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ELECTRICAL ENGINEERING

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FEASIBILITY STUDY OF POWER INCREASE FOR GAS ENGINE POWER PLANTS

Master's Thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, 18.08.2014.

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PREFACE

This thesis work is made for Wärtsilä Finland Oy Services, Electrical and Automation unit. The main goal was to study feasibility of power increase for gas engine power plant.

I would thank my instructor Daniel Nylund for instructions and guidance during the thesis work. I would give thanks to employees in Solutions Sales Support and Technology Development. I would also thank the supervisor Kimmo Kauhaniemi and the evaluator Timo Vekara.

I would like to thank my parents Tiina and Kari for all guidance and advices. I am also thankful to my closest relatives and friends for helpfulness and good memories. I would also give big thanks to my mother-in-law Merja for all help and support. Special thanks to Nora who has been next to me in good and challenging times.

Vaasa, 18.8.2014

Jaakko Tiihonen

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SYMBOLS AND ABBREVIATIONS

Symbols

cos φ	Power factor
f	Frequency
n	Rotation speed
I	Current
p	Pole pair number
P	Power
P_{in}	Input power
P_{out}	Output power
S	Apparent power
U	Voltage
η	Efficiency

Abbreviations

AC	Alternating current
CT	Current transformer
DC	Direct current
GIS	Gas-Insulated Switchgear
PLC	Programmable Logic Controller
rpm	Round per minute
SF_6	Sulfur Hexafluoride
UNIC	UNIfied Controls
WECS	Wärtsilä Engine Control System
WISE	Wärtsilä Information System Environment
WOIS	Wärtsilä Operator's Interface System
XLPE	Cross-linked Poly Ethylene

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ABSTRACT

In commercial markets all companies have to seek new opportunities to make profit. In power plant business it means feeding more electricity to the national grid or other loads. One way to make power plant business more profitable is to buy more engines, but it can be quite expensive related to the benefit. Another limitation can be space if the owner doesn’t have any extra room for power plant extension. Increasing power for engines can be a good option.

The goal of the thesis work is to study feasibility of power increase in certain gas engine power plants. For the engine mechanical power increase there is already a proper design. The electrical side has not been studied in this scale. This thesis studies the following electrical components of the studied power plants: generator, cables, medium voltage switchgear and transformer. Some of the power plants have only generators in the Wärtsilä scope of supply. In these cases the study is made with the information available.

This work is a part of a business case studying how Wärtsilä could increase the customer’s profit in certain conditions. The results will show how much output can be increased in different power plants without any modifications or with only minor modifications.

The main result of this thesis work is that 40 percentage of the investigated installations can be modified easily to fulfill the requirements of power increase. In 12 percentage of the installations, there is no need to do any modifications for electrical hardware. Eight percentage of the cases needs major modifications. In 28 percentage there is a need for medium size modifications and in 12 percentage of the cases there was not enough data for feasibility study. In general power increase would be a good opportunity to Wärtsilä to commercialize this study for certain gas engine power plants. This could give more value to the customer and would also benefit the business of Wärtsilä.

KEYWORDS: Power increase, power plant, gas engine

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TIIVISTELMÄ

Kaupallisilla markkinoilla yritykset pyrkivät löytämään keinoja voiton kasvattamiseksi. Voimalaitosliiketoiminnassa voitto kasvaa syöttämällä enemmän sähköä joko kansalliseen verkkoon tai muihin kuormiin. Yksi keino lisätä liiketoiminnan kannattavuutta on ostaa lisää moottoreita voimalaitokseen, mutta tämä voi olla kallista hyötyihin nähden. Yksi rajoittava tekijä on tila, jossa voimalaitos sijaitsee. Moottoreiden tehonnosto voi olla yksi ratkaisuista, jolla pystytään mahdollisesti kasvattamaan tuottoa ilman suuria investointeja.

Tämän diplomityön tarkoituksena on tutkia tehonnoston mahdollisuuksia ja vaikutuksia tietyissä Wärtsilän kaasuvoimalaitoksissa. Moottoreiden mekaaniselle tehonnostolle on olemassa jo käypä ratkaisu, joten tämä työ keskittyy sähköiseen tehonnostoon, jota ei tällä tavoin ole vielä tutkittu. Työ sisältää seuraavien sähköisten komponenttien käsittelyn voimalaitoksissa: generaattori, kaapelit, keskijännitekojeisto ja muuntaja. Joissakin voimalaitostapauksissa vain generaattori on ollut Wärtsilän toimituksessa, jolloin laskennat on tehty saatavilla olleilla tiedoilla.

Tämä työ on osa Wärtsilän projektia, jonka tarkoituksena on tarjota asiakkaalle mahdollisuus suurempaan liikevoittoon. Työn tulokset näyttävät kuinka paljon tehoa voidaan nostaa erilaisissa tapauksissa ilman uusia investointeja tai vain pienillä muutoksilla.

Tutkituista laitoksista 12 prosentissa ei tarvitse tehdä muutoksia laitteistoihin, 40 prosentissa muutokset ovat pieniä, 28 prosentissa muutokset ovat keskisuuria ja 8 prosentissa muutokset ovat todella mittavia. 12 prosentissa tapauksista ei ollut riittävästi tietoa, jotta tehonnoston toteutettavuusselvitys näille laitoksille olisi ollut mahdollista. Tehonnoston tuotteistaminen voisi olla Wärtsilälle hyvä vaihtoehto. Tämä uusi tuote antaisi hyvät mahdollisuudet Wärtsilälle lisätä markkinaosuutta ja antaa asiakkaille lisäarvoa voimalaitoksiinsa.

AVAINSANAT: Tehonnosto, voimalaitos, kaasumoottori

1 INTRODUCTION

Companies want to make good products and also be a profitable investment to shareholders. This should be made at low costs and at the same time high quality products and services should be provided to customers. Wärtsilä power plants are made to produce energy in different ways. The amount of energy which can be produced is related to engines’ outputs. Wärtsilä has now an ongoing business case, where they are seeking solutions for power increase in gas engine power plants. Power increasing would provide an opportunity to produce more energy only by making small or medium size modifications in the plants. If the energy producer would want to produce more energy, it usually would require investigations to new engines which is a big scale investment.

This study is made for Electrical and Automation unit of Wärtsilä Services and its goals are to investigate if power increase in Wärtsilä gas engine power plants is possible to made, and what modifications is needed to increase power in specific cases. Totally 67 different projects are involved in this study and six of them are presented with more details in this thesis.

Chapter 2 includes presentation of Wärtsilä Power Plants and Services. The chapter deals with different kind of power plants depending on the fuel used to produce energy. Chapter 3 is introduces the electrical components of a power plant. The first one is generator. Its main principles, structure, protection systems and coolants are introduced. After the generator, the medium voltage switchgear is introduced. The last section in Chapter 3 introduces transformer and its principles.

Chapter 4 is about increasing power in power plants. It includes formulas for all components and calculations for example for current withstand possibilities. Chapter 5 deals with six different projects. The needed changes in these power plants vary case by case.

Chapter 6 is discussion. It includes the results and conclusions for power increasing; in which of the cases it is a very good solution for the customer and in which cases it is not so profitable. The guidelines for future cases are also introduced. What should be done if power increasing project were considered to some other type of power plant installations; what facts has to be taken into account and what are the most critical parts of the projects? In summary this thesis work and the results of the study are shortly presented.

2 WÄRTSILÄ POWER PLANTS

This chapter includes power plant function principles and explains what kind of power plants and operating modes Wärtsilä has to offer. Each of the power plant type and its benefits are also introduced.

2.1 Power plant operating principle

Power plant main task is to produce energy. Energy can be produced in different ways, but the main principals are usually the same. Figure 1 shows one example of a power plant. As we can see, main components are the engine and the generator. In this case waste heat is used to warm up water on customer site. Power plant structure drawing is in Figure 2.

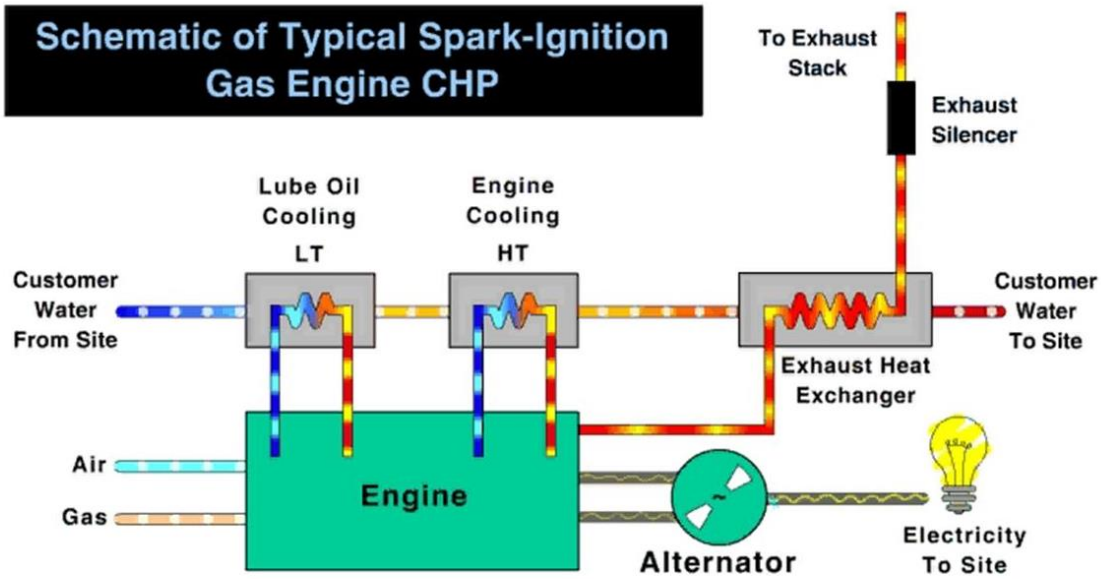


Figure 1. Schematic picture of a power plant (Gandras 2014).

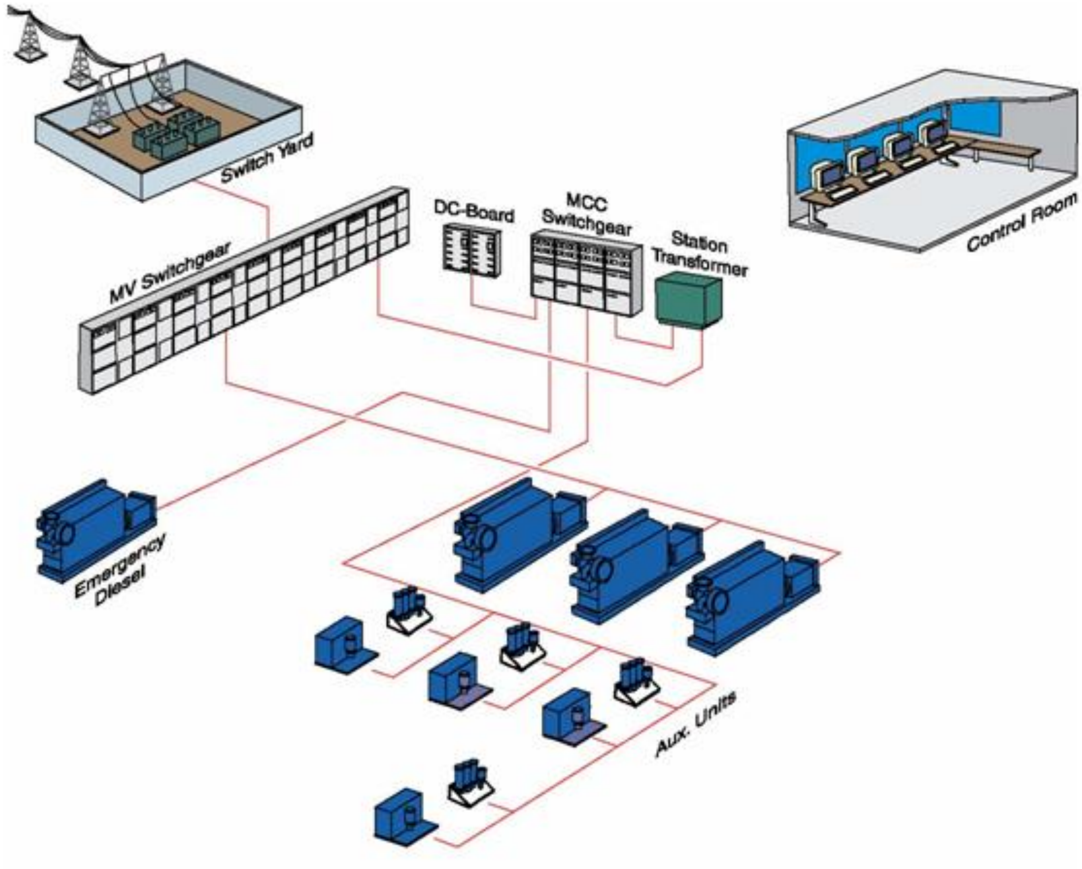


Figure 2. Power plant structure from electrical point of view (Wärtsilä 2011).

2.2 Power plants offered by Wärtsilä

Wärtsilä Power Plants is a leading global supplier of modern, high efficient and dynamic power plants. It has huge experience in design, construction and turnkey supply of power plants. Each year Wärtsilä executes over 50 power plant projects and at the end of 2012 it had almost 54 GW of power installed in power plants in 169 countries worldwide. If the main or auxiliary engines at marine applications are also added, Wärtsilä had over 189 GW installed engines worldwide. (Wärtsilä 2012: 2, Wärtsilä 2013: 14.)

Wärtsilä can provide multi-fuel solutions to the global power generation market, including the next load modes: base load generation, peak load, load following and industrial self-generation applications. Wärtsilä can provide applications for oil and gas industry.

Output ranges of power plants are from 1 to 500 M. Wärtsilä can also provide long-term operation and maintenance agreements. Installation location can be in a metropolitan area or in a challenging remote location. (Wärtsilä 2012: 2.) Figure 3 shows the range of products that Wärtsilä can supply for different outputs.

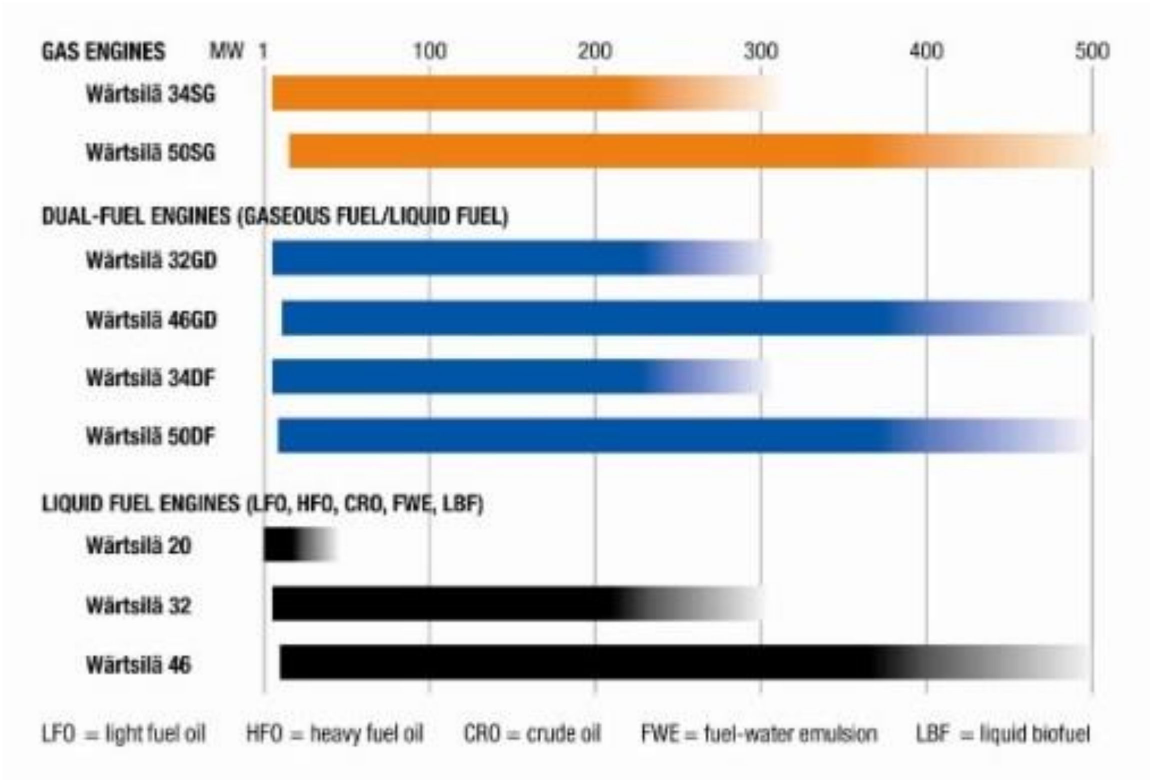


Figure 3. Wärtsilä power plant output range (Wärtsilä 2014c).

Wärtsilä can provide various operating modes (Wärtsilä 2012: 8):

- Base load generation.
  - The technology is proven in base load applications with close to 49 GW of references worldwide.
- Rapid load following in the morning.
- Starting and loading units one by one as the load increases.

- Peaking during high demand periods.
- Balancing wind power i.e. “Wind chasing”.
- Starting, loading and stopping rapidly when wind conditions change.
- System balancing.
    - Fast frequency regulation and efficient spinning reserve.
- Ultra fast, zero-emissions, non-spinning grid reserve for any contingency situation.
    - Starting and producing power in just 1 minute, and reaching full power in just 5 minutes.
- Fast grid black start in case of a power system black out.

2.3 Wärtsilä oil power plants

Wärtsilä oil power plants are made for low emission and high efficiency. Their long term reliability makes them very good for stationary base load and standby applications. Wärtsilä has delivered liquid-fuelled power plants over 36 GW worldwide. (Wärtsilä 2012: 22.)

The benefits of oil power plants include (Wärtsilä 2012: 22):

- Fuel flexibility, the ability to run on heavy fuel oil, light fuel oil, crude oil, emulsified fuels or liquid biofuel
- Fast start-up, less than 5 min from hot standby to full plant load
- High efficiency resulting in low generation cost
- Excellent long-term reliability
- Large worldwide reference base and proven performance.

2.4 Wärtsilä gas power plants

Wärtsilä gas power plants are designed for optimal performance and have wide range of power production applications, for example grid reserve or base load generation. Power plants have very high energy efficiency and offer fast and flexible capacity. (Wärtsilä 2012: 14–15.)

The benefits of gas power plants include (Wärtsilä 2012: 14–15):

- Net plant electrical efficiency of over 52% in combined cycle mode
- Excellent plant availability and reduced need for backup capacity due to multi-unit installation
- Full plant output at high altitudes and in hot and dry ambient conditions
- High part-load efficiency due to multi-unit installation
- Agile dispatch, able to supply megawatts to grid within one minute and 5 minutes to full plant load
- Grid black-start capability
- Minimal water consumption with closed circuit radiator cooling
- Stepwise investment with smaller risks and optimised profit generation
- Low gas fuel pressure requirement
- Maintenance schedule independent of the number of starts or stops.

2.5 Wärtsilä dual-fuel power plants

Wärtsilä dual-fuel power plants are using engines that can operate on natural gas, light fuel oil, heavy fuel oil or on a number of other liquid fuels. The fuel can be changed while the engine is running. This offers huge fuel flexibility. Fuel type can be changed to another if the first one runs out. (Wärtsilä 2012: 18–19.)

The benefits of dual-fuel power plants include (Wärtsilä 2012: 18–19):

- Fuel and operational flexibility
- High efficiency
- Low emission rates
- Excellent reliability
- Operational cost advantages
- Easy adaptation to grid load variations.

3 ELECTRICAL COMPONENTS OF POWER PLANT

The main components of a power plant are introduced in this chapter. The main characteristics of all components are briefly presented. For these components currents or compared effects of mechanical power increase are calculated in Chapter 4.

3.1 Generator

The engine rotates the generator in a power plant. When generator rotates, it converts engine’s rotation to electric energy. Electric energy is generated when electric conductor is moving in a magnetic field. Voltage is induced to the conductor, the amount varies according to the intensity of the magnetic field, length of the conductor and moving speed. Electric current is formed to the conductor when it is connected to a closed circuit. (Huhtinen, Korhonen, Pimiä, and Urpalainen 2008: 297.) ABB generator and Wärtsilä engine in base frame are in Figure 4.

The wounded excitation winding round the rotor obtains a moving magnetic flux in the generator. Exciting current is conducted to the coil by brushes or slip-ring. (Huhtinen et al. 2008: 297.) Electric voltage induces to the stator windings. The electric voltage increases as a function of the magnitude of magnetic field and number of rotor turns. The three-phase power is generated in three windings, which are in an angle of 120 degrees to each other. (Huhtinen et al. 2008: 297.)

Generators used in power plants can be divided to high and slow speed synchronous generators. High speed generators are used in the steam turbines and slow speed generators in the water turbines. (Huhtinen et al. 2008: 297.)

Figure 4. ABB generator and Wärtsilä engine in base frame (Wärtsilä 2011).

3.1.1 Structure of generator

Usually the power plant generator rotor is made of moulded steel and package includes shaft. For example gas engine is connected to shaft directly of via gearbox. In frame of the rotor are milled grooves in which excitation winding is placed. If the generator is rotating at 3000 rpm, the pole pair number is one and there are two magnetic poles in the generator. (Huhtinen et al. 2008: 299.)

The windings of the rotor are normally copper mixed with silver. Exciting current is conducted to the windings of the rotor by brushes and slip-rings. The exciting current is direct current (DC). (Huhtinen et al. *2008*: 299.)

When the rotor is rotating, electric voltage is induced to the stator windings. If hydrogen is used as the generator's coolant, the stator frame is made gas-tight and designed to handle possible gas explosion. (Huhtinen et al. 2008: 299.)

Stator core is shaped in a certain way so that the magnetic flux flows in desired manner inside the generator. The stator winding is usually water-cooled. The laminated core has small gaps in which cooling gas can circulate. (Huhtinen et al. 2008: 299.)

3.1.2 Generator protection systems

Generator is protected from faults by automation of the power plant. Automation measures the number of electrical and mechanical quantities and, if necessary, disconnects the generator from the grid and stops the engine. The protection system is usually implemented via programmable logic controller (PLC). The following factors can start generator's protection (Huhtinen et al. 2008: 299.):

- Generator's reverse power (generator act like motor)
- Winding overheating
- Too low cooling water or oil pressure or flow
- Rotor shaft vibrations
- Bearing overheating
- Electrical faults.

3.1.3 Coolants

The cooling system of the generator is using gas or water. Cooling gas is typically hydrogen or air. The winding of the stator is usually water-cooled. Cooling liquid is treated completely non-salted water, and the circulation is closed. Heat energy is transferred to condensation water via heat exchangers. Hydrogen and oxygen make an explosive mixture. Because of that there is a system in the generator that can ventilate hydrogen away and change it to nitrogen in case of a fault situation or generator stop. Warmed up hydrogen will be cooled in heat exchanger and then blown back inside the generator. (Huhtinen et al. 2008: 300.)

The generator manufacturer gives limit values for cooling gas temperature and time rate of change. Moisture in cooling gas may cause punch-through. It is prevented by drying the cooling gas in a dryer. (Huhtinen et al. 2008: 300.)

Cooling is an important part of the power increase to avoid the temperature rise. The ambient temperature plays a large role in the temperature rise of the generator. If the outdoor temperature is very high, the generator may have to be oversized.

3.1.4 Synchronization of the generator

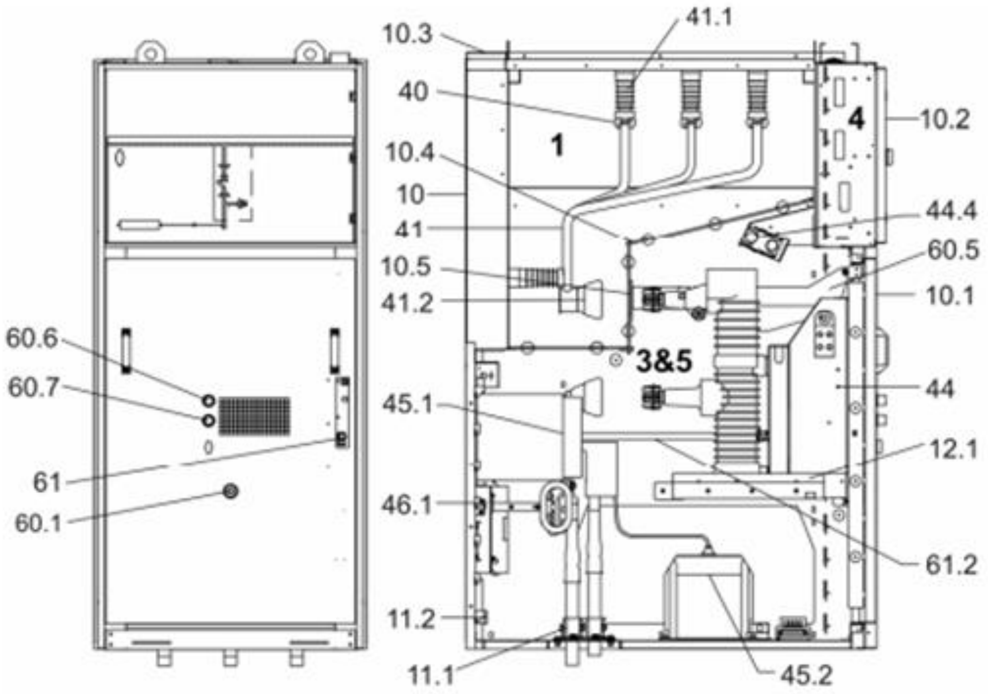
The generator cannot be connected safely to the grid, unless it is first synchronized near to frequency, voltage and phase angle of the grid. A difference in the frequency would cause significant stress to the generator and engine and also disturbances to the grid. (Huhtinen et al. 2008: 300.)

In a normal situation synchronization is done by automation of power plant. It can also be handled manually from control room with double frequency meter, double voltage meter and synchroscope. When synchronizing manually, generator's protection system is still in operation. If the generator's circuit breaker connects too large voltage, frequency or phase difference, the protection system will disconnect the generator immediately from the grid. When generator is successfully connected to the grid, the engine output must be increased, otherwise reverse power protection will trip. (Huhtinen et al. 2008: 300.)

3.2 Medium voltage switchgear

The switchgear main task is to make and break generator connection to the grid. (Nylund 2012.) It is a complex device which contains needed connection, protection, control and monitoring equipment. Open indoor switchgears have been common solutions in the medium voltage grid. They are normally implemented by cubicle installations, where cubicles are separated from each other by partition walls. Nowadays open switchgears have been replaced by closed switchgears in medium voltage network. These closed switchgears are factory-assembled and insulation can be air or SF_6-gas. (Elovaara and Haarla 2011: 117–118.) SF_6 insulated switchgear can also be called GIS (Gas-Insulated Switchgear). GIS will be 10-15 % smaller than the old open switchgear. (Nylund 2012: 3.) An example of switchgear compartments is in Figure 5.

The switchgear protection system gets information from the relay if there is for example overcurrent or overvoltage in the system. If so, the relay will open circuit breaker to avoid damages in the equipment. If circuit breaker cannot break the circuit, then the main circuit breaker breaks it. (Nylund 2012: 5.)



10	Enclosure	**10.4**	Non-metallic partition
10.3	Pressure relief flap	**10.5**	Non-metallic shutter
10.2	Door of LV-compartment	**44.4**	Control wiring plug connector
10.1	Door of HV-compartments	**44**	Withdrawable part
41	Branch conductor	**61**	Earthing switch operating mechanism
40	Busbar	**61.2**	Operating shaft for earthing switch
41.1	Post insulators for branch bars	**60.1**	Moving mechanism for withdrawable part
41.2	Fixed contact	**60.5**	Lever (shutter lifting)
46.1	Earthing switch	**60.6**	Opening pushbutton
45.1	Current transformers	**60.7**	Closing pushbutton
11.2	Main earthing bar	**45.2**	Voltage transformers
11.1	Cable clamp	**12.1**	Track for withdrawable part

Figure 5. Compartments of withdrawable type switchgear (ABB 2005: 9).

3.3 Transformer

A transformer is an electric machine, the main task of which is to transform magnitude of voltage or current. A step-up transformer is in Figure 6. Part of the electric power is disposed to losses. Because of these power losses, output power P_2 is smaller than input power P_1. These power losses are ohmic loss (load loss) and iron loss. Ohmic losses are formed in windings and iron losses in iron core. (Aura et al. 1996: 27.)

Figure 6. Step-up transformer outside of the power plant (Wärtsilä 2011).

The magnitude of AC voltage can easily be changed by a transformer. Structure of a transformer is very simple, there are no moving parts. (Aura et al. 1996: 7.) Below is a structure figure of a single-phase transformer, Figure 7.

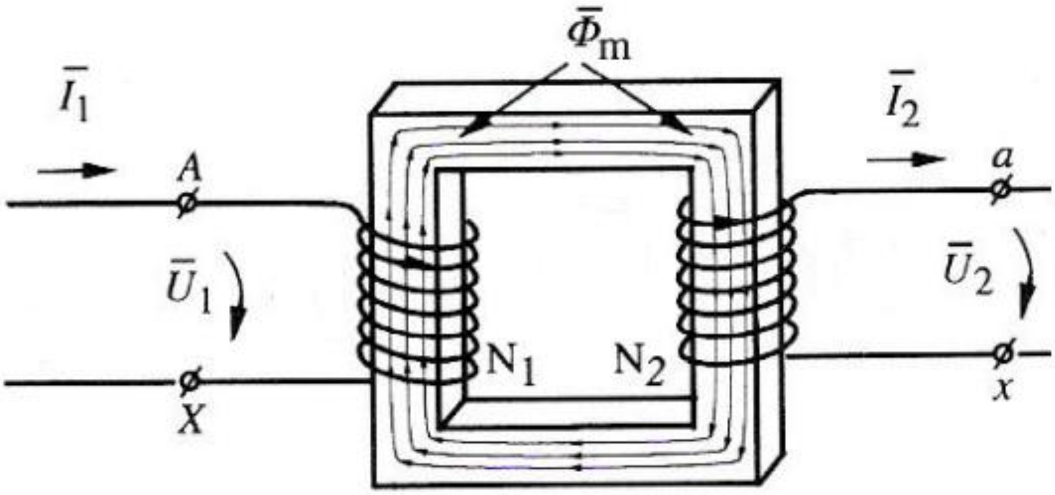


Figure 7. Structure of a single-phase transformer, where N_1 is the number of turns of primary winding, N_2 is the number of turns of secondary winding, U_1 is the primary voltage, U_2 is the secondary voltage, I_1 is the primary current, I_2 is secondary current and Φ_m is magnetic flux (Huurinainen 2006). Picture has been modified.

Transformer consists of an iron core, in which two coils are insulated from each other. Alternating current is supplied to the primary winding, which forms a changing magnetic flux to the iron core. The magnetic flux induces voltage to secondary winding, and its magnitude depends on transformation ratio of the transformer. (Huhtinen et al. 2008: 301.)

Transformers can be divided to groups according to their tasks: power transformers, isolation transformers, voltage transformers and current transformers. The power transformers convert voltage U_1 (primary voltage) to U_2 (secondary voltage) avoiding unnecessary losses in transmission of the electricity. The isolation transformers insulate an electrical device, which voltage is U_2, from electrical grid. The voltage and current transformers can be called instrument transformers and they convert voltage or current to suitable value for measuring instruments or relays. (Huhtinen et al. 2008: 301.) Different kinds of transformer types are shown in Figure 8. In Figure 9 can be seen the structure of a transformer.

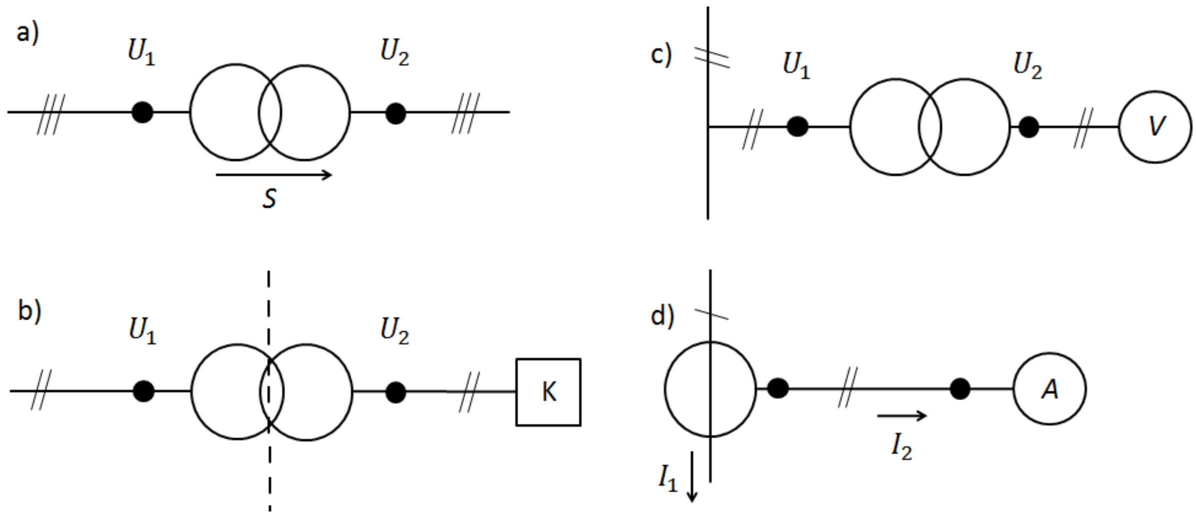


Figure 8. Different types of transformers, where U_1 is the primary voltage, U_2 is the secondary voltage, S is electric power, I_1 is the measured current, I_2 is auxiliary current and K is protective voltage. The power transformer (a), the isolation transformer (b), the voltage transformer (c) and the current transformer (d).

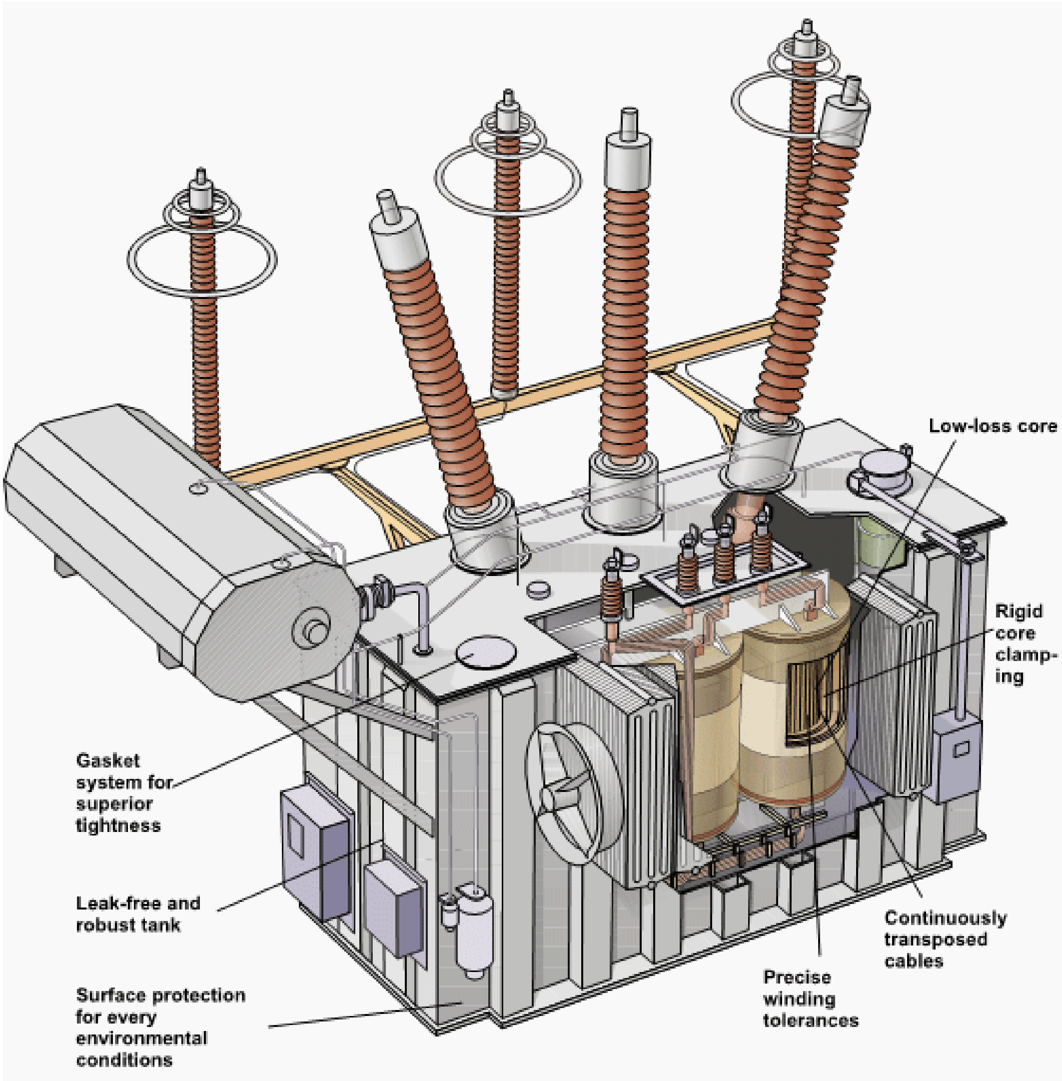


Figure 9. Basic transformer structure (Electrical Engineering Portal 2014).

3.4 Instrument transformers

It is technically very difficult and expensive to manufacture meters and relays when currents and voltages are high. For this reason instrument transformers are used for protection and measurement purposes. The instrument transformers can be divided into two different main categories, current- and voltage transformers. The main task of the instrument transformer is to isolate the measuring circuit from the main circuit and reduce current or voltage to suitable value for measuring devices. (Hukka 2011: 11–13.)

The main task of a current transformer is to reduce primary current. The number of turns in primary side is small and in the secondary side it is big and therefore way the current in the secondary side is lower than in the primary side. When low impedance device is connected to the secondary side will the secondary voltage be low. In this way the measuring device needs not withstand high current, but can measure them. This will affect positively the price of the measuring device. (Hukka 2011: 11–13.)

When using a current transformer, it should be noticed that the secondary side does not remain open. If measurement device is removed, the secondary side must be short-circuited. If it remains open the current of the primary side will magnetize the iron core and it will be quickly saturated. The high magnetic flux will increase iron losses, in which case the transformer will be overheated and destroyed. Further the high magnetic flux will induce dangerous high voltage because of the secondary coil high turns. (Hukka 2011: 11-13.)

For example a current transformer rating 1000 A / 5 A 5P10 20 VA means that primary rated current is 1000 A, secondary rated current is 5 A, nominal power is 20 VA and class is 5P10. In 5P10 the letter P means that the current transformer is for protection purpose, 5P10 means that combined error is less than 5% when it is subjected to 10 times its nominal current. If ratings are the same but class is cl 0.5, it means that this current transformer is for measuring purpose. Class 0.5 guarantees that the ratio error of currents are 0.5 percentage or less. (Scheider Electric 2000.) Example of a current transformer is in Figure 10.

Figure 10. ABB TPU 4 series current transformer (ABB 2010: 1).

4 INCREASING POWER IN POWER PLANT

Required mechanical power increase for Wärtsilä 34SG (for example 20V34SG, where 20 means number of cylinders, V means that it is a V-engine, 34 means the diameter of the cylinder in centimeters and SG means that the engine is a gas engine with spark plugs) engines is 50 kW per cylinder. For 34SG C-output class engines power is 450 kW per cylinder and when added extra 50 kilowatts total power will be 500 kW per cylinder and called C2-output class.

Mechanically the engine can reach the required power increase if some critical parts are changed and the engine control system is tuned. With these modifications the power of the engine can be increased.

Wärtsilä has delivered 67 installations in which Wärtsilä 34SG C-output class engines are installed. There are two different generator suppliers. From the suppliers I asked for information of the generator, whether it can handle the increased mechanical power of gas engine and if so, what is the new efficiency.

There is no need to calculate short circuit currents because the components are not changed in power plant. This work is only studying feasibility for power increase. The rated output of the generator is not increased, only the generator is loaded higher than the nominal load. The generator short circuit reactance will not change. If the generator of power plant is changed, new precise short circuit calculations are needed.

4.1 Mechanical power increase

Peak pressure sensors are needed because they measure the peak pressure in the cylinder. New shims must be installed to the connecting rod so that the compression ratio will be changed. The prechambers must also be changed. After this the combustion process will be better and will have a good affect to the efficiency of the engine. When the combustion process is better and efficiency will be higher, the engine needs more air. The turbochargers need also tuning, nozzle rings of turbocharger must be changed. This modification lets more air to go through the turbocharger. The mechanical output increase from C to C2 is not a difficult operation. Wärtsilä is manufacturing new 34SG C2 output engines at the factory. So, the design is already existing for output increase modification.

4.2 Generator calculations

With values from suppliers for the engine new mechanical outputs and efficiencies can be calculated. Electrical power can be calculated by:

$$P_{\mathrm{out}} = \eta P_{\mathrm{in}}, \tag{1}$$

where η is the efficiency, P_{out} is the output power and P_{in} is the input power.

When electrical power was calculated can apparent power be calculated using equation 5 and 3:

$$P = \sqrt{3}UI\cos\phi, \tag{2}$$

where P is the power, U is the voltage, I is the current and cos φ is power factor.

$$S = \sqrt{3}UI, \tag{3}$$

where S is the apparent power, U is the voltage and I is the current.

Combining equations 2 and 3, we get:

$$P = S\cos\phi \tag{4}$$

and

$$S = \frac{P}{\cos\phi}\,. \tag{5}$$

Generator's new current can be calculated by:

$$I = \frac{S}{\sqrt{3}U}\,. \tag{6}$$

4.3 Transformer calculations

To resolve the ratio of the transformer the needed calculations have to be made. Using this ratio the secondary current which is going to the medium voltage switchgear can be resolved.

The transformation ratio of the transformer can be calculated by:

$$\mu = \frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}, \tag{7}$$

where U_1 is the primary voltage, U_2 is the secondary voltage, N_1 is the number of turns of primary winding, N_2 is the number of turns of secondary winding, I_1 is the primary current and I_2 is the secondary current.

And after modification, I_2 can be calculated from:

$$I_2 = \frac{U_1}{U_2} I_1 \tag{8}$$

With these formulas the needed values can be calculated for every case included in this study. Calculations for every case where made with excel and results can be found from Appendix 9.

5 CASE STUDIES

From totally 67 cases, this chapter includes six installation projects where power increase can be done with no, or small modifications, or in the worst case, increasing can be done only with major component changes. At first a case, where there is no need for component changes, is introduced. Secondly, one project is introduced, where minor component changes are needed. The last four cases need medium or major component changes.

WOIS (Wärtsilä Operator's Interface System), WISE (Wärtsilä Information System Environment) and PLC (plant automation) software needs modifying in every case to correspond to the increasing power and current. Also, UNIC C3 engine control system needs to be retrofitted or software needs to be modified, depending on the existing engine control system. When retrofitting UNIC C3 there is a need to software modifications for WOIS, WISE and PLC and there might also be a need for new hardware, always depending on the case. This study is focused on the electrical part of a power plant, automation is only checked if there is a need to retrofit UNIC C3. Plant automation is not checked.

Protection relay settings need to be changed to match new current. If settings are not changed, the protection system will not work as it should. This would lead to serious damages if some fault occurs in the system.

The generator suppliers' values are valid only if the following criterias are met:

- 40 or 50 °C ambient temperature (the value is depending on the supplier)
- 1000 masl (meters above sea level) altitude
- cos φ is 0.8

5.1 Case 1 – The power plant number 41

This project is located in the United States of America. It is commissioned in 2011 and started the same year. There are six Wärtsilä 20V34SGs and mechanical output per cylinder is 435 kW (8700 kW per engine) and total mechanical output of the engines is 52.2 MW. The maximal electrical output of the installation is 63.3 MVA. The overview of the power plant is Figure 11.

Figure 11. Picture from power plant (Wärtsilä 2014).

After mechanical power increase, output per cylinder will be 480 kW and the total per engine will be 9600 kW. When supplier confirmed new values for efficiency and that the generator is capable to handle the increasing mechanical power, generator new apparent power (*S*) and current (*I*) could be calculated using Equations 5 and 6:

$$P_{\text{out}} = \eta \cdot P_{\text{in}} = 0.9743 \cdot 9600 = 9353.3 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9353.3}{0.8} = 11692 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{11692 \cdot 10^3}{\sqrt{3} \cdot 13800} = 490 \text{ A}$$

After calculations the current withstand of the components must be checked, which was also done in this study.

In this installation the following assumptions had to be made, because Wärtsilä doesn’t have that information in their database:

- The main transformer can handle the increasing current and power.
- The cables can withstand the increasing current and power.

After power increase in this installation, there is no need of any new components. Current transformers and circuit breakers have been sized so that increased current will not exceed their nominal currents. The primary current for current transformer in generator income (BAE) is 600 A, outgoing feeder (BAO) and bus-coupler feeder (BAB) 3000 A. The nominal current for circuit breaker in BAE is 1200 A, BAO and BAB 3000 A. One outgoing feeder can handle the whole plant current if the other one breaks for some reason. In Figures 12 and 13 we can see a part from single line diagram.

In this power plant there is only need to modify protection relay settings due to increased current. The existing engine control system is UNIC C3, so there is no need to upgrade it.

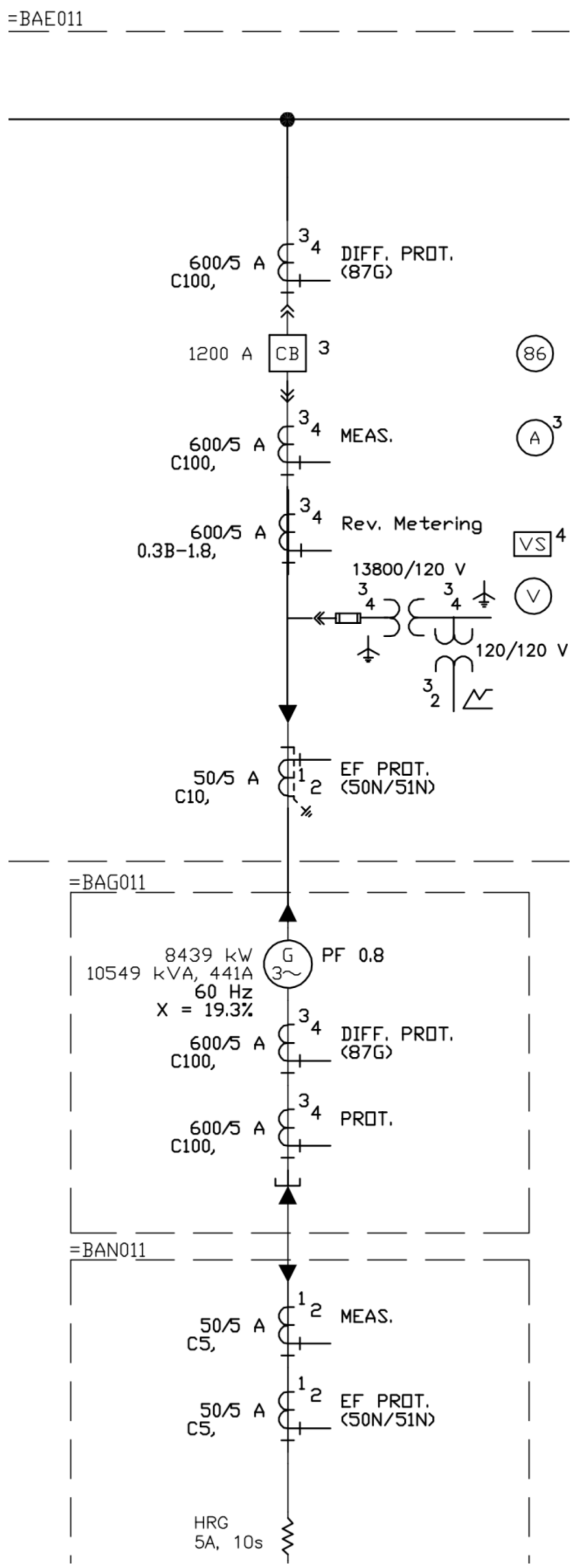


Figure 12. Generator cubicle (BAE) drawing in power plant number 41 (Wärtsilä 2014a).

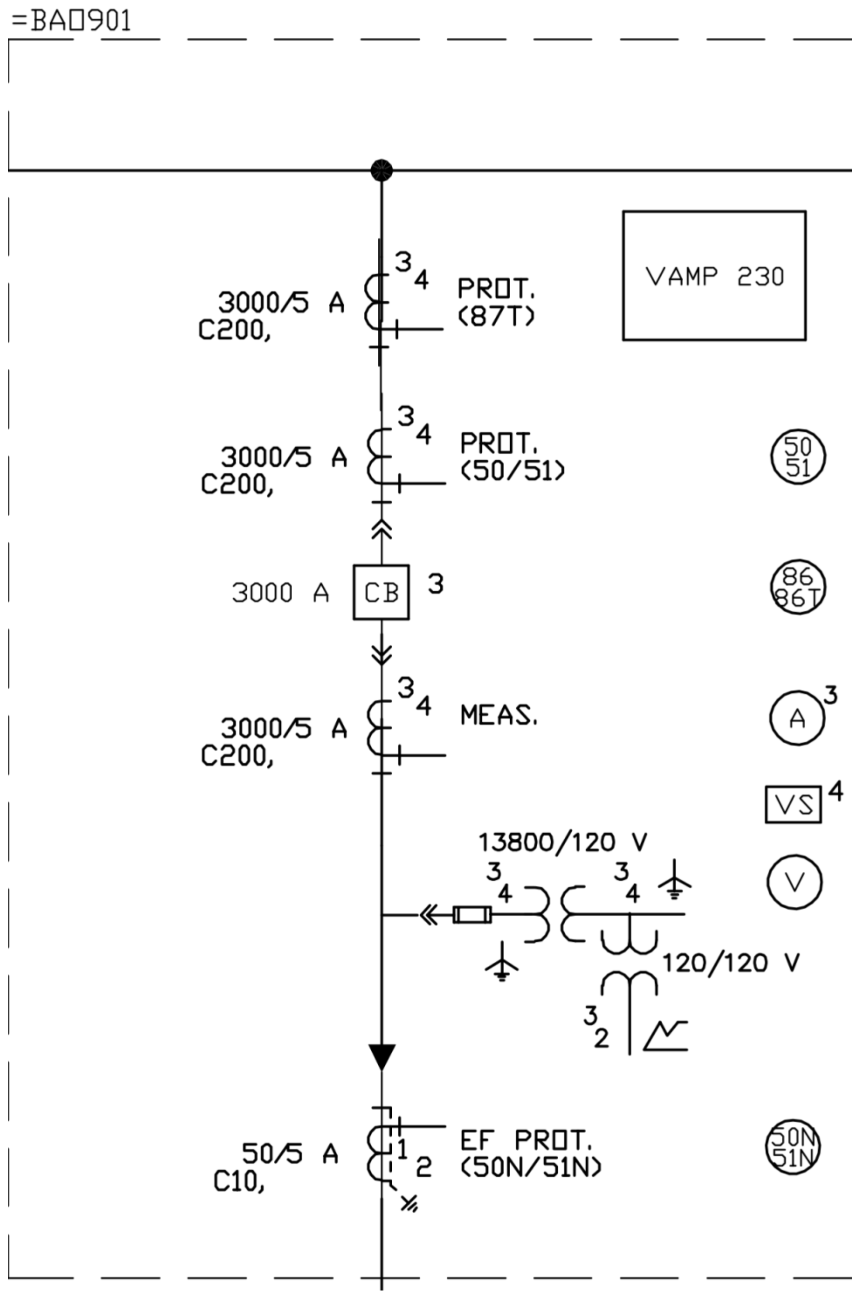


Figure 13. Outgoing feeder (BAO901) drawing in power plant number 41 (Wärtsilä 2014a).

5.2 Case 2 – The power plant number 18

This power plant is located in Russia and production started in 2008. In the installation there are two Wärtsilä 20V34SG engines and mechanical output per cylinder is 450 kW (9000 kW per engine) and total mechanical output of the installation is 18 MW. The maximal electrical output of the power plant is 21.8 MVA.

The mechanical output per cylinder will be 500 kW and the engine's total output 10000 kW after the output increase of the engine. The supplier confirmed that the generator can handle the increased mechanical output of the engine and they also gave information of the new efficiency. Then the new apparent power (*S*) and current (*I*) values for the power plant could be calculated. Finally capability of the installation to handle new current can be checked. The current is calculated using Equation 6 and the apparent power using Equation 5. Using these equations following values are resulted:

$$P_{\text{out}} = \eta P_{\text{in}} = 0.973 \cdot 10000 = 9730 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9730}{0.8} = 12163 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{12163 \cdot 10^3}{\sqrt{3} \cdot 6300} = 1114.6 \text{ A}$$

In this installation the following assumptions had to be made, because Wärtsilä does not have that information in their database:

- The main transformer can handle the increasing current and power.

- The new current transformers will fit to the medium voltage switchgear.
- The cable correction factors have been used from other installation.

After power increase there is a need to change the current transformers because the new current of the generator will exceed current transformers’ primary current. Other components will withstand the new power and current. The rated current for outgoing feeder’s circuit breaker (BAO901) is 2500 A and it is smaller than the generator’s new current (1114.6 A). BAO902 is similar to BAO901. The bus tie breaker’s (BAP901) rated current is 1250 A. The medium voltage cables are 1x400 Cu XLPE cables and there are three cables in one phase. The main current is 1114.6 A and in conductor 371.5 A. Total correction factor used in this is 0.54 and full capacity for 1x400 Cu XLPE cable is 720 A, so reduced capacity for this cable is 390 A (720 A times 0.54), see Appendix 7. Cables can handle the increased current, because the reduced capacity is higher than the current in one conductor. You can see a part of the single line drawing in Figures 14 and 15. This power plant is using WECS8000 engine control system. Upgrading engine control system to UNIC C3 is needed that the power increase for gas engine would be possible.

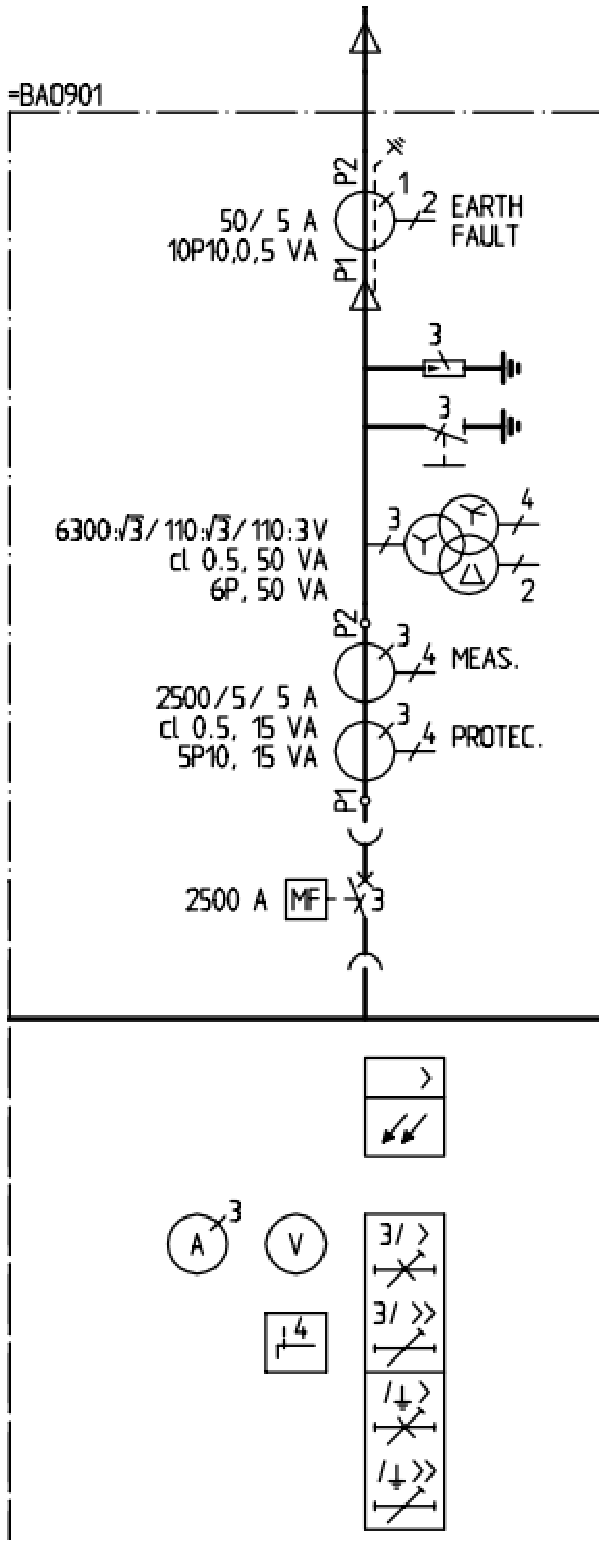


Figure 14. Outgoing feeder (BAO901) drawing in the power plant number 18 (Wärtsilä 2014a).

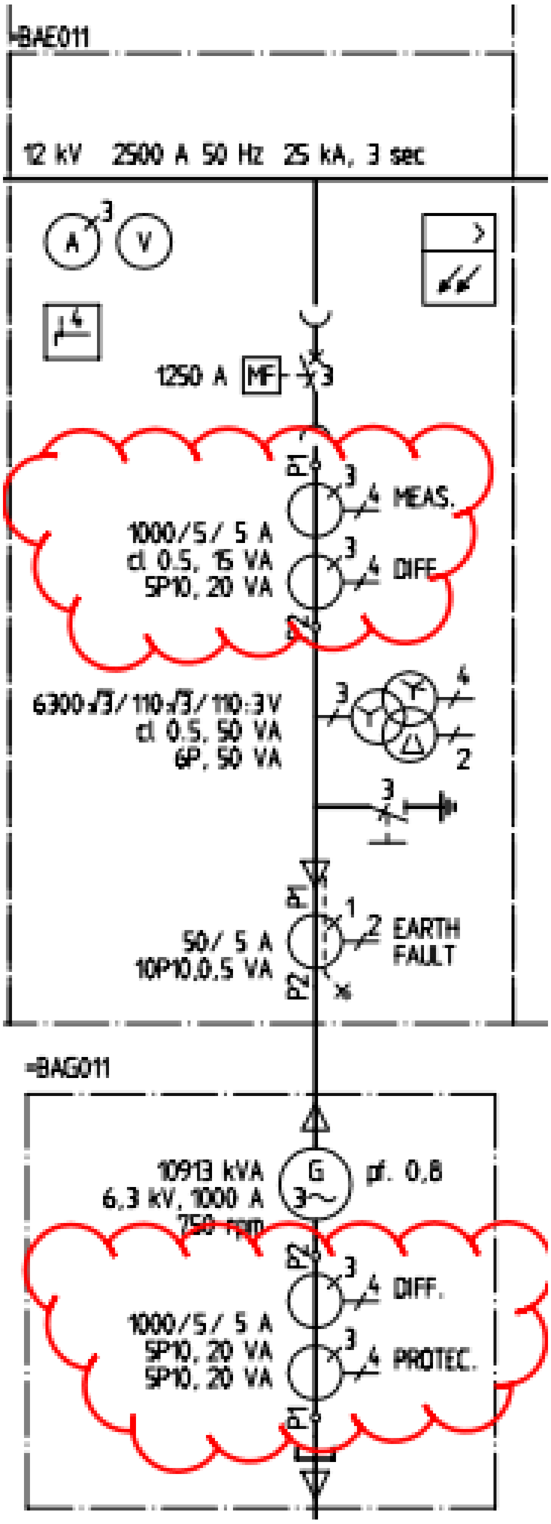


Figure 15. Generator cubicle drawing in the power plant number 18 (Wärtsilä 2014a).

To summarize, the needed modifications in power plant number 18 are:

- New current transformers
- Protection relays' setting modifications to correspond new current
- New engine control system UNIC C3.

5.3 Case 3 – The power plant number 65

The installation is located in Nigeria. There are six Wärtsilä 20V34SG engines, which mechanical output per cylinder is 450 kW and total output per engine is 9000 kW. The total output of power plant is 54 MW and maximal electrical output is 65.5 MVA.

When the mechanical output of the engine will be increased to 10000 kW (500 kW per cylinder) the electrical output will increase to 12.198 MVA. When the limits of the generator and new efficiency were confirmed by the supplier, the new apparent power and current for this generator could be calculated by using Equations 5 and 6:

$$P_{\mathrm{out}} = \eta P_{\mathrm{in}} = 0.9758 \cdot 10000 = 9758 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9758}{0.8} = 12198 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{12198 \cdot 10^3}{\sqrt{3} \cdot 11000} = 640 \text{ A}$$

In this installation the following assumptions had to be made, because Wärtsilä does not have that information in their database:

- The main transformer can handle the increasing current and power.
- The new current transformers and circuit breakers will fit to the medium voltage switchgear.
- The cables can withstand the increasing current and power.
- Only three engines full power can go through one outgoing feeder (BAO901 or BAO902), otherwise busbar and BAO circuit breaker nominal currents will be exceeded.

Because of power increase the current from the generator will increase. The current transformers must be changed because their rated primary current will be exceeded, the circuit breaker in generator incomer (BAE) must also be changed due to new current that will exceed breaker’s rated current (630 A). These modifications must be done for all generator incomers in the power plant (BAE011-BAE061). Outgoing feeders (BAO901 and BAO902) circuit breaker rated current is 2500 A and this is not exceeded if only full current of three engines will go through this breaker. The BAE and BAO parts of the single line diagram are in Figures 16 and 17. The engine control system is WECS and this must be changed to UNIC C3 to meet the requirements of power increase.

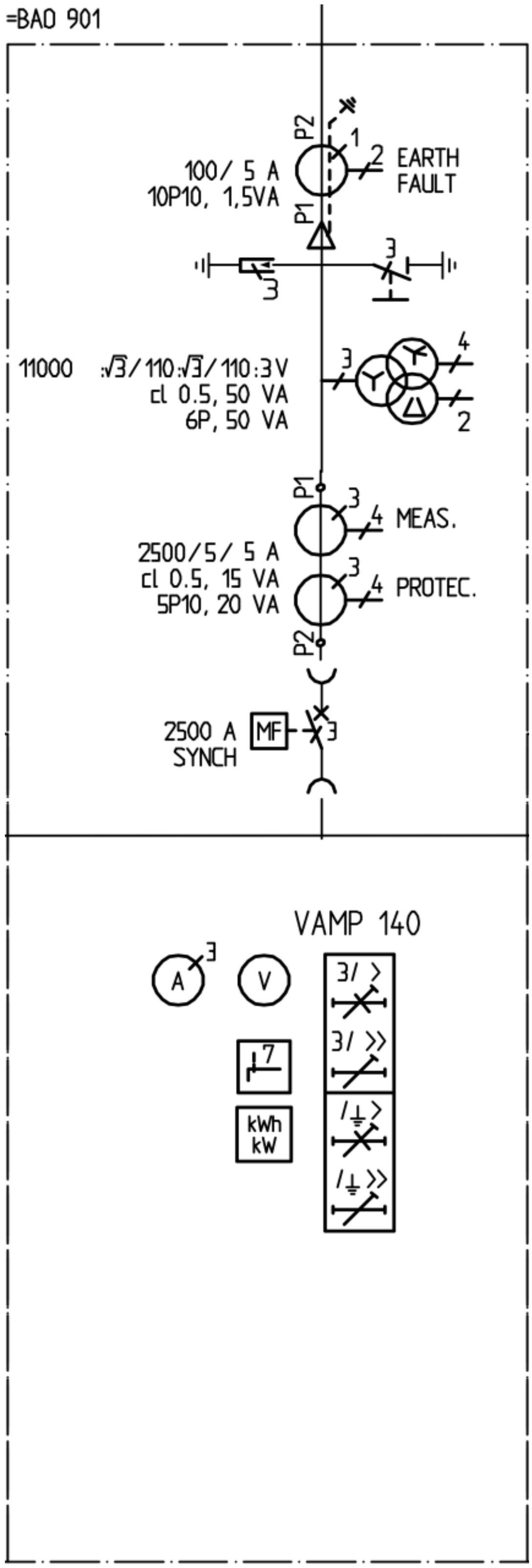


Figure 16. Outgoing feeder (BAO901) drawing in the power plant number 65 (Wärtsilä 2014a).

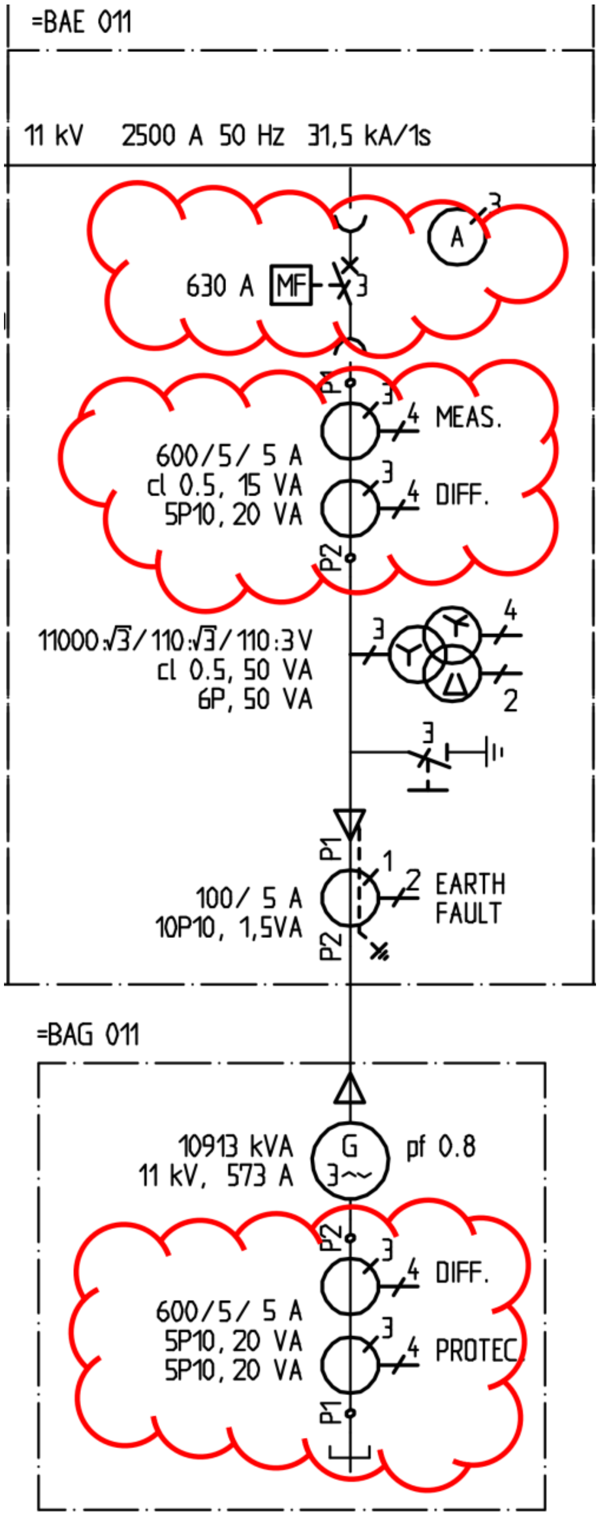


Figure 17. Generator incomer (BAE011) drawing in the power plant number 65 (Wärtsilä 2014a).

To summarize, the needed modifications in power plant number 65 are:

- New current transformers
- New generator income circuit breakers
- Protection relays’ setting modifications to correspond new current
- New engine control system UNIC C3.

5.4 Case 4 – The power plant number 61

The power plant is located in Russia. The first start was in 2009. In this installation there are six Wärtsilä 20V34SG engines, each of those has an output power 450 kW per cylinder, total 9000 kW per engine. Total mechanical output is 54 MW and electrical output is 65.5 MVA. We can see a picture taken outside of the installation in Figure 18.

Figure 18. Picture from outside of power plant (Indust cards 2014).

The generator supplier confirmed that the mechanical output of the engine can be raised to 10000 kW (500 kW per cylinder) and they also gave information of new efficiency. After that the new apparent power (*S*) and current (*I*) for the generator could be calculated by using Equations 5 and 6:

$$P_{\mathrm{out}} = \eta P_{\mathrm{in}} = 0.9758 \cdot 10000 = 9758 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9758}{0.8} = 12198 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{12198 \cdot 10^3}{\sqrt{3} \cdot 10500} = 671 \text{ A}$$

In this installation the following assumptions had to be made, because Wärtsilä does not have that information in their database:

- The main transformer can handle the increasing current and power.
- The new current transformers and circuit breakers will fit to the medium voltage switchgear.
- One additional cable per phase will fit to the medium voltage switchgear and to the generator.
- If the full power of three engines is going to one BAO, rated currents will be exceeded.
- If four engines full power is going to one busbar, rated currents will be exceeded.

Increased generator current will affect the medium voltage system. There is a need to change the current transformers because their primary current 600 A will be exceeded. The generator incomers circuit breakers must also be changed because the current from generator (671 A) exceeds circuit breakers rated current (600 A). Existing cables between the generator and the medium voltage switchgear are 1x300 Cu XLPE 2 per phase. According to Appendix 8 the new current per cable with increased current will be 335.5 A which exceeds the reduced current carrying capacity. It is calculated: total correction factor times current carrying capacity. So there is a need for one more cable per phase. After adding this extra cable per phase current in one cable is 223.66 A which is smaller than cable's reduced current carrying capacity. In Figures 19 and 20 you can see BAO- and BAE part of the single line diagram. In Figures 21 and 22 can be see the whole single line diagram. In this power plant there is WECS engine control system and this must be changed to UNIC C3 to fulfil the requirements of power increase.

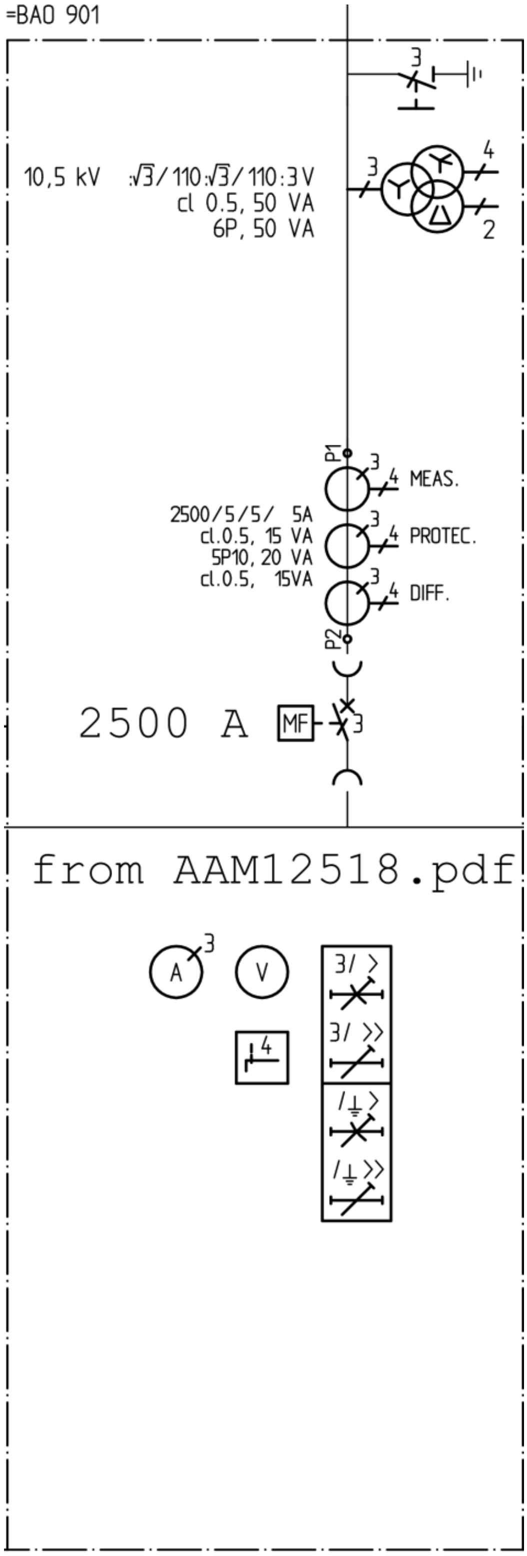


Figure 19. Outgoing feeder (BAO901) drawing in the power plant number 61 (Wärtsilä 2014a).

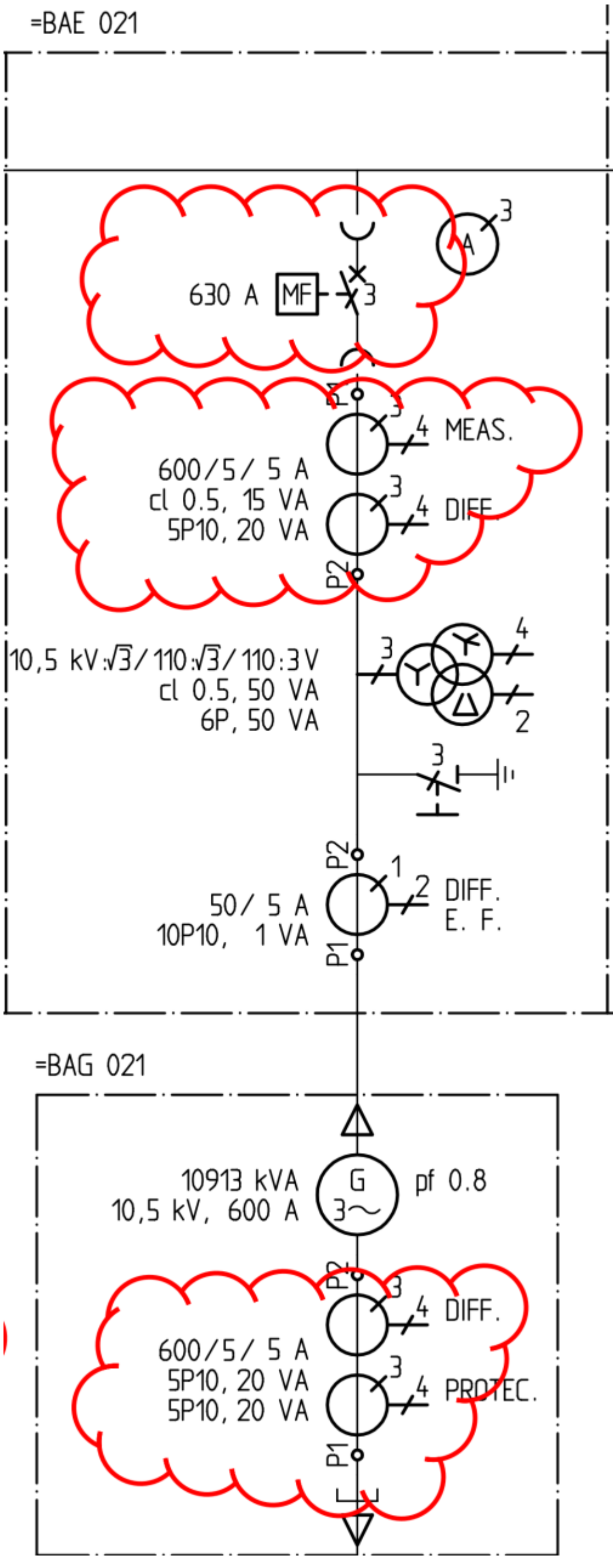


Figure 20. Generator cubicle (BAE 021) drawing in the power plant number 61 (Wärtsilä 2014a).

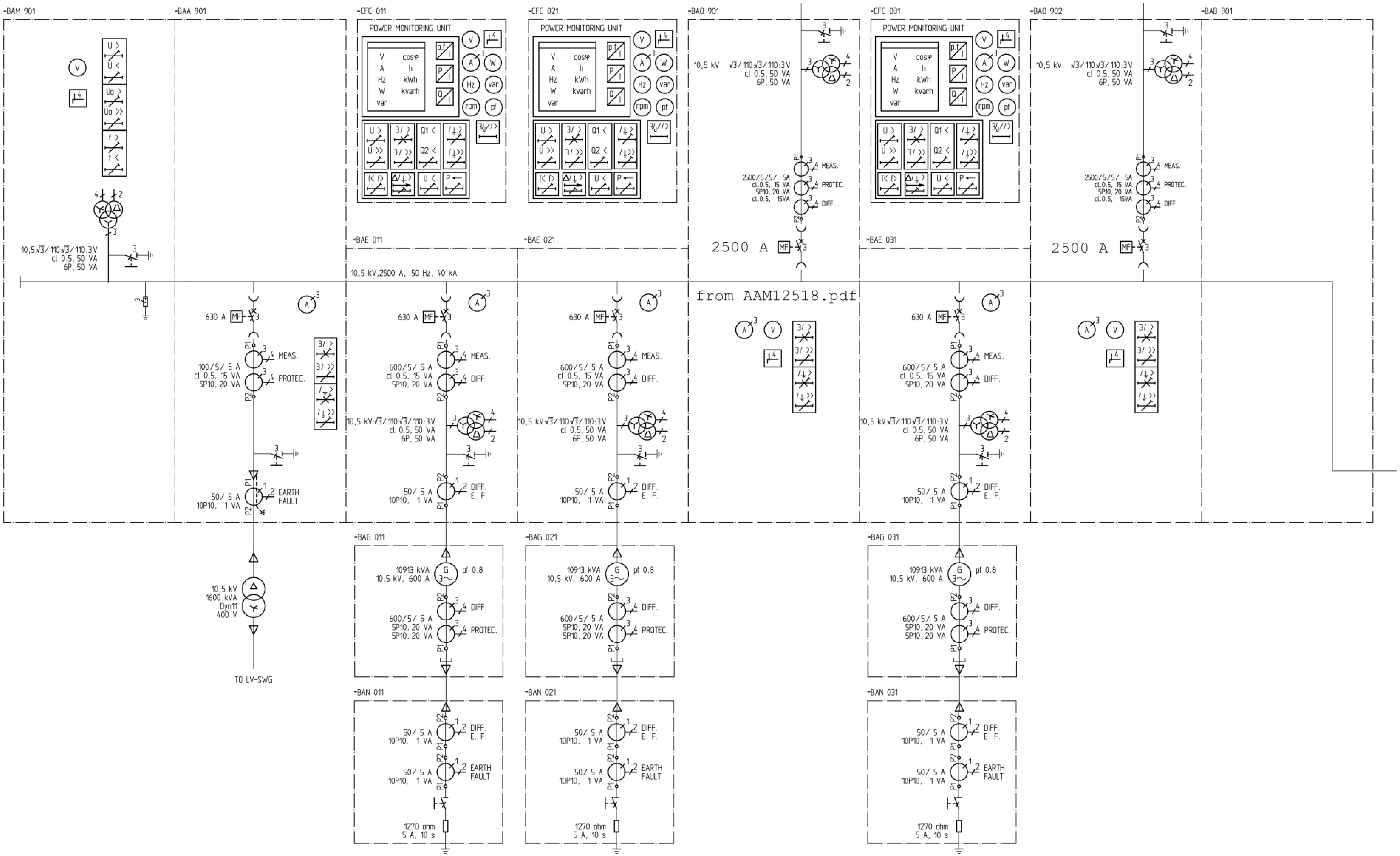


Figure 21. Single line diagram in the power plant number 61. (Wärtsilä 2014a).

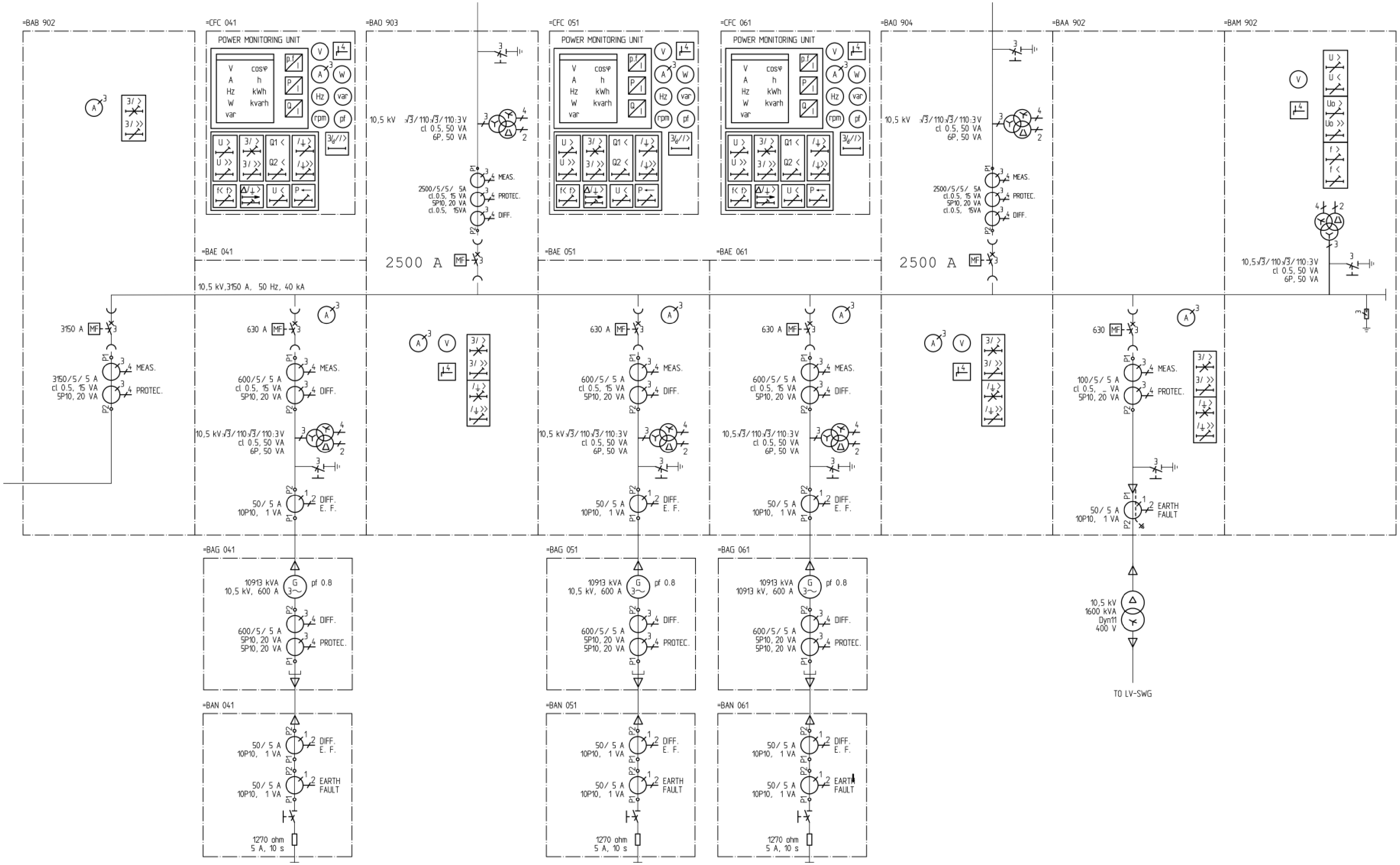


Figure 22. Single line diagram in the power plant number 61. (Wärtsilä 2014a).

To summarize, the needed modifications in power plant number 61 are:

- New current transformers
- New generator income circuit breakers
- Protection relays' setting modifications to correspond new current
- One additional cable per phase
- New engine control system UNIC C3.

5.5 Case 5 – The power plant number 51

Installation is located in Bangladesh and the engine was started 2008. It contains one Wärtsilä 20V34SG engine and its mechanical output is 9000 kW. The total electrical output of the power plant is 10.9 MVA. A picture from inside the engine hall is in Figure 23.

The supplier informed that the mechanical output can be increased from 9000 kW to 9856 kW, and they also informed the new efficiency. The power increase was small because the generator is limiting it. I calculated new current (*I*) and apparent power (*S*) for the generator using equations 5 and 6:

$$P_{\mathrm{out}} = \eta P_{\mathrm{in}} = 0.974 \cdot 9856 = 9600\ \mathrm{kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9600}{0.8} = 12000\ \mathrm{kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{12000 \cdot 10^3}{\sqrt{3} \cdot 11000} = 630 \text{ A}$$

Figure 23. Picture of genset from power plant number 51 (Samuda 2014).

In this installation the following assumptions had to be made, because Wärtsilä does not have that information in their database:

- The main transformer can handle the increasing current and power.
- The new current transformers and circuit breakers will fit to the medium voltage switchgear.
- The cables can withstand the increasing current and power.

Due to the increased generator current, in this power plant there is a need to change current transformers, both in the generator incomer (BAE011) and in the outgoing feeder (BAO901). The new current exceeds current transformer primary current (600 A). Also BAE011 and BAO901 circuit breakers rated current (630 A) will be exceeded and those must be replaced. The undersized components are circled in Figures 24 and 25.

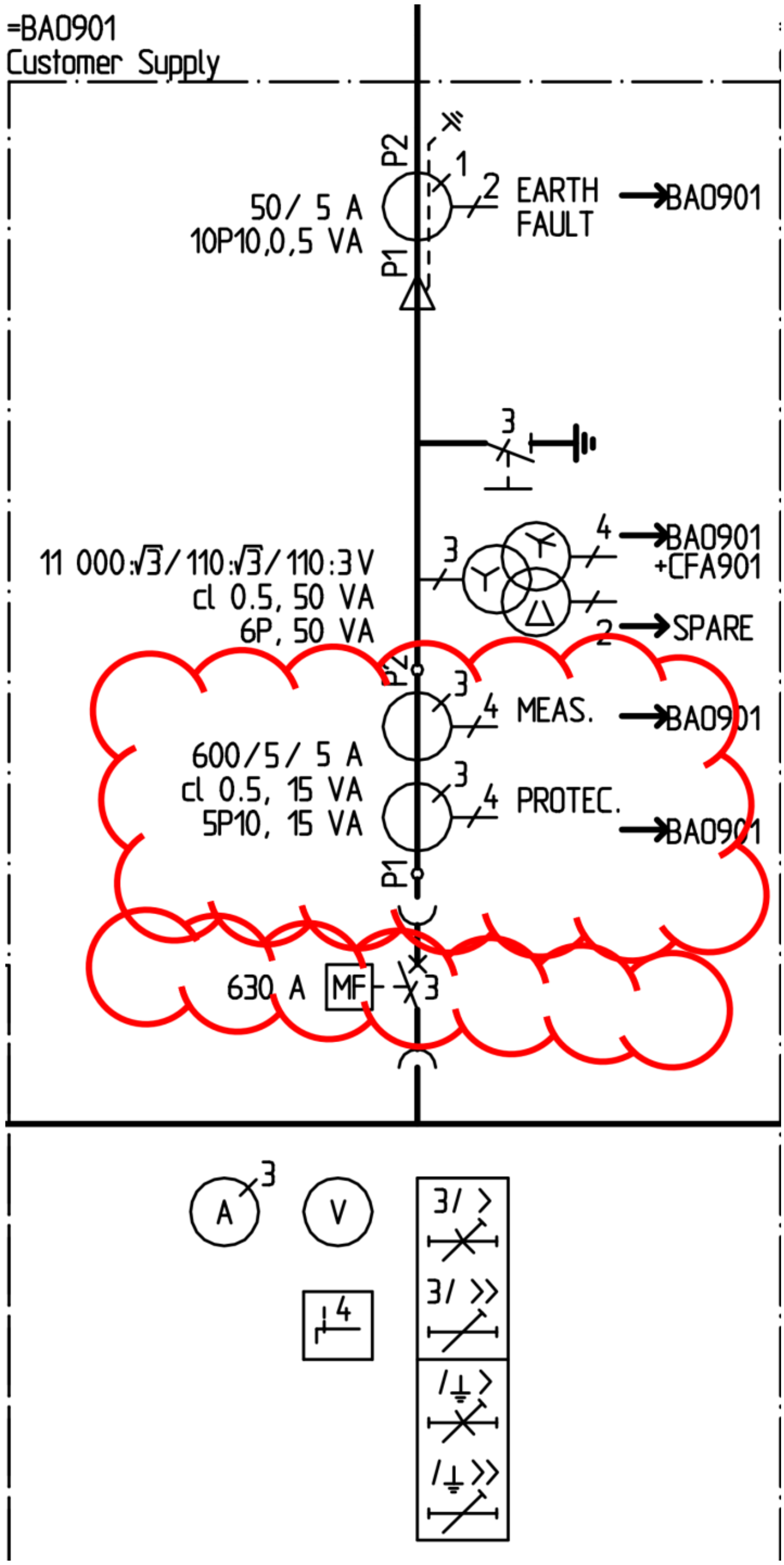


Figure 24. Outgoing feeder (BAO901) drawing in the power plant number 51. Components that need to be changed are circled in red (Wärtsilä 2014a).

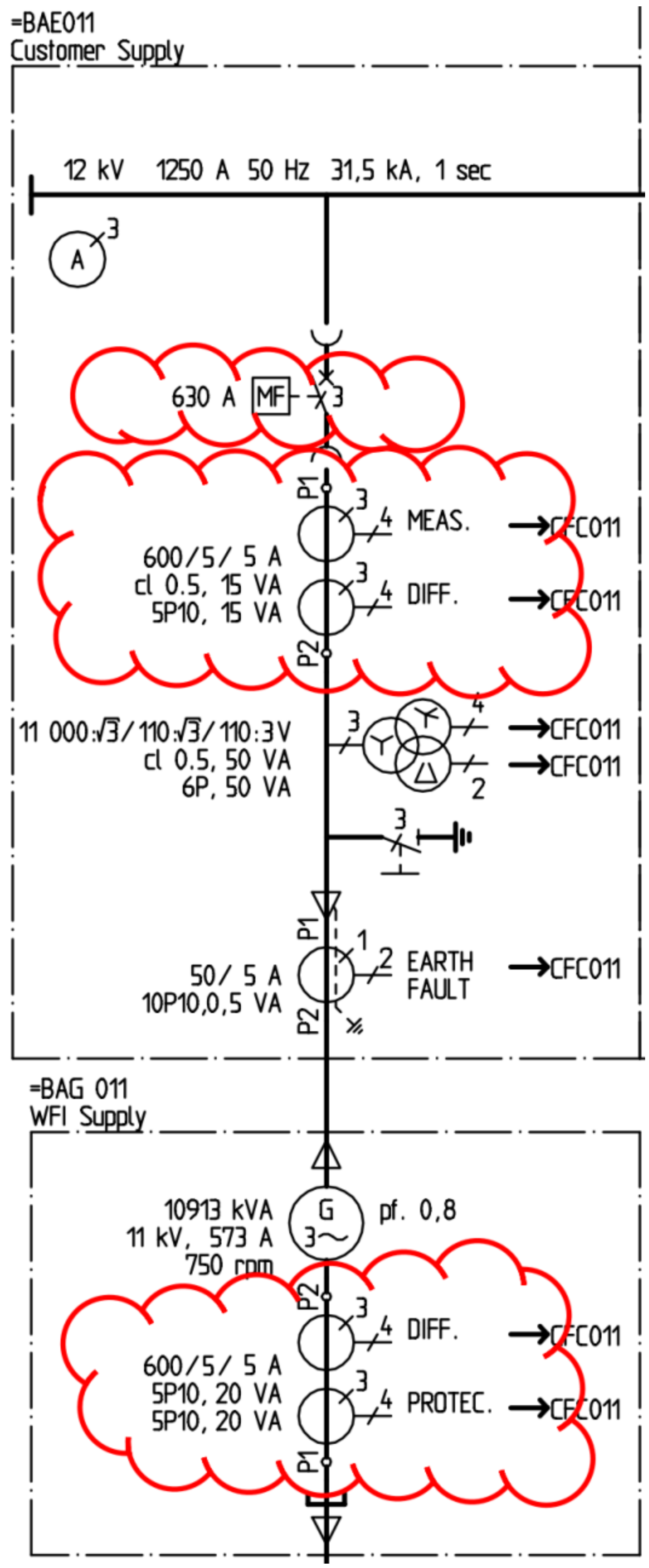


Figure 25. Generator cubicle (BAE 011) drawing in the power plant number 51. Components that need to be changed are circled in red (Wärtsilä 2014a).

To summarize, the needed modifications in power plant number 51 are:

- New current transformers
- New generator incomer (BAE011) and outgoing feeder (BAO901) circuit breakers
- Protection relays' setting modifications to correspond new current
- New engine control system UNIC C3.

5.6 Case 6 – The power plant number 17

This power plant is located in South Korea and started 2009. There are three Wärtsilä 20V34SG gas engines and each of them has a mechanical output 8700 kW (435 kW per cylinder) and electrical output 10549 kVA.

The generator's supplier confirmed that the maximum power of the engine can be 8706 kW, and 435.3 kW per cylinder. There is only 6 kW and 0.5 kW per cylinder increase compared to the original engine. In this case the generator itself is the limiting component. Other components will withstand a minor current increase. The new current (*I*) and apparent power (*S*) for the generator could be calculated using equations 5 and 6:

$$P_{\text{out}} = \eta P_{\text{in}} = 0.974 \cdot 8706 = 8480 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{8480}{0.8} = 10600 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{11600 \cdot 10^3}{\sqrt{3} \cdot 6600} = 927 \text{ A}$$

In this installation the following assumptions had to be made, because Wärtsilä does not have that information in their database:

- The main transformer can handle the increasing current and power.
- The cables will withstand the increasing current and power.
- If three engine full power is going to one busbar or one BAO, rated currents will be exceeded.

Due to the undersized generator, the power increase cannot be implemented to this power plant. The generator limits are so tight that the power increase will be very small.

The generator will be changed to new one that it will handle 10000 kW, that the engine will fulfil the requirements of C2 output class. New current values are calculated:

$$P_{\text{out}} = \eta P_{\text{in}} = 0.974 \cdot 10000 = 9740 \text{ kW}$$

$$S = \frac{P}{\cos\phi} = \frac{9740}{0.8} = 12175 \text{ kVA}$$

$$I = \frac{S}{\sqrt{3}U} = \frac{12175 \cdot 10^3}{\sqrt{3} \cdot 6600} = 1065 \text{ A}$$

Due to increased generator current the new current transformers need to changed, because its rated current will be exceeded. If either BAB901 bus tie breaker or BAB902 bus tie breaker is open at a time, busbars and breakers will handle the exceeded current. In Figures 26 and 27 can see part from single line diagram. The whole single line diagram is in Figure 28 and 29.

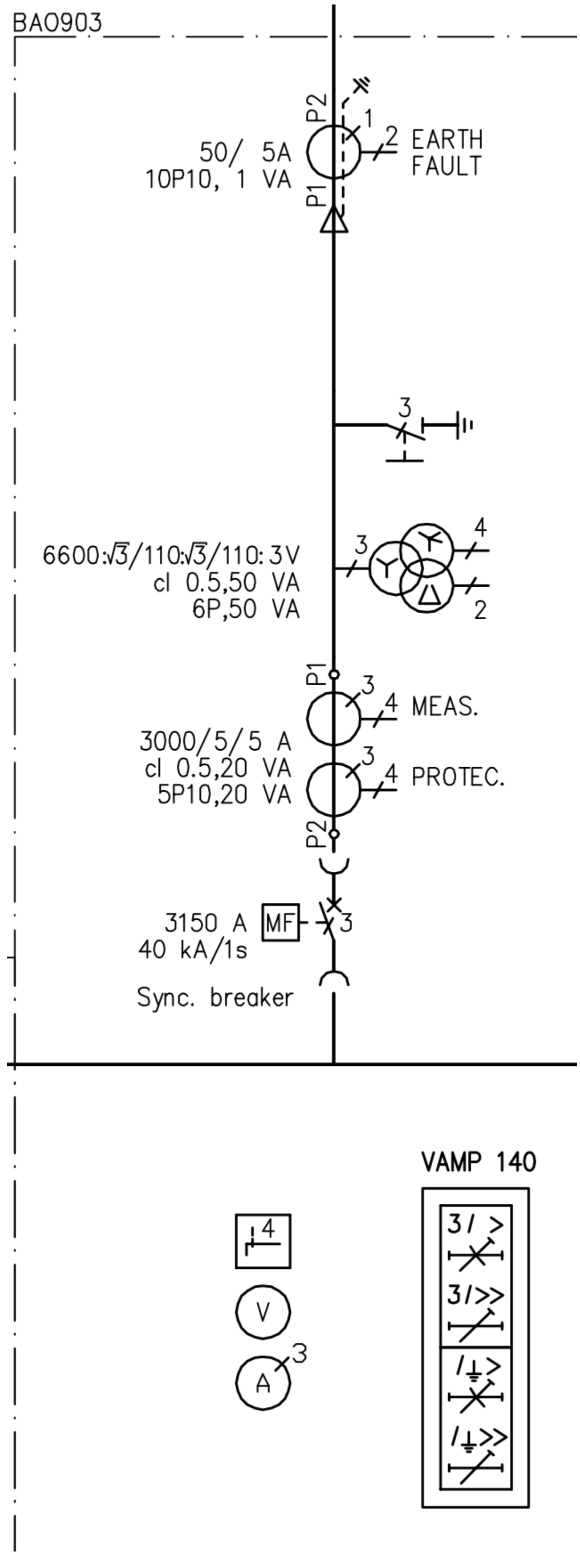


Figure 26. BAO part of the single line diagram from power plant number 17. Components that need to be changed are circled in red (Wärtsilä 2014a).

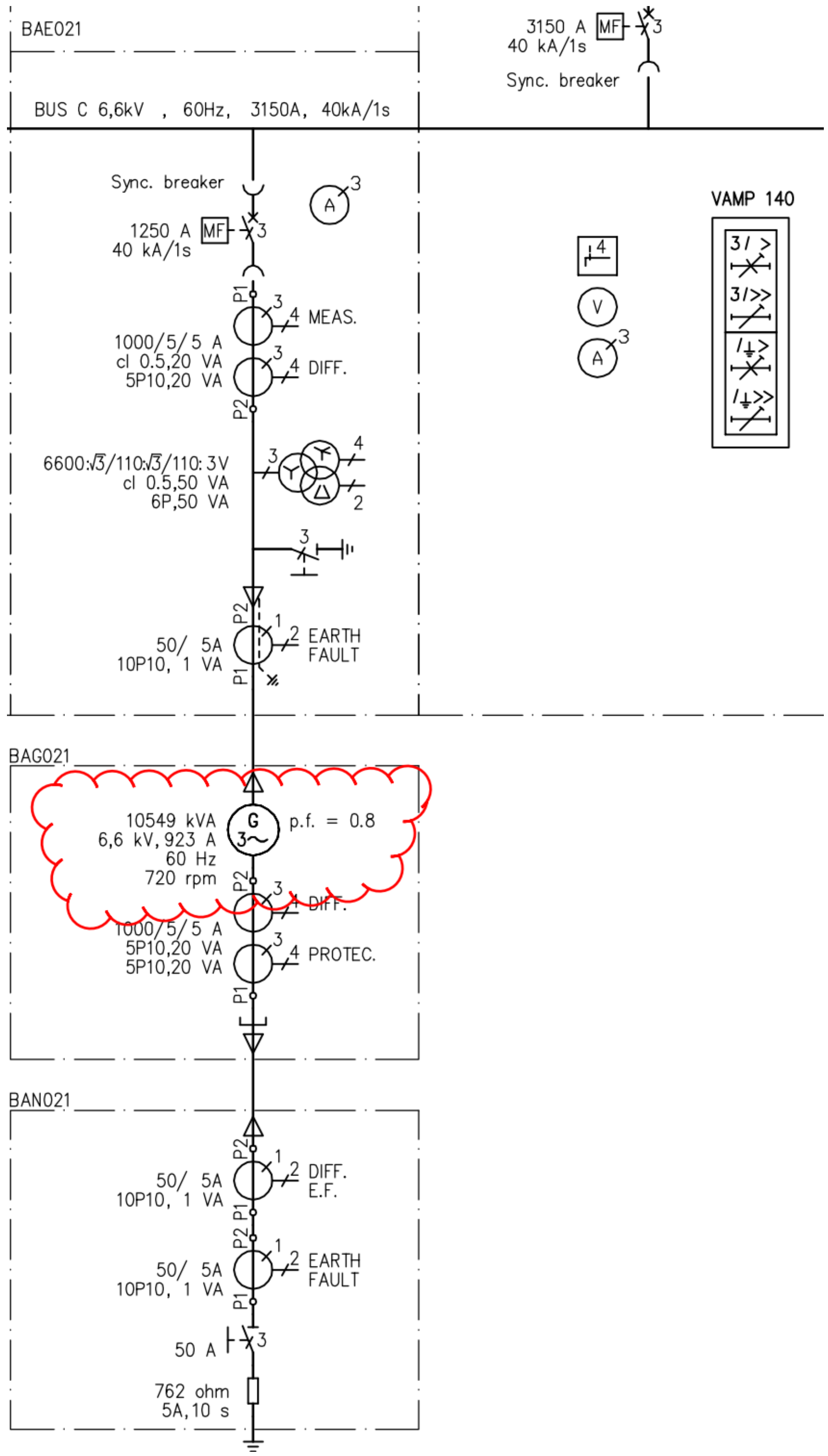


Figure 27. BAE of single line diagram from power plant number 17. Components that need to be changed are circled in red (Wärtsilä 2014a)

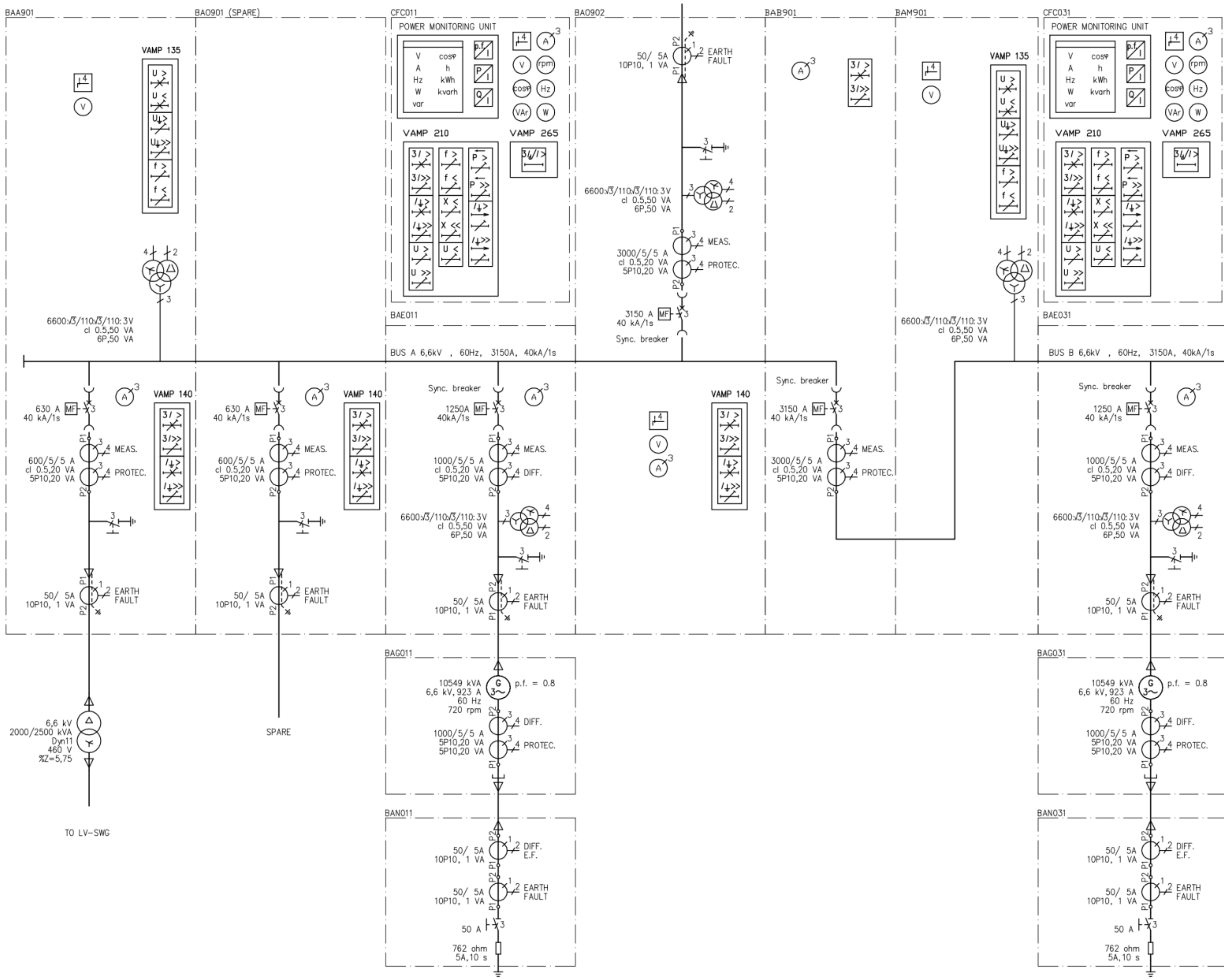


Figure 28. Single line diagram in the power plant number 17. (Wärtsilä 2014a).

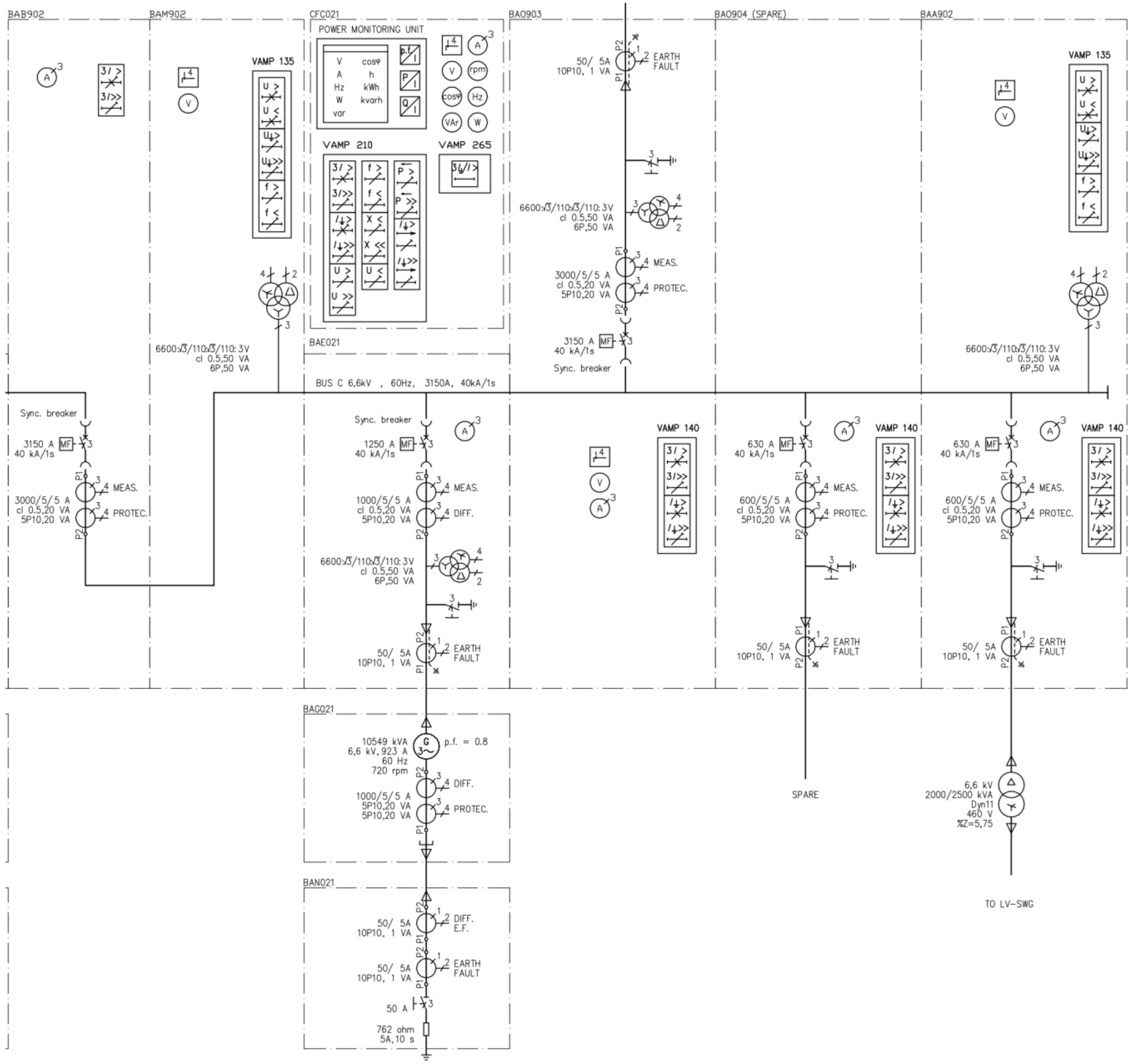


Figure 29. Single line diagram in the power plant number 17. (Wärtsilä 2014a).

To summarize, the needed modifications in power plant number 17 are:

- New generator
- New current transformers
- Protection relays' setting modifications to correspond new current.

6 DISCUSSION

This thesis work is a part of the business case that examines feasibility of power increase for gas engine power plants. The target engines are Wärtsilä 34SG C-output. Their mechanical output is 450 kW per cylinder. The output will be increased to C2-output level which is 500 kW per cylinder.

For this thesis work six power plants were picked up, of which is written more about in Chapter 5. Only in one of the cases the generator was designed so close to the maximum design output rate, that its power cannot be increased without generator change. A totally different was the case where only the protection relay setting needs to be modified. Other cases needed current transformer changes and/or circuit breaker changes in BAE and/or BAO. In one of the cases there was a need to add more cable per phase between generator and medium voltage switchgear. For the remaining 61 installations of the business case the capability to power increase is shown in Appendix 9.

In most of the installations there is a need to change the current transformers (CT). The reason for this is that the CTs have been dimensioned in engineering stage so close to the rated current of the generator. New current transformers can be installed to the medium voltage switchgear but there is a need to revise protection relay settings. The new values ensure that the protection relays will work as they are designed to.

The circuit breakers (CB) are also undersized components. The circuit breakers are located between the generator and the medium switchgear (BAE), between the medium switchgear and outgoing feeder (BAO) or in the bus-coupler feeder (BAB). If the rated current is exceeded, the circuit breaker cannot interrupt the current without breaking itself. In this study there is no need to calculate short-circuit currents because any components that produces short-circuit current are not changed.

The third issue is the cables. There is very limited amount of data for cables in installations in Wärtsilä database. One reason for the lack of information is that cables have not been in Wärtsilä's scope of supply in specific power plant projects. In some cases the size of the cable is only mentioned, but no reference for correction factors or materials of the cable are given. The correction factor values varied between from 0.49 to 0.8 in cases where cable calculations were found from Wärtsilä's database. This increases uncertainty when you have to use assumptions in calculating current carrying capacity of the cables and when the variation is this big as mentioned above.

The needed changes for the power plants can be found in Table 1.

Table 1. The needed component changes to make the power increase possible in these six power plants.

Installation number	**Parts to be changed**
41	-
18	Current transformers (CTs)
65	CTs and generator cubicle (BAE) circuit breakers (CBs)
61	CTs, BAE CBs and add one cable per phase more
51	CTs, BAE CBs and outgoing feeder (BAO) CBs
17	Generator and current transformers (CTs)

There were only few installations in which the generator itself was the limiting factor. In some cases there was not any spare capacity, in other words, the generators were designed very close to the maximum design ratings. In some cases there were no possibilities to do any power increase at all. This because the generator supplier informed that there was more harmonics in the grid than usually. If these generators would be relocated to some other place, the power increase might be possible to make.

You can see the existing and the new values of the power plants in Table 2.

Table 2. Case study results in table format.

Installation number	***U*** **(V)**	***P*** **(kW)**	**Current *I* (A)**	**Calculated *P* (kW)**	**Calculated *S* (kVA)**	**Calculat-ed *I* (A)**
41	13800	8700	441	9600	11692	489
18	6300	9000	1004	10000	12163	1115
65	11000	9000	573	10000	12198	640
61	10500	9000	600	10000	12198	671
51	11000	9000	576	9856	12000	630
17	6600	8700	926	10000	12175	1065

In some components there has not been put any extra capacity and it can be supposed that might be a cost issue. The buyer of the power plant wants to get the installation at a good price. To minimize extra capacity in components is perhaps one way to reduce costs. On the other hand this will decrease the capacity for power increase in the future.

Power increase is possible in certain cases and it would be a good way for Wärtsilä to provide new products and services for the customers. If the customer wants more power but cannot do any extensions due to lack of space, and in the same time their engines has a possibility to increase power, this might be a very good alternative to increase output of the power plant.

When comparing these six cases of power plants (see Table 3), power plants commissioned 2007 need only minor (only CTs) or medium changes (CTs, CBs and more cable in one power plant) to electrical components to assure the power increase. The installation number 17, commissioned year 2008, was the only one where the generator itself was the component that limited the power increase.

Table 3. Year of the commission of the six power plants.

Installation number	**Year of commissioning**
41	2010
18	2007
65	2007
61	2007
51	2007
17	2008

The power increase is also profitable to the customer when high investments in new engines are not required. If a customer has ten 20V34SG C-output engines and is considering to buy one more, the power increase for the customer's existing engines could be a good option. By increasing ten engines mechanical output from 9000 kW to 10000 kW the customer gets 10 times 1000 kW = 10000 kW more power. That power increase is more than one 20V34SG C-output (9000 kW) engine. In Table 4 total output of power plant in different number and output class combination can be seen.

Table 4. Total output according to different number of engines and output classes.

Number of the engines	**Output class**	**Power plant total mechanical output, kW**
10	C	90 000
10	C2	100 000
11	C	99 000

This thesis can be used only as a guideline for future cases. This is because detailed information from the suppliers could not be received due to the tight schedule. This thesis gives an overall look to different projects and what will be the major issues in future power increasing. In future enquiries the whole power plant should be examined properly and the suppliers should give more detailed information about the components.

Power increasing can be a new and innovative product for Wärtsilä. This could be offered for the customers as an alternative to new engines. The power increase can give the customer more profit and would also have a positive effect on Wärtsilä future orders. If commercialized, this would grow Wärtsilä's product- and service range and increase the company's market share.

7 SUMMARY

This thesis work was a part of a business case in Wärtsilä and studies opportunities for power increase in gas engine power plants. The power plants in this thesis have Wärtsilä 34SG C-output engines. The mechanical output of the engine can be increased with quite simple modifications. This study examined the opportunity of power increase in the electrical part of the power plant. If the power increase is possible to make with minor or medium modifications to the electrical components, this could be a good alternative to a new engine and the needed electrical components. In case the power plant has not any room for extension this could be the only way to increase power.

The main electrical components in the power plant are the generator, cables, medium voltage switchgear and transformers. The supplier of the generator confirmed whether the generator could withstand the increased power of the engine and also informed new efficiency value. According to this information the new apparent power and current were calculated. The medium voltage switchgear was also inspected it can withstand the new current.

This study introduced six different power plant cases. The main results of these six installations can be found in Table 5.

Table 5. The needed part changes in six cases.

Installation number	**Generator**	**Current Transformer**	**BAE Circuit Breaker**	**BAO Circuit Breaker**	**Extra cable**
41					
18		X			
65		X	X		
61		X	X		X
51		X	X	X	
17	X	X			

The results of this study can be used only as a guide for power increasing cases. The report gives good overall look to mechanical power increasing in Wärtsilä power plants. Due to the assumptions had to be made because of missing information, recommend for the future cases the power plant and its components should be inspected more specific.

The study revealed that power increase is possible to make in a reasonable way in most of the cases. This means that only minor or medium changes have to be done. Power increasing products or services could be a good addition to Wärtsilä's product range. Today and in the future the customers are very aware of costs and they want to provide high quality energy to their own customers at a reasonable price. Nowadays life cycle of a product is an important issue, and power increase could be a way to extend the life cycle of the whole power plant.

LIST OF REFERENCES

ABB (2005). *Uniswitch Medium Voltage Switchgear*. Operation and Maintenance Manual. 56 p. Available from Internet: <http://www05.abb.com/global/scot/scot235.nsf/veritydisplay/9acbf39cd9075341c12573d7004999e3/$file/unis14gb%200801%20operation.pdf>

ABB (2010). *TPU 4x.xx Indoor supporting current transformers.* Product catalog. 9 p. [cited 31.7.2014]. Available from Internet: <http://www05.abb.com/global/scot/scot235.nsf/veritydisplay/d3ac57c587a9aa73c1257c3700432b40/$file/TPU%204x.xx%20en.pdf>.

Aura L. and Tonteri A. (1996). *Sähkökoneet ja tehoelektroniikan perusteet*. Porvoo ; Helsinki ; Juva : WSOY. 544 p. ISBN 951–0–20167–7.

Electrical Engineering Portal (2014). *An overview of Large Power Transformer – LPT (Characteristics, Costs and Pricing)*. Website. [cited: 25.6.2014]. Available from Internet: <http://electrical-engineering-portal.com/an-overview-of-large-power-transformer-lpt>.

Elovaara J. and Haarla L. (2011). *Sähköverkot 2: verkon suunnittelu, järjestelmät ja laitteet*. Helsinki : Otatieto. 551 p. ISBN 978-951-672-363-4.

Gandras (2014). *Power plants complete with diesel and gas engines.* Website. [cited: 25.6.2014]. Available from Internet: <http://gandras.net/new/en/equipment/power-plants/gas-and-diesel-engines>.

Huhtinen, M., Korhonen, R., Pimiä, T. and Urpalainen, S. (2008). *Voimalaitostekniikka*. Helsinki: Opetushallitus. 342 p. ISBN 978–952–13–3476–4.

Huurinainen, Ville. *Jakelumuuntajan elinkaaritutkimus.* Bachelor's thesis. Electrical Power Engineering. Tampere University of Applied Sciences.

Indust cards (2014). *Power plants around the world.* Website. [cited: 16.6.2014]. Available from Internet: <http://www.industcards.com/Tarasovskoye-field.jpg>.

Jouni, Hukka (2011). *Sähkönmittauksen muutosprosessin muodostaminen Corbel Oy:lle.* Bachelor's thesis. Electrical Power Engineering. Pohjois-Karjalan Ammattikorkeakoulu.

Nylund, Carl-Johan (2012). *Design control and protection for medium voltage switchgear.* Bachelor's thesis. Electrical Power Engineering. Novia University of Applied Sciences.

Samuda (2014). *Samuda Chemical Complex Limited website.* [cited: 16.6.2014]. Available from Internet: <http://www.scclbd.com/ content.php?pageid=7>.

Schneider Electric (2000). *Cahier technique no. 195. Current transformers: specification errors and solutions.* [cited: 31.7.2014]. Available from Internet: <http://www2.schneider-electric.com/documents/technical-publications/en/shared/electrical-engineering/breaking-techniques-switchgear/general-knowledge/ect195.pdf>.

Wärtsilä (2011). *Power plants Products & Solutions, ELWIS*; General information. Internal website.

Wärtsilä (2012). *Power Plants Product Catalogue, 2nd edition.* 99 p. [cited 6.5.2014]. Available from Internet: <http://www.wartsila.com/file/Russia/1278526776145a1267106724867–Power–Plants–Product–Catalogue–2012–2nd–edition.pdf>.

Wärtsilä (2013). *Power Plants Solutions*, 3rd edition. 125 p. [cited: 6.5.2014]. Available from Internet: <http://www.wartsila.com/file/Wartsila/en/1278518335887a1267106724867–Power–Plants–Solutions–2013––3rd–Edition.pdf>.

Wärtsilä (2014a). Wärtsilä Integrated Document Management (IDM). Database.

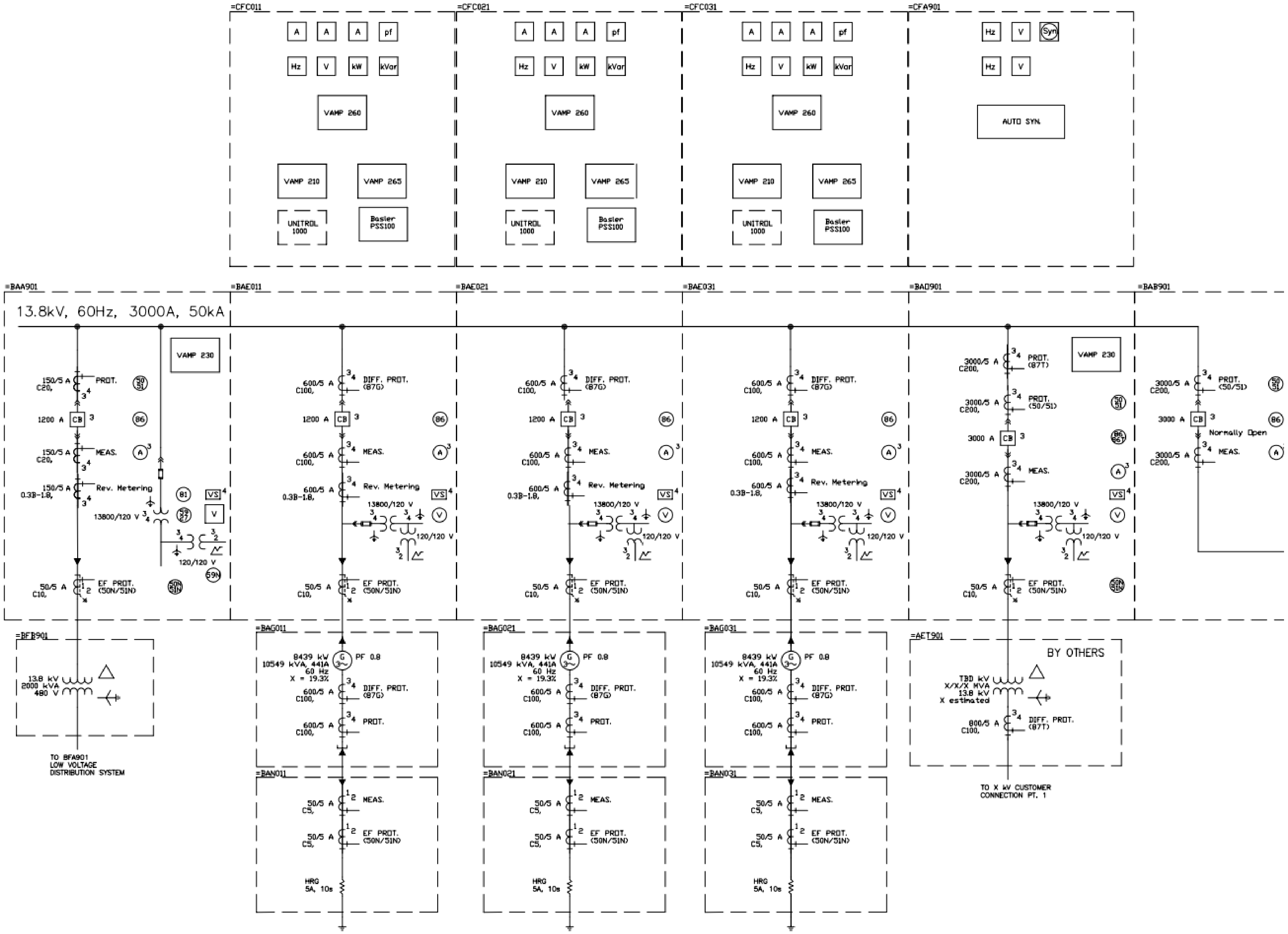
Wärtsilä (2014b). Wärtsilä Digital Media Library (DML). Database

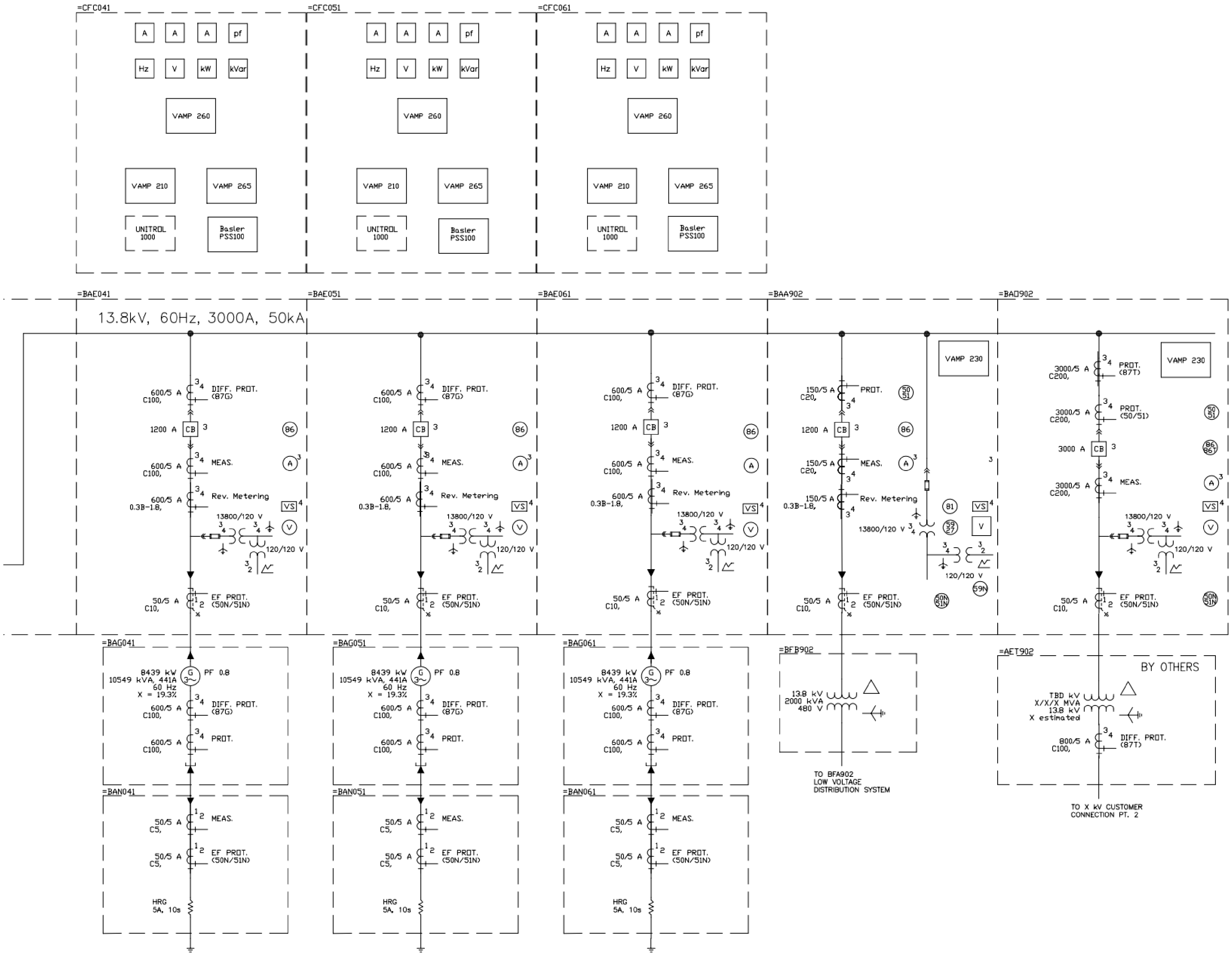
Wärtsilä (2014c). *Wärtsilä Power Plants - flexible, efficient and environmentally advanced energy solutions*. Website. [cited: 25.6.2014]. Available from Internet: <http://www.wartsila.com/fi/power-plants/technology/overview>.

Western Electric (2003). *How a motor works*. Website. [cited: 31.7.2014]. Available from Internet: <http://www.westernelectric-motors.com/T-topics_How_motor_works.htm>.

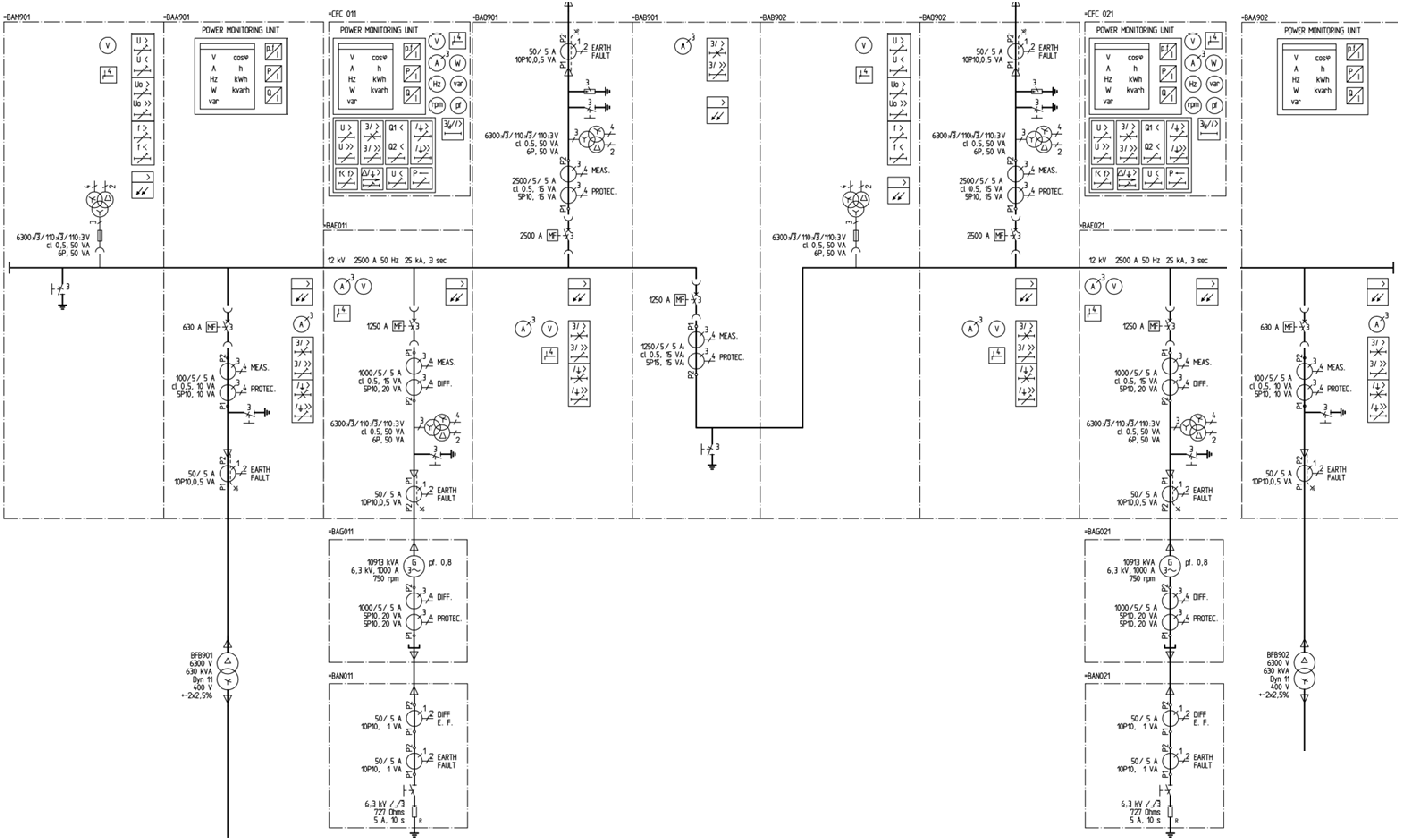
APPENDICES

Appendix 1. Single line drawing for case 1.

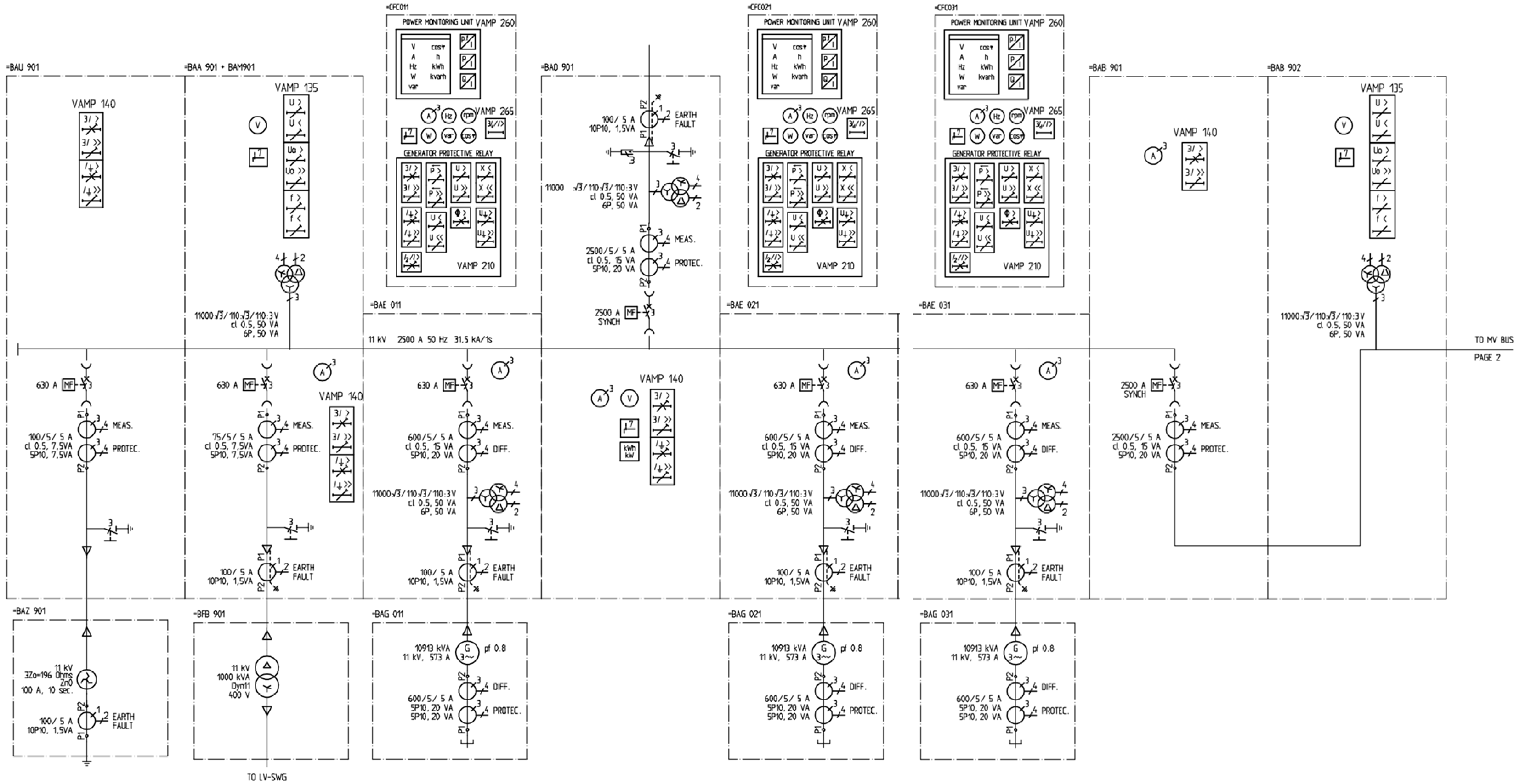


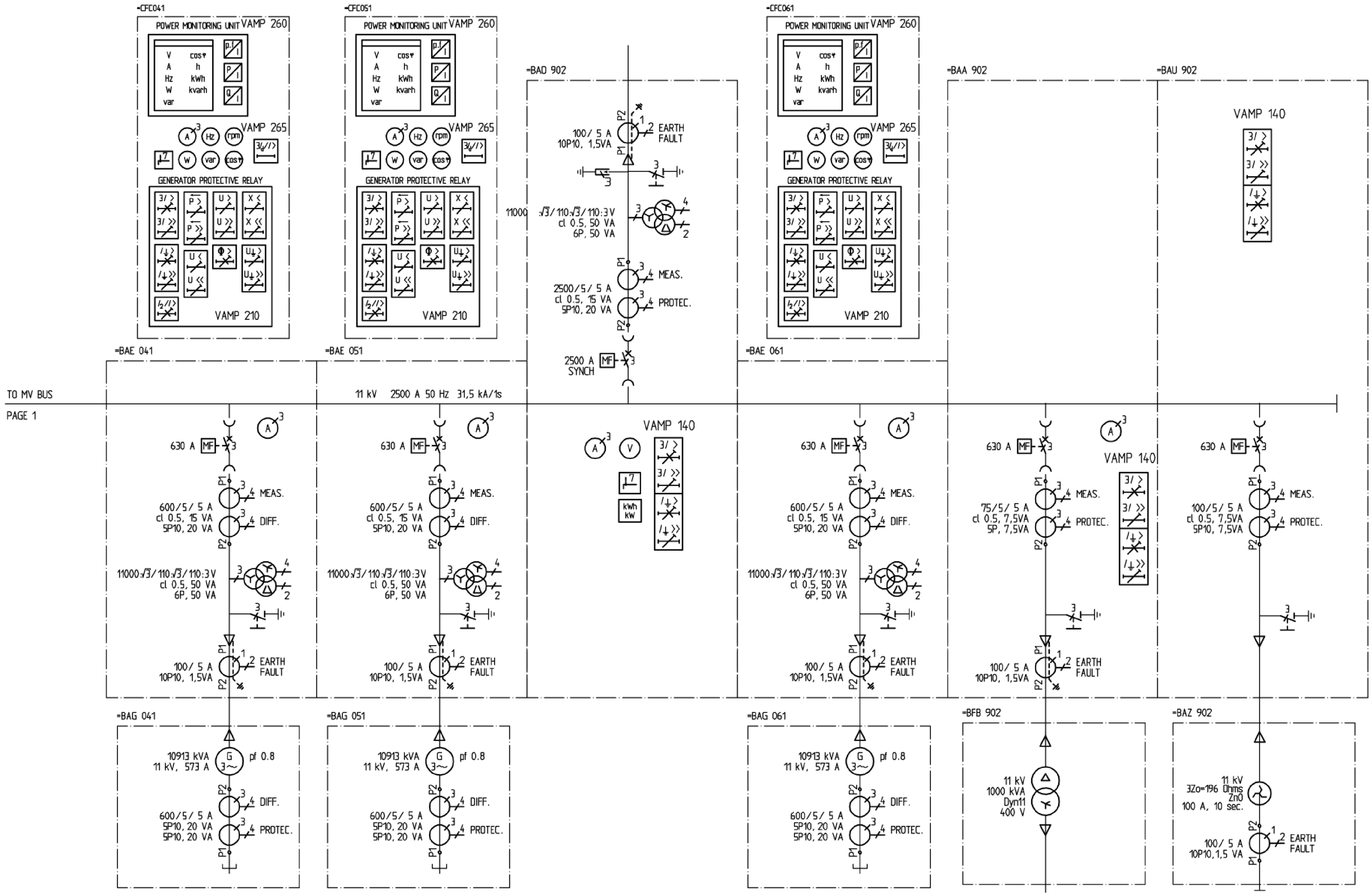

=CFC041
=CFC051
=CFC061
VAMP 260
VAMP 210
VAMP 265
UNITROL 1000
Basler PSS100
=BAE041
=BAE051
=BAE061
=BAA902
13.8kV, 60Hz, 3000A, 50kA
DIFF. PROT. (87G)
MEAS.
Rev. Metering
EF PROT. (50N/51N)
VAMP 230
PROT. (87T)
PROT. (50/51)
=BAG041
=BAG051
=BAG061
8439 kW
10549 kVA, 441A
60 Hz
X = 19.3%
PF 0.8
=BAN041
=BAN051
=BAN061
HRG
5A, 10s
=BFB902
13.8 kV
2000 kVA
480 V
TO BFA902
LOW VOLTAGE
DISTRIBUTION SYSTEM
=AET902
BY OTHERS
TBD kV
X/X/X MVA
13.8 kV
X estimated
DIFF. PROT. (87T)
TO X kV CUSTOMER
CONNECTION PT. 2

Appendix 2. Single line drawing for case 2.

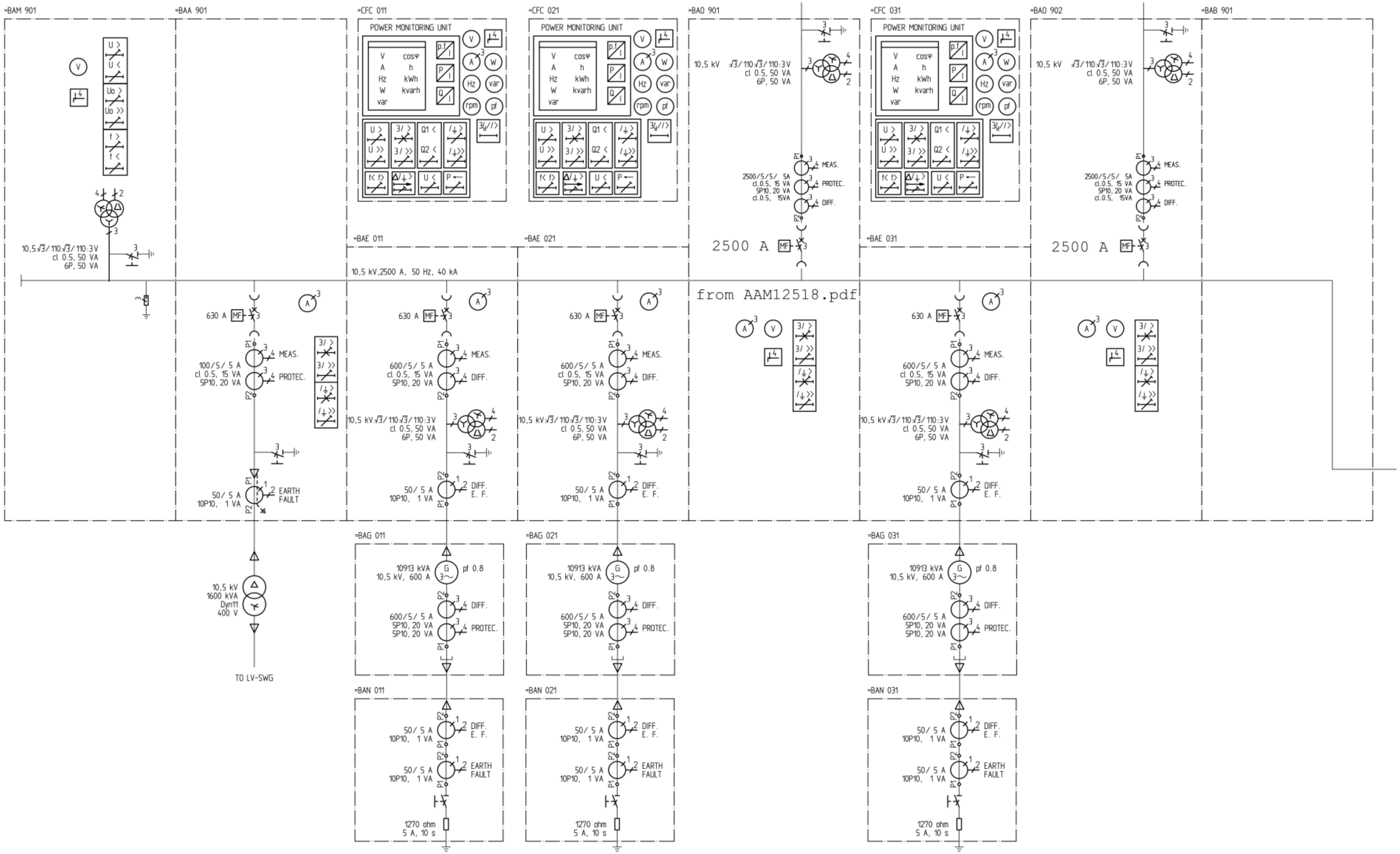


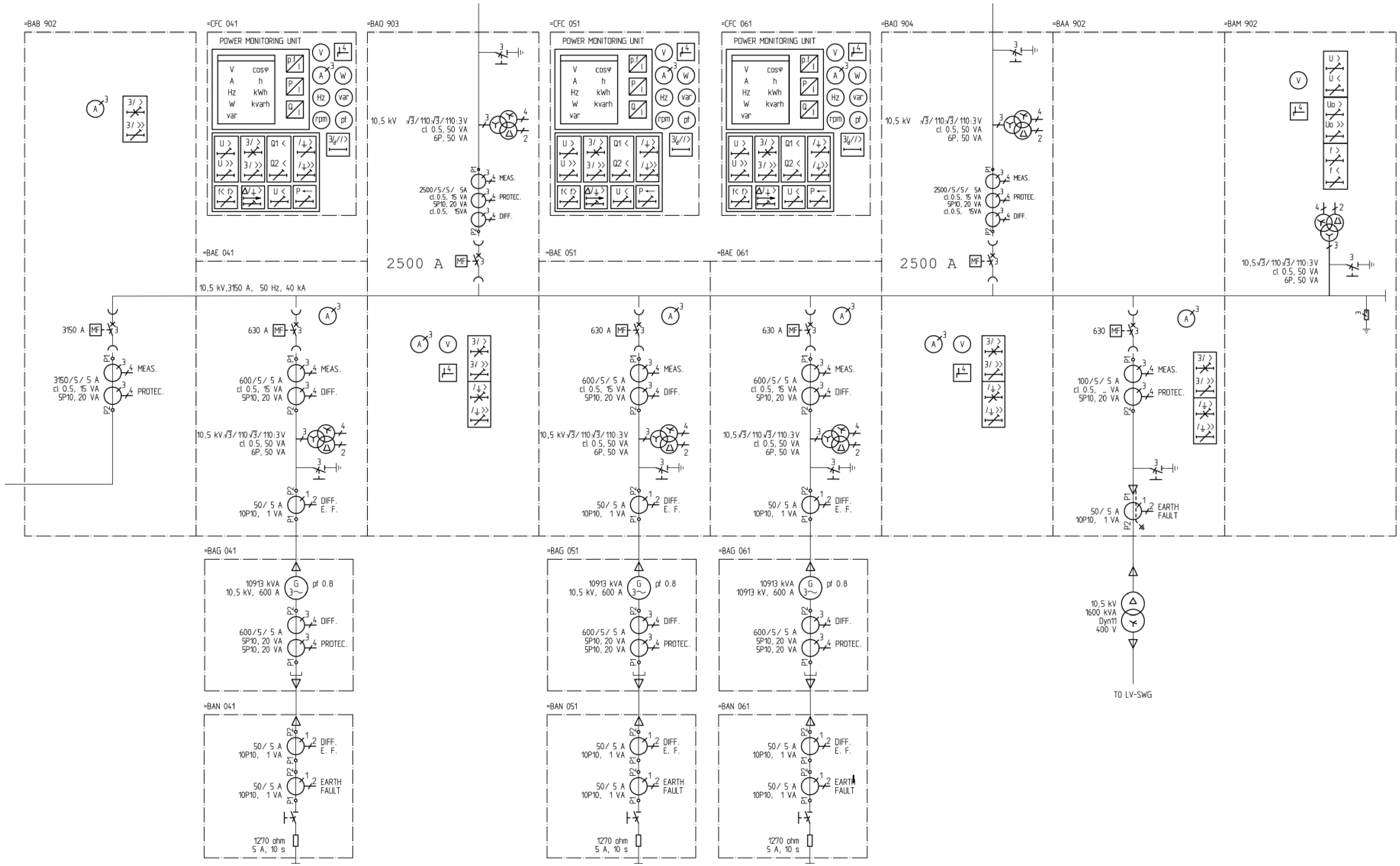
Appendix 3. Single line drawing for case 3.



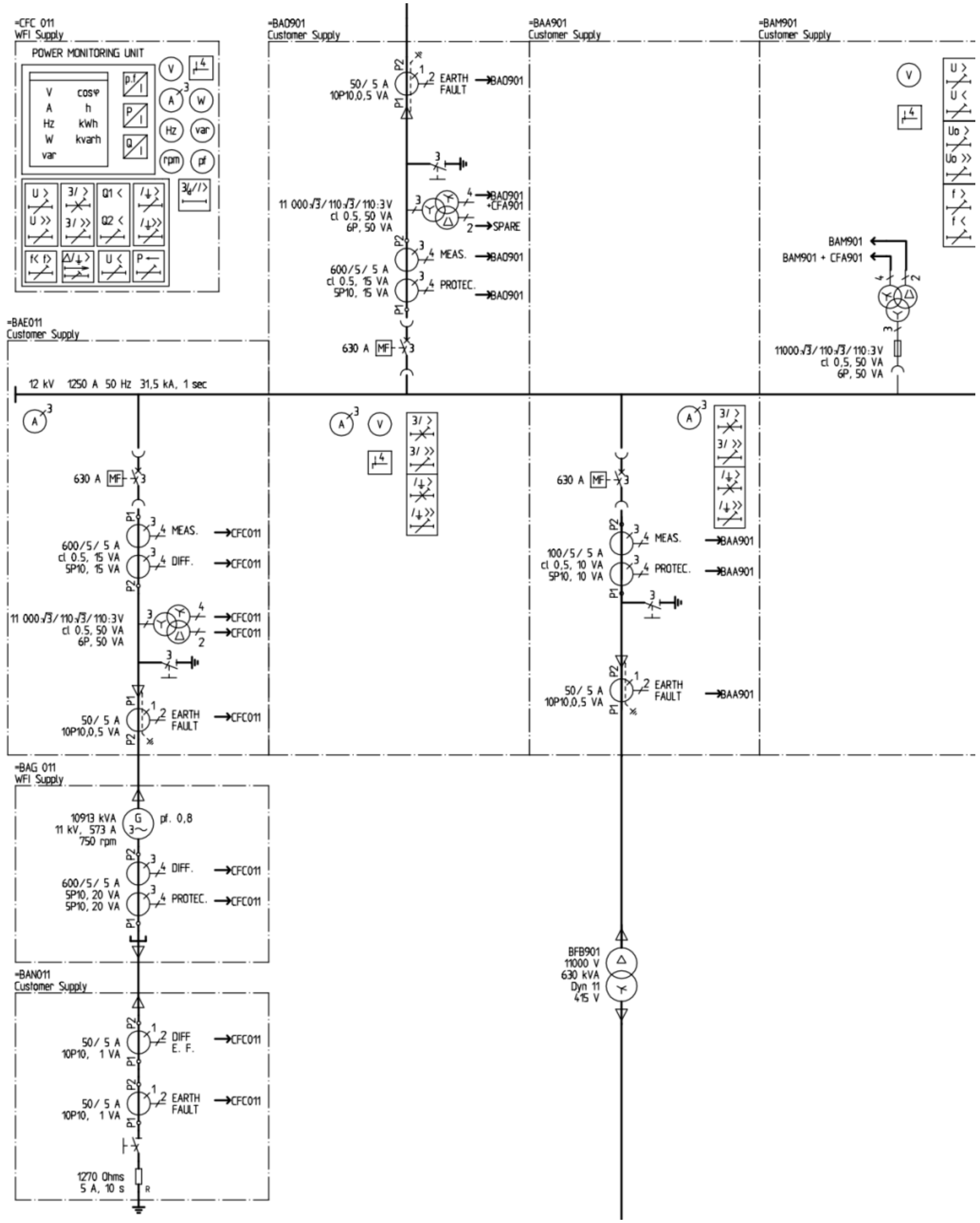

=CFC041
POWER MONITORING UNIT VAMP 260
VAMP 265
GENERATOR PROTECTIVE RELAY
VAMP 210
=CFC051
=CFC061
=BAO 902
100/ 5 A
10P10, 1,5VA
EARTH
FAULT
11000 √3/ 110√3/ 110:3V
cl 0.5, 50 VA
6P, 50 VA
2500/5/ 5 A
cl 0.5, 15 VA
5P10, 20 VA
MEAS.
PROTEC.
2500 A
SYNCH
=BAA 902
=BAU 902
VAMP 140
=BAE 041
=BAE 051
=BAE 061
TO MV BUS
PAGE 1
11 kV 2500 A 50 Hz 31,5 kA/1s
630 A
600/5/ 5 A
cl 0.5, 15 VA
5P10, 20 VA
DIFF.
11000√3/ 110√3/ 110:3V
cl 0.5, 50 VA
6P, 50 VA
75/5/ 5 A
cl 0.5, 7,5VA
5P, 7,5VA
100/5/ 5 A
cl 0.5, 7,5VA
5P10, 7,5VA
=BAG 041
=BAG 051
=BAG 061
10913 kVA
11 kV, 573 A
pf 0.8
600/5/ 5 A
5P10, 20 VA
5P10, 20 VA
=BFB 902
11 kV
1000 kVA
Dyn11
400 V
=BAZ 902
11 kV
3Zo=196 Ohms
ZnO
100 A, 10 sec.
100/ 5 A
10P10,1,5 VA

Appendix 4. Single line drawing for case 4.

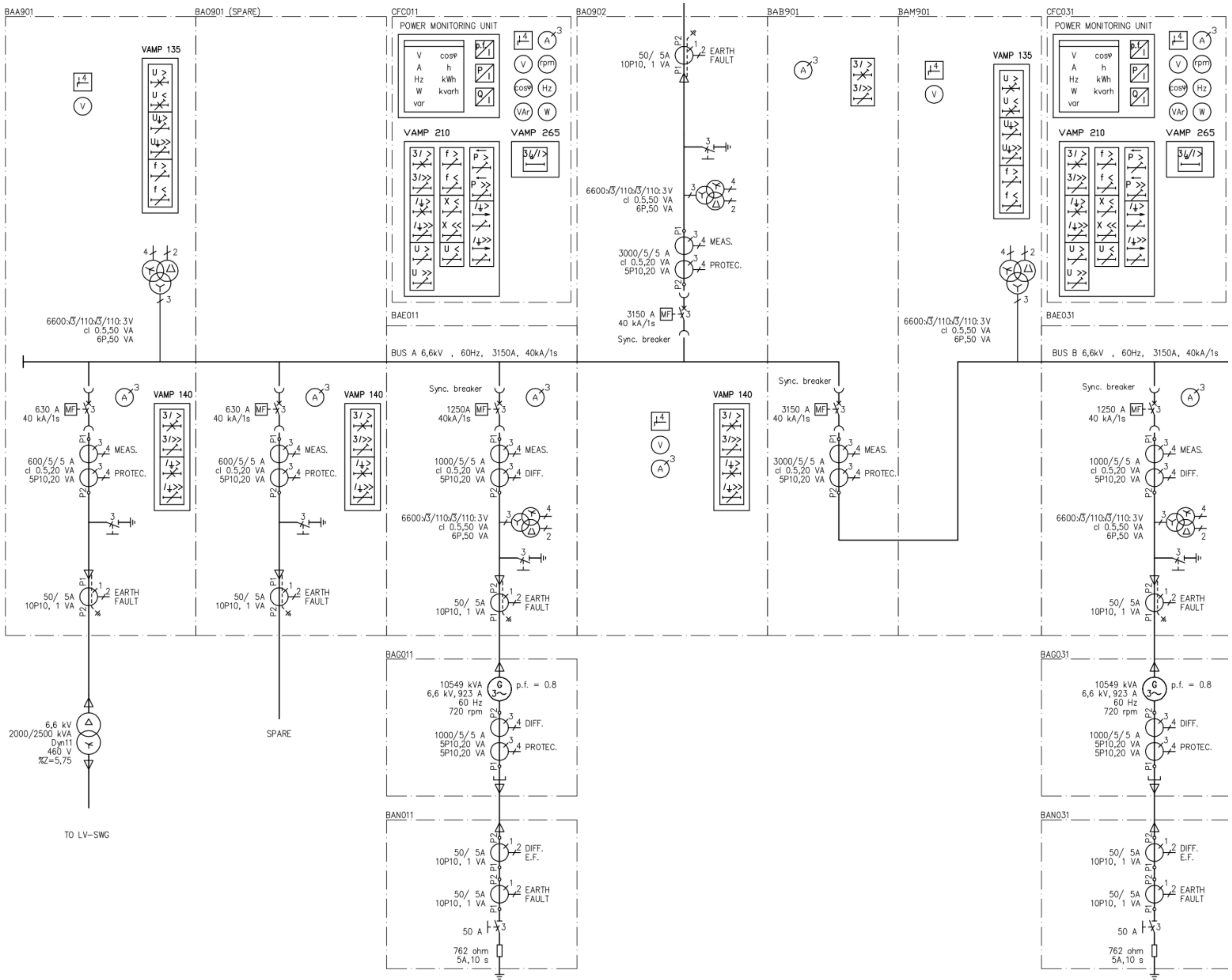


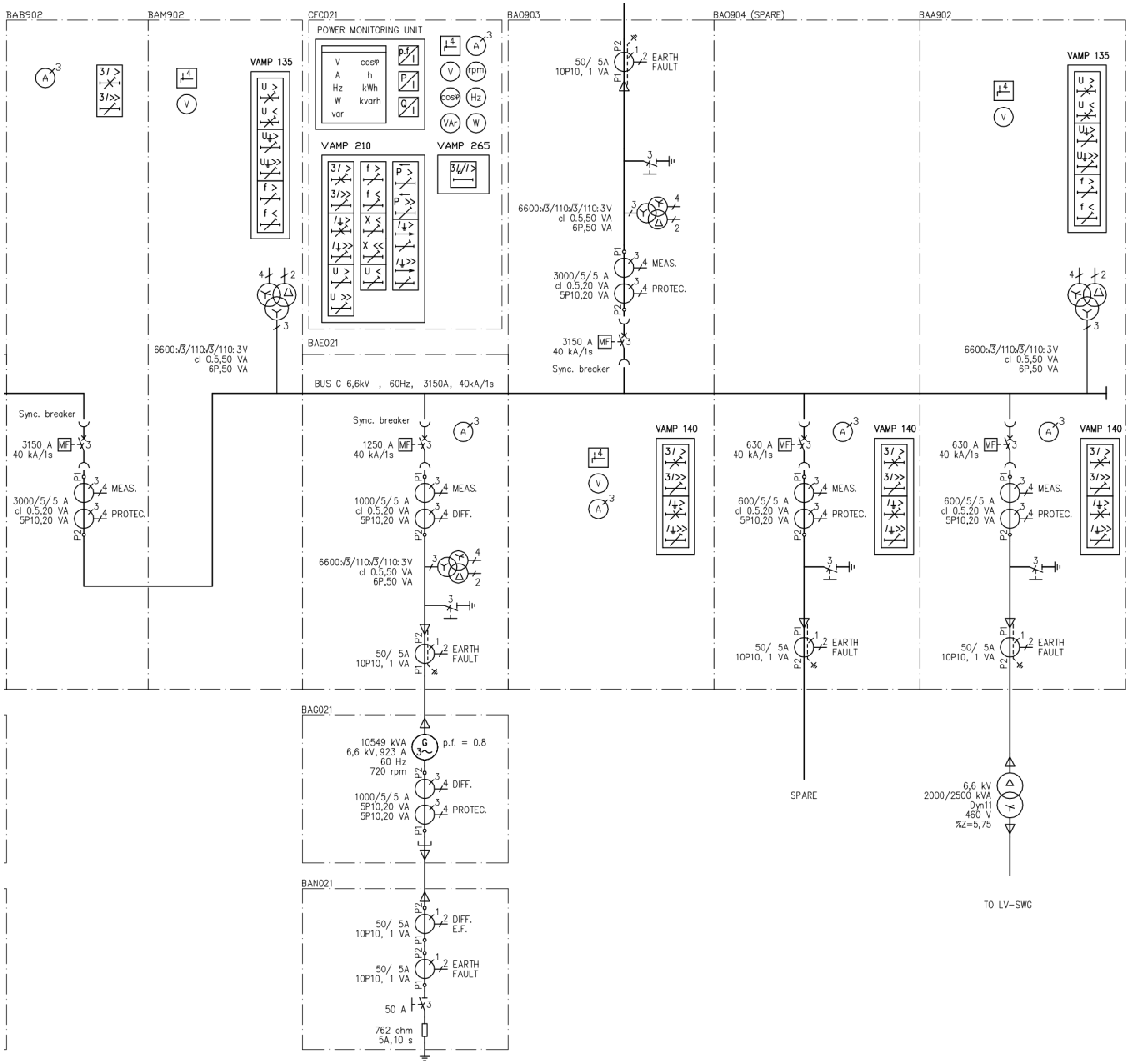

=BAB 902
=CFC 041
=BAO 903
=CFC 051
=CFC 061
=BAO 904
=BAA 902
=BAM 902
POWER MONITORING UNIT
V cosφ
A h
Hz kWh
W kvarh
var
10,5 kV √3/110√3/110:3V
cl 0.5, 50 VA
6P, 50 VA
2500/5/5/ 5A
cl.0.5, 15 VA
5P10, 20 VA
cl.0.5, 15VA
MEAS.
PROTEC.
DIFF.
2500 A
=BAE 041
=BAE 051
=BAE 061
10,5 kV,3150 A, 50 Hz, 40 kA
3150 A
630 A
3150/5/ 5 A
cl 0.5, 15 VA
5P10, 20 VA
600/5/ 5 A
100/5/ 5 A
10,5 kV√3/110√3/110:3V
50/ 5 A
10P10, 1 VA
E. F.
EARTH FAULT
10,5√3/110√3/110:3V
=BAG 041
=BAG 051
=BAG 061
10913 kVA
10,5 kV, 600 A
pf 0.8
=BAN 041
=BAN 051
=BAN 061
1270 ohm
5 A, 10 s
10,5 kV
1600 kVA
Dyn11
400 V
TO LV-SWG

Appendix 5. Single line drawing for case 5.



Appendix 6. Single line drawing for case 6.




BAB902
BAM902
CFC021
POWER MONITORING UNIT
BAO903
BAO904 (SPARE)
BAA902
VAMP 135
VAMP 210
VAMP 265
V cosφ A h Hz kWh W kvarh var
50/ 5A 10P10, 1 VA
EARTH FAULT
6600:√3/110:√3/110:3V cl 0.5,50 VA 6P,50 VA
3000/5/5 A cl 0.5,20 VA 5P10,20 VA
MEAS.
PROTEC.
3150 A 40 kA/1s
MF
Sync. breaker
BAE021
BUS C 6,6kV , 60Hz, 3150A, 40kA/1s
1250 A 40 kA/1s
1000/5/5 A cl 0.5,20 VA 5P10,20 VA
DIFF.
VAMP 140
630 A 40 kA/1s
600/5/5 A cl 0.5,20 VA 5P10,20 VA
BAG021
10549 kVA 6,6 kV, 923 A 60 Hz 720 rpm
p.f. = 0.8
1000/5/5 A 5P10,20 VA 5P10,20 VA
SPARE
6,6 kV 2000/2500 kVA Dyn11 460 V %Z=5,75
TO LV-SWG
BAN021
DIFF. E.F.
50 A
762 ohm 5A,10 s

Appendix 7. The cable calculation to installation number 1 power plant, used as refecence in cases where not found own cable calculation.

Cable calculations

Title:	Generator - MV switchgear	Made:	SMP
Client:	Wärtsilä	Date:	01/10/2007
Project:		Rev. No:	
Doc. No.:	DBAA315671	Rev. date:	

Load information:

System voltage	**10500**	V
Total current	**600.00**	A
Apparent power	**10.91**	MVA
Active power		MW
COS φ		

Correction factors:

Ambient temperature	**0.96**	**25** °C
Grouped cables	**0.61**	
Thermal resistivity	**0.93**	**1.2** W/m
Total correction factor	**0.54**	

Calculated values:

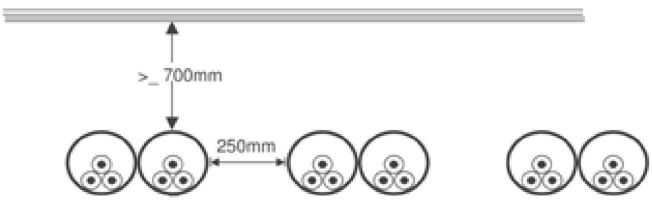
Current carrying capacity	**630**	A
Reduced current carrying capacity	**340.9**	A
Current / conductor	**300.0**	A

Conductor temperature **75** °C

Cable information:

Recommendation **Cu, XLPE, 2x3x(1x300), cable**

Notes:



Cable data:

Size (sqmm)	Full capacity (A)	Reduced capacity (A)	
1x240	560	303	
1x300	630	341	Selected cable
1x400	720	390	

Appendix 8. The cable calculation to installation number 61 power plant.

c/tec **Cable calculations**

Title:	From Generators to MV switchgear	Made:	THAX01
Client:	Wärtsilä	Date:	04.04.2007
Project:		Rev. No:	-
Doc. No.:	DBAA109434	Rev. date:	-

Load information:

System voltage	**10500**	V
Total current	**600.00**	A
Apparent power	**10.91**	MVA
Active power		MW
COS φ		

Correction factors:

Ambient temperature	**0.96**	**25** ℃
Cables in conduits	**0.80**	
Two adjacent conduits	**0.87**	
Six groups of conduits	**0.79**	
Thermal resistivity	**0.93**	**1.2** W/m
Total correction factor	**0.49**	

Calculated values:

Current carrying capacity	**630**	A
Reduced current carrying capacity	**309.3**	A
Current / conductor	**300.0**	A

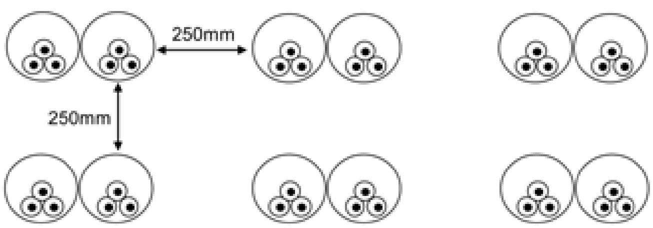
Conductor temperature **86** ℃

Cable information:

Recommendation **Cu, XLPE, 2x3x(1x300), Cables / Generator**

Notes:

Sizing based on Gorse Tehcnical Data -manual



Cable data:

Size (sqmm)	Full capacity (A)	Reduced capacity (A)	
1x240	560	275	
1x300	630	309	Selected cable
1x400	720	353	

Appendix 9. Table for capability for power increase to other installations.

Installation number	U (V)	Pm (kWm)	I (A)	New Pm (kWm)	New S (kVA)	New I (A)	Power increase possible	What need to change	Assumptions	Assumptions
1	10500	9000	600	10000	12198	671,0	Yes	CTs and BAE CBs	Main transformer and BAO CBs will handle new power and current and new CBs and CTs will fit to MV switchgear	
2	11000	9000	576				No	Due harmonic waves		
3	11000	9000	585	10000	12198	640,0	Yes/No	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	If full power BAB901 CB must be open. Busbar2 rated current will be exceeded
4	11000	9000	576	9856	12000	630,0	Yes	CTs	Step-up transformer, main transformer and cables will handle new power and current and new CTs will fit to MV switchgear	
5	11000	7200	457	8000	9746	512,0	Yes	CTs, Busbar	Step-up transformer, main transformer and cables will handle new power and current and new CTs and busbar will fit to MV switchgear	
5	11000	9000	576	9856	12000	630,0	Yes	CTs, Busbar	Step-up transformer, main transformer and cables will handle new power and current and new CTs and busbar will fit to MV switchgear	
6	11000	9000	576				No	Due harmonic waves		
7	11000	9000	572,7	10000	12198	640,0	Yes	CTs	Main transformer will handle new power and current and new CTs will fit to MV switchgear	
8	11000	9000	572,7	10000	12198	640,0	Yes	CTs	Main transformer will handle new power and current and new CTs will fit to MV switchgear	
9	11000	6970	457	7680	9356	491,0	Yes	CTs	Main transformer and cables(should be OK, used reference) will handle new power and current and new CTs will fit to MV switchgear	BAE011->BAO901 etc, if all power to one BAO,
9	11000	3888	255	4320	5238	275,0	Yes	CTs	Main transformer and cables(should be OK, used reference) will handle new power and current and new CTs will fit to MV switchgear	its CB rated current exceed
10	13800	8700	441,3	9600	11712	490,0	Yes	-	Only generator data available	
10	13800	8700	441,3	9600	11712	490,0	Yes	-	Only generator data available	
11	11000	9000	573	10000	12198	640,0	Yes	CTs and BAO CB	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	
12	11000	9000	576				No	Due harmonic waves		
13	6000	9000	1053	10000	12150	1169,0	Yes	CTs	Main transformer and cables will handle new power and current and new CTs will fit to MV switchgear	
14	6000	4050	473	4500	5462	526,0	Yes	CTs	Step-up transformer, main transformer and cables will handle new power and current and new CTs will fit to MV switchgear	
15	6300	4050	445	4490	5450	499,0	Yes	CTs	Main transformer, step-up transformers and cables will handle new power and current and new CTs will fit to MV switchgear	
16	6600	7200	697	8000	9760	854,0	Yes	CTs	Main transformer and cables will handle new power and current and new CTs will fit to MV switchgear	
17	6600	8700	926	8706	10600	927,0	Yes	Generator	Main transformer and cables will handle new power and current	
18	6300	9000	1004	10000	12163	1115,0	Yes	CTs	Main transformer will handle new power and current and new CTs will fit to MV switchgear	
19	6600	7200	767	8000	9720	850,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
19	6600	9000	959	9959	12100	1058,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
20	6600	7200	766	8000	9720	850,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
21	6600	9000	958	9959	12100	1058,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
22	6600	9000	959	9959	12100	1058,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
23	11000	9000	576	9856	12000	630,0	Yes	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	BAE011->BAO901 etc, if two or more engine full power to one BAO, its CB rated current exceed

Installation number	U (V)	Pm (kWm)	I (A)	New Pm (kWm)	New S (kVA)	New I (A)	Power increase possible	What need to change	Assumptions	Assumptions
24	11000	9000	576	9856	12000	630,0	Yes	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	BAE011->BAO901 etc, if two or more engine full power to one BAO, its CB rated current exceed
25	13800	8700	441	9600	11724	490,0	Yes	-	Main transformer and cables will handle new power and current	
26	13800	8700	432	9600	11692	489,0	Yes	-	Main transformer and cables will handle new power and current	North and south bus to the own BAO, otherwise busbars' and BAO CBs' rated current exceeded
27	11000	9000	576	9856	12000	630,0	Yes	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	
28	11000	9000	576	9856	12000	630,0	Yes	CTs	Main transformer and cables will handle new power and current, turbine not taken into account and new CTs will fit to MV switchgear	
29	6600	7200	766	8000	9720	850,0	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
30	6600	9000	958	9959	12100	1058,5	Yes	-	Only generator data available	
31	6600	9000	958	9959	12100	1058,5	Yes	CTs	Main transformer, MV switchgear and cables will handle new power and current and new CTs will fit to MV switchgear	
32	11000	9000	576	9856	12000	629,8	Yes	-	Only generator data available	
33	6600	9000	959	9959	12100	1058,5	Yes	-	Main transformer, MV switchgear and cables will handle new power and current	
34	6600	3915	411	4365	5276	462,0	Yes	1 cable / phase more	Main transformer and new cable fits both MV switchgear and generator side will handle new power and current	
35	6300	9000	1003	10000	12163	1115,0	Yes	CTs	Main transformer will handle new power and current and new CTs will fit to MV switchgear	Two engine full power can go to one BAO or three engines full power in one busbar, otherwise rated current exceeded.
36	11000	9000	573	10000	12198	640,0	Yes	CTs	Main transformer, step-up transformers and cables will handle new power and current and new CTs will fit to MV switchgear	
37	10500	9000	603	9784	11900	654,0	Yes	CTs and BAE CBs	Main transformer, outgoing feeder and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	
38	11000	7200	460	8000	9730	511,0	Yes	CTs	Main transformer will handle new power and current and new CTs will fit to MV switchgear	BAE011->BAO901 etc, if two engine full power to one BAO, its CB rated current exceed
39	6300	9000	1003	10000	12163	1114,6	Yes	-	Only generator data available	
40	11000	9000	576	9856	12000	630,0	Yes	-	Only generator data available	
41	13800	8700	441	9600	11692	489,0	Yes	-	Main transformer and cables will handle new power and current	
42	11000	9000	577	10000	12200	640,0	Yes	CTs	Main transformer and cables(should be OK, used reference) will handle new power and current and new CTs will fit to MV switchgear	
43	11000	9000	576				No	Due harmonic waves		
44	11000	9000	576	9856	12000	630,0	Yes	-	Main transformer, cables and CTs will handle new power and current	
45	11000	9000	576	9856	12000	630,0	Yes	CTs	Step-up transformer, main transformer and cables will handle new power and current and turbine not taken into account and new CTs will fit to MV switchgear	
46	13800	8700	441	9600	11712	490,0	Yes	-	Main transformer and cables(should be OK, used reference) will handle new power and current	
47	13800	8638	432	9560	11643	487,0	Yes	-	Main transformer and cables will handle new power and current	
48	11000	7200	457	8000	9746	512,0	Yes	CTs	Main transformer and cables (Gen<-> step-up trafo used reference) will handle new power and current and new CTs will fit to MV switchgear	
49	11000	9000	576	9856	12000	630,0	Yes	CTs	Main transformer and cables (should be OK, used reference) will handle new power and current and new CTs will fit to MV switchgear and turbine not taken into account	

50	11000	9000	576	9856	12000	630,0	Yes	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	
51	11000	9000	576	9856	12000	630,0	Yes	CTs, BAE and BAO CB	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	
52	10500	9000	603	9784	11900	654,0	Yes	CTs and BAE CBs	Main transformer will handle new power and current and new CBs and CTs will fit to MV switchgear	If full power BAB901 CB must be open, otherwise busbar and BAO CB rated current will be exceeded
53	11000	9000	576	10000	12175	639,0	Yes	CTs	Main transformer and cables(should be OK, used reference) will handle new power and current and new CTs will fit to MV switchgear	
54	11000	9000	576	9856	12000	630,0	Yes	-	Only generator data available	
55	11000	7200	460	8469	10300	541,0	Yes	CTs	Main transformer and cables will handle new power and current and new CTs will fit to MV switchgear	
56	11000	9000	585	10000	12198	640,0	Yes	CTs and BAE CBs	Main transformer, cables and MV busbar will handle new power and current and new CBs and CTs will fit to MV switchgear	
57	11000	9000	573	10000	12198	640,0	Yes	CTs and BAE CBs	Main transformer, cables and MV busbar will handle new power and current and new CBs and CTs will fit to MV switchgear	
58	11000	9000	508	10000	12198	640,0	Yes	CTs and BAE CBs	Main transformer, cables and MV busbar will handle new power and current and new CBs and CTs will fit to MV switchgear	
59	11000	9000	576	9856	12000	630,0	Yes	CTs, BAE CB	Main transformer, cables and MV busbar will handle new power and current and new CBs and CTs will fit to MV switchgear	
60	11000	9000	576	10000	12175	639,0	Yes	-		
61	10500	9000	600	10000	12198	671,0	Yes	CTs, BAE CBs and 1 c	Main transformer will handle new power and current and new cable fits both MV switchgear and generator side and and new CBs and CTs will fit to MV switchgear	If full power max 3 engine's power to one BAO and max 4 engine's power to one busbar, otherwise rated currents exceeded
62	11000	9000	576	10000	12175	639,0	Yes	CTs	Main transformer and cables(should be OK, used reference) will handle new power and current and and new CBs and CTs will fit to MV switchgear	If full power BAB901 CB must be open, otherwise BAO CB rated current will be exceeded
63	13800	9000	441	9788	11921	499,0	Yes	-	Main transformer and cables will handle new power and current	
64	10500	4050	267	4500	5456	300,0	Yes	CTs and BAE CBs	Main transformer will handle new power and current	
64	10500	9000	600	10000	12198	671,0	Yes	CTs and BAE CBs	Main transformer will handle new power and current and new CBs and CTs will fit to MV switchgear	If full power BAB902 CB must be open, otherwise BAO CB rated current will be exceeded
65	11000	9000	573	10000	12198	640,0	Yes	CTs and BAE CBs	Main transformer and cables will handle new power and current and new CBs and CTs will fit to MV switchgear	If full power BAB901 CB must be open, otherwise BAO CB and busbar rated current will be exceeded
66	13800	8700	442	8991	10913	457,0	Yes	-	Main transformer will handle new power and current	
67	10500	9000	603	9784	11899,79	654	Yes	CTs and BAE CBs	Main transformer, cables(should be OK, used reference) and BAO CBs will handle new power and current and new CBs and CTs will fit to MV switchgear	