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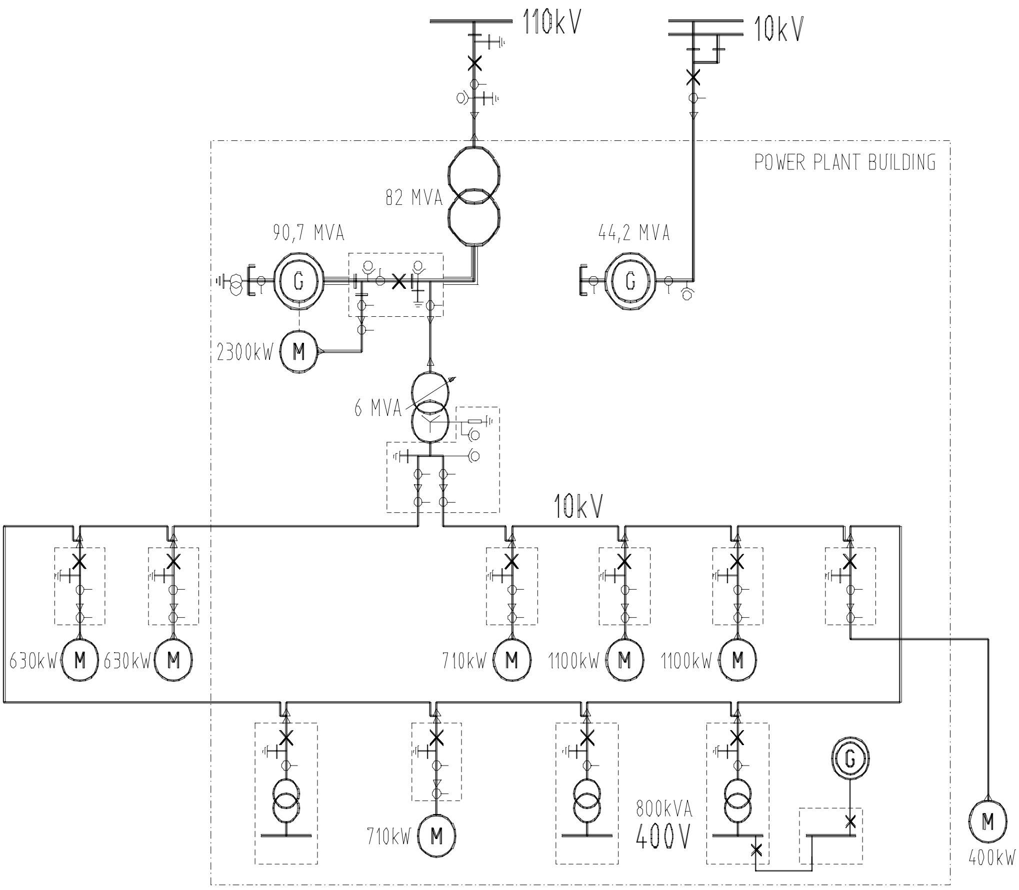

TECHNICAL RESEARCH CENTRE OF FINLAND

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Abstract

A centralised network is the most common network solution in today's power plants. In this study a centralised and a decentralised network were designed in order to compare them economically and technically. The network of the Kirkniemi (Lohja, Finland) power plant was used as a model case. The emphasis of this study was on economical aspects, but also the most important technical aspects were considered.

The decentralised network requires less space and less cabling since there is no switchgear building and distribution transformers are placed closer to the consumption. Medium voltage motors and distribution transformers build up a ring. Less cabling and an absent switchgear building cause considerable savings.

Component costs of both of the networks were estimated by using data from completed power plant projects. Component costs of the decentralised network were smaller than those of the centralised network.

An essential question of the network is the relay protection and associated fault location. Simulations for the decentralised network were done in order to find a way to carry out earth fault protection and location. It was found out that in high resistance earthed system the fault distance can be estimated by a relatively simple method.

The decentralised network uses a field bus, which offers many new features to the automation system of a power plant. Many-sided information can be collected from the protection devices in order to schedule maintenance duties at the right time. Through the field bus it is also possible to control remotely a power plant.

The decentralised network is built up from ready-to-install modules. These modules are tested by the module manufacturer, which reduces the need for field testing dramatically. The workload needed in the project management and engineering of a power plant drops also due the modules. During the lifetime of a power plant, maintenance is easier and more economical.

Preface

The basic structure of an electrical network of a power plant has been the same for many years. Centralised radially operated network has proven its functionality and reliability. The basic idea of a network has not changed although there have been a number of changes in automation and control of a power plant. Decentralisation is the most advanced way to carry out things in modern automation. However, it is not yet a common way to carry out things in the electricity distribution of a power plant. The idea of this study came from Fortum Engineering.

This study is a part of the TESLA – Information Technology and Electric Power Systems – technology programme and was made in order to find out if there are economical benefits in a decentralised network of a power plant. The most important technical aspects were also considered in order to see if a decentralised network could be technically completed.

The authors want to express their thanks to:

Heikki Viskari, Fortum Engineering	for the idea of the subject of this study and for providing the information and useful advice needed for completing this study,
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Seppo Hänninen, VTT Energy	for the simulation of the earth faults,
Fortum Engineering, VTT Energy and Tekes, the National Technology Agency	for the financial support.

Mr. Pekka Mannila has mainly written this report and Professor Matti Lehtonen has written the parts concerning earth fault protection.

Espoo 28.12.1999

Authors

Contents

List of symbols

I_{0c} the capacitive earth fault current of the loop

I_{0mit} the measured sum current

I_{0x} the compensated sum current

I_{0X1} the compensated current at the first end of the loop

I_{0X2} the compensated current at the second end of the loop

x_1 the distance from the first feeding end

x_2 the distance from the second feeding end

1. Introduction

The basic solution of existing electrical networks of power plants has been unchanged for several decades. A network of a power plant is characterised by centralised radial distribution network, centralised auxiliary supply system and detached switchgear building. Centralisation requires a lot of cabling and space, which causes a notable amount of costs.

In a decentralised network of a power plant, distribution transformers are placed close to the consumption in the field and the network is looped. By using decentralisation and a looped network, demand for space and cabling is smaller. Reduced demand for cabling and space means lower costs. In some cases benefits of a decentralised network are more than savings in cabling costs and absent construction costs of the switchgear building. Smaller building area can be a considerable advantage in a limited urban site of a power plant.

The goal of this study was to find out if there are economical benefits in a decentralised network compared to a centralised one and to see if using present economical technology, one can carry out earth fault protection. Centralised and decentralised networks of a power plant were designed by using a real case. Costs of different systems were compared, earth faults of the decentralised network were simulated, short-circuit currents and cable power losses were calculated.

2. Formation of networks used in comparison

2.1 Model network

In Kirkniemi, Lohja, Finland there is a combined cycle power plant. The factory area of Kirkniemi is connected to the national grid with two 110 kV power lines. The power demand of the Kirkniemi paper factory is about 130 MW from which the power plant produces 105 MW under the nominal circumstances. The network solution is a typical centralised solution. This network was chosen to be used as a model network in this study. Centralised and decentralised networks were designed in order to compare them with each other. The centralised solution was modified from the present network of the Kirkniemi power plant. The decentralised solution was designed to correspond functionally with the modification of the network of the Kirkniemi power plant.

2.2 Centralised network

The centralised network used in this study is presented in Figure 1. It is a typical centralised solution with a medium voltage (6 kV) bus bar and radially fed motors and transformers.

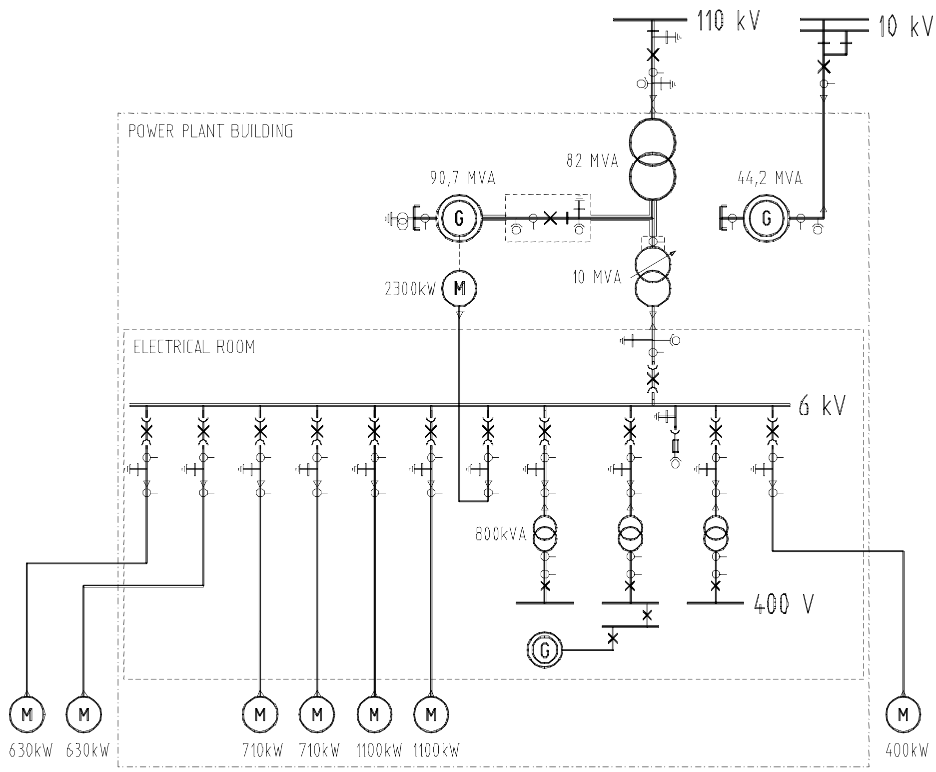


Figure 1. The centralised network used in the comparison.

The station service transformer feeds the bus bar, which is located in the detached switchgear building. The biggest motor is used to start the gas turbine. This motor determines the size of the station service transformer. The rating of the transformer is 10 MVA 10/6 kV.

Distribution transformers are located in the switchgear building and every motor is fed radially from there. There are eight 6 kV motors and three 0,8 MVA 6000/400 V transformers connected to the medium voltage network. Distribution transformers feed 87 pieces of 400 V motors in the field.

The protection of the centralised network consists of a normal short-circuit protection based on an overcurrent relay and a directional earth fault protection. Additionally the medium voltage switchgear is equipped with a so-called 100 ms busbar protection, which is locked by feeder protection.

2.3 Decentralised network

The decentralised network used in this study is presented in Figure 2. There is no medium voltage switchgear and no switchgear building. Cables of the looped network are connected directly to the poles of the station service transformer and build up a ring where MV-motors and distribution transformers are connected in series in the field of a power plant.

The start motor is fed directly from the generator bus bar and the circuit breaker of the generator is used as a circuit breaker of the start motor also. This solution demands two extra circuit disconnectors, which could be placed either to the circuit breaker unit of the generator or the bus bar joint box. By doing this one can lower the size of the transformer from 10 MVA to 6 MVA and one switchgear compartment can be replaced with two disconnectors. The bus duct of the station service transformer is replaced with a cable connection.

In the beginning of the starting of the gas turbine, the generator disconnector is open and the starting motor disconnector is closed. Closing the generator circuit breaker starts the starting motor. When the gas turbine has started, the generator circuit breaker and the starting motor disconnector are opened and the generator disconnector is closed. After this the gas turbine can be synchronised with the network by using the generator circuit breaker.

Distribution transformers are located in the field close to the consumption. 400 V motors build up groups depending on the location and the size of the motor. In these groups motors are connected in series and every group is radially fed from the distribution transformers. There are seven 10 kV motors and three 0,8 MVA 10/0.4 kV distribution transformers connected to the MV-ring. One 10 kV motor is connected to the generator bus. Distribution transformers feed 87 pieces of 400 V motors in the field.

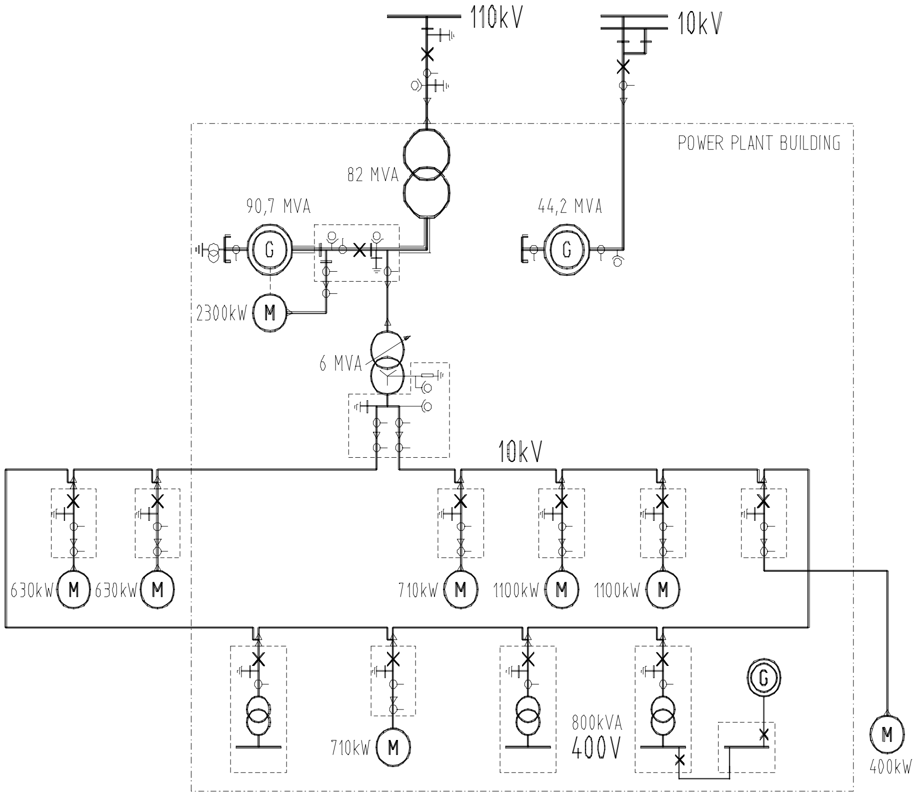


Figure 2. The decentralised network used in the comparison.

The protection of the decentralised network consists of a short-circuit protection based on an overcurrent relay and an earth fault protection based on a zero sequence overcurrent relay. In the decentralised solution, the main problem of protection is the location of an earth fault in order to enable a fast disconnection of the faulty line section and continuation of use.

2.4 Calculation of cable costs

Locations of the motors were taken from the motor lay-out drawings of the Kirkniemi power plant. A co-ordinate system was made with help of the lay-out of the Kirkniemi power plant. By using this co-ordinate system it was possible to calculate the length of cables in different networks. In order to simplify the calculation it was assumed that motors are located in the middle of squares of the co-ordinate system.

A distance calculated between two points was not the shortest distance (a straight line), because this would be impossible to carry out in a power plant. When two points were on the same level, distance between them was calculated by drawing a straight line between the points. This line was used as a hypotenuse of a right-angled triangle and the distance between two points was the combined length of the sides of the triangle. When two points were on different levels, distance between them was calculated by calculating the distance as if the points were at the same level and adding the differential of the heights of the points.

Results of the calculation of the cable costs are not absolute values of different networks because estimates were used. Results should be regarded as rough estimates. However, results can also be regarded useful estimates because same assumptions were applied to both of the network solutions. It would not have been rational to increase the accuracy of the calculation because it would not presumably have affected the calculated relative values.

2.4.1 Medium voltage cabling

Cable type and lengths of the centralised network were taken from the cable list of the existing network. Cable lengths of the decentralised network were calculated by the method described in Chapter 2.4 and cable type was chosen to be adequate for normal load and short-circuit currents of the network.

Costs of the cables were from the offer of a Finnish cable company. Cost per meter includes mounting and material when cable racks are ready. Costs of the cable terminals are an average of indoor and outdoor cable terminals.

Distribution transformers were placed close to the consumption in the decentralised network. Places of the distribution transformers were chosen with help of the lay-out. There is an optimal solution for places of the distribution transformers but this solution was not calculated. An optimal solution would have been too complicated to solve and it would not be possible to carry out in practice.

2.4.2 Low voltage cabling

Cable lengths of the centralised and decentralised networks were calculated in the way described earlier. There were 87 pieces of 400 V motors in the LV-comparison. All the 400 V motors were not found in the motor lay-out drawings and the data of a few motors were missing. However, most of the motors were included in the comparison and to have motors missing in comparison would not presumably change calculated relative values significantly. Smaller than 400 V motors were not included because their number was very low.

A part of the motors of the decentralised network were connected in series. The principle of the LV-distribution network is presented in Figure 3. If motors were located in the same point of the co-ordinate system, the distance between the motors was assumed to be three meters. Motors connected in series were chosen from motors located in the same room of the power plant with help of the lay-out. Optimisation in series connection was not done because a calculated optimal solution is not necessarily possible in practice.

As mentioned in the previous chapter, distribution transformers were placed close to the consumption by using the lay-out. Placing of the distribution transformers would be a separate optimisation task and was not done in this study because of its complexity and the fact that it can not be carried out in practice.

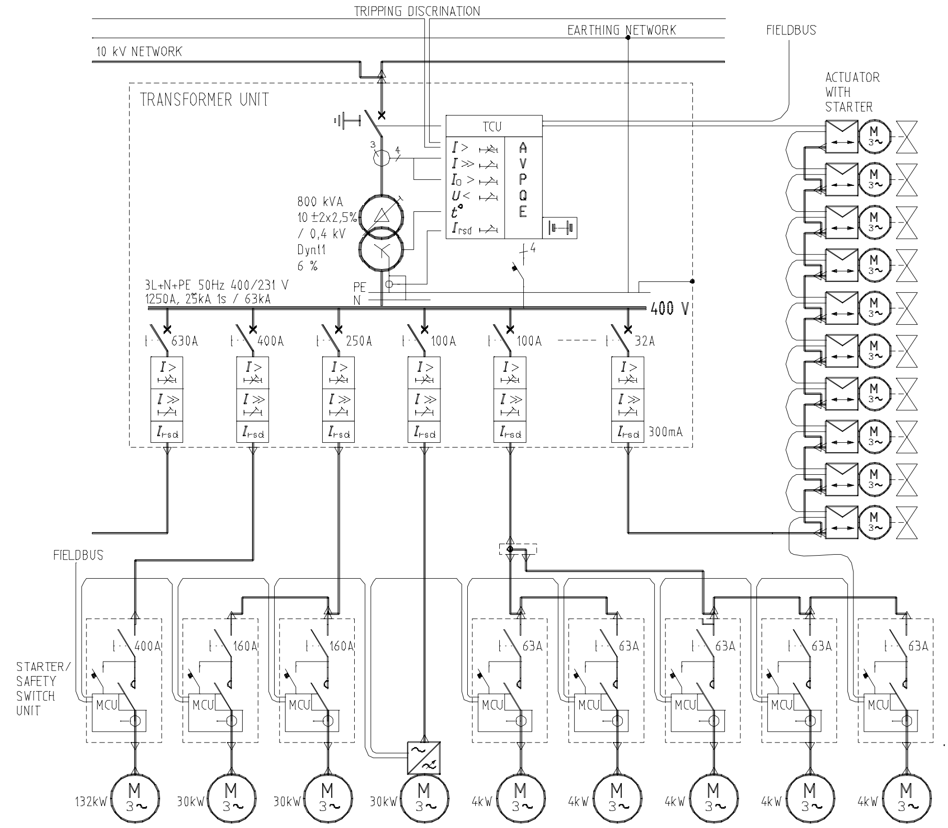


Figure 3. The principle of the LV-distribution network of the decentralised network.

2.4.3 Absent cabling

There is a lot of cabling, which is absent from the decentralised network. This cabling includes MV- and LV-cabling. Missing feed cables of the station service transformer were the biggest saving of MV-cabling. There is no need to cable e.g. a position of a safety switch, which means a considerable saving in the whole system.

2.5 Calculation of switchgear building costs

The main idea behind the decentralised network is that there is no centralised motor control centre. The volume of the motor control centre of the Kirkniemi power plant was calculated and multiplied by cost per cubic meter.

Cost per cubic meter of the switchgear building was estimated by using data from different completed power plant projects. An expert in the field from a Finnish power plant supplier did this estimation.

2.6 Calculation of component costs

Component costs of a network solution were estimated by using data from different completed power plant projects. Costs include equipment, installation, testing and commissioning.

Components needed are different depending on the network solution. As mentioned in Chapter 2.3 the start motor is fed directly from the generator bus bar and the circuit breaker of the generator is used as a circuit breaker of the start motor in decentralised network (Figure 2). This solution makes it possible to choose a smaller and more economical transformer.

A module connected to the station service transformer of the decentralised network is shown in Figure 2. It includes the same transformer protection functions with the station service transformer of the centralised network and in addition the measuring devices needed in the protection of the decentralised network. It is therefore more complicated and expensive.

Every MV-motor has a motor starter in the decentralised network. This motor starter is placed next to the motor as shown in Figure 3. These motor starters are not used in the centralised network.

As mentioned in Chapter 2.3 and shown in Figure 2 there is no medium voltage switchgear in the decentralised network. This means that these component costs will not appear in the decentralised network.

Distribution transformers are modules, which are plugged to the MV-ring in the decentralised network (Figure 2). These modules are compact and include equipment needed in protection and distribution. Therefore they are more expensive than distribution transformers in the centralised network, but they include some equipment that must be added to the centralised network e.g. 400 V switchboards and LV-feeder. There is only one 400 V switchboard for reserve diesel power machine in the decentralised network.

The principle of the low voltage network of the decentralised network is shown in Figure 3 Network is composed of distribution transformers close to the consumption, safety switch/motor starter modules by motors or devices with integrated starters. Many motors can be connected in series in starters or detached branching nodes. Safety switch/motor starter modules are used only in the decentralised network. Regular safety switches are hence not needed any more.

2.7 Calculation of technical aspects

The main goal of this study was to calculate costs of two different network solutions in order to see if it is economically reasonable to use looped decentralised network. There are also many technical aspects, which have to be considered when a network of a power plant is built. The protection of a network is a very important technical aspect. Therefore earth fault simulation and short-circuit power calculation were included in this study. Some interest was also paid to losses of networks because it was assumed that bringing transformers closer to the consumption would decrease losses of the decentralised network.

2.7.1 Earth fault simulation

Earth fault simulation was made with Alternative Transient Program (ATP). ATP is a universal program system for digital simulation of transient phenomena of electromagnetic as well electromechanical nature. With it complex networks and control systems of arbitrary structure can be simulated. It is a commercially available program. [1]

Following assumptions were made with the decentralised network:

- ring included only one type of cable,

- earth capacitances of motors of the ring were small and could therefore be disregarded.

2.7.2 Calculation of power losses

Calculation of power losses was made with EDSA AC Load Flow program, which is one feature of the EDSA Professional System Analysis program. It is a commercially available program which has many analysis capabilities.[2] It was used to calculate losses of MV-side, LV-transformers and LV-cabling for both of the systems. For the decentralised solution a case was also calculated where the MV-ring of the network is open.

Load of the station service transformer was estimated from the mean power of the Kirkniemi power plant. The average mean power from January 1998 to November 1998 was 2,1 MW. Losses were calculated for 2,8 MVA load, which meant 28% load for the centralised network (10 MVA), and 45% load for the decentralised network (6.3 MVA).

There are many motors, which are not running simultaneously in a power plant. Losses were calculated for 80% of the total output of the LV-motors of every distribution transformer.

More detailed information about calculation of losses and its results are given in Appendix A.

2.7.3 Short-circuit currents

Calculation of short-circuit currents was made also with EDSA Professional System Analysis program. It has a special feature for short circuit calculation.[3] Short-circuit currents were calculated only for the decentralised network. Calculated short-circuit currents are three-phase short circuits.

The subtransient short-circuit current of the 110 kV network was estimated to be 25 kA. This estimation is little higher than the actual subtransient short-circuit current in Kirkniemi but it was chosen in order to leave some space for its growth.

Values of the generator and the transformers used were taken from the values of the Kirkniemi power plant. However, some values had to be estimated. This was done with help of the IEC909 standard.

More detailed information about calculation of short-circuit currents and its results is to be found in Appendix B.

3. Results of the study

3.1 Costs of the decentralised network compared to the centralised one

Economical comparison of two previously introduced network solutions is shown in Table 1.

Table 1. Different costs of two network solutions presented with relative values.

	Centralised solution	Decentralised solution
MV-cabling		
share of total costs [%]	2,6	3,9
cost of cable	100	48
cost of cable terminal	100	124
sum of MV-cabling	100	68
LV-cabling		
share of total costs [%]	2,3	2,7
cost of cable	100	40
cost of cable terminal	100	100
sum of LV-cabling	100	54
Cabling not needed in the decentralised net		
share of total costs [%]	3,1	0
cost of cable	100	0
cost of cable terminal	100	0
sum of cabling not needed in the decentralised net	100	0
All the cabling		
share of total costs [%]	8,0	6,6
sum of all the cabling	100	38
Motor control centre		
share of total costs [%]	33,2	0
cost of motor control centre	100	0
Components		
share of total costs [%]	58,8	93,4
cost of motor control centre	100	73
Total costs of network solution	100	46

Costs of the centralised network were chosen to be a comparing point. They have been marked with a comparing number 100. When a cost of the decentralised network is 75% of an analogous cost of the centralised network, it has been presented by a comparing number 75.

The total costs of MV-cabling were reduced to 68 with the decentralised network. Cost of cable was reduced to 48. Cost per meter of the cable was lower and less cable was needed. More cable terminals were needed in the decentralised network and although they were cheaper than cable terminals of the centralised network, cost of cable terminal rose up to 124. It was calculated that every MV-motor had a starter, which needed two cable terminals, and the looped solution meant also two extra cable terminals. The shares of total costs were 2.6% for the centralised network and 3.9% for the decentralised one.

Cable used in LV-calculation was the same for both of the solutions. Decentralisation dropped the length of the cabling to 40 and cost of cable terminal was the same for both of the solutions meaning an overall drop of the total cost of LV-cabling to 54. The shares of total costs were 2.3% and 2.7%.

In the centralised network there was cabling which was not needed in the decentralised one. The share of total costs of this cabling in the centralised network was 3.1%.

The share of total costs of all the cabling was 8.0% for the centralised network and 6.6% for the decentralised network of this study. Cost of all the cabling of the decentralised network dropped to 38. By using decentralisation cables are shorter and there is a lot of cabling, which is not needed in the decentralised network.

Switchgear building causes 33.2% of total costs of the centralised network. There is no motor control centre in the decentralised network.

Components of network solutions cause the largest share of total costs in both of the networks. This share is 58.8% in the centralised network and 93.4% in the decentralised network. The higher share of total costs of the decentralised network was due to the fact that an expensive motor control centre is not needed.

Total costs of the decentralised network were reduced to 46. This considerable reduction was due to the fact that motor control centre caused about 1/3 of total costs in the centralised network and components were more economical for the decentralised network. Cabling had a very little contribution to this considerable reduction.

3.2 Results of simulation of earth faults

An essential question when comparing the different technical network solutions is the relay protection and associated fault location. This is a problematic issue especially in the case of earth faults in looped systems.

This problem was studied by simulation for three different alternative cases:

1. the system neutral is unearthed,

2. the earth fault current is compensated by a neutral reactor,

3. the neutral is high resistance earthed.

In the simulation it was assumed that the same cable type and construction is used over the entire loop and that the motor capacitances are small when compared to the cable capacitances and can be neglected. For the fault location, the following results were obtained:

1. In an unearthed case the distance computation requires that in both of the outgoing feeders the earth fault current is measured in phasor form. Hence, directional relays are needed.

2. In a compensated neutral system the distance computation is a very complicated task, and can not be based solely on directional relays.

3. In high resistance earthed systems the fault distance can be estimated using a relatively simple method, if the resistor is selected so that its current is at least three times the capacitive earth fault current of the loop. The only information needed is the magnitude of the zero sequence current in the two outgoing feeders. The additional benefit is that the earth fault protection can be based on simple overcurrent relays measuring the sum current.

In what follows, the proposed earth fault location method for resistance earthed system is described. Let I_{0mit} be the measured sum current and I_{0c} be the total capacitive earth fault current of the loop. The measured current is first compensated for the capacitive component as follows:

$$I_{0x}^2 = I_{0mit}^2 - 0.25\, I_{0c}^2 \qquad (1)$$

The compensated sum current I_{0x} is computed for both of the outgoing directions, resulting to I_{0X1} and I_{0X2}. The distance of the earth fault from the feeding point is now computed as follows:

$$x_1/x_2 = I_{0X2}/I_{0X1} \qquad (2)$$

and if the distance is expressed as a per unit value (0...1), the fault distance, when defined along the feeder 1, is obtained as follows:

$$x_1 = 1/(I_{0X1}/I_{0X2} + 1) \quad (3)$$

The accuracy of the method has been estimated in Tables 2 to 4. For the Tables, it was assumed that the fault resistance is small compared to the earthing resistance. In cable systems this is a reasonable assumption.

According to the Tables 2 to 4, the method is more accurate the closer to the loop midpoint the fault occurs. The highest errors are met when the fault happens close to the feeding end, for instance in the case of 3*Ic resistor current, the error in this case can be about 3% of the loop length.

In practice the fault location accuracy also depends on the quality of the current measurement. In an extreme case, increasing of the resistor current might be required. The measurement sensitivity mostly depends on the current transformer accuracy class. If a core balance current transformer is used for sum current measurement, the minimum fault current that allows for reliable fault location is around 0.5 A.

Table 2. The computed earth fault distance in a resistance earthed cable loop. First column shows the actual (simulated) fault distance as a p.u. value compared to the loop length. I_{0X1} and I_{0X2} are the sum currents in the feeding points and last column is the fault distance computed by the proposed method. Resistor current is 10 times the capacitive earth fault current (= 50.5 A).

Actual distance	I_{0X1}/A	I_{0X2}/A	Computed distance
0.0	71.3	1.34	0.018
0.1	64.2	6.88	0.097
0.2	57.0	14.1	0.198
0.3	49.8	21.3	0.299
0.4	42.7	28.3	0.399
0.5	35.6	35.6	0.500
0.6	28.4	42.7	0.600
0.7	21.3	49.8	0.700
0.8	14.1	57.0	0.802
0.9	6.88	64.2	0.903
1.0	1.34	71.3	0.982

Table 3. The computed earth fault distance in a resistance earthed cable loop. First column shows the actual (simulated) fault distance as a p.u. value compared to the loop length. I_{0X1} and I_{0X2} are the sum currents in the feeding points and last column is the fault distance computed by the proposed method. Resistor current is three times the capacitive earth fault current (= 15.4 A)

Actual distance	I_{0X1}/A	I_{0X2}/A	Computed distance
0.0	21.2	0.7	0.032
0.1	19.0	1.39	0.068
0.2	16.8	3.72	0.181
0.3	14.7	5.93	0.287
0.4	12.5	8.11	0.393
0.5	10.3	10.3	0.500
0.6	8.11	12.5	0.606
0.7	5.93	14.7	0.713
0.8	3.72	16.8	0.819
0.9	1.39	19.0	0.932
1.0	0.7	21.2	0.968

Table 4. The computed earth fault distance in a resistance earthed cable loop. First column shows the actual (simulated) fault distance as a p.u. value compared to the loop length. I_{0X1} and I_{0X2} are the sum currents in the feeding points and last column is the fault distance computed by the proposed method. Resistor current is two times the capacitive earth fault current (= 10.6 A).

Actual distance	I_{0X1}/A	I_{0X2}/A	Computed distance
0.0	14.13	0.5	0.034
0.1	12.62	1.96	0.134
0.2	11.12	1.98	0.151
0.3	9.62	3.56	0.270
0.4	8.11	5.09	0.386
0.5	6.61	6.61	0.500
0.6	5.09	8.11	0.614
0.7	3.56	9.62	0.730
0.8	1.98	11.12	0.849
0.9	1.96	12.62	0.866
1.0	0.5	14.13	0.966

3.3 Results of calculation of power losses

Power losses of the centralised network were 18 kW in normal use. These power losses consisted of losses of MV-ring LV-transformers (10 kW) and LV-cabling (8 kW). These power losses were less than 1% of the power, which was fed to the network.

Two different situations were calculated for the decentralised network: MV-ring was looped and MV-ring was open. Power losses were 16 kW for the looped and 20 kW for the open ring. Power losses of MV-ring and LV-transformers were 12 kW and power losses of LV-cabling were 4 kW for the looped ring. Power losses of MV-ring and LV-transformers were 16 kW and power losses of LV-cabling were the same (4 kW) for the open network. In all the situations the power losses were less than 1% of the power fed to the network.

The main transformer caused power losses of 177 kW in normal use. The total power losses of the normal use were only about 1% less with the decentralised network when the network was looped. Power losses were therefore insignificant considering the total losses of the power plant.

More detailed distribution of the power losses is given in Appendix A.

3.4 Results of calculation of short-circuit currents

The short-circuit current of the MV-ring of decentralised network was 6.4 kA (App. B). This value did not exceed the rated 1 s current of the chosen cable (11.4 kA). A smaller cable could have been chosen if the rated 1 s current had been the most crucial factor. The load capacity of a cable determines the size of a cable of the decentralised network. When cable is open close to the station service transformer, current has only one way to flow and then the beginning of the cable is heavily loaded (App. A3).

4. Discussion

4.1 Economical aspects of the decentralised network

One goal of this study was to find out if a decentralised network in a power plant had any potential economical benefits. Centralised and decentralised network solutions were compared and this comparison showed that savings in the decentralised network are significant. These savings would be about 1% of the costs of the whole power plant. The networks used in this study were reduced from the Kirkniemi power plant due to the fact that not all the expenses could be calculated. Calculations were made only for one case, but results can be considered useful estimates because calculated savings were caused by material and building costs, which will be absent from the decentralised network.

Comparison of costs was purposely limited to cabling, motor control centre and components because otherwise this study would have expanded too much. Cost of DC system, diesel system, UPS system, motors and automation were not calculated.

Every module of the decentralised network would include an auxiliary supply device for protection and control devices. It is common that modern automation does not require a centralised DC system with its own premises. There would not be need for a centralised DC system in the decentralised network and this would cause more savings to its advantage.

Diesel generator would be connected to one of the distribution transformers in both of the systems. The space needed for the diesel generator is in the motor control centre of the centralised network. This space must be found close to the distribution transformer of the decentralised network and might cause some extra costs but these costs can not be significant in the total costs of a power plant.

UPS system would be needed in both of the systems and it would cost about the same for both of the systems.

The voltage level of the decentralised network was raised to 10 kV. This meant that light RMU-based breakers and smaller cable could be used. Defining the voltage level of the decentralised network is an optimisation task, which was not done in this study. Higher voltage level would raise motor price about 7 - 25%.

Automation is a very important part of a network of a power plant. A lot of cabling is needed in the automation of the centralised network. The automation of the decentralised network uses field bus for data transfer, protection and control. Costs of the field bus were not estimated in this study. From technical point of view field bus has many benefits which are hard to capitalise.

Decentralised network means a new different way to think and carry out things in a power plant. One main idea is to build the network from ready-to-install modules. A module includes many separate devices and testing is done by the manufacturer of a module. Need for testing in power plant decreases significantly and a power plant supplier benefits economically from this. Module thinking reduces the amount of installation and also the amount of work needed in a project management and engineering. These benefits are hard to capitalise.

There is no switchgear building in the decentralised network. This causes the largest saving in investments and might also affect the site cost and placement of a power plant in a borderline case. Maintenance costs of the switchgear building will be saved during the lifetime of a power plant. Distribution transformer modules have to be placed into the field close to the consumption. This reduces slightly the investing saving.

4.2 Technical aspects of the decentralised network

The MV-ring provides a double feed for every MV-motor and distribution transformer. The short-circuit power of the decentralised network is higher than in the centralised network. Therefore the quality of electricity also is better. Less cable is needed in the decentralised network. Thus there would be a smaller fire load in a power plant.

One idea of the decentralised network is to decrease amount of installation work and testing in a power plant. This is possible with ready-to-install modules, cables and plug-in connectors.

Ready-to-install modules needed in the decentralised network are station service and distribution transformer modules, MV-motor starter and LV-motor starter/safety switch modules. These are not available products, but can be assembled from available components.

Station service transformer module would include transformer itself, protection devices for the network and the transformer and easy-to-install plug-in connector for MV-ring. It would resemble a pad-mounted substation. Transformer part could also be separated into its own module.

Distribution transformer module would include transformer itself, transformer control unit with safety functions and plugs for LV-connection. The size of the distribution transformer could be chosen to be moderate if soft starter were used with larger motors. Module could be brought to its place at the right time saving installation time.

MV-motor starter module would include modern multifunctional protection relay, measuring device and easy-to-install plugs. This starter module can be bought after a motor has been selected or the whole module could be integrated to a motor making it easier to control project management and engineering.

LV-motor starter/safety switch module would include motor control unit with safety functions, safety switch and easy-to-install plugs. Several modules could be connected directly in series or using a special branching nodes.

Cables with terminals could be manufactured in a factory like other components of the decentralised network. Network would be constructed from prefabricated components. This would increase demands on cleanliness and carefulness of different phases of the installation.

All the modules are located in the process environment of a power plant. This sets high demands on the encapsulation of modules. In the centralised network only professionals have an access into the switchgear building. Because equipment is placed in the field in the decentralised network, access to the equipment must still be limited to professionals. Covers of the modules must be locked in order to avoid an unauthorised access to modules.

A fault of the MV-ring takes off the current in the whole distribution network. After the location of a fault is disconnected, the use of the network can be continued with an open MV-ring.

Automation with a field bus is technically more advanced than a traditional solution of a power plant. It makes it possible to collect versatile data of different components. This available data can be collected to the automation system and converted to illustrative form to be used in condition monitoring. This enables timely maintenance of components of the decentralised network. Field bus offers also a possibility to control remotely a power plant. Control room does not have to be located in a power plant any more.

4.3 Future of the decentralised network

Many technical aspects of the decentralised network must be considered and solved in the future. However, this does not mean that everything must be done all the way from the beginning. A lot of devices and solutions are already available. It is a question of finding available devices and solutions and combining them into a new concept.

A power plant is a very complex system. A network of a power plant is a part of the whole. A change in a basic structure of a network means changes in the entire power plant. Today’s automation and protection devices are advanced and they allow changes to be made as required. The decentralised network can be completed with today’s technology. Some new products must be assembled from today’s products. The entire power plant must be designed in a new way. This requires co-operation between many different professionals in the power plant business.

Decentralisation is a new way to build up a network of a power plant. Therefore the biggest obstacle for the decentralised network is old and conservative opinion about how a network of a power plant must be built. During the study it became clear that there are economical benefits of decentralisation. Economical arguments are a good start in changing old and conservative opinions. Yet the whole of the decentralised network is so tempting that it can not be left without further interest. This interest will become concrete as future research co-operation between Fortum Engineering and VTT Energy, Technical Research Centre of Finland.

5. Summary

The network of the Kirkniemi power plant was used as a model both for a centralised and a decentralised network solution. The centralised network used in this study was a typical centralised solution with medium voltage (6 kV) bus bar and radially fed motors and transformers (Figure 1) The decentralised network used in this study had a MV-ring, no medium voltage switchgear and no motor control centre. Cables of the looped network were connected directly to the poles of the station service transformer. MV-motors and distribution transformers were connected in series in the field of the power plant (Figure 2).

Cable, motor control centre and component costs of both of the network solutions were calculated. The total cabling costs of the decentralised network were 38% from the analogous costs of the centralised network. There was no motor control centre in the decentralised network. This caused a large saving in the total costs of the network solution. Components had the largest share of total costs in both of the solutions. The component costs were 27% smaller with the decentralised network and the total costs of the decentralised network were 54% smaller than with the centralised network.

Earth faults of the decentralised network were simulated in order see if it were possible to locate them. In high resistance earthed systems the fault distance can be estimated using a relatively simple method, if the resistor is selected so that its current is at least three times the capacitive earth fault current of the loop. The only information needed is the magnitude of the zero sequence current in the two outgoing feeders. The additional benefit is that the earth fault protection can be based on simple overcurrent relays measuring the sum current solely.

Cable power losses and short-circuit currents were calculated with the EDSA-program. The difference of the cable power losses was insignificant concerning the total losses of the power plant. Short-circuit currents of the decentralised network did not exceed the short time withstand current of the cable chosen.

This study showed clearly that the decentralised network had economical benefits compared to the centralised one. All the essential costs of the network were calculated and the ones, which were ignored, would cause more savings to the decentralised network.

The decentralised network offers many interesting features from the point of view of a power plant owner. During the lifetime of a power plant, maintenance (lighting, air conditioning, etc.) costs of a switchgear building will be saved, because there is no motor control centre in the decentralised network.

The decentralised network uses a field bus for data collection, transfer and control. Protection devices of the decentralised network are capable of collecting a vast amount of information from different devices of the network. For example, a modern motor control unit (MCU) measures and collects very diversified data. This data can be transferred to the automation system and be used for fault diagnosis. By doing so it is possible to schedule timely maintenance of components. Field bus offers also a possibility to control remotely a power plant.

The decentralised network is built up from ready-to-install modules. Ready-to-install modules need less testing in the field during the commissioning and during the lifetime of a power plant, because this work is already done by the module manufacturer. Broken component modules can easily be changed and less repair work will be needed.

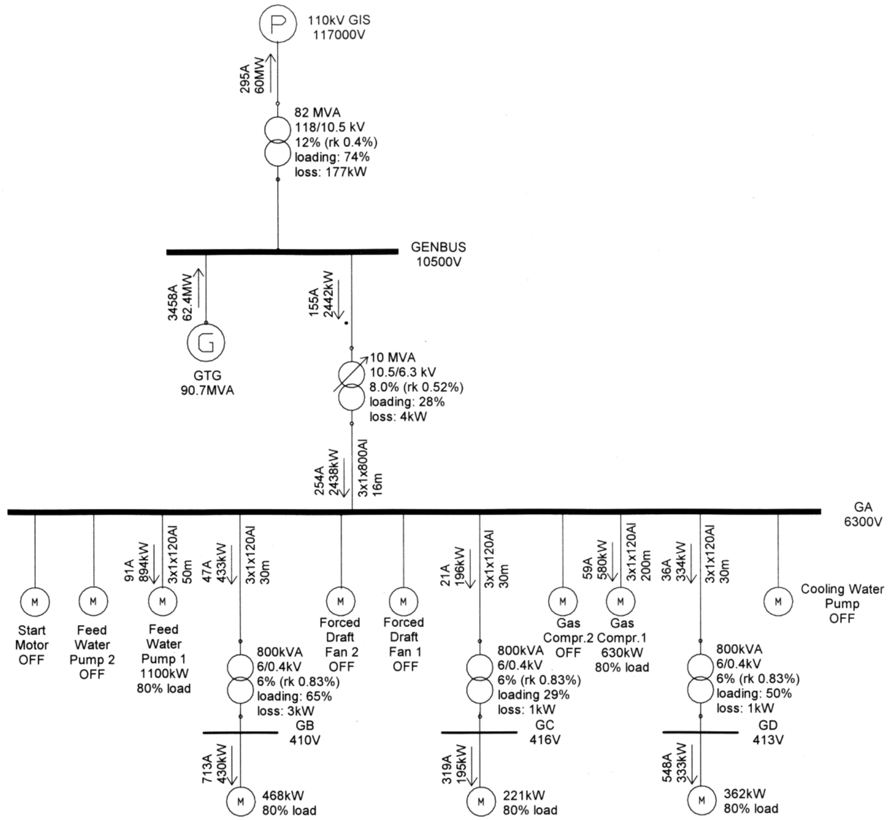
References

[1] General information about the ATP program [online]. Available at: http://www.vmt.bme.hu/eeug/atp_info.htn [cited: 5.10.1999]

[2] EDSA AC Load Flow Brochure [online]. Available at: http://www.edsa.com/demos.htm [cited: 5.10.1999]

[3] EDSA AC Short Circuit Brochure [online]. Available at: http://www.edsa.com/demos.htm [cited: 5.10.1999]

Appendix A: Calculation of power losses.

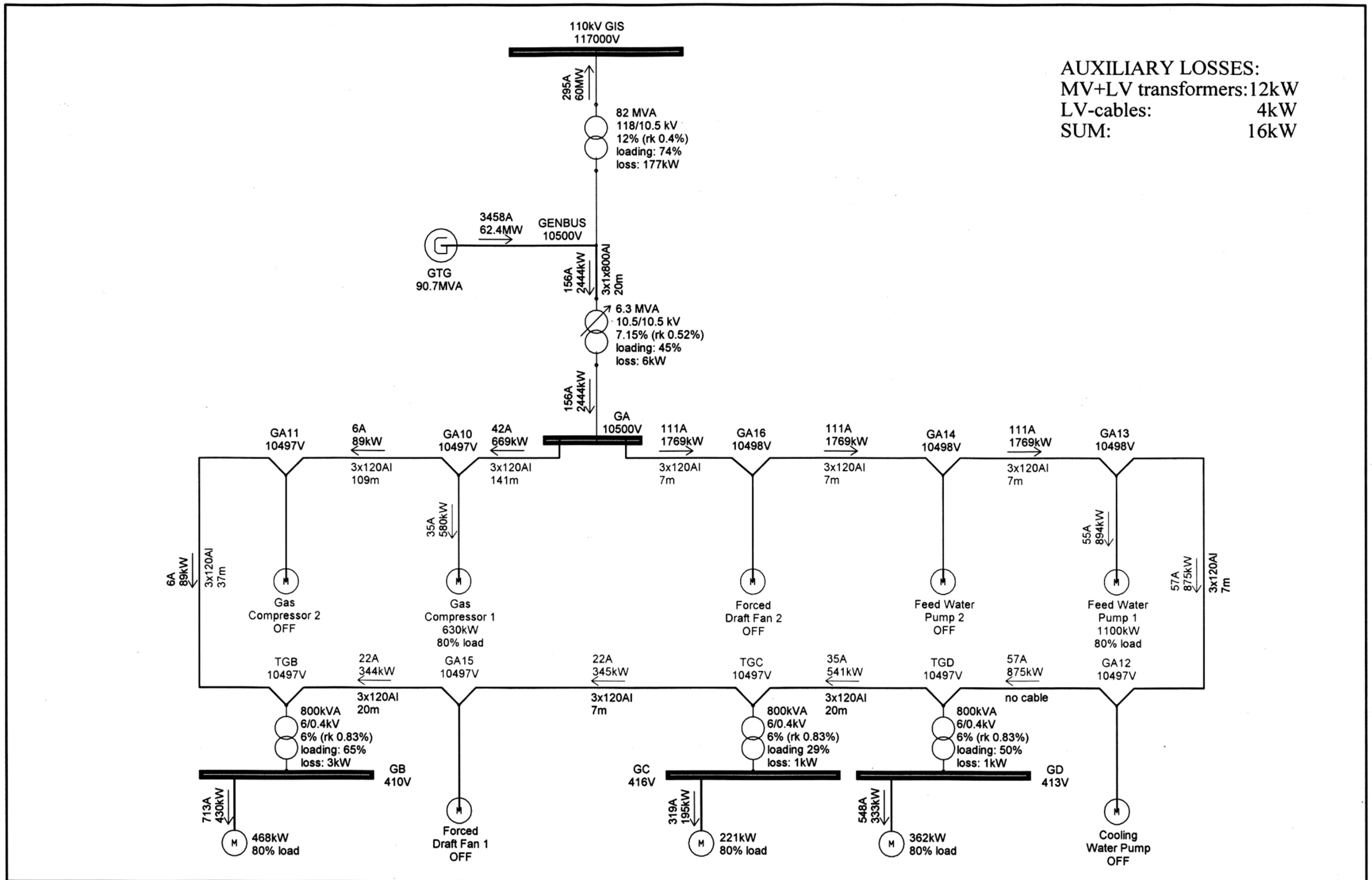


AUXILIARY LOSSES:

MV+LV transformers:	10kW
LV-cables:	8kW
SUM:	18kW

IVO POWER ENGINEERING OY 12.1.1999 TUOMAS VISKARI	POWER PLANT KIRKNIEMI (modified) TRADITIONAL RADIAL DISTRIBUTION Load Flow Calculation	Scenario:1 Normal Operation

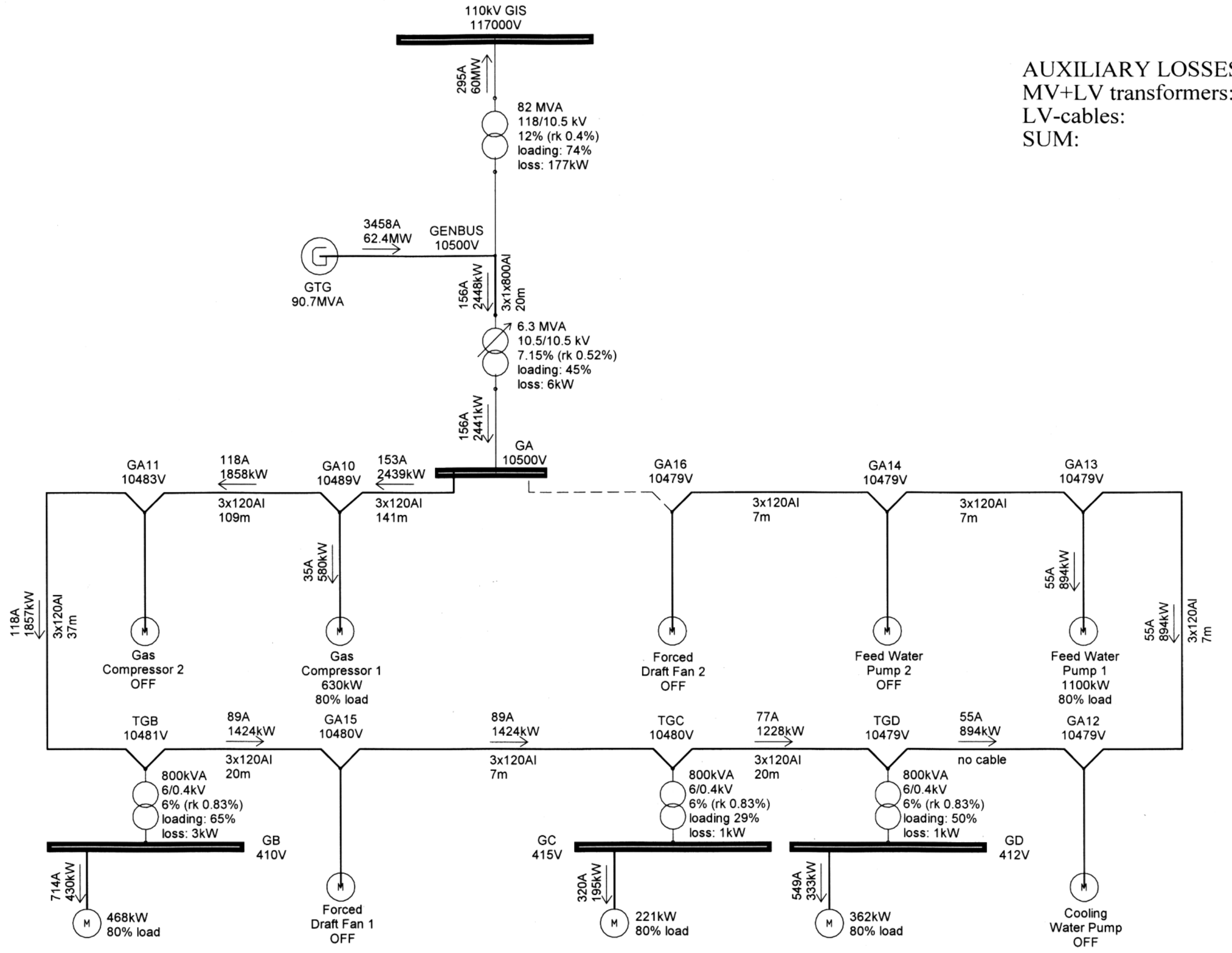
A2



IVO POWER ENGINEERING LTD 12.1.1999 Tuomas Viskari	POWER PLANT KIRKNIEMI (modified) MV-RING DISTRIBUTION Load Flow Calculation	Scenario1: Ring Operation IVO GROUP

A3

AUXILIARY LOSSES:
MV+LV transformers: 16kW
LV-cables: 4kW
SUM: 20kW



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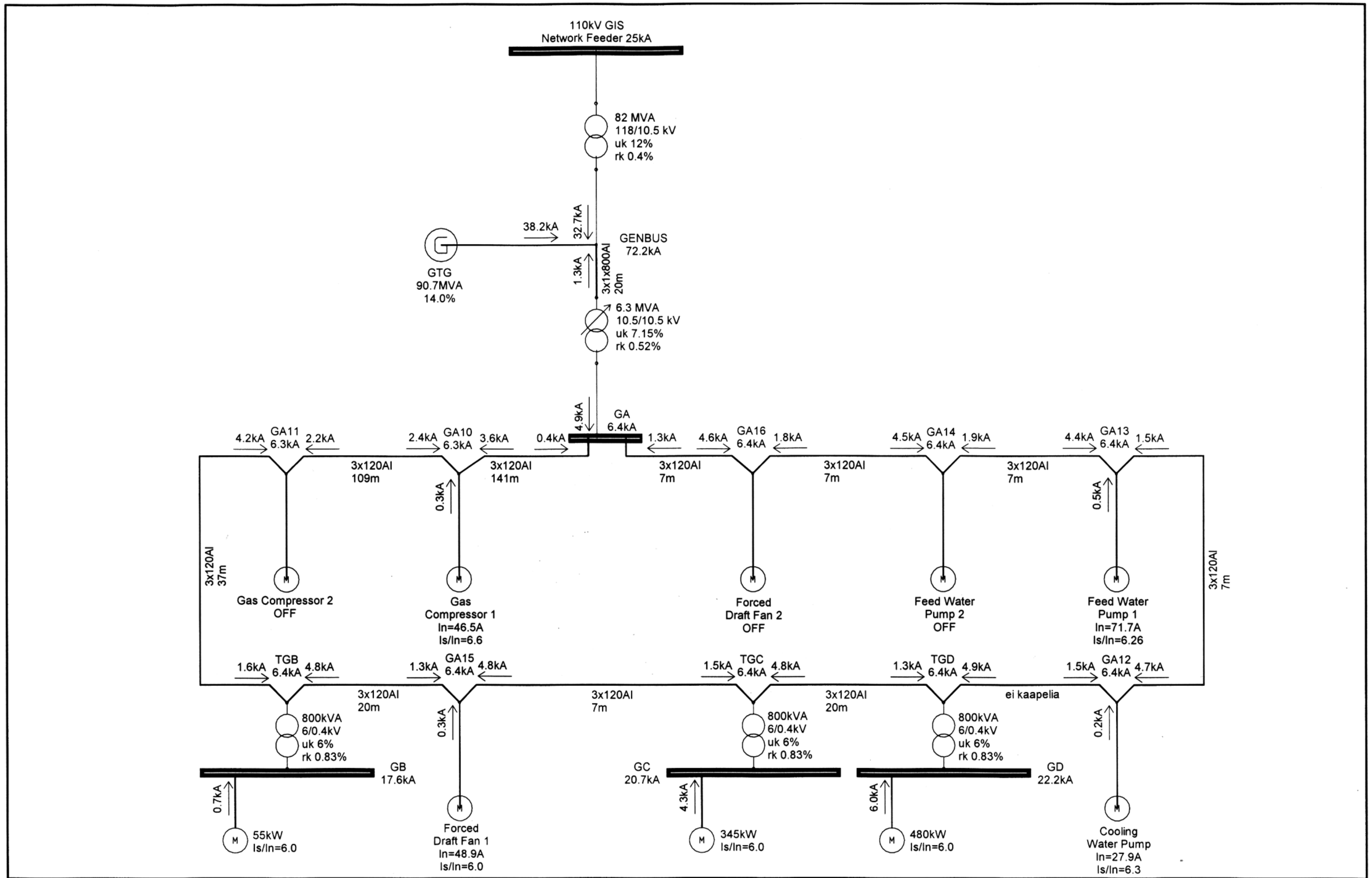
Appendix B: Calculation of short-circuit currents.



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Title

Decentralised electrical distribution network in power plants

Abstract

A centralised network is a dominating network solution in today's power plants. In this study a centralised and a decentralised network were designed in order to compare them economically and technically. The emphasis of this study was on economical aspects, but also the most important technical aspects were included.

The decentralised network requires less space and less cabling since there is no switchgear building and distribution transformers are placed close to the consumption in the field of a power plant. MV-motors and distribution transformers build up a ring. Less cabling and an absent switchgear building cause considerable savings.

Component costs of both of the networks were estimated by using data from fulfilled power plant projects and turned out to be smaller for the decentralised network.

Simulations for the decentralised network were done in order to find a way to carry out earth fault protection and location. It was found out that in high resistance earthed system the fault distance can be estimated by a relatively simple method.

The decentralised network uses a field bus, which offers many new features to the automation system of a power plant. Diversified information can be collected from the protection devices in order to schedule only the needed maintenance duties at the right time. Through the field bus it is also possible to control remotely a power plant.

The decentralised network is built up from ready-to-install modules. These modules are tested by the module manufacturer decreasing the need for field testing dramatically. The work contribution needed in the electrification and the management of a power plant project reduces also due the modules. During the lifetime of a power plant, maintenance is easier and more economical.

Keywords
power plants, power distribution, distribution networks, power generation, decentralisation, field buses, MV-rings, relays, protection, fault detection

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