sockets, gas detection, fire detection and security cameras. The locations and cabling routes have been previously decided at the power plant site itself, which means that the required items have to be ordered from the site. Also, the cabling of all of the equipment would run straight down from the cable ladder, which runs along the wall of the

engine hall. The purpose is to create a guideline that can be used in such a way that a proper number of cables and conduits could be ordered beforehand and not from the site.

The first part of this thesis covers the equipment generally and explains what they are and why they are used. The second part displays the results and the information gathered to come up with different ideas regarding the locations of the equipment.

## 2 ELECTRICAL EQUIPMENT

The generator is protected and controlled with different equipment and devices, and for different reasons. The neutral point of a generator is typically grounded through a resistor, which requires its own cubicle. Circuit breakers are required for the protection of high fault currents, and choosing the breaker to have vacuum as an interrupting medium requires additional overvoltage protecting equipment in a surge arrester and capacitors, which also requires their own cubicle. The generators output is controlled with an excitation control system, which has a control panel that is to be located next to the generator. This chapter goes through the three equipment mentioned generally. Figure 1 shows an example single-line diagram with the different equipment involved in protecting the generator.

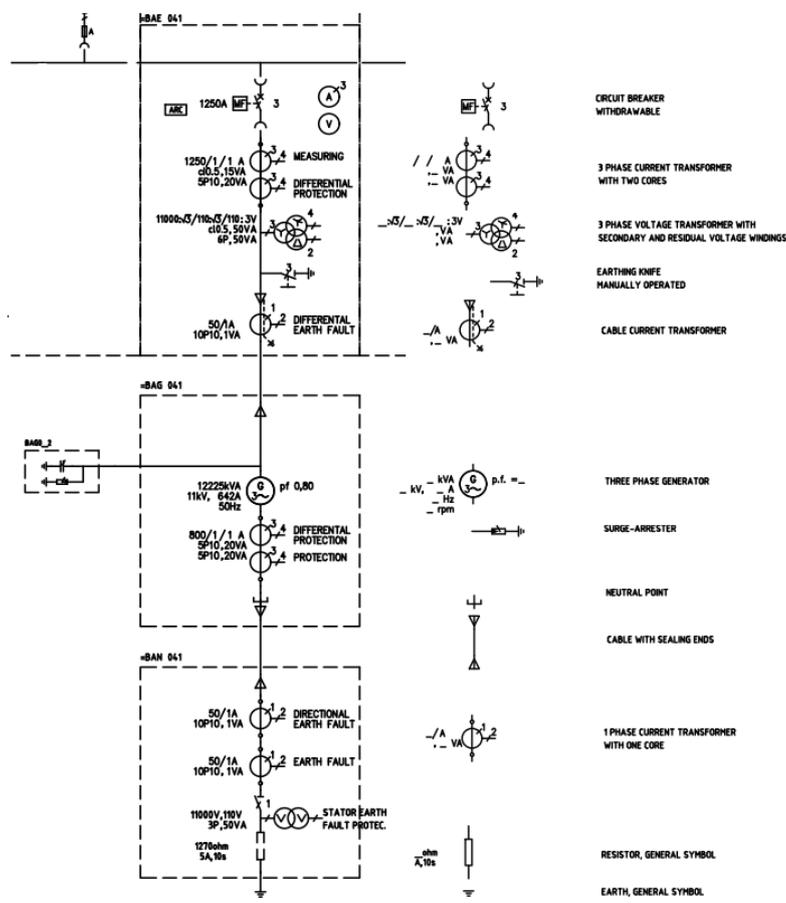


Figure 1. Example of a detailed single-line diagram of a generator [22].

## 2.1 System Grounding

In general, system grounding, or the intentional connection of a phase or neutral to ground has the following purposes:

1. Controlling the voltage with respect to earth, or ground, within predictable limits
2. Provide fault currents a path to flow that allows detection by automatic devices, such as relays to disconnect the source of voltage from the faulted devices. /2/

Another type of grounding is equipment or safety grounding, where non-electrical metallic elements are interconnected and grounded, and has the following purposes:

1. Reduce electric shock to personnel
2. Provide adequate current capability in case of ground fault
3. Provide a low impedance return path for earth fault current in order for the protective devices to work. /1/

### 2.1.1 Generator Neutral Grounding

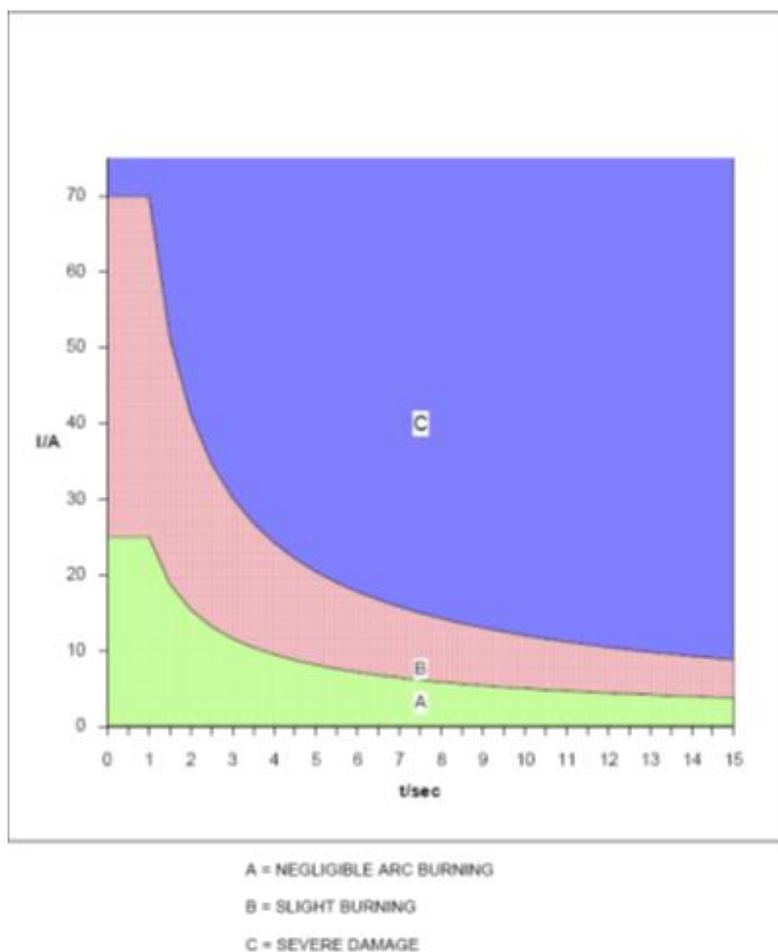
When comparing the neutral grounding of a generator to a transformer, there are some important differences to consider. First of all, a generator can withstand heating effects and mechanical forces worse than a transformer. For example, a generator may be required to withstand a less than 10 p.u. (1 p.u. is equal to generator-rated current) short circuit, when a transformer may be required to withstand a 25 p.u. current. Also, a generator may be able to withstand only 25% of the heating effect when compared to a transformer. This percentage can drop down to 10% if the current is unbalanced. /2/

In a generator, the three sequence reactances are not equal when compared to a transformer. The zero-sequence reactance has the lowest value, and the positive-sequence reactance varies as a function of time. This means that a generator will

have a higher ground-fault current than a three-phase current, if the generator is solidly grounded. /2/

Another thing to consider when grounding a generator is the ground voltage level. This should be limited due to generators having less insulation thickness, resulting in a reduced voltage-impulse withstand capability. /2/

If using a solidly grounded generator, internal ground fault currents can be high, which can damage the laminated core of the generator. The damage caused is proportional to the energy released and fault time, as indicated in Figure 2 /1/. These fault currents exist until the generator voltage decays since they cannot be interrupted by the generator circuit breakers. For this reason, the level and duration of the current should be limited. /2/



**Figure 2.** Effect of the fault current on the stator core versus time /1/.

In conclusion, there are five main objectives in grounding a generator neutral point, all of these are related to the protection of the generator and associated equipment and they are as follows:

1. To minimize damage for internal ground faults.
2. To limit mechanical stresses in the generator for external ground faults.
3. To limit transient and temporary overvoltages on the generator insulation.
4. To provide means of system ground fault detection.
5. To coordinate with protection with other equipment on the same voltage level. /4/

If a generator is rated for solid grounding, a solidly grounded neutral can be used, but in general standard generators require a resistor/reactor to be connected between the neutral and ground to limit the ground fault to be less than the momentary three-phase fault current. /2/

In general, the most suitable grounding method for medium voltage generators is high resistance grounding. For low voltage systems, the generator is usually solidly grounded. /4/

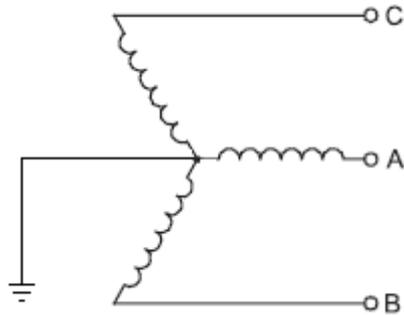
### **2.1.2 Methods for Generator Grounding**

System grounding can be categorized into two types of grounding methods: solid grounding and impedance grounding. The latter can yet be divided into several sub-categories: resistance grounding and reactance grounding. /4/

### **2.1.3 Solidly Grounded Generator**

When using a solidly grounded generator the neutral point is solidly connected to the ground without any impedance. This method is not recommended for industrial and utility generators, because the ground-fault current is high and the damage is proportional to  $I_s^2 \cdot t$ , which means that there is a possibility of extensive damage to the internal stator winding in ground faults. There is also a risk of abnormal third-

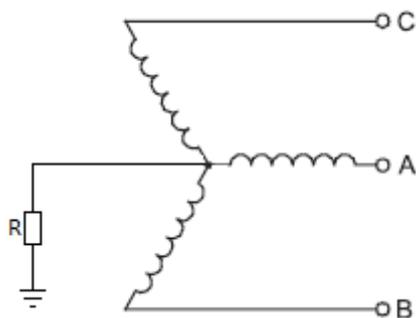
harmonic current flow. This type of system grounding is therefore not used in any of Wärtsilä power plants. /4/



**Figure 3.** Solidly grounded neutral /2/.

#### 2.1.4 Resistance Grounded Generator

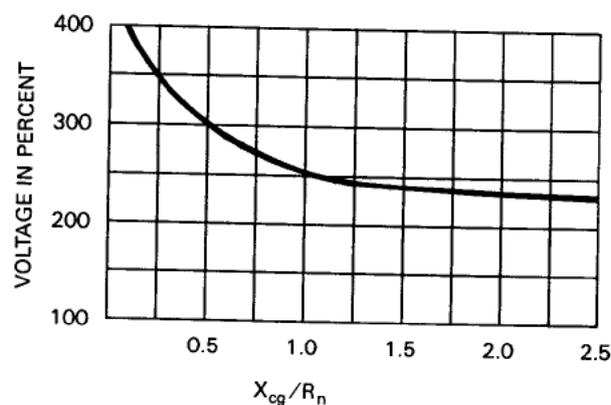
A resistance grounded generator has the neutral point of a generator connected to the ground through a resistor, limiting the line-to-ground fault current. Two types of resistance grounding methods are used: high resistance and low resistance. /2/



**Figure 4.** Resistance grounded neutral /2/.

High resistance grounding is accomplished by limiting the fault current to under 25 A using a resistor and/or transformer. This method of grounding is the most common in medium voltage generator neutral point grounding and has many advantages.

Firstly, the restricted fault current levels limit mechanical and fault damage on the generator and it is relatively simple and inexpensive in design. A high resistance grounded system also limits the transient overvoltages down to around 250% from restriking ground faults, as seen in Figure 5. The lowered fault current allows for service continuity since the first ground fault does not require the equipment to be shut down. It also gives a possibility for signal tracing or a pulse system that will help in locating the ground fault. The lowered fault levels also eliminate flash hazards to personnel and make it possible for selective relaying to be used. /2/

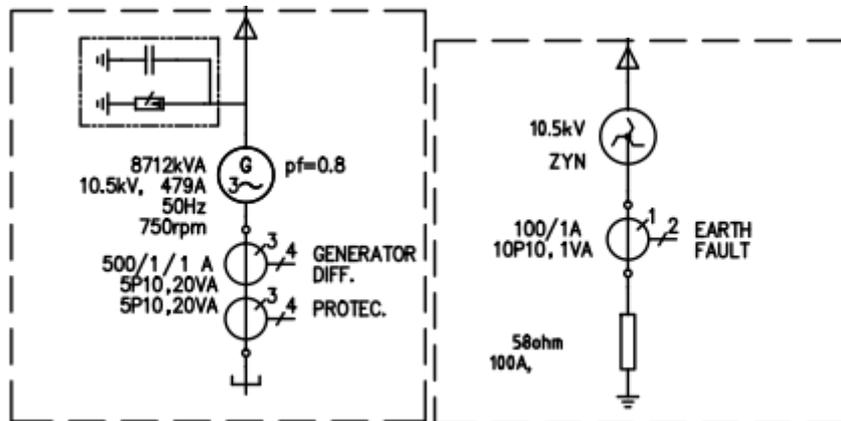


$C_g$  = capacitance of all three phases to ground ( $3 C_o$ )  
 $X_{cg} = 1/2 \pi f C_g$ ,  $f$  - operating frequency  
 $R_n$  = effective neutral resistance

**Figure 5.** Overvoltage levels in contrast to  $X_{cg}/R_n$  ratio /1/.

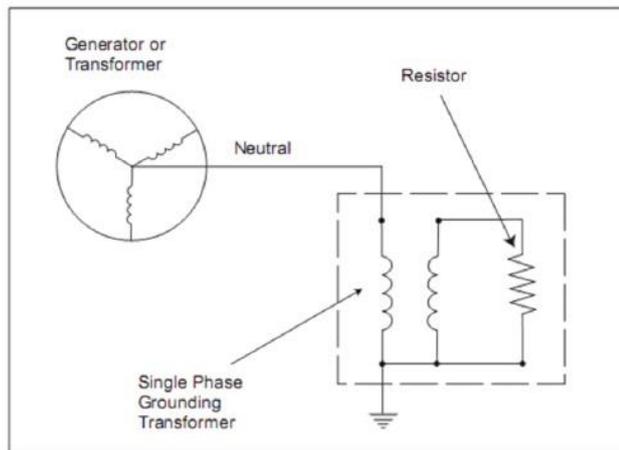
It is also possible to use a zigzag transformer which is used to create a common neutral grounding point for all of the generators connected in the same medium

voltage busbar. These are rarely used in Wärtsilä power plants, but are sometimes used at the demand of the customer.



**Figure 6.** Resistance grounded neutral using a common zigzag transformer.

When using a transformer-resistor combination a single-phase distribution transformer is used, where the resistor is connected to the secondary. The primary of the transformer is connected between the generator neutral and ground. This kind of setup is used in systems where block transformers or auxiliary transformers are used to supply power for the auxiliary equipment. The purpose of the grounding transformer is to measure the earth fault voltage and to stabilise the measurement.

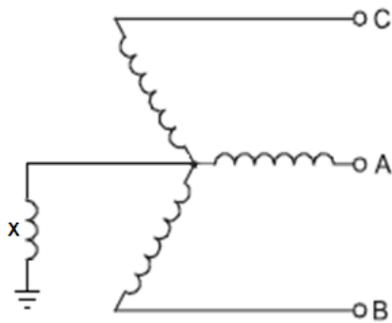


**Figure 7.** Resistance grounding using a grounding transformer /5/.

Low resistance grounding limits the fault current to above 25 A, typically between 50 A and 400 A in industrial applications /1/. Unlike high resistance grounding, the fault current in low resistance grounding is high enough to force the affected machine to be removed from the system as fast as possible. This method of grounding is not commonly used due to the possibility of extensive damage from higher fault currents. /4/

### 2.1.5 Low Reactance Grounded Generator

In this method, a reactor is connected between the neutral and ground, limiting the ground-fault current to at least 25% and preferably 60% of the three-phase fault current /2/. This value is usually higher than that of a resistance grounded system. It is typically used in generators that are directly connected to a distribution system with a solidly grounded neutral /4/.



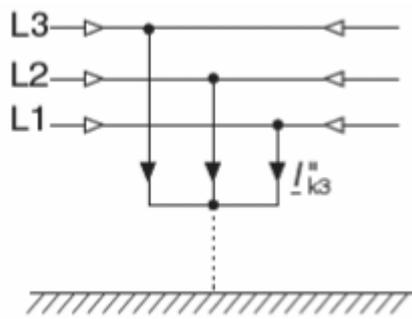
**Figure 8.** Reactance grounded neutral /2/.

## 2.2 System Circuit-breaking

The power system must be equipped with switching devices that are able to disconnect the current in case of fault currents, such as a short-circuit. Short-circuits in the power system can be caused by equipment failures, human errors and weather conditions such as lightning strikes. A short-circuit results in high currents flowing through the system and its equipment and even a very short fault time can cause extensive damage to the equipment. /19/

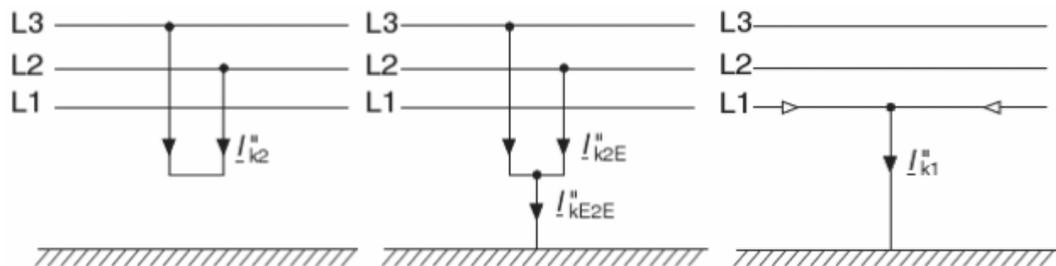
Therefore, the system is equipped with devices that detect and protect against these short-circuits and for this reason it is necessary to know the minimal short-circuit currents that may occur in the system. The fault currents must be quickly and safely cut off by breakers, switches and fuses. Short-circuits with a ground connection can cause interference with communication circuits and nearby pipelines as well as result in an unwanted step, touch and grounding voltages. The current of a line-to-ground fault is determined by the type of neutral grounding used. /15/

There are different types of short-circuits that can occur in a three-phase AC system /15/. These faults can be categorized as being symmetrical or unsymmetrical. A symmetrical fault includes a three-phase short-circuit with or without ground connection. This means that all three phases are short-circuited and often with a ground connection. This type of fault is the most severe, but happens rarely. /16/



**Figure 9.** Symmetrical short-circuit /15/.

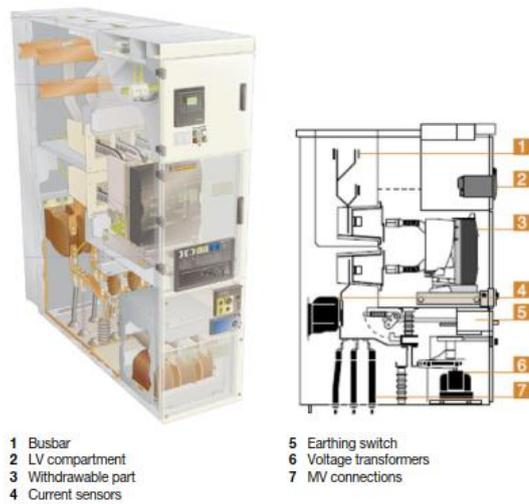
Unsymmetrical faults include a two-phase short-circuit with or without ground connection and a single-phase, or line-to-ground short-circuit. In an unsymmetrical fault the three phases become unbalanced, unlike in a symmetrical fault where the system remains symmetrical, meaning that the phases are displaced by an equal angle. /16/



**Figure 10.** Unsymmetrical short-circuits /15/.

### 2.2.1 Switchgear for Medium Voltage Systems

Medium voltage switchgear consists of separate cubicles, which are installed indoor and side by side. Typically used switchgear types in Wärtsilä power plants are either ABB UniGear ZS1 or Schneider Electric MCFSet. These cubicles are metal-clad types and air-insulated and have five compartments. /14/



**Figure 11.** Schneider Electric MCSet compartments /14/.



**Figure 12.** ABB UniGear ZS1 compartments /14/.

The main busbar compartment (B or 1) contains copper busbars, which are supported by cast resin insulators to withstand dynamic forces caused by short-circuit currents and are rated for nominal currents and short-circuit currents. /14/

The main device compartment (A or 3) contains a circuit breaker and accessories. The circuit breaker is either a SF<sub>6</sub> or vacuum type and is connected between the busbar compartment and the cable compartment. /14/

The cable terminal compartment (C or 4,5,6 & 7) contains cable terminals, current transformers, which are used to measure phase currents for measuring devices and relays, voltage transformers, cable current transformers, which are used to measure earth fault currents for relays, an earthing switch and surge arresters, which limit overvoltages. /14/

The secondary equipment compartment (D or 2) contains fuses, wiring, connections and terminals for the secondary equipment. Optional items include instrumentation, such as A-meters, V-meters, and kWh-meters, measuring transducers, and protection relays. /14/

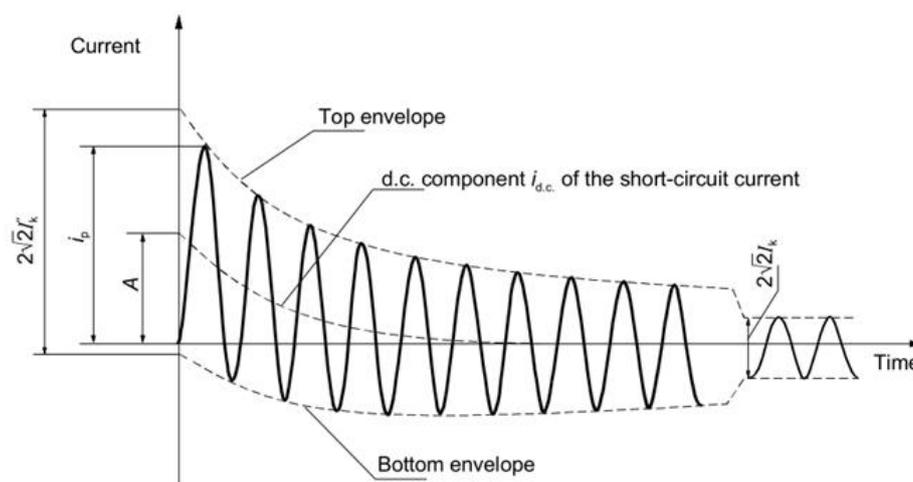
The gas exhaust ducts, or arc relief channels are positioned above the switchgear. All compartments except the secondary equipment compartment are fitted with a pressure-relief flap to the exhaust duct, which removes any hot gases or particles out of the switchgear. This happens when an arc fault occurs in the switchgear. The arc heats the air explosively due to very high temperatures, which causes a rise in pressure in enclosed spaces. /14/

### **2.2.2 Choosing of Switchgear**

When choosing the switchgear, there are a few things to consider. The first thing needed is the nominal voltage of the system. The nominal voltage determines the maximum rated voltage, power frequency withstand voltage and the lightning impulse withstand voltage ratings of the switchgear. Knowing the maximum rated voltage of the switchgear gives you options in choosing the nominal current of the switchgear and busbar, as well as the short-circuit withstand capacity of the switchgear. It is necessary to know the short-circuit currents and powers fed from the grid and generators before selecting the short-circuit rating of the switchgear. /14/

### 2.2.3 Short-circuit Calculations

Short-circuits can be either a near-to-generator or far-from-generator type. In a near-to-generator short-circuit the AC part of the current runs asymmetrically until decaying to a sustained short-circuit current. If the short-circuit current is twice the rated current of at least one of the generators in the system it is considered to be a near-to-generator type. /15/



$I_k^{\prime}$  = initial symmetrical short-circuit current

$i_p$  = peak short-circuit current

$I_k$  = steady-state short-circuit current

$i_{d.c.}$  = d.c. component of short-circuit current

$A$  = initial value of the d.c. component  $i_{d.c.}$

**Figure 13.** Diagram of a near-to-generator short-circuit /17/.

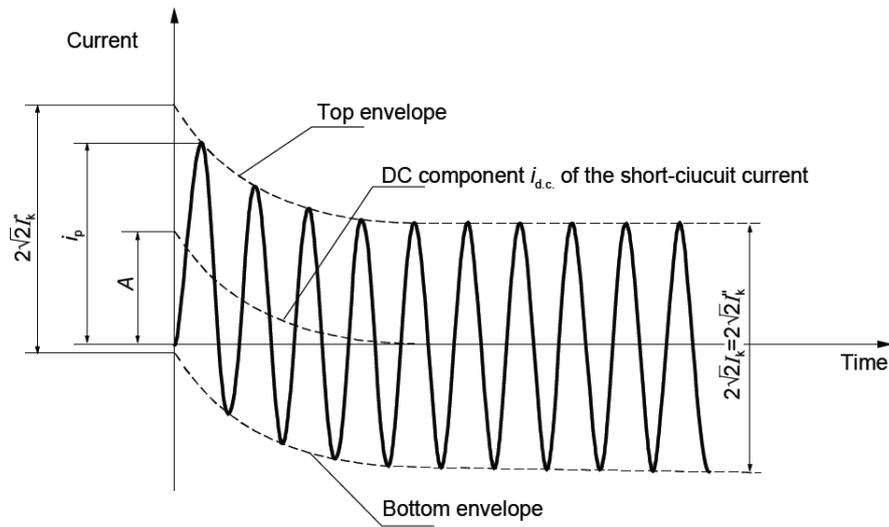
Since the impedance of a synchronous generator consists primarily of reactance and is variable with time, the short-circuit current starts at a high value and decays into a steady-state value after some time. Also, since the speed and field excitation voltage remain relatively constant within the short time considered, the change in the value of the current, since its initiation, may be assumed to be explained by the reactance of the machine. /27/ /28/ /29/

For simplicity, three values for the reactance are used for the purpose of calculating short-circuit current at specific times. The sub-transient reactance ( $X_d''$ ) is known as the apparent reactance of the stator winding at the instant the short-circuit occurs. It is used to determine the current flow during the first few cycles of the fault current. The sub-transient time period typically lasts for no more than two cycles, or 40ms in a 50Hz network. /27/ /28/ /29/

The transient reactance ( $X_d'$ ) is used to determine the current following the sub-transient period, and is effective for up to 0.5 seconds, depending on the design of the machine. Self-excited generators, which have an AVR supplied by the output of the generator, are unable to force a steady-state level of a three-phase fault current. This means that the generator stops working after the transient period. /27/ /28/ /29/

The synchronous reactance ( $X_d$ ) is used to determine the current after the steady-state period is reached. This is not effective until several seconds after the short-circuit occurs and is not generally used in short-circuit calculations. /27/ /28/ /29/

In a far-from-generator short-circuit the AC part of the current remains constant as seen in Figure 14.



- $I_k''$  = initial symmetrical short-circuit current  
 $i_p$  = peak short-circuit current  
 $I_k$  = steady-state short-circuit current  
 $i_{d.c.}$  = d.c. component of short-circuit current  
 $A$  = initial value of the d.c. component  $i_{d.c.}$

**Figure 14.** Diagram of a far-from-generator short-circuit /17/.

The initial symmetrical short-circuit current can be calculated with the one the following equations:

$$I_k'' = \frac{c \cdot U_N}{\sqrt{3} \cdot Z_k} = \frac{c \cdot U_N}{\sqrt{3} \cdot \sqrt{R_k^2 + X_k^2}} \quad \text{Equation 1.}$$

Where,  $U_N$  = nominal voltage,  $c$  = voltage factor,  $Z_k$  = short-circuit impedance. The voltage factor is standardized as 1.05 for voltages under 1kV and 1.1 for voltages over 1kV. /17/

$$I_k'' = \frac{c \cdot S_k''}{\sqrt{3} \cdot U_N} \quad \text{Equation 2.}$$

Where,  $U_N$  = nominal voltage,  $S_k''$  = initial symmetrical short-circuit power in the circuit. /14/

The peak short-circuit current can be calculated with the following equation:

$$i_p = \kappa * \sqrt{2} * I_k'' \quad \text{Equation 3.}$$

Where,  $\kappa = 1.02 + 0.98e^{-3\frac{R}{X}}$ , but a value of 1.8 can be used if the exact value is unknown. /17/

The symmetrical short-circuit breaking current is the short-circuit current at the point of the circuit breaker opening /18/. This value is usually used to determine the breaking capacity of the circuit breaker. For far-from-generator faults the breaking current is  $i_b = I_k''$ . For near-to-generator faults the breaking current is  $i_b = \mu * I_k''$ , where  $\mu$  is a factor defined by the minimum time delay of the breaker and current ratios as seen in Figure 15. /17/

|   |     |                      |
|---|-----|----------------------|
| $\mu = 0.84 + 0.26 \cdot e^{-0.26I_k''/I_{rG}}$ | for | $t_{min} = 0.02s$    |
| $\mu = 0.71 + 0.51 \cdot e^{-0.30I_k''/I_{rG}}$ | for | $t_{min} = 0.05s$    |
| $\mu = 0.62 + 0.72 \cdot e^{-0.32I_k''/I_{rG}}$ | for | $t_{min} = 0.10s$    |
| $\mu = 0.56 + 0.94 \cdot e^{-0.38I_k''/I_{rG}}$ | for | $t_{min} \geq 0.25s$ |

**Figure 15.**  $\mu$  values for different time delays /17/.

The d.c. component of the short-circuit current can be calculated with the following equation:

$$i_{d.c.} = \sqrt{2} * I_k'' * e^{-2\pi f t \frac{R}{X}} \quad \text{Equation 4.}$$

Where, f = nominal system frequency, t = breaking time

#### 2.2.4 Switchgear Circuit Breaker Ratings

The switchgear has various ratings that are used to confirm proper protection against fault currents in the system. The rated current ( $I_r$ ) is the r.m.s value of the current which the equipment should be able to handle continuously. /17/

The rated short time withstand current ( $I_k$ ) is the r.m.s value of the current which the equipment should handle in a closed position during a specified short time, 1s or 3s. For example, if the equipment has a rated short time withstand current rating of 50kA / 1s, it tells us that the equipment fulfils thermal requirements for an initial symmetrical short-circuit current ( $I_k''$ ) of under 50kA for a fault duration of one second. /17/

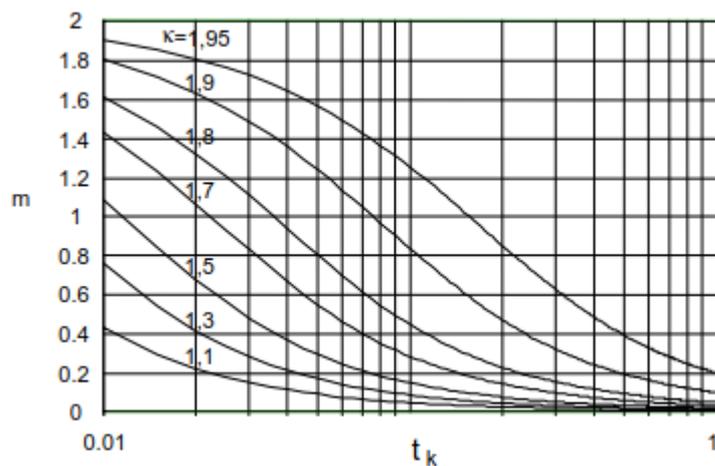
The rated peak short time withstand current ( $I_{pk}$ ) is the peak current that occurs with the first major loop of the rated short time withstand current. The standard value is 2.5 (for 50Hz and 2.6 for 60Hz) times the rated short time withstand current for HV systems and 1.5-2.2 times for LV systems. For a 50kA rated circuit breaker the rated peak withstand current is therefore 125kA, which means that the calculated peak short-circuit current ( $I_p$ ) has to be under 125kA. /17/

The rated short-circuit making current ( $I_{ma}$ ) is the maximum value that the circuit breaker is capable of making and maintaining on an installation in short-circuit. This value must be greater than or equal to the rated peak short time withstand current. /17/

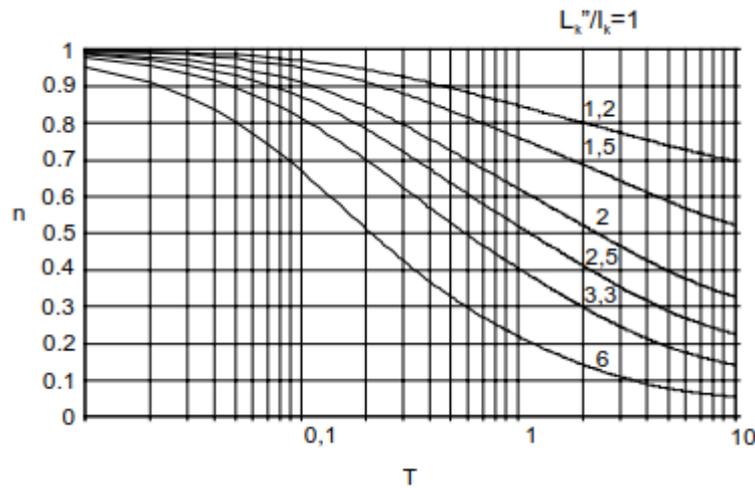
The thermal short-circuit current ( $I_{th}$ ) contains both the AC and DC components of the short-circuit current and is calculated with the following equation:

$$I_{th} = I_k'' * \sqrt{m + n} \quad \text{Equation 5.}$$

Where,  $m$  = the factor for the heat effect of the d.c. component of the short-circuit current and  $n$  = the factor for the a.c. component. Because the fault current decays with time the thermal fault current is not used instead of the initial symmetrical fault current when defining the short-circuit rating of the switchgear. /17/



**Figure 16.** Factor  $m$  dependence on the factor for the calculation of peak short-circuit current ( $\kappa$ ) and the duration of the short-circuit /30/.



**Figure 17.** Factor  $n$  dependence on the dependence of the initial short-circuit current and the steady-state short-circuit current  $(I_k''/I_k) / 30$ .

The rated short-circuit breaking current ( $I_{sc}$ ) is the highest current that the circuit breaker is capable of breaking at its rated voltage. It consists of the r.m.s value of the a.c. component and the percentage of the d.c. component. The percentage of the d.c. component can be calculated with the following equation:

$$DC\% = e^{-\frac{T_{op} + T_r}{\tau}} \quad \text{Equation 6.}$$

Where,  $T_{op}$  = minimum opening time of the breaker,  $T_r$  = minimum relay operating time, which is 10 ms at 50 Hz (according to IEC 62271-100) and  $\tau$  = time constant, which depends on the breaker type, but is 45 ms in most cases. So, for a circuit breaker with a minimum opening time of 45 ms, the percentage of the d.c. component would be 29,457%. /17/

The d.c. component of the breaking current can then be calculated from the following equation:

$$I_{DC} = I_{sym} * \sqrt{2} * DC\% \quad \text{Equation 7.}$$

Where,  $I_{sym}$  = symmetrical short-circuit current (or the rated short time withstand current).

Finally, the asymmetrical rating current can be calculated from the following equation:

$$I_{asym} = I_{sym} * \sqrt{1 + 2 * (DC\%)^2} \quad \text{Equation 8.}$$

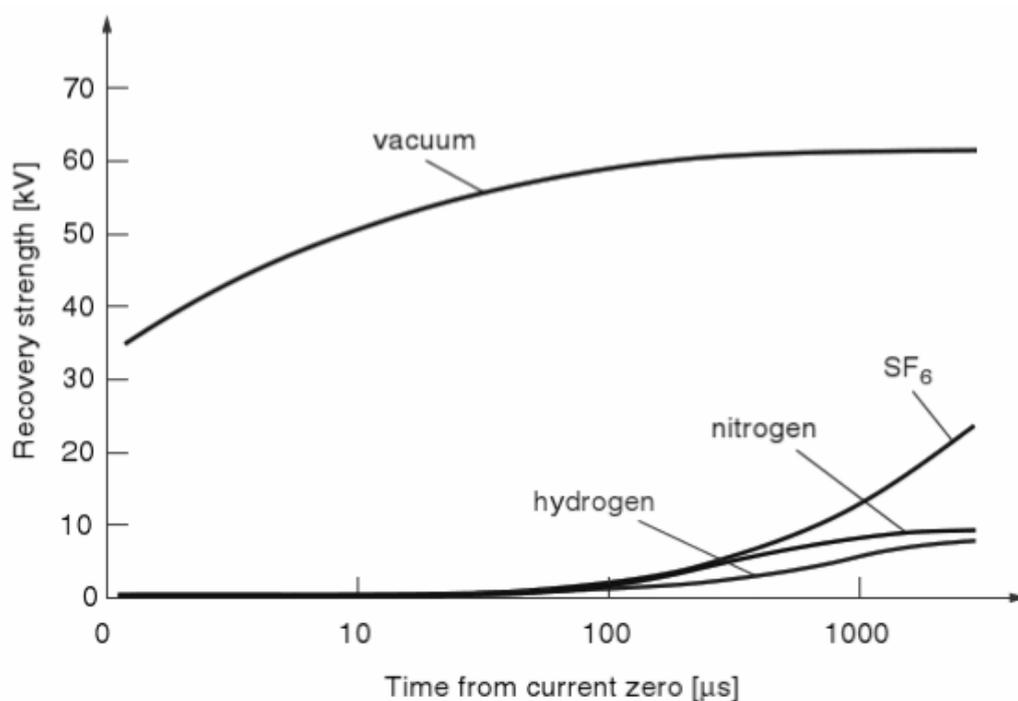
This means that a switchgear with a DC% of 29,5% and a rated short time withstand current of 40kA has a rated peak short time withstand current of 100kA, a rated d.c. component of the breaking current of 16,669kA and a rated asymmetrical breaking current of 43,334kA. /17/

### 2.2.5 Circuit Breakers

The two types of circuit breakers used in the switchgear are either of SF<sub>6</sub> or vacuum type and are operated by protection relays that detect any abnormalities in the system. The separation of the contacts in the circuit breaker can happen at any time during the sine wave of an alternating current. The current will then flow through an arc between the contacts, independent of the type of circuit breaker used, which must be extinguished. In order to interrupt the current, the breaker must wait for a natural current zero. /20/

HV SF<sub>6</sub> circuit breakers were developed in the late 1950s and have since been the preferred type of interrupting medium. They have a high dielectric strength, high thermal interruption capabilities, high heat-transfer performance and a fast thermal recovery and dielectric recovery. /20/

MV vacuum circuit breakers have been highly used since the 1960s as a reliable option for current interrupting and have recently gained a dominant position in power distribution systems. They have a much greater dielectric strength and shorter dielectric recovery time and are dominant up to a voltage of about 150kV as illustrated in Figure 18. This type of breaker is mechanically simpler than the other types, consisting basically of a fixed and a moveable contact in a vacuum bottle. The gap between the contacts is very small producing a short arc length and a low arc voltage, giving the circuit breaker a long electrical life. /20/



**Figure 18.** Dielectric recovery comparison graph after breaking a current of 1600 A /20/.

The vacuum circuit breaker is used for its rapid dielectric recovery, but they have a drawback. The breakers are likely to generate overvoltages when interrupting fault currents. These overvoltages can be different when compared to other switching

device types, because of the special properties of the vacuum. Therefore, when using a vacuum breaker as a generator protection device, there is a need for additional surge protective equipment. /21/

There are three main reasons overvoltages happen when breaking a current. Current chopping, or the premature breaking of a current before it reaches a value of zero naturally concerns all circuit breakers that are sized to break short-circuit currents and occur when interrupting small currents. The overvoltage caused by this phenomenon is not considered a problem for modern generators, since techniques have been developed to restrict these overvoltages. /21/

Pre-striking between contacts of the breaker occur when closing the breaker and is unavoidable at the end of closing due to the dielectric strength of the interval being lower than the applied voltage. The magnitude of the voltage will diminish until the contacts have closed. /21/

Re-ignition occurs randomly with a probability of 12% when the arcing time is low. In this phenomenon, the contact gap is not sufficient enough to tolerate the transient recovery voltage and will cause another arc. The voltage will increase gradually until the contacts have moved to extinguish the arc. /21/

The vacuum circuit breaker is also able to interrupt high-frequency currents after a re-ignition or pre-strike. Since the breaker is attempting to break the current repeatedly, the recovery voltage increases after every attempt, causing multiple re-ignitions or restrikes. This can potentially cause very high overvoltages, which requires additional protection. /20/

### **2.3 Excitation System**

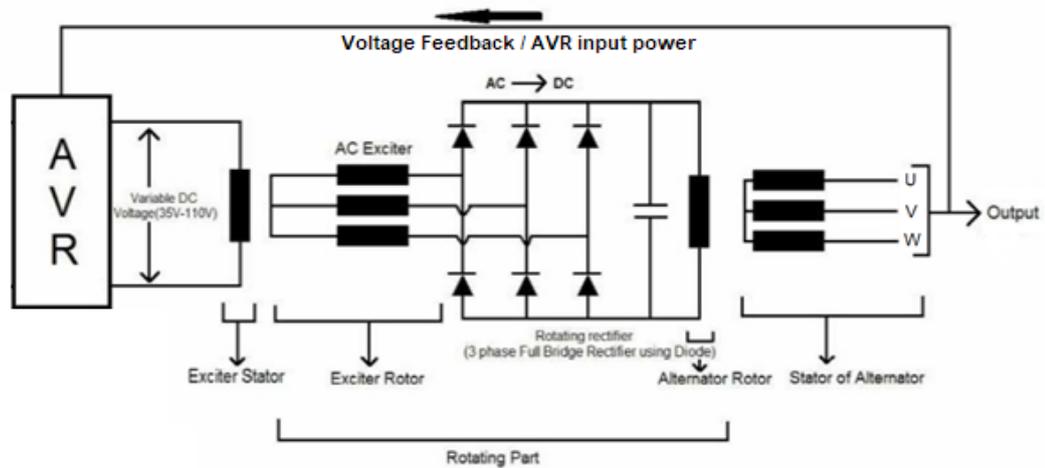
The excitation system of a generator consists of an exciter and an excitation control system. The function of the exciter is to supply the generator with a DC field current. The excitation control system is used to control the amount of current supplied to the generator field winding by the exciter. The exciter can be one of three types: a DC exciter, a static exciter or an AC exciter. /11/

Using a DC exciter means that there is a small DC generator installed on the same shaft as the rotor. This means that the exciter produces power when the rotor rotates. The output from the exciter controls the magnetic field to produce a constant voltage output by the generator. The DC current is fed to the rotor via slip rings. /13/ DC exciters have been highly replaced by AC exciters since the 1960s due to their large size. /11/

The second method used are the AC exciters, which can be divided into two types: the rotating and stationary rectifier systems. Both of these use an AC generator as the source of excitation power, which is typically on the same shaft as the generator. The AC output of the exciter is then rectified with either stationary or rotating rectifiers, which can be either controlled or non-controlled. /11/

AC exciters with stationary rectifiers feed the dc output to the main generator via slip rings. If controlled rectifiers are used, the controller controls the dc output of the ac exciter and if non-controlled rectifiers are used, the controller controls the field of the ac exciter. /11/

AC exciters with rotating rectifiers, which are also known as brushless exciters, eliminates the need for slip rings and brushes. This reduces maintenance and dust, which in return improves reliability and is the preferred method used in all of Wärt-silä power plants. /11/



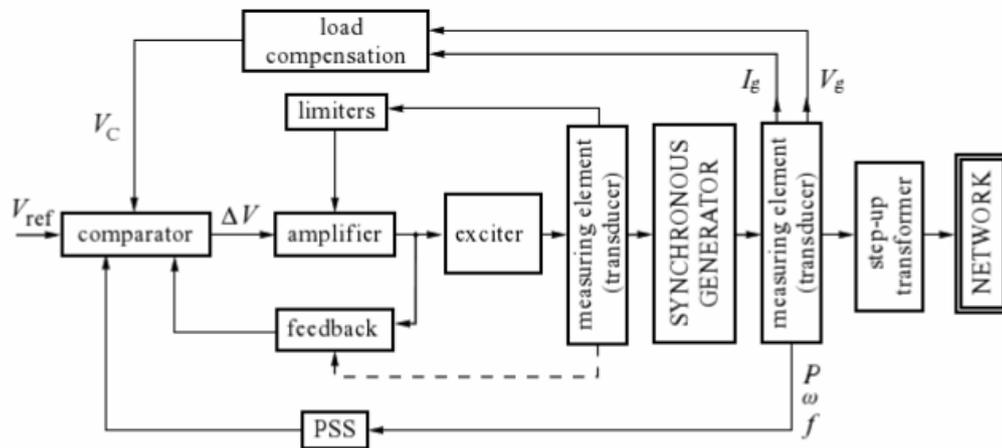
**Figure 19.** Example of brushless excitation system /26/.

The final method used are static exciters, which gets its DC power from the output of the generator by using high power thyristors to rectify the AC current in order to produce a DC current which is fed to the rotor via slip rings. This method does not require another rotating machine and eliminates any maintenance or operation issues related to it. During startup, a large battery bank is used to provide needed power for excitation. /13/

### 2.3.1 Control Modes of the Excitation System

The excitation control system can be controlled with three types of operating modes, Automatic Voltage Regulation mode, or AVR mode, reactive power (Var) control mode and power factor control mode. The generator can further be categorized as being controlled in an island system or a utility system /9/.

In the AVR mode the controller measures the output voltage of the generator and adjusts the dc output excitation current in order to maintain the voltage at a set value. In the Var control mode and power factor control mode the controller measures the output voltage and current of the generator and adjusts the excitation current in order to maintain the reactive power or power factor at a set value. /9/



**Figure 20.** Excitation control system block diagram with AVR mode /11/.

The figure above shows a block diagram of the excitation control system. The purpose of the measuring element is to measure the current, voltage, power and frequency of the generator. The load current  $I_g$  and terminal voltage  $V_g$  are compensated and compared with the desired voltage reference  $V_{ref}$ , if the used control mode is AVR. The difference of these values is amplified and used to change the output of the exciter, and generator field current, so that the values are the same. The regulation is stabilized with a feedback loop taken from either the amplifier or the exciter. /11/

The control system can also be used in a manual mode, or field current regulation mode, where the controller maintains the excitation current at a set value.

### 2.3.2 Island System

The island system is used on ships and isolated power plants, such as in mines or small islands. The voltage of the system is determined by the generators and the AVR. The reactive load of the generator varies depending on the system and the control mode used is therefore voltage control, either with or without droop and with or without cross-current compensation. With the AVR mode, the controller

automatically maintains the output voltage of the generator at a set value, by controlling the amount of current supplied to the generator field winding by the exciter. /9/

Voltage control without droop can be used with single generators when the generator maintains only the terminal voltage at a pre-set value. The voltage droop control can be used in a single unit operation, in a parallel operation with other units in an island system or in parallel operation with a rigid utility. With increasing reactive power, the line voltage drops in a droop control mode. The voltage droop can be compensated by using a cross-current compensation, where the line voltage will not change with the reactive load. /9/

### **2.3.3 Utility System**

The utility system is used on base load stations and the voltage of the system is determined by the utility. The generators cannot usually affect the voltage and the control methods used are either power factor control or reactive power control. /9/

The power factor control method keeps the angle constant regardless of the output power, while the reactive power control method keeps the reactive power constant regardless of the output power. These are only useable when the generator is connected to a large power system, where other synchronous machines determine the voltage and can absorb reactive power. /9/

## **2.4 Generator Excitation Methods**

There are several methods in supplying the excitation control system with needed input power, the controller then supplies a DC output to the exciter stator, which is attached to the generator. The AC output of the exciter rotor is then rectified to a DC output into the generator rotor and ultimately induced onto the stator. This process requires the controller to have a strong power source to produce the required amount of excitation current when needed. Without it the generator may not be able to recover voltage during a fault or a motor start and could lead to damage or a shut

down due to loss of field. Choosing the proper method is important to ensure correct operation of the generator set. Each method has its benefits for different applications, and are usually chosen by the electrical characteristics of the loads and the short circuit requirements. /12/

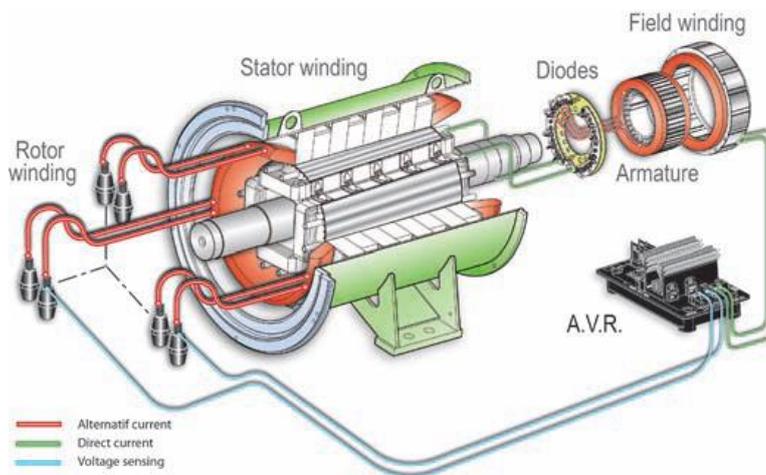
The methods described in the following chapters all have various advantages and disadvantages, such as a short-circuit boost capability, an ability to tolerate high overloads or heavy motor starting or having a good transient response.

A short-circuit boost capability means that the generator can be given a voltage boost in case of a short-circuit in the system, which causes a high drop in the output voltage. When this type of fault occurs, the controller will try to increase the excitation power, but since the output voltage of the generator drops, it does not have enough power to do so. /10/

Transient response, or step response, indicates the reaction behavior on load changes. When more load is applied, more current is required from the generator. This drops the generator voltage and forces the controller to react and adjust the voltage level by adjusting the excitation field voltage. /10/

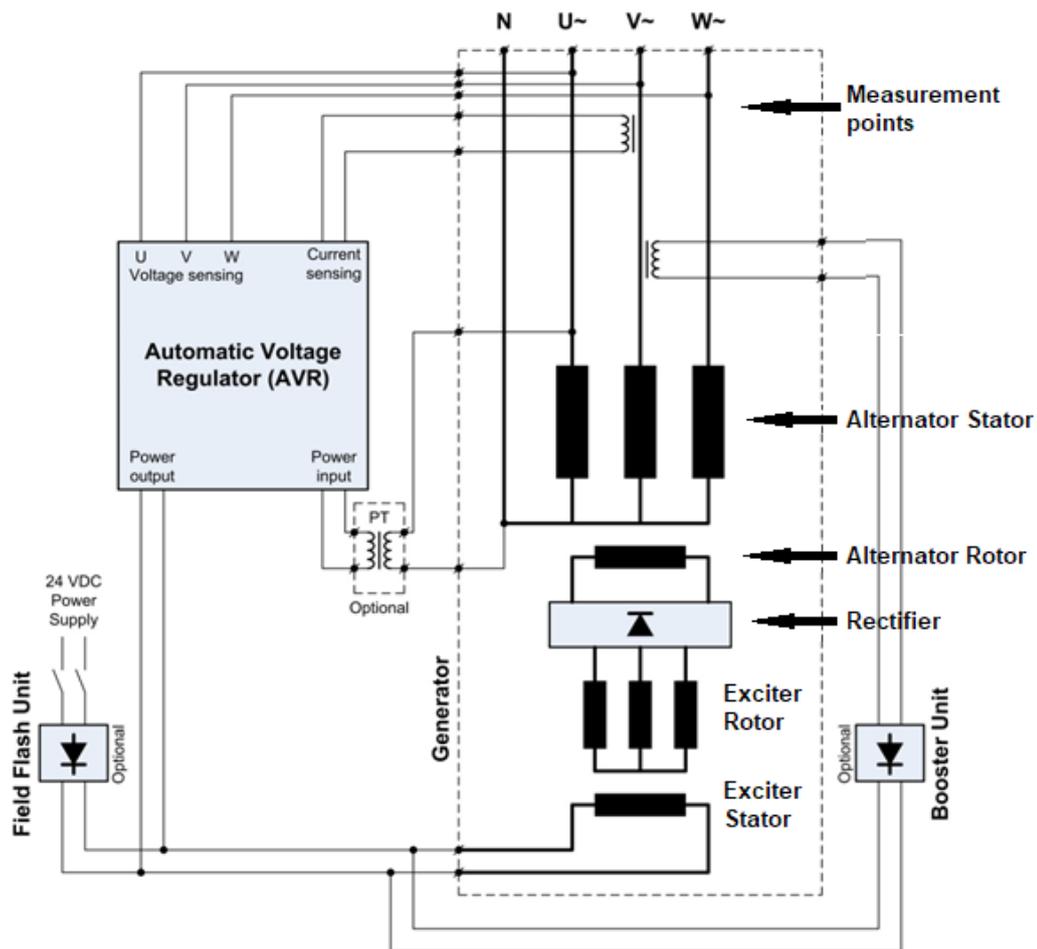
#### **2.4.1 Self or Shunt Excited Generator**

A self-excitation, or shunt excitation method is typically used in low voltage industrial generators and basic back-up generators. It uses the output of the generator stator to get power for the AVR input, the same output is used for voltage sensing /12/. This version has no provided boost in case of a short circuit /9/. The basic shunt excitation offers benefits in cost and simplicity, but does not tolerate high overloads and does not have a short circuit capability /10/.



**Figure 21.** Generator excitation system with self-excitation /10/.

The shunt transformer can be equipped with either an AC boost or a DC boost. A shunt transformer with AC boost has its excitation boosted by a current transformer in case of a short circuit. A DC boosted shunt transformer gets its boosted excitation power from a separate DC supply /9/. These are typically used in HV generators and are in fact the most commonly used excitation method in Wärtsilä power plants. The boosted shunt excitation offers benefits with fault current and heavy motor starting support, as well as better transient response, but the cost is higher than a basic shunt /10/.



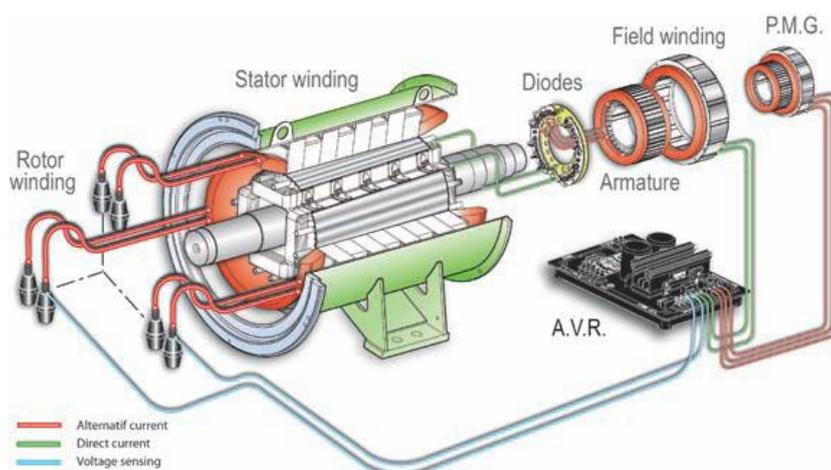
**Figure 22.** Shunt supplied excitation system /10/.

As in the figure above, the AVR voltage sensing is connected to the generator stator and is used to control the field strength of the exciter to maintain the output at a constant.

The field flash unit creates residual magnetism enough to build up to full voltage with the initial current for a very short time. It is used for the initial creation of the field and needed after a long standstill time. The booster unit provides a voltage boost when the voltage of the generator drops below 70% of nominal. This can happen after a short circuit in the busbar and is used to prevent the generator circuit breaker from not tripping. The power transformer, or PT, is used to bring down the voltage level from the generator for the input of the AVR. /10/

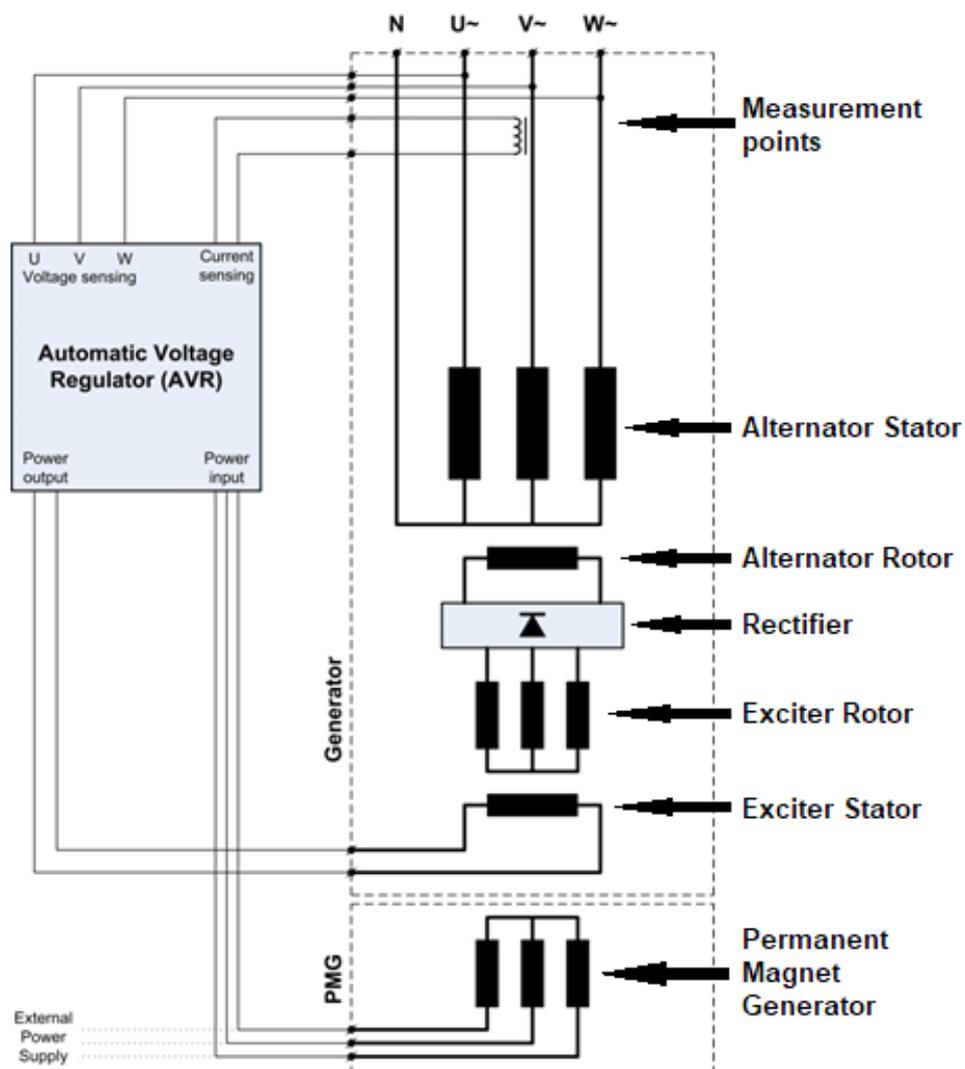
## 2.4.2 Separately Excited Generator

A separately excited generator uses a permanent magnet generator, or PMG in short, mounted at the end of the generator to supply the AVR. This is typically used in HV generators, but can also be applied to LV generators /9/. It is the most common method for applications with high performance requirements for motor starting, selective coordination, and non-linear loads /12/. The benefits of a PMG excited generator include a natural voltage build-up (instead of relying on residual magnetism), support for fault currents and heavy motor starting, and a better transient response, but adding a PMG to the end of the generator increases costs and adds weight and length to the generator /10/.



**Figure 23.** Generator excitation system with a PMG /10/.

The PMG rotates, producing AC voltage which is rectified by the controller (AVR in Figure 21). The DC voltage is then transmitted onto the exciter stator (field winding in Figure 21). The exciter rotor (armature in Figure 21) then produces an AC voltage which is rectified with rotating rectifiers (diodes in Figure 21). This DC voltage then appears in the main generator field, or rotor, which induces a higher AC voltage in the generator armature, or stator. The output voltage is finally measured by the AVR and compared to the set value.



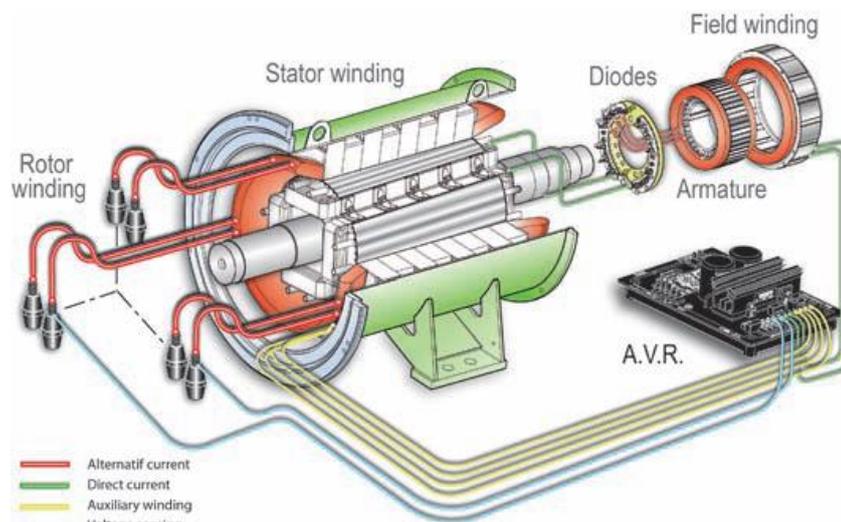
**Figure 24.** PMG or externally supplied excitation system /10/.

In the figure above, the AVR gets its power from either a PMG or from an external power supply.

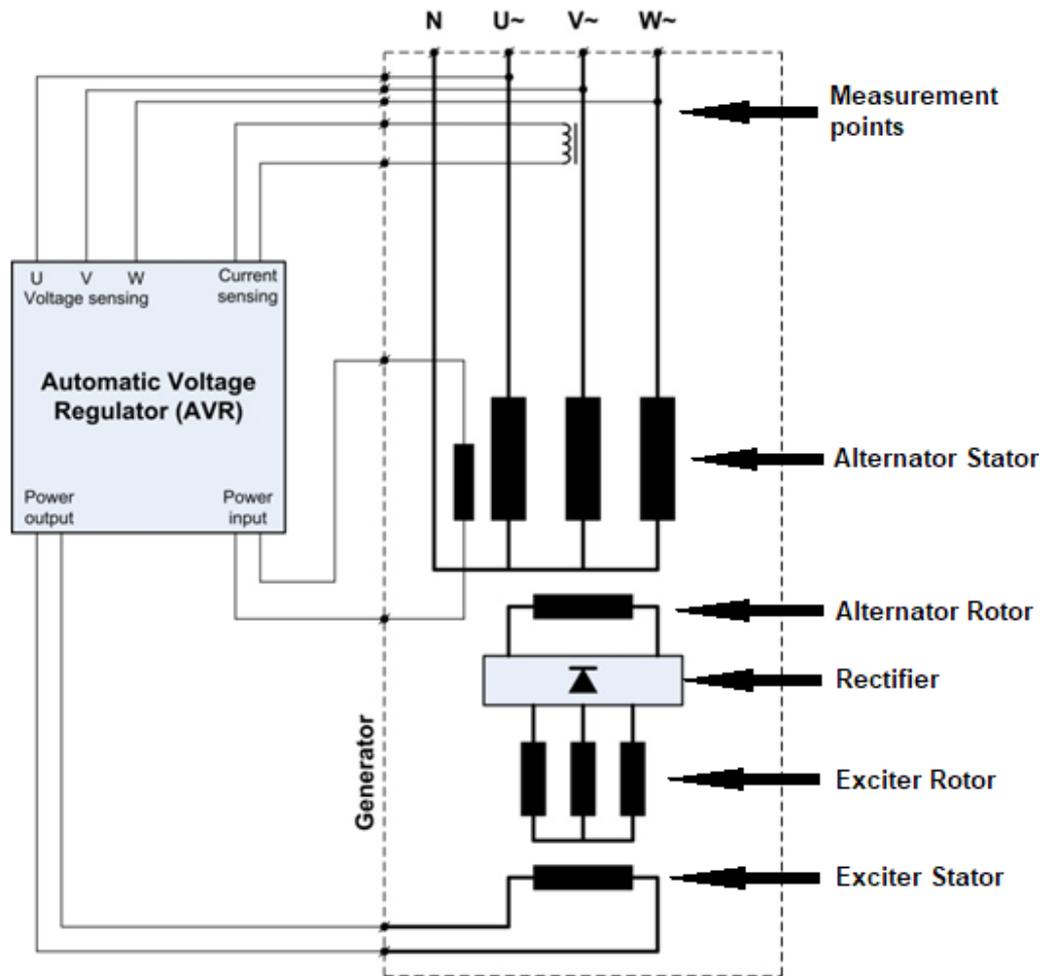
### 2.4.3 Auxiliary Winding

This type of excitation is used in wire wound LV generators. The excitation power is taken from additional wires mounted in the stator slots and does not require a separate boost /9/. Using an auxiliary winding in the excitation system means the

generator has fault current and heavy motor starting support, as well as better transient response, and it is also independent of load harmonics. This does however cost more than a basic shunt system. /10/



**Figure 25.** Generator excitation system with auxiliary winding /10/.



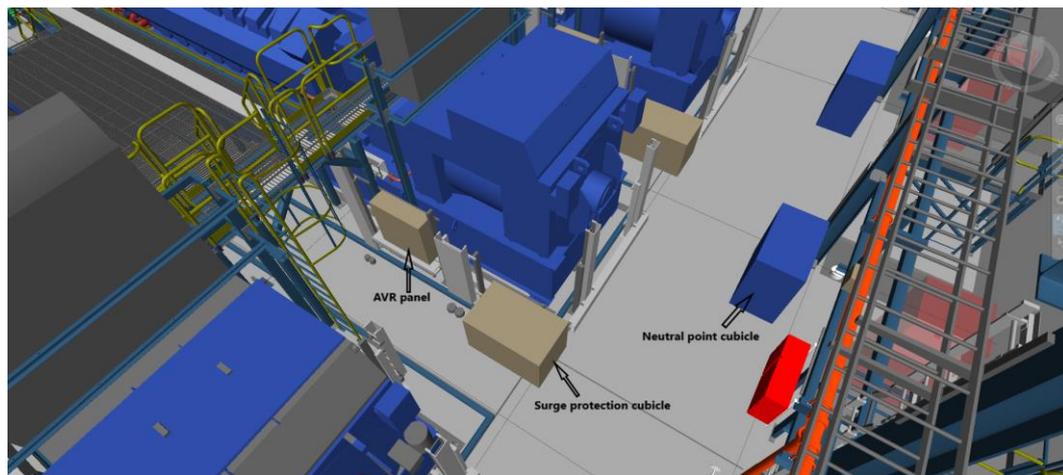
**Figure 26.** Excitation supplied by generator auxiliary winding /10/.

In the figures above, the AVR gets its input power from auxiliary windings in the generator stator.

### 3 ELECTRICAL EQUIPMENT AND THEIR LOCATIONS

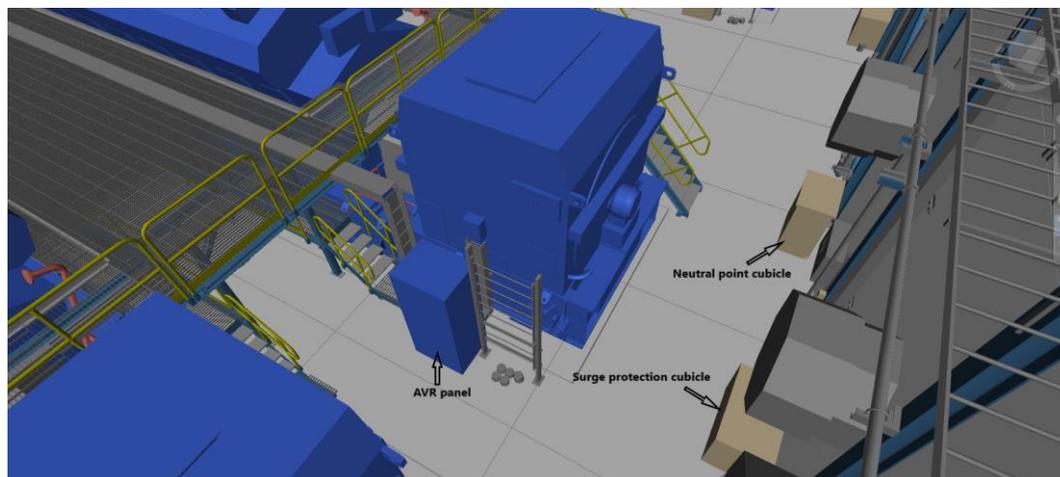
The goal for this portion of the thesis was to find out the locations, dimensions and suppliers of the three electrical equipment near the end of the generator. The information was gathered from 65 different Wärtsilä power plant projects since 2013, with a power output ranging from 30MW to 500MW. The figures are taken from 3D models made for the power plants using a software called NavisWorks. This tool was also used to find out the exact locations and dimensions for each of the equipment.

This chapter will go through the details of the equipment that will be installed near the end of the generator set. Some of them will have special requirements on where they may be located. The area will also be installed with civil objects, such as stairways, which will be taken into consideration. Other items that need to be considered are cable raceways and ladders near the generator as well as ventilation units located at the generator end wall of the engine hall. There must also be sufficient room for generator maintenance, which also limits the area of where the equipment can be located.



**Figure 27.** Example of equipment locations with W34 engines.

The above figure is taken from a project with W34 engines. It has an AVR panel sized as 300\*1000\*1000 mm, a SPC sized as 840\*1390\*910 mm and a NPC sized as 730\*1130\*1400 mm. All dimensions are depth\*height\*width.



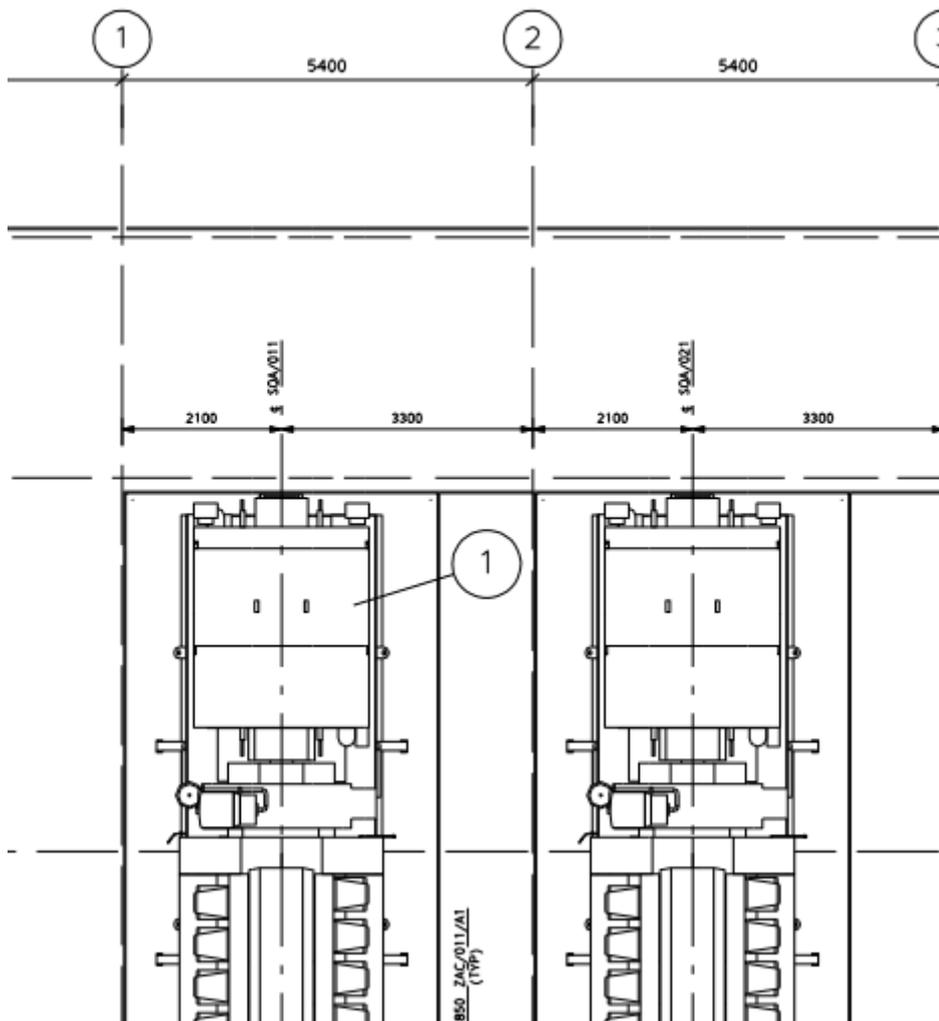
**Figure 28.** Example of equipment locations with W46 engines.

The above figure is taken from a project with W46 engines. It has an AVR panel sized as 805\*1006\*2305 mm, a SPC sized as 840\*1390\*910 mm and a NPC sized as 730\*1130\*1410 mm.

Out of the 65 projects 18 have W46/W50 engines and 47 have W32/W34 engines. The projects are categorized into W46/W50 and W32/W34 because of their size and typical dimensions between the generator sets.

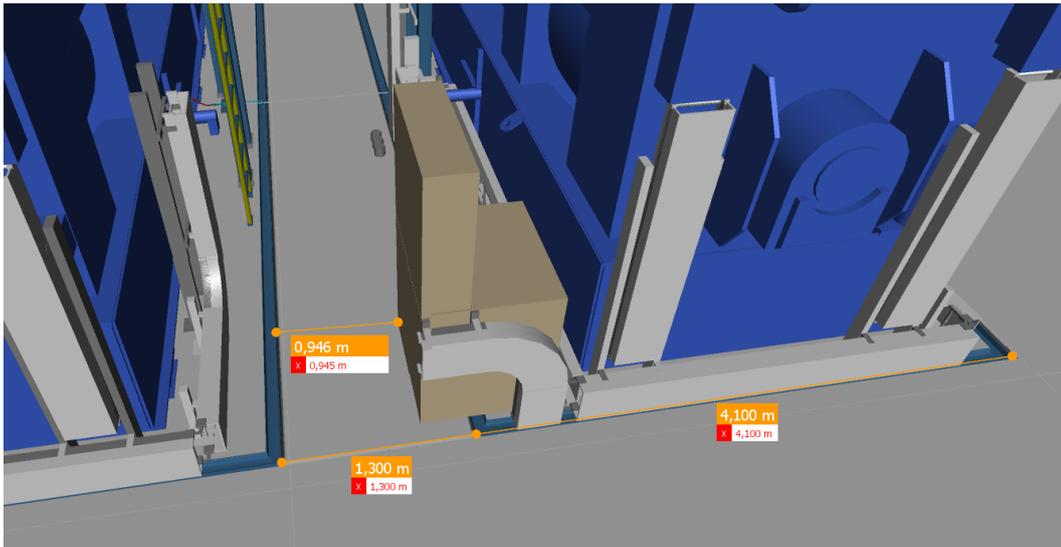
Furthermore, six of the eighteen larger generator sets have additional surge protection and only one of the projects has all three equipment installed close to the generator itself. The setup on where these equipment are located can be seen in Figure 28.

From the smaller generator sets, 24 out of the 47 projects have additional surge protection and 17 of these have all three equipment located near the generator. Information of the locations of all the equipment can be found in detail in each of their respective chapters 3.1, 3.2 or 3.3.

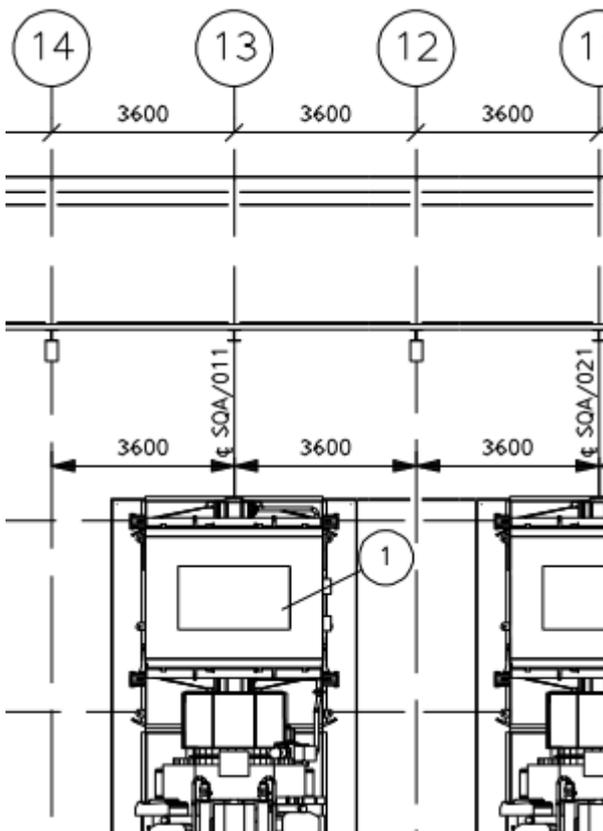


**Figure 29.** Typical dimensions of a generator set section with W32/W34 engines.

The smaller generator sets are installed in areas with a diameter of 5400 mm. Since the width of the foundations where the generator sets are installed is 4100 mm, it leaves a space of 1300 mm between two foundations. This, however, does not mean that the equipment must be installed in that space, because they can be installed quite close to the generator itself, on top of the foundation. As seen in Figure 30, the NPC and AVR panel are installed to the right side of the generator, leaving an empty area with a width of 945 mm between the other generators foundation.

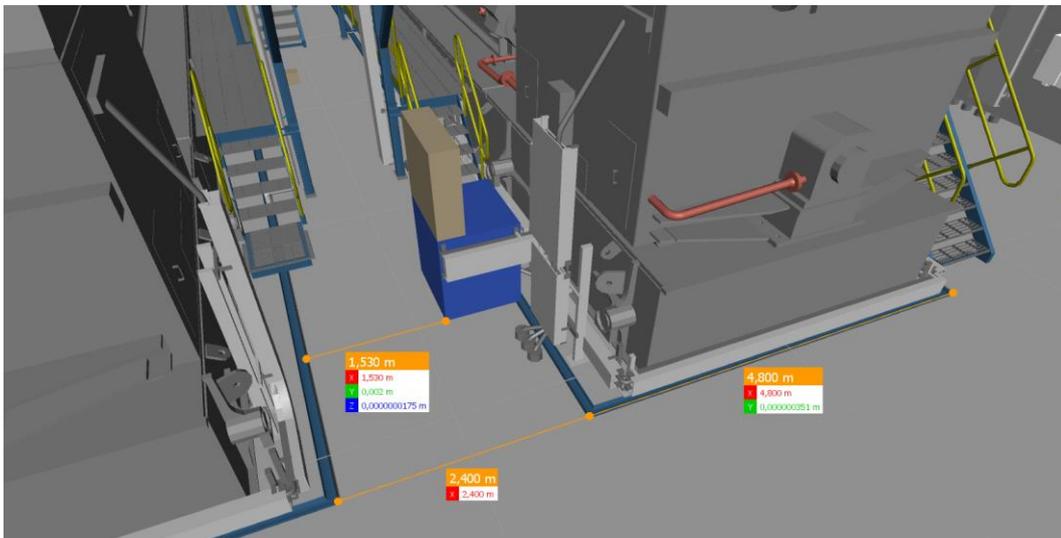


**Figure 30.** Dimensions between two generator sets with W34 engines.



**Figure 31.** Typical dimensions of generator set section with W46/W50 engines.

The generator sets with the bigger engines have a larger section, by 1800 mm. They also require more space between two generator sets, because of the additional stairways and maintenance levels. This means that the space between the foundations is typically 2400 mm, 1100 mm bigger than that of the generator sets equipped with the smaller engines. If the NPC is installed on the right side of the generator, as in Figure 32, a free space with a width of 1530 mm is left between the next foundation.

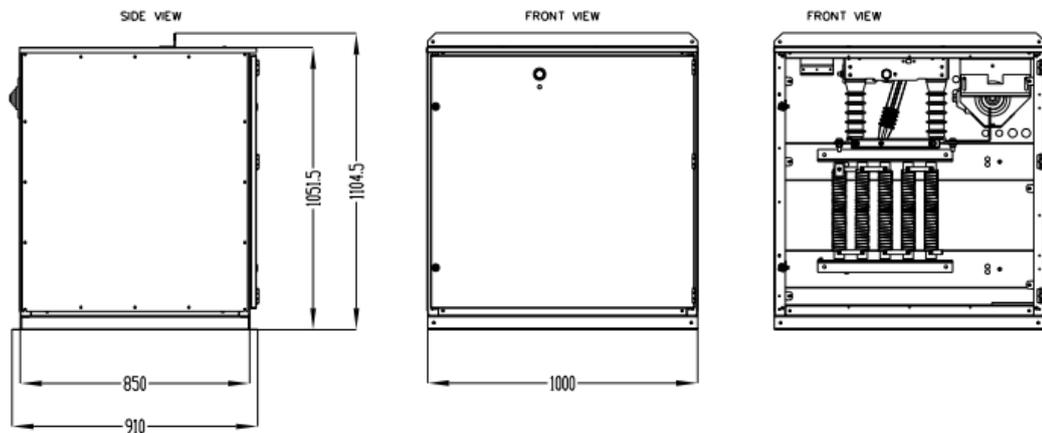


**Figure 32.** Dimensions between two generator sets with W50 engines.

The generator sets are also categorized depending on the engine control system or UNIC used. UNIC C1 is the first generation, which includes W32 and W46 engines. These are no longer being sold and should therefore not be taken into consideration when choosing standard locations for the electrical equipment. UNIC C3 includes W34 and W50 engines and UNIC C2 includes the new W31 engines. The difference between the different UNIC units is the size of the AVR control panel used.

### 3.1 Generator Neutral Point Cubicle

The generator neutral point cubicle is a piece of equipment used when selecting a resistance grounded generator neutral. It includes a resistor, a disconnectable busbar link, for disconnecting the resistor from the generator, and two cable current transformers. Optional items include a disconnecter, space heater, vacuum contactor and a single-phase voltage transformer. The cubicle size is dependent on the size and value of the resistor.



**Figure 33.** Neutral point cubicle drawing & dimensions example /6/.

If an additional grounding transformer is being used it must be dimensioned to be able to handle the rated current, meaning the power rating must be equal to the rated line-to-neutral voltage times the desired neutral current.

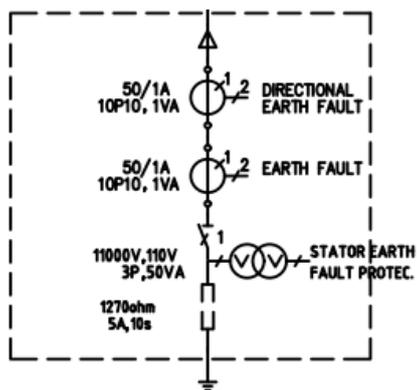
$$S_N = \frac{U_N}{\sqrt{3}} * I \quad \text{Equation 9.}$$

The grounding transformer will not be located in the engine hall or near the generator itself.

The resistance of the resistor is calculated using Ohm's law, by dividing the line-to-neutral voltage by the rated current, the resistor is rated for 10 s.

$$R = \frac{U_N}{\frac{I}{\sqrt{3}}} \quad \text{Equation 10.}$$

Most commonly the resistor is measured to give the fault current a value of 5 A. This means that in an 11 kV generator, the resistance would be 1270  $\Omega$ . Other not so commonly used values for the current are 10 A and 50 A.



**Figure 34.** Typical single-line diagram of a neutral point cubicle.



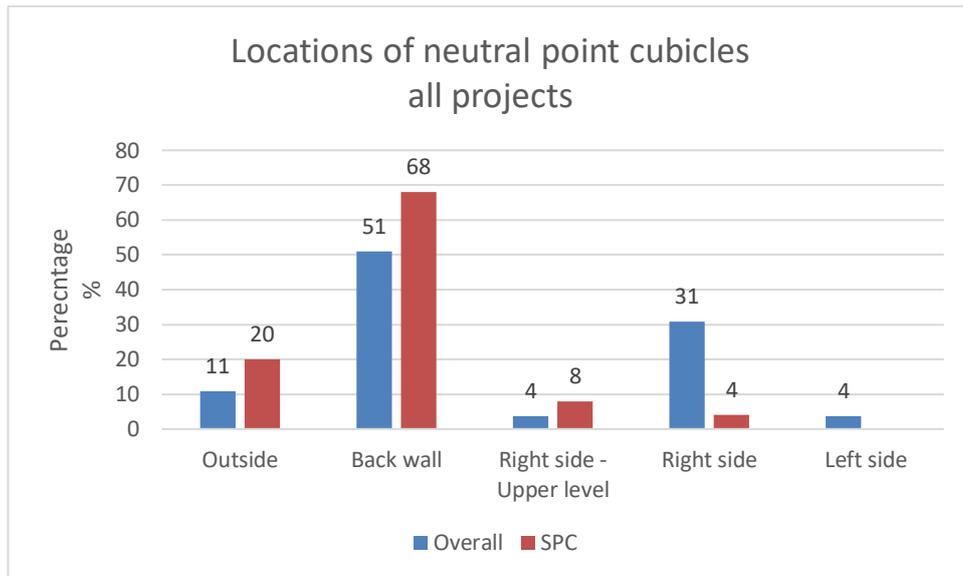
**Figure 35.** Example of a neutral point cubicle [7].

Since the size of the neutral point cubicle depends highly on the manufacturer and resistor sizing they should therefore be categorized by the manufacturer. There are basically three main manufacturers: ABB, Elkamo and NEEQ. Other manufacturers include M. S. Resistances and AEPL. Some of Elkamo made NPCs are sized and built so that they can be installed under the AVR control panel. When the NPC has been sized as 910\*1003\*1105 and the AVR control panel as 300x1000x1000 or 300x1000x1400 the two have been installed on top of each other.

**Table 1.** Typical neutral point cubicle dimensions by different manufacturers.

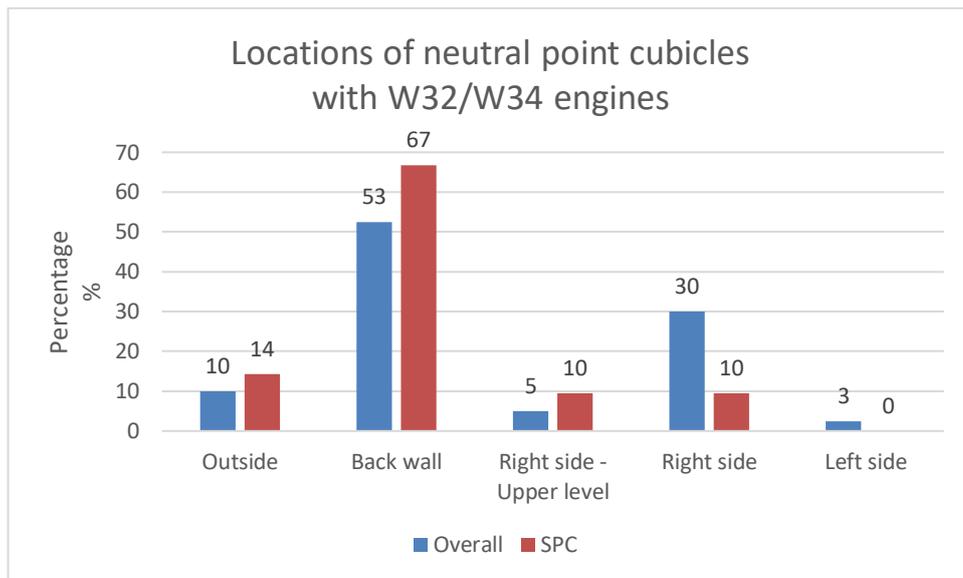
| Manufacturer | NPC Depth (mm) | NPC Width (mm) | NPC Height (mm) |
|--------------|----------------|----------------|-----------------|
| ABB          | 730            | 1130           | 1400            |
| Elkamo       | 910            | 1000           | 1105            |
| NEEQ         | 890            | 890            | 1500            |
| Others       | 800            | 1280           | 1100            |

Next, the previous locations used for the neutral point cubicles will be analysed. First from all the projects, then from projects with the smaller engines and lastly from projects with the bigger engines.



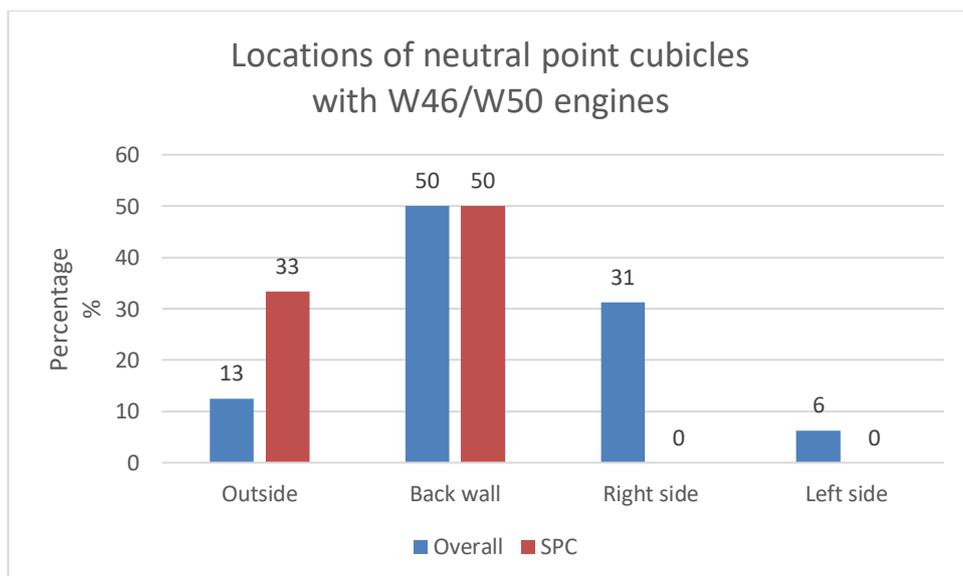
**Figure 36.** Locations of neutral point cubicles all projects.

The most common location, when looking at all the projects, is the back wall with a percentage of 51%. Another quite common location was at the right side of the generator set. When looking at all the projects with additional surge protection the percentage of NPCs located at the back wall increases to 68% with the next common location being outside of the engine hall, instead of the right side of the generator set.



**Figure 37.** Locations of neutral point cubicles with W32/W34 engines.

The locations for the neutral point cubicle do not change much when excluding the larger generator sets from the equation. The only small change is the slight increase with the cubicle being on the right side when all three pieces of equipment are used.

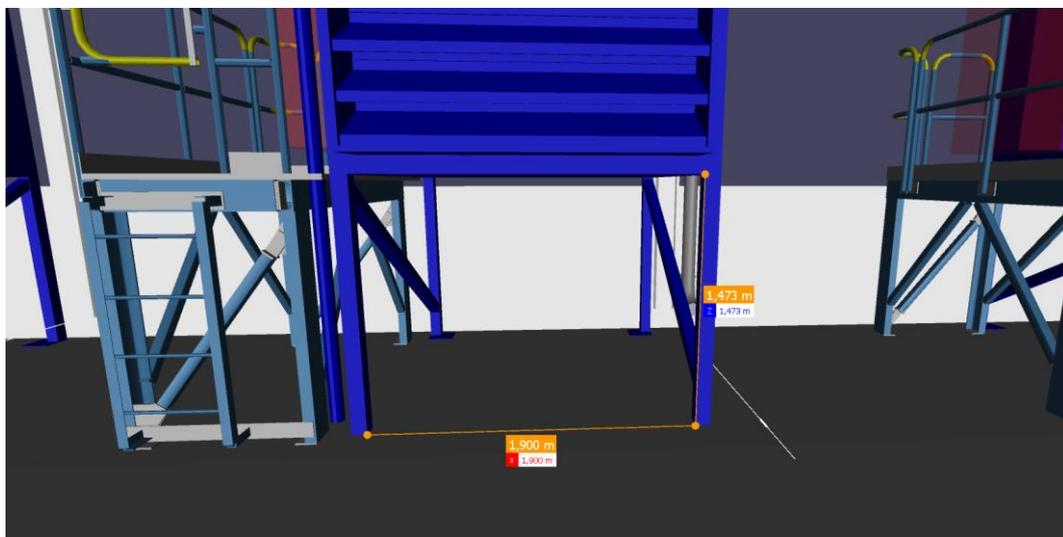


**Figure 38.** Locations of neutral point cubicles with W46/W50 engines.

Half of the neutral point cubicles are located at the back wall when looking at only projects with the larger generator sets. The other common location used was outside the power house when additional surge protection was used or on the right side of the generator when no surge protection was used.

In conclusion, the most common location for the neutral point cubicle has been the back wall of the engine hall. The next most common location has been outside of the hall, when looking at only the projects with all three of the equipment installed near the generator. It should be noted that if the cubicle is installed outside, there are no significant increase in costs or complications.

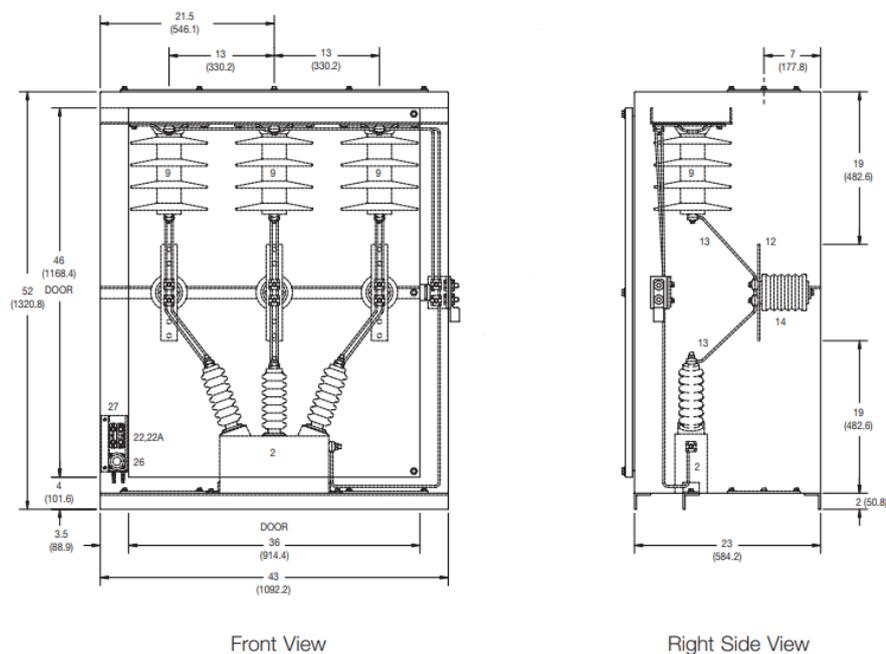
When the neutral point cubicle is installed outside, it should be located under the air conditioning unit HVAC. The space under this unit is varying, but is typically about 1900mm in depth, 1900mm in width and 1500mm in height.



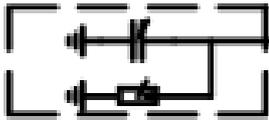
**Figure 39.** Dimensions under a HVAC unit outside the engine hall.

### 3.2 Surge Arrester and Capacitor Cubicle

When the chosen breaker type is vacuum, the generator will be equipped with additional surge protective equipment in a surge arrester and surge capacitors. These will be installed in a separate cubicle and must be installed in close proximity to the generator, in order to guarantee the best protection. The surge capacitors are installed in parallel with the surge arrester and are connected between the phases and ground. The surge arresters are used to cut the voltage peaks, limiting the maximum voltage to the generator. The surge capacitors are used to increase the impulse voltage rise time, controlling the rate of which the resultant voltage rises. Together they reduce the turn-to-turn voltages in the first coils of the generator winding, protecting the insulation. /21/



**Figure 40.** Generator surge protection cubicle drawing & dimensions /21/.

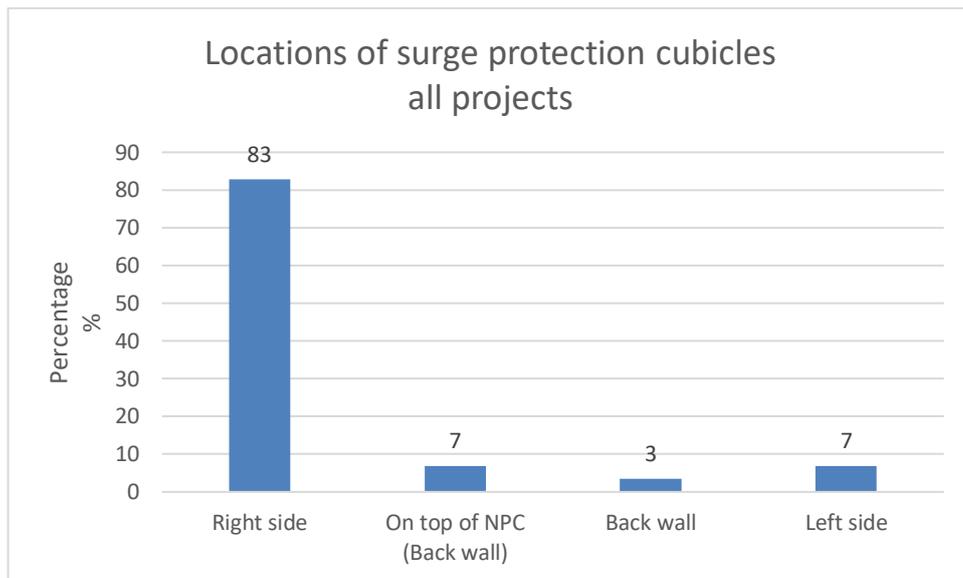


**Figure 41.** Typical single-line diagram of a surge protection cubicle /22/.



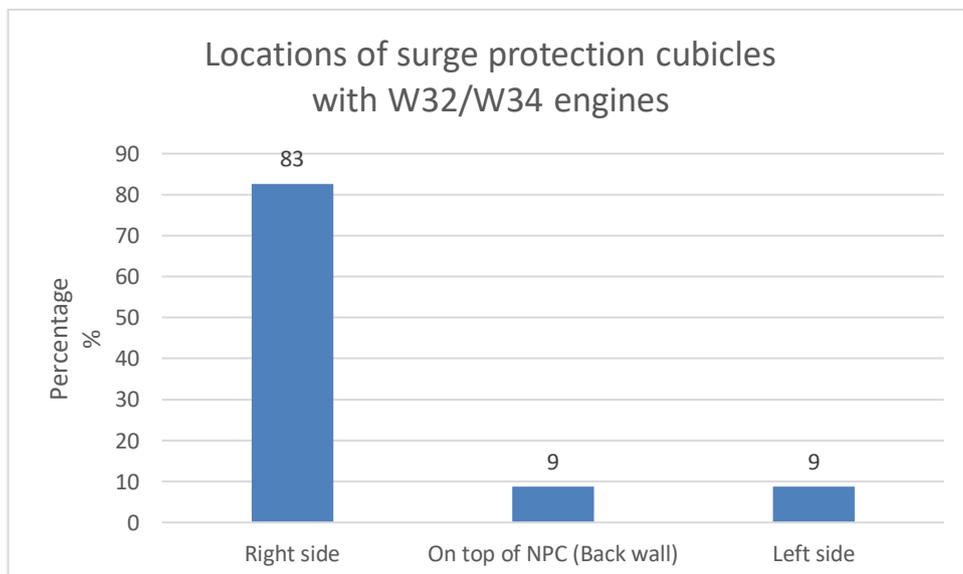
**Figure 42.** Example of a generator surge protection cubicle /21/.

Almost all of the SPCs are manufactured by ABB and the size of these cubicles is typically 840\*1390\*910mm. There was one project where the SPC was manufactured by NEEQ, the dimensions of the cubicle was 830\*700\*700mm, which means it is a lot narrower.



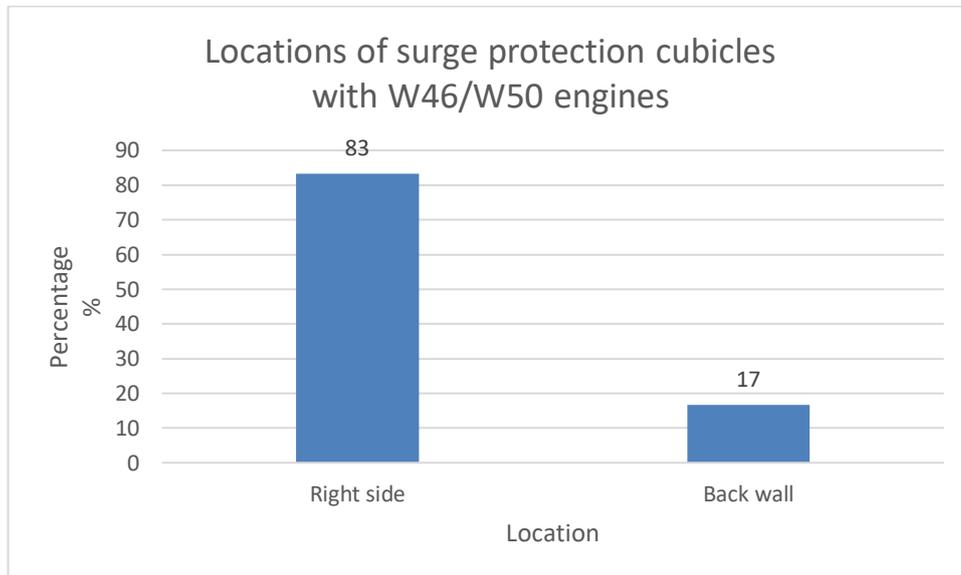
**Figure 43.** Locations of surge protection cubicles all projects.

The dominant location for the cubicle is on the right side of the generator, when looking at all projects.



**Figure 44.** Locations of surge protection cubicles with W32/W34 engines.

When discarding the larger generator sets, the locations used for the cubicle does not really change at all.



**Figure 45.** Locations of surge protection cubicles with W46/W50 engines.

When looking at only projects with the larger generator sets, the most common location is still on the right side of the generator. We can therefore conclude that the cubicle should be installed on the right side of the generator.

### 3.3 Generating Unit Control Panel

The generating unit control panel is a piece of equipment which includes apparatus such a thermostat, a fan-and-filter unit, an outlet filter, miniature circuit breakers, auxiliary contacts, a residual current breaker, relays, earthing busbars, an emergency stop push-button, a busbar, an automatic voltage regulator, and lots of terminal blocks and interface modules. The locations of all of the apparatus' can be seen in Figure 46 and Figure 47.

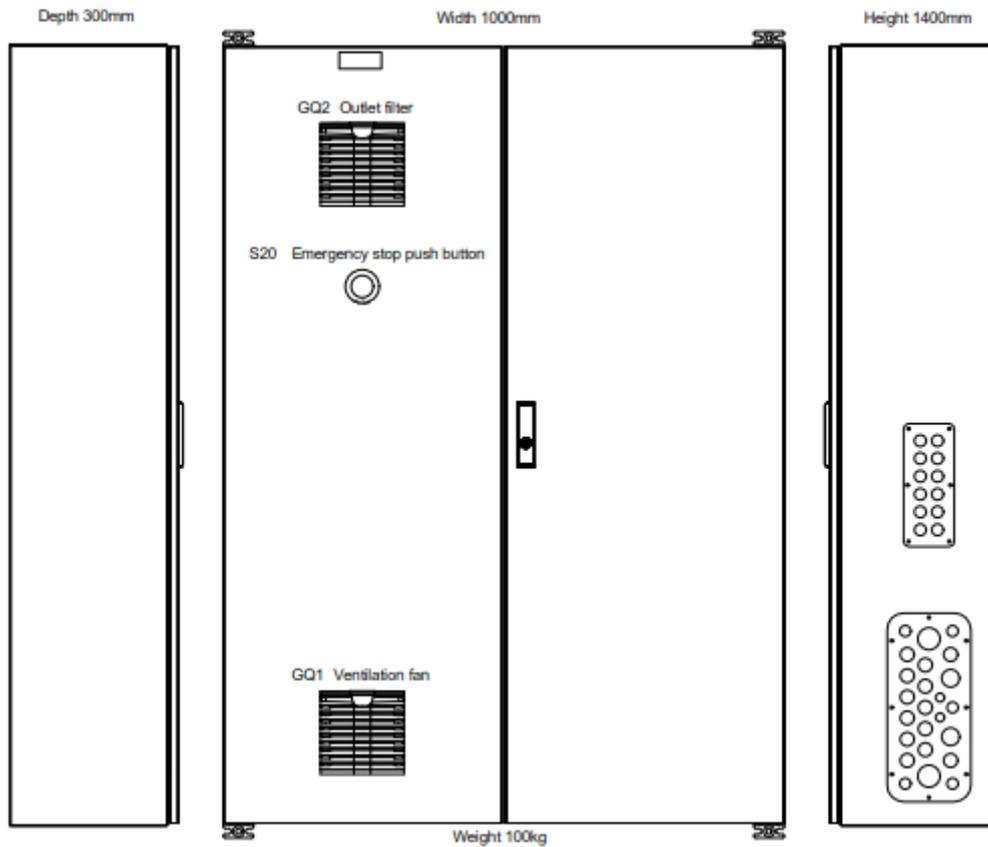


Figure 46. Generating unit control panel drawing of exterior and dimensions /23/.

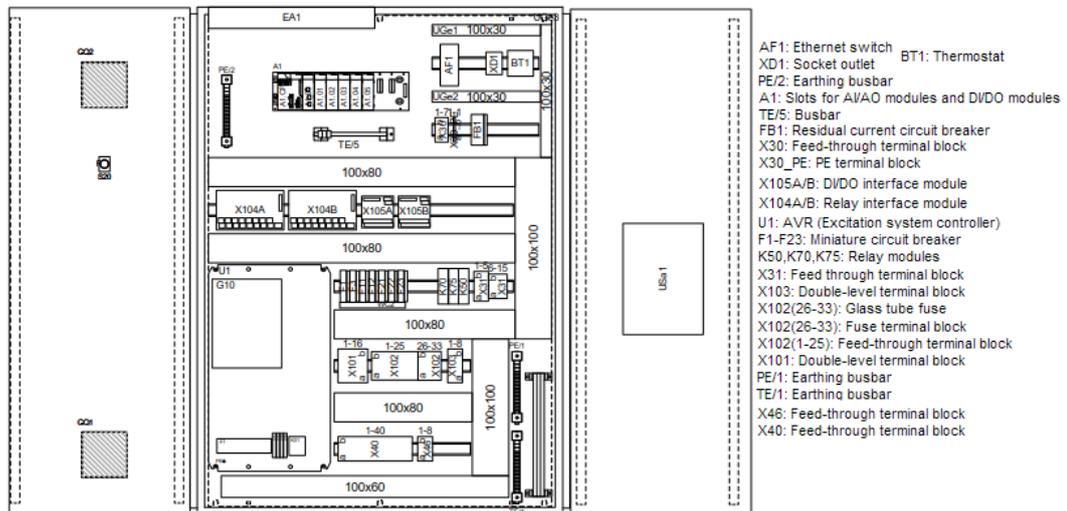


Figure 47. Generating unit control panel drawing of interior /23/.

The most important one for the user is the AVR plate U1, which is located in the bottom left of the figure above. A closer look at the plate is shown in Figure 48.

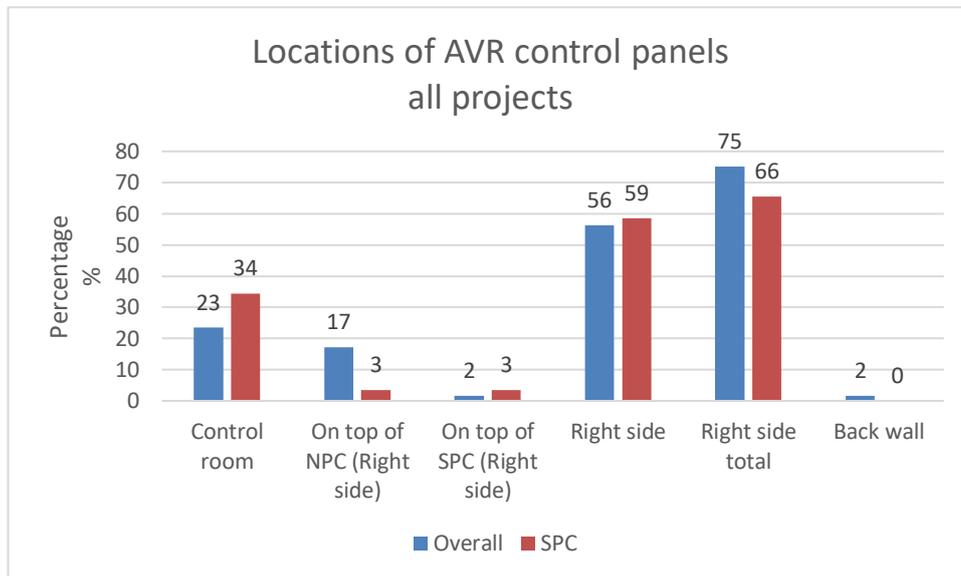


**Figure 48.** AVR plate, with the AVR ABB UNITROL 1020 (G10) with Wärtsilä logo /24/.

The AVR control panel has been previously installed in varying sizes. The typical size for UNIC C3 engines is 300\*1000\*1400mm. The AVR control panels for the older UNIC C1 engines are much larger in size up to 805\*1006\*2305mm due to them having all of the I/O panels inside of them used for various measurements. Since the UNIC C1 units are no longer being sold they don't need to be taken into consideration in this analysis. The future of Wärtsilä engines is the W31 model or UNIC C2, which will have an AVR control panel sized as 500\*800\*1800mm.

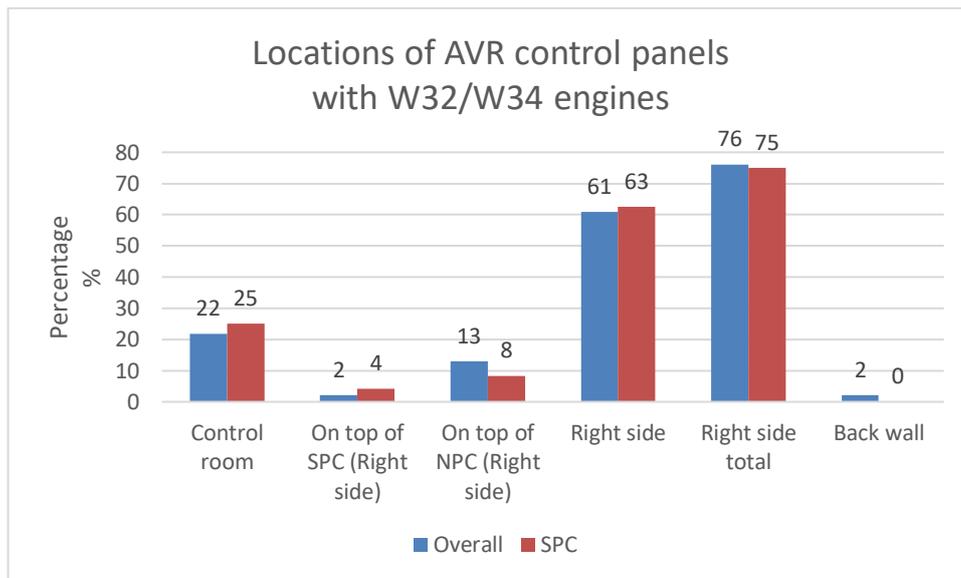
Another thing to consider for the future is an additional panel that must be located next to the AVR control panel. This new panel includes the DC distribution for the generator set and will be sized as 300x760x760mm for UNIC C3 engines. The new

UNIC C2 engines will have this new panel installed together with the AVR control panel and does not need to be considered separately.

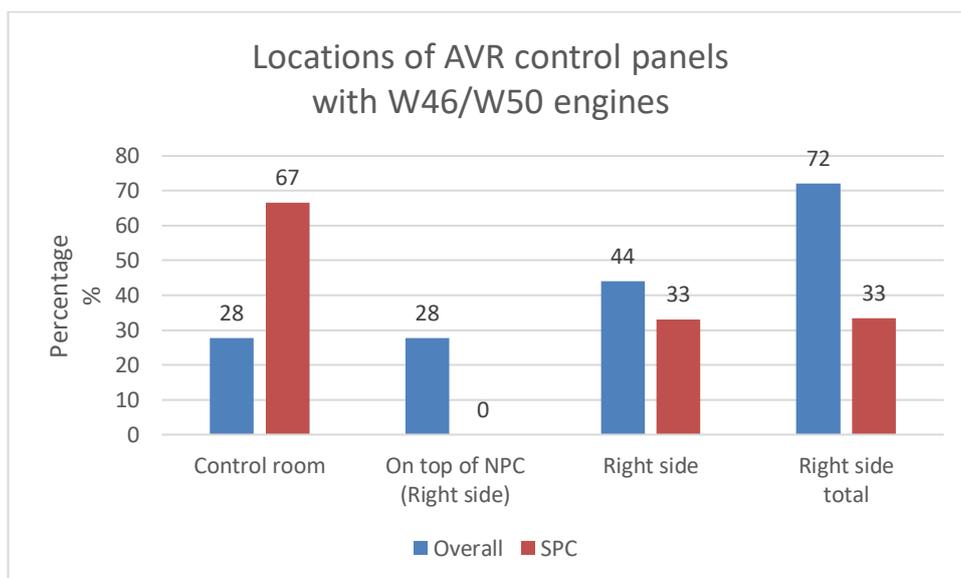


**Figure 49.** Locations of AVR control panels all projects.

The AVR control panel has been typically located on the right side of the generator, either by itself or on top of the neutral point cubicle or the surge protection cubicle. In some cases, the AVR control panel is located in the control room of the power plant site. When determining the standard location for the equipment this location should not be considered, but it should be installed near the generator set itself.



**Figure 50.** Locations of AVR control panels with W32/W34 engines.



**Figure 51.** Locations of AVR control panels with W46/W50 engines.

After comparing the projects with the smaller generator sets and the larger generator sets, the common location for the AVR control panel remain consistently on the right side of the generator. It can be therefore concluded that the panel should be located on the right side of the generator as standard.

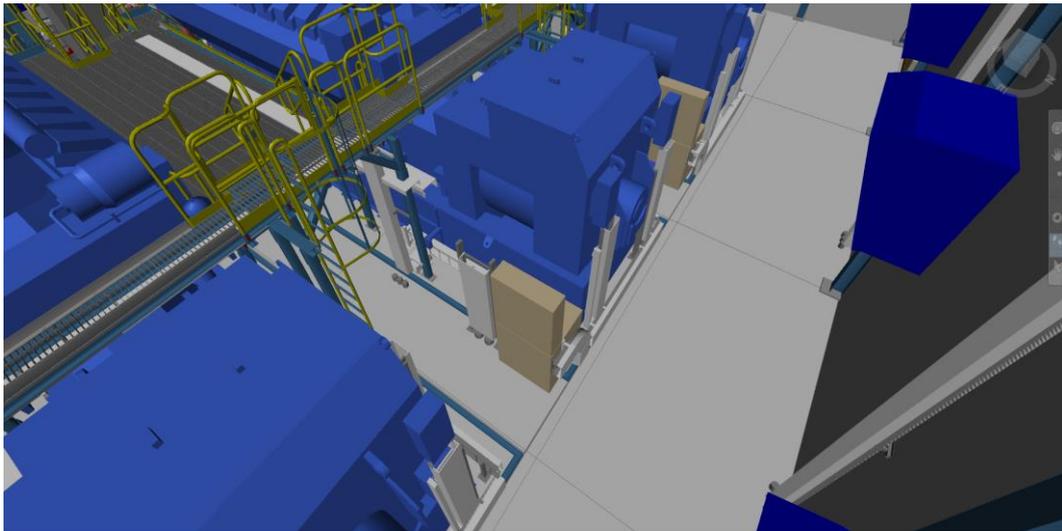
### 3.4 Equipment Layout

Since the UNIC C1 units are no longer being sold, and the locations for the UNIC C2 units have already been decided, these conclusions will only include the UNIC C3 units, or W34 and W50 engines.

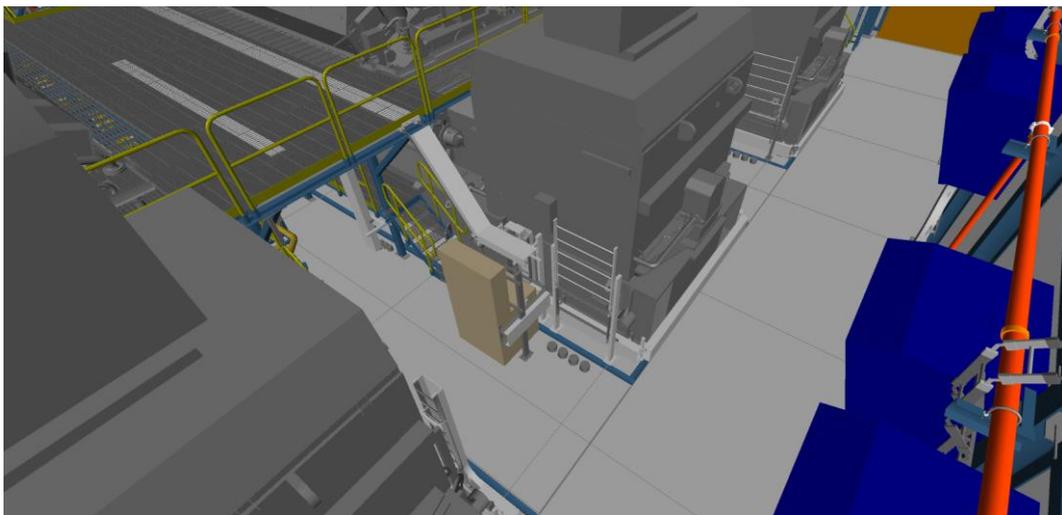
Using the information from the previous chapters we can compile the following cases that could be applied for future projects. The first two cases are for the neutral point cubicle, the third and fourth cases are for the surge arrester cubicle and the fifth case is for the AVR control panel.

Case 1: In projects with the SF6 circuit breakers, the neutral point cubicle should be installed under the AVR control panel. The size of the cubicle in such applications has been 910\*1003\*1105mm (D\*W\*H) in previous projects. The only supplier of this size of cubicle has been Elkamo.

Case 2: In all other situations, the neutral point cubicle should be installed outside, under the HVAC unit, or inside next to the generator end wall if there is insufficient space under the HVAC unit. This also applies to all projects with vacuum circuit breakers. The space under the HVAC unit is typically around 1900x1500mm (W\*H), so the height of the cubicle should not exceed 1400mm.



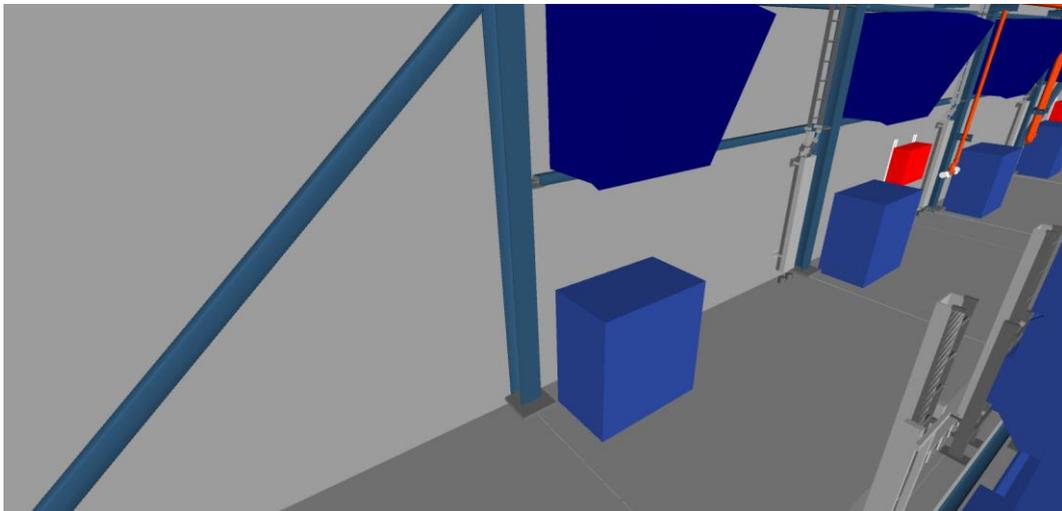
**Figure 52.** Case 1: neutral point cubicle installed under the control panel in a project with W34 engines.



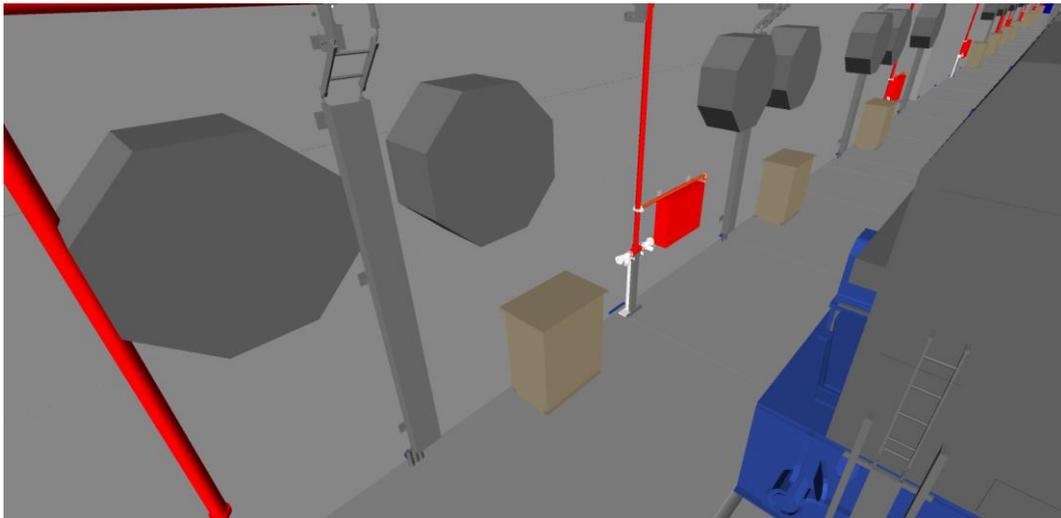
**Figure 53.** Case 1: neutral point cubicle installed under the control panel in a project with W50 engines.



**Figure 54.** Case 1: neutral point cubicle installed under the control panel in a project with W50 engines.



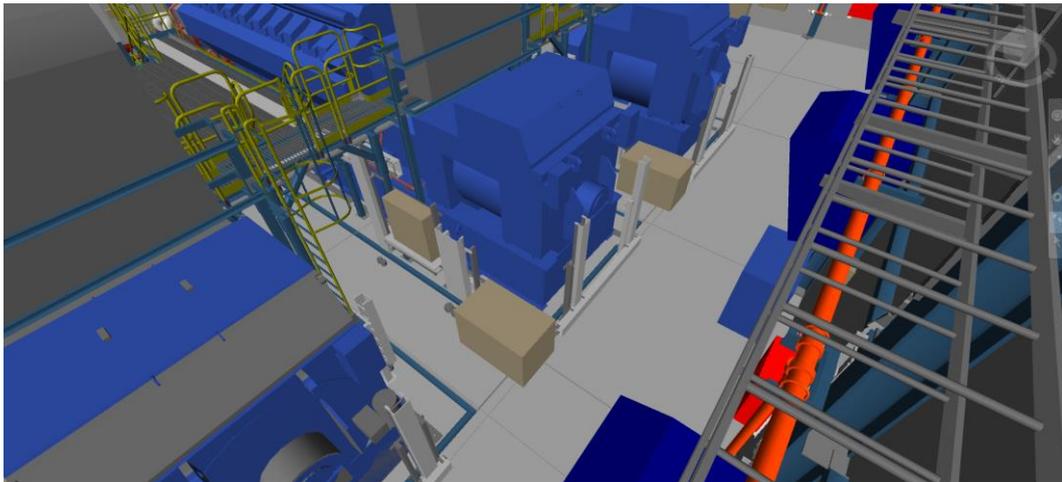
**Figure 55.** Case 2: neutral point cubicle installed next to the back wall in a project with W34 engines.



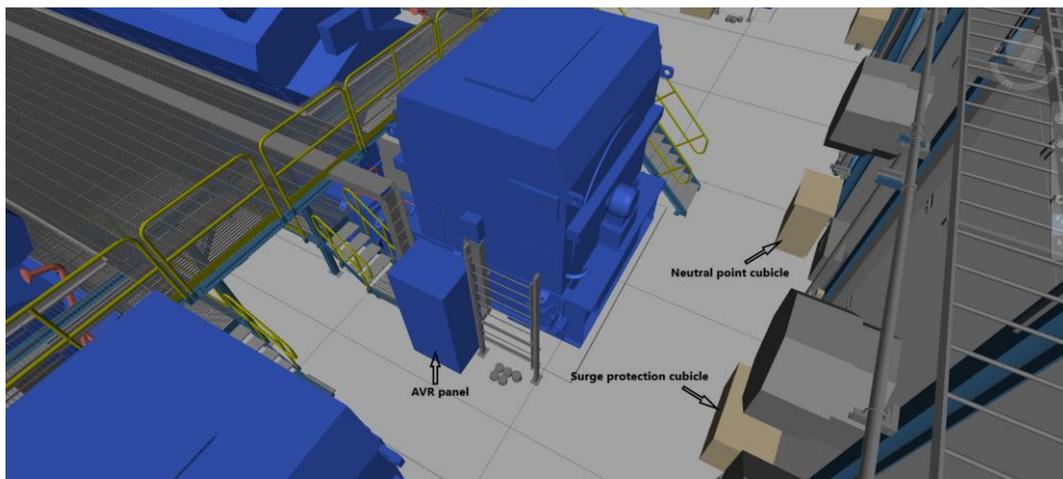
**Figure 56.** Case 2: neutral point cubicle installed next to the back wall in a project with W50 engines.

Case 3: The surge arrester cubicles should be installed next to the generator for the W34 engines. For the W50 engines there might not be sufficient room next to the generator, in this case the cubicle should be located next to the generator end wall.

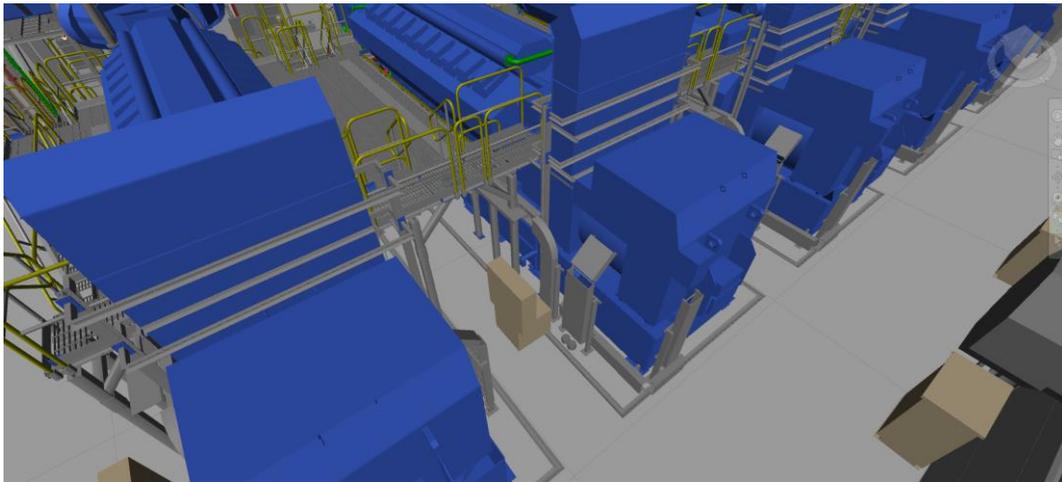
Case 4: The surge arrester cubicle could also be located in the same way as in case 1, where it is installed under the AVR control panel. This method cannot however be used with the current ABB cubicles. There was one project where the cubicle was supplied by NEEQ and in this situation, it was installed under the AVR control panel. The cubicle was sized as 830\*700\*700mm, compared to the typical ABB models sized as 840\*1390\*954mm. The current ABB models are twice as wide and also are cabled from the side, making them very impractical.



**Figure 57.** Case 3: The surge arrester cubicle is installed next to the generator in a project with W34 engines.

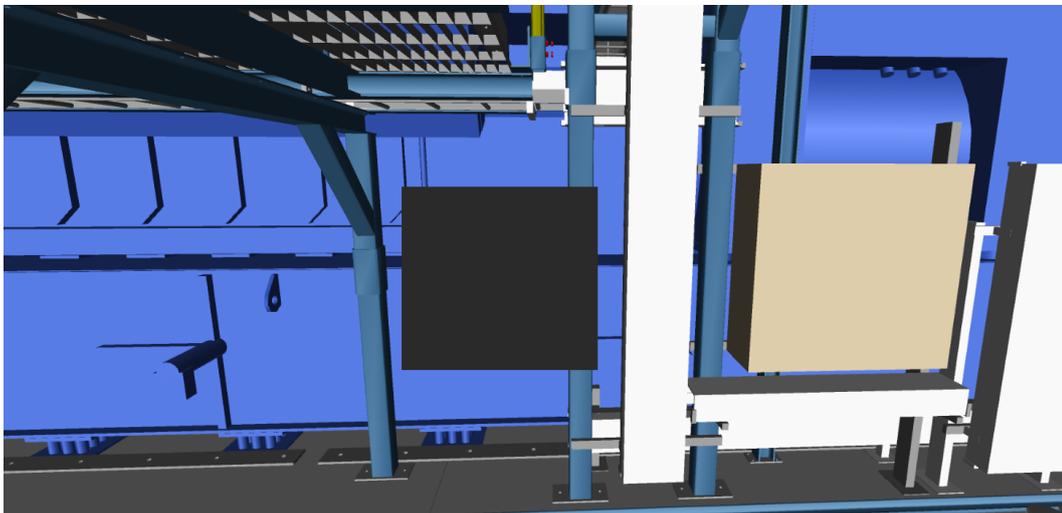


**Figure 58.** Case 3: The surge arrester cubicle is installed next to the wall in a project with W46 engines.

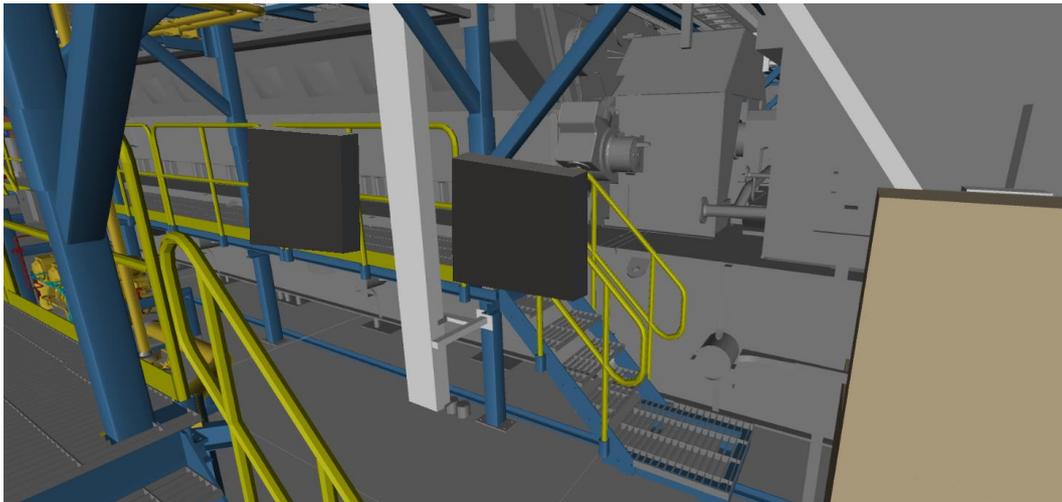


**Figure 59.** Case 4: The surge arrester cubicle is installed under the control panel in a project with W34 engines.

Case 5: The AVR control panels should always be installed next to the generator. The new panel should also be installed next to the generator. Examples for the locations of the new control panel can be seen in Figures 60 and Figure 61.



**Figure 60.** Case 5: Possible locations for the panels in a project with W34 engines.



**Figure 61.** Case 5: Possible locations for the panels in a project with W50 engines.

Finally, some additional thoughts and suggestions for the cubicles. In the future, if all the neutral point cubicles were ordered and manufactured with the same or similar dimensions, independent of the supplier or resistor size, they could be sized so that they all could be located either under the control panel or under the HVAC unit. This would make it so that in any project, there would never be a neutral point cubicle taking extra space next to the generator end wall and that all the cubicles would be installed in the same manner.

The same suggestions apply for the surge arrester cubicles as well. If the cubicles could be ordered in a more compact size, such as the one mentioned in case 4, they could always be installed in the same location for each project.

Having the luxury of knowing the locations of the cubicles even before ordering them, would make the process much faster and save important resources that can be used elsewhere.

### **3.5 Auxiliary Electrification on the Generator End Wall**

The generator end wall of the power house has various equipment installed on it. The locations and cabling of these auxiliary equipment are decided on site. This forces the site team to order additional items after the installation locations have been decided. The objective of this part of the thesis is to collect information on the electrification from previous projects and form a guide for future projects for possible standardisation. The included equipment are as follows:

- Lighting system (lighting, sockets or panels, switches, emergency lighting & exit lighting)
- Fire detection system (fire detectors, push buttons, sounders & beacons)
- Gas detection system (gas detectors, sounders & beacons)
- Video surveillance (sockets & cameras)

The lighting is typically installed by wall mounting at a height of 2200-2500mm, this includes the emergency & exit lighting. The sockets or panels are installed at a height of 1700mm and the switches at a height of 1000mm. The installation height of the fire and gas sounders & beacons vary, but a common height is around 2500mm. The push buttons for the fire detection system are installed at a height between 1400-1700mm. The surveillance cameras are installed at the height of the maintenance level, typically around 3000mm. There are, however, locations with exceptions for these installation heights, such as the service bridge area and the doorways.

All of these needs to be electrified and the planning is done on site. This leads to inefficient methods that can increase costs and the duration of the project. The purpose for this analysis is to form a guidance that allows for the correct amount of materials to be ordered in the main delivery. In past projects the cabling has been done separately for each piece of equipment, where the cable runs down directly from the raceway.

The proposal is to add an additional raceway that runs horizontally from each of the generator sets cable raceways. The raceway will be placed at such height that all

the equipment can be properly cabled from the raceway. A rough example is presented in Figure 62. The black lines represent the cables and the cable raceways. The black rectangles, squares and circles represent all the equipment that is installed on the end wall of the engine hall.



**Figure 62.** Engine hall generator end wall electrification example.

When the electrification is done in this manner it makes it possible for all of the required items to be ordered together with the main delivery for each project. This also cleans up the wall from all of the cables that run down from the cable raceway.

## 4 CONCLUSIONS

Completing a project and being able to handover the power plant is very crucial for the success of the company. Any resources and time that is wasted will be a setback. My goal when making this thesis was to give out ideas that Wärtsilä can use in order to save those precious resources and man-hours. Another thing that was taken into consideration was the limited space that there is around the end of the generator sets in the engine hall. The space may become even more limited, since a bigger hall costs more money, and saving money is a priority for every company. This means that the engineers who plan the locations for the electrical equipment may have to be creative, which takes time and can create tight areas within the engine hall. With my ideas, I hope to guide the members involved in arranging the locations for the equipment, so that these situations can be avoided.

Both the saving of resources and man-hours will come from well thought out pre-planning. Following my suggestions, I hope Wärtsilä can create new standards making it possible to choose the locations of each equipment for every single project without the need for any extra work. This is not as easy as it may seem though, since the suppliers are the ones who manufacture the cubicles. If, however, the suppliers are able to manufacture the equipment so that they are properly dimensioned for Wärtsilä's purposes, it could equate to considerable profits considering how many projects Wärtsilä has in a single year. When the neutral point cubicle is installed either under the control panel or the HVAC unit instead of next to the generator end wall, it can even make it possible to have a smaller engine hall. Even a slight decrease in the length of the hall means that less supplies are needed.

The profits gained from being able to order enough items for the electrification of the generator end wall with the initial order could also be substantial considering the amount of time and money that is wasted when ordering them from the site itself.

All things considered, I do hope that this thesis is of use for Wärtsilä and that they will take my suggestions into consideration.

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