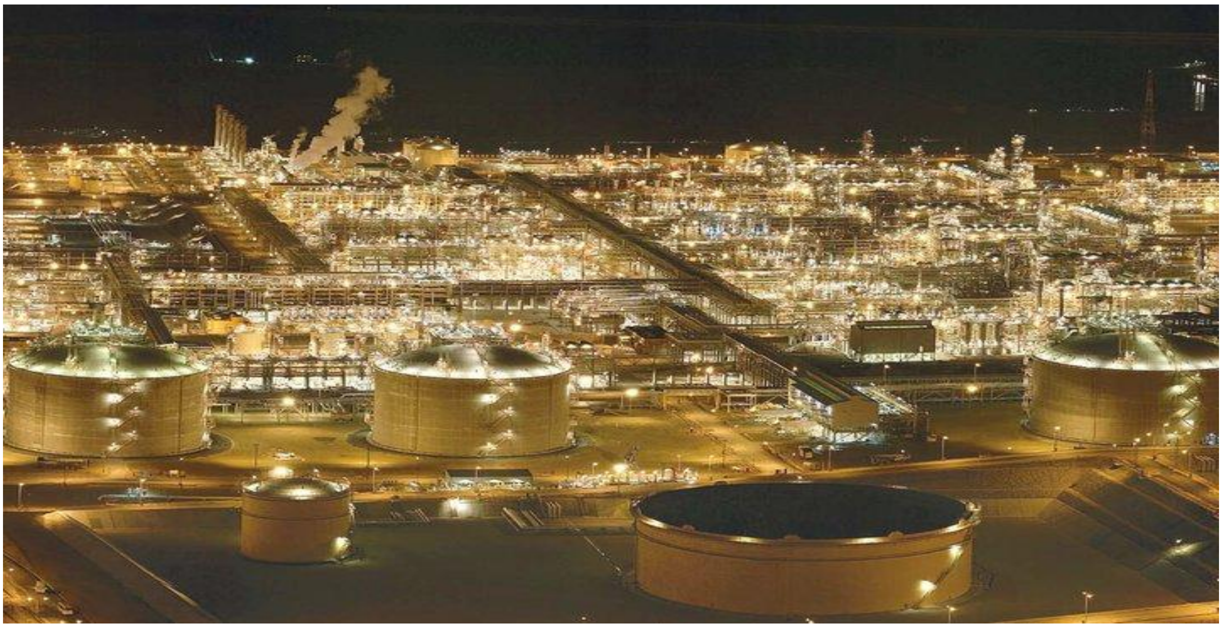

Design of Electrical Power Supply System in an Oil and Gas refinery

Master of Science Thesis in Electric Power Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2011

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Abstract

The electrical system shall be designed economically for continuous and reliable services, safety to personnel and equipments, ease of maintenance and operation, minimum power losses, protection of equipment mechanically, interchangeability of equipments and addition of the loads. In order to achieve the above goals and obtain the desired results, a scientific study based on different theories and practical experiences will be needed.

In this study, the power supply of one unit of a petroleum refinery in Iran, the criteria and the methods of designs of normal networks, electrical equipments and protections of the system have been discussed and investigated. A single line diagram will be presented as the outcome of the design. The above so called "single line diagram" includes 20kV, 6.3kV and 420V voltage levels. In the second phase, the designed single line diagram is consequently simulated by the power system analyzer software. The study will eventually cover the followings; load flow, short circuit current and motor starting.

The intention of the above research is to create solutions in different ways electrical loads should be categorized in this energy industry as well as energizing these loads by a stable power supplies. In addition, the key role of the short circuit impedance of the transformers in control of the short circuit current will be presented. Furthermore, the selection procedures of the electrical equipments and accessories including cables, transformers, circuit breakers, relays and etc. are presented. Then, the following factors such as the size of equipments, losses and voltage drops will be checked by load flow study. In the meantime, a comprehensive study of the short circuit current calculation is implemented and can be observed how the system can be checked by the results of this study. In the dynamic study of the system, the biggest motor starting is simulated and the impacts of the voltage dip due to starting of this motor on the other running motors are shown.

Since numerous types of equipments on one hand and the research on the economical matters on the other hand are time consuming, the scope of this report will mainly concentrate on the technical factors and as a result, it does not cover the economical aspects. Moreover, high standard engineering in the oil and gas industry is essential to design of electrical systems. It is noted that more economical options are acceptable as long as they end up with the same technical results or better.

Keywords: Power supply, Oil and Gas, Distribution network, Electrical system in hazardous area, Relay selection, Circuit breaker selection, motor starting, Short circuit calculation, Load flow.

Acknowledgements

Hereby, I would kindly like to thank my examiner Dr. Tuan Anh Le for his professional advices after reviewing my reports. I would also like to appreciate all of my lecturers at Chalmers University of Technology for their dexterous knowledge that I received from them.

Many thanks to my supervisor Mr. Hesam Tehrani for his invaluable technical supports at Joint Venture of Bina Consultant Engineers Company and Petro Andish Technology Company.

I would like to appreciate my wife who accompanied me patiently during my studies.

I dedicate this report to my parents who always inspired me to study academically and supported me unconditionally in my life.

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Introduction

1

In this chapter, the overview of the thesis is presented by specifically defining the background, objectives and the scope of the work.

1.1 Background

In this practical project, The Design of Power Supply in one of Iran's oil and gas refineries is investigated. In these kinds of projects, the job is usually done in two main stages; basic design and detail design. In the basic design stage, the location and process of refinery is studied and a rough estimate of load types and demand is consequently obtained. While in the next step, different kinds of networks and supplies (based on technical and economical situation) are surveyed and the best choice is selected and basic calculations, drawings and specifications are consequently provided. Although all these documents lead to our main goals of our project, however they will not be sufficient for the implementation of the project.

In the detail design, we expect to issue precise drawings which are considered our preference for purchasing material (procurement) and executing the project at site (infrastructure). So, in this step all necessary engineering detail works should be done completely. It is crucial to note that all the detailed documents must meet the project requirements specified and defined during the basic design.

Here, it has been tried to have a comprehensive view on the basic design and the detail design. To achieve this, main parameters of an electrical system have been discussed and the methods of design of different parts presented.

1.2 Motivation

Nowadays, utilizing energy resources is considered one of the most challenging tasks around the globe. Among all of the world's existing energy resources, oil and gas have key roles in supplying human needs. Thus, finding the most optimal and efficient ways to effectively use this important resource is an essential. Undoubtedly, electrical engineering does have a big influence on this industry and many measurements must be taken in order to obtain stable electricity. Thus, working academically on the above subject and achieving a positive result can be considered a breakthrough in energy industry and peoples' lives.

In addition to the above fact, study on this project assists engineers to obtain a profound knowledge in the power system of oil and gas that can be counted as a good path for considering the design of power supply in similar energy industry.

1.3 Objectives

- To obtain deep understanding of electrical systems in the above mentioned industry.
- To know how to design a stable power system in the different projects by using a relevant software.
- To be able to analyze new power system in case of any possible problems and capability of finding the issues and solving them (trouble shooting).
- To obtain an ability of predicting the possible problems that may happen in power system.

1.4 Scope of the thesis

Having a stable network in this industry is crucially important and power outage during operation could cost lots of money and time. So, an electrical expenditure is considered with little or no value when it comes in comparison to total above mentioned huge costs. Therefore, it is worth it spending time and energy during the design of stable networks to avoid any possible costly failure in the future.

In this thesis the electrical system of one unit of a refinery with two 20kV feeders and two main voltage levels of 6.3Kv and 0.42kV have been studied. Although in descriptive parts it has been tried to illustrate the subject with a general discussion about other voltage levels, but in calculative sections only the above mentioned voltage levels have merely been considered based on work scope of the Company.

The main purpose of this thesis is to design a power supply with the right selection of electrical equipments. Therefore, other topics such as grounding, battery charger and UPS have not been discussed in details.

1.5 Organization of the thesis

This report consists of 7 Chapters as follows; - In the first Chapter an overview of the thesis is presented. - In the second Chapter the basic design criteria is defined. – Third chapter contains the static design of the network including Load Flow and Short circuit study. –In the forth chapter dynamic behavior of the system is studied - In chapter 5, protections of the system by methods of selection of the Circuit breakers, relay and electrical equipments in hazardous areas have been presented. - In the last chapter, the conclusions of the thesis for having a stable and reliable system have been discussed.

1.6 Description of the Company

This thesis has been carried out at JV of Petro Andish Technology Company and Bina Consultant Engineers. The main activities of the Company are basic study, detail design, cost estimation, construction management and supervision on EPC projects in Oil and Gas industry in the different engineering departments including Electrical, Mechanical, Instrumentation, Process and Piping.

This report contains a case study in one unit of Bandar Abbas refinery with total power demand of 200 MW.

2

Method of Design

In this Chapter the method of design of a network has been discussed. As a start point the ABB manual for designing of a plant is presented. In addition, the design criteria are introduced to define the limitations of the engineering work. Next, preparation of load list and cable sizing are discussed as the bases of the design of the network. These jobs must be done before designing of the power supply to feed the load which will be discussed in the Chapter 3.

2.1 Methodology

In this project, the refinery power supply is simulated by ETAP software. In addition some electrical standard are the design criteria. Some big companies' manual such as ABB Ltd. is used as references.

To have a better overall understanding on how an electrical power supply system in a plant should be designed, the ABB Electrical power supply procedure is shown in the following page; [10]

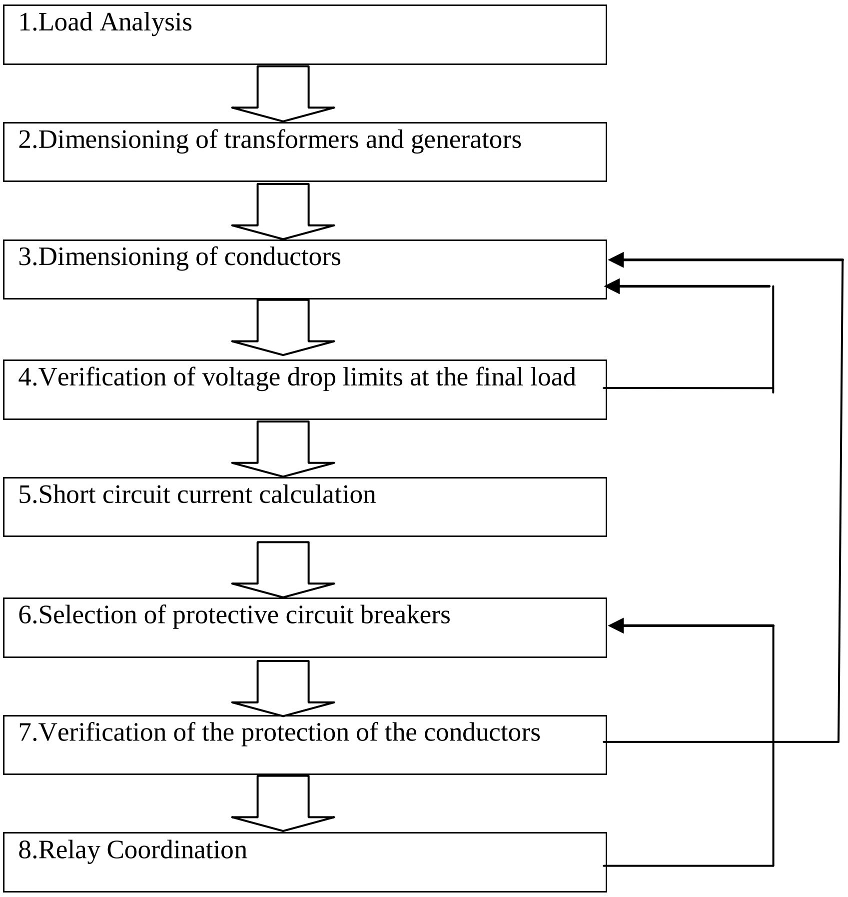


Figure 2.1: Design of Power Supply in a Plant

1. **Load analysis**:

- Definition of power absorbed by the load and relevant position

- Definition of the position of power centers (switchboards)
- Definition of the path and calculation of the length of connection elements
- Definition of the total absorbed power, taking into accounts the utilization factors and demand factors

2. Dimensioning of transformers and generators:

- 15 till 30 percent margin should be considered for future

3. Dimensioning of conductors:

- Evaluation of the current passing through conductors
- Definition of the conductor type and insulation material
- Definition of the cross section and the current carrying capacity
- Calculation of the voltage drop at the load current in normal and transient (motor starting...) operation

4. Verification of the voltage drop limits at the final load

- If the voltage drop is not in the limit, stage 3 should be modified

5. Short circuit current calculation

- Maximum value at the bus bar and minimum value at the end of the line

6. Selection of protective circuit breakers with:

- Breaking capacity higher than the maximum prospective short circuit current
- Rated current no lower than load current
- Characteristics compatible with the type of protected load (motors, capacitors...)

7. Verification of the protection of the conductors

- Verification of the protection against over load: The rated current or the set current of the circuit breaker shall be higher than the load current but lower than the current capacity of the conductor
- Verification of the protection against short circuit: The specific load through energy by the circuit breaker under short circuit condition shall be lower than the specific energy let through energy which can be withstood by the cable ($I^2t \leq k^2S^2$)
- In case of obtaining negative outcome, all the above stages shall be repeated from stage 3

8. Verification of the coordination with other equipments (Relay coordination)

- In case of obtaining negative outcome, all the above stages shall be repeated from stage 6

Definition of other components

The following stages in producing documents will be discussed just after preparation of the Front End Engineering Design (FEED) and the basic documents which contains the basic design criteria and specifications.

Load list is the first document that should be prepared to show the load and required power. Then, considering the voltage level and load list, the preliminary single line can be designed. Next, will be the selection and sizing of the equipments that should be considered. Although load balance document helps us have some preliminary calculation, however, in order to have precise calculation after sizing the cables (considering voltage levels specified in the basic documents), Load flow study must be carried out and at the same time short circuit study must be taken into account. In this stage, the results of both studies should be checked and in case of getting undesirable results, transformer can be adjusted by the impedance or size in order to achieve the desirable results. Since tap changers must be used to correct any possible voltage drop during start up and operation at site, it is recommended to avoid changing tap changer during design anyway sometimes it is inevitable and it is however advised to adjust "tap changer" in order to avoid increasing the size of the transformers. Consequently, after studying our short circuits and load flows, selecting the circuit breakers is advisable. In the final stage, motor starting shall be studied and final modifications will be performed (if necessary).

2.2 Design criteria

In order to be certain that our design has acquired technical quality, the engineering part of the job must be done according to the standards and technical specifications. Hereunder, some important criteria are presented.

2.2.1 Voltage level

The following voltage levels have been selected for electrical system at the rated frequency of 50 HZ. Equipments will be suitable for continuous operation with voltages variation within 5% of nominal values.

Table 2.1: Voltage levels

SERVICE	**NOMINAL VOLTAGE(V)**	**PHASE**
Generation	11,000	3
Main distribution	132,000	3
Intermediate distribution	20,000	3
Emergency power(Black start)	6,000	3
Back up supply ring	20,000	3
Motors > 2500 kW	11,000	3
Motors>160 kW and <2500 kW	6,000	3
Motors >0.4 kW and <160 kW	400	3
Motors <0.4 kW	230 or 400	1 or 3
Lighting circuit	230	1
Power socket	400	3
Instrument power supply system	230	1
Control voltage for contactors	230	1
Control voltage for switchgears	110 DC	

2.2.2 Voltage drop limits

Normal operation voltage drop

In this project, cable voltage drops at load shall be limited to the following values according to IPS-E-EL-100. [8]

At the loads terminals: 5%

Transient voltage drop:

The transient voltage dips during motor starting:

At motor terminals: 15%

2.2.3 Short circuit current limits

Power systems with a voltage in excess of 1000 V shall be designed somehow that the RMS value of the a.c. components of the short-circuit breaking current of the circuit breakers shall not exceed 25 KA as per IEC 60056. [5]

For power systems with a voltage less than 1000 volt, the RMS value of the a.c. component of the short circuit breaking current of circuit breaker designed shall be as per IEC 60947-2 and shall not exceed 50 KA.[1]

2.2.4 Power factor

The overall system power factor, inclusive of reactive power losses in transformers and other distribution system equipment shall not be less than 0.85 lagging at rated design throughout of the plant. The power factor shall be determined at the terminals of the generator(s).

2.2.5 Transformer

In case of trip on one transformer, another transformer should be able to withstand the entire downstream load. In addition each transformer should at least have 20% spare in normal operation according to IPS-E-EL-100. [8]
The short-circuit voltage in percent V_K% according IEC 60076-5 for 2.5 MVA and 12.5 MVA should be 6% and 8% respectively.[4]

2.3 Preparation of load list

This document shows the loads in each refinery unit. Usually required loads are specified by process department and supplementary information is completed by mechanical and then electrical departments. It should be noted that preliminary data are just estimated data and the precise data will be reached from vendors during project. These are objectives of issuance of this document:

- Recognizing industrial and non-industrial loads of projects in order to provide single line diagrams, cable schedules, cable route plans….
- Control of loads variations during the design and construction of the project and updating the relevant data.
- Specifying total loads of switchgears and MCC's and consequently their normal current.
- Transformer sizing.
- Calculation of total loads of the project in order to generator sizing for local power plant or purchasing demand power from regional electric power company.
- Calculation of the emergency loads and method of providing (emergency generator rating calculations)
- Determination of the maximum load of the project in order to specifying power demand.

This document is a reference for design and issuance of other related documents and following data must be indicated in the load list:

***Duty types*:**

This is a factor that shows load operation status and it is very important factor in load summary calculations in terms of to what extent the load contributes in power consumption. The following duty types may be considered for a load.

- Continuous operation:
  When the consumer works and consumes the electrical power continuously.
- Stand by operation:
  These loads do not work in the normal situation and they are known as a backup .They run or come into the circuit only when their considered normal load(s) fail.
- Intermittent operation:
  If some loads in the group for special process purpose come into the circuit alternatively, they are considered as intermittent loads.

***Feeding types*:**

Different methods of feeding for different loads can be considered as follows;

- Normal feeding (N):
  These loads are fed from just normal buses and incase of any fault the loads will lose their power supply.
- Normal feeding with reacceleration (NR)
  These kinds of loads are fed from normal bus bars too, but in case of short interruption power (usually under voltage) they are capable of restarting so fast.
- Essential feeding:
  The feed is assured by an emergency power generator.
- Vital feeding:
  It implies that no interruption in the power supply is allowed.

Load types and required power

- Motor loads
- Heaters
- Lighting & Socket loads
- UPS & DC loads

As an electrical engineer, one is responsible to calculate electrical consumed power and rated power. For this, data for motor efficiency must be available that can be extracted from standards for various power types of motors. In this report Iranian Petroleum Standard (IPS) has been used. [8]
The base of calculation is mechanical power (electrical output power) divided by efficiency resulted in electrical absorbed power (electrical input). By knowing mechanical power, a rated motor can be selected with considering environmental condition and temperature. To see the motor ratings, please refer to Appendix D.

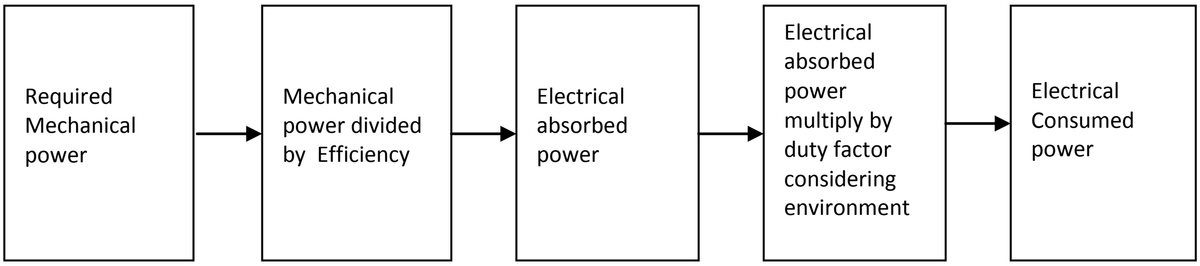


Figure 2.2: Consumed power calculation

Absorbed power versus rated power

Since motors are rated according to output power, the absorbed power (input power) can be lower or higher than rated power due to its operating efficiency.

Example

If mechanical power and efficiency are 17 kW and 0.9 then rated power and absorbed power equal 18.5 kW and 18.88 kW respectively. But if we use a motor with better efficiency such as 0.95 then rated and absorbed powers are 18.5 kW and 17.89 kW.

Factors:

The following factors should be considered while total load is calculated.

- Load factor (LF) = mechanical power divided by rated power
- Efficiency of motor considering load factor (efficiency varies in different load factors)
- Power factor considering load factor (power factor varies in different load factors)

- Starting power factor for motors
- Duty factor =Utilization Factor

2.4 Cable sizing

For determination of electrical power cables it is necessary to do the following studies:

- Cable Ampacity
- Short circuit withstanding current
- Voltage drop

Since there are different methods for physical arrangement of cables as well as a possibility of having different environmental and physical conditions, therefore before cable sizing, it is necessary to accurately consider the physical and environmental condition of cable route.

Cable Ampacity

By considering load wattage, voltage, power factor and electrical efficiency it is possible to calculate the current that passes through the cable in the ideal situation

$$I = \frac{W}{\sqrt{3} \times V \times EFFICIENCY \times POWER\ FACTOR}$$

By having ampacity easily cable cross section can be selected but this cross section in real situation must be calculated considering physical and environmental conditions. Respectively, cable capacity for passing current depends on ambient condition and method of laying cable.

If the cable is buried underground, passing above ground or in the water, different de-rating factors should respectively be applied.

In this project, all the cables are buried cables and the following de-rating factors such as ambient temperature, soil temperature, soil thermal resistance, type of cable armor, distance between adjacent cables, burial depth and etc. have been taken into account according to IEC 600502. [2]

After calculating the ampacity of the cable cross section, it can be selected but should still be checked against the short circuit withstanding ability and voltage drop.

Cable Short circuit withstanding current

The cables must also be evaluated against short circuit rating current. All cables should be able to withstand the highest symmetrical short circuit current of the network at the point of consideration. Short circuit withstanding time is usually considered 1 second and is supposed maximum conductor temperature not to exceed 150ºC for PVC sheathed , 250ºC for XLPE insulated and 160ºC for oil pregnated insulation cables.

The general formula for cable short circuit current is:

$$I = \frac{K \times A}{\sqrt{t}}$$

Where

t= Short circuit time duration

A= Cable cross section in mm

ISC = Effective short circuit current level as r.ms value

K= Depends on the cable conductor and insulation material

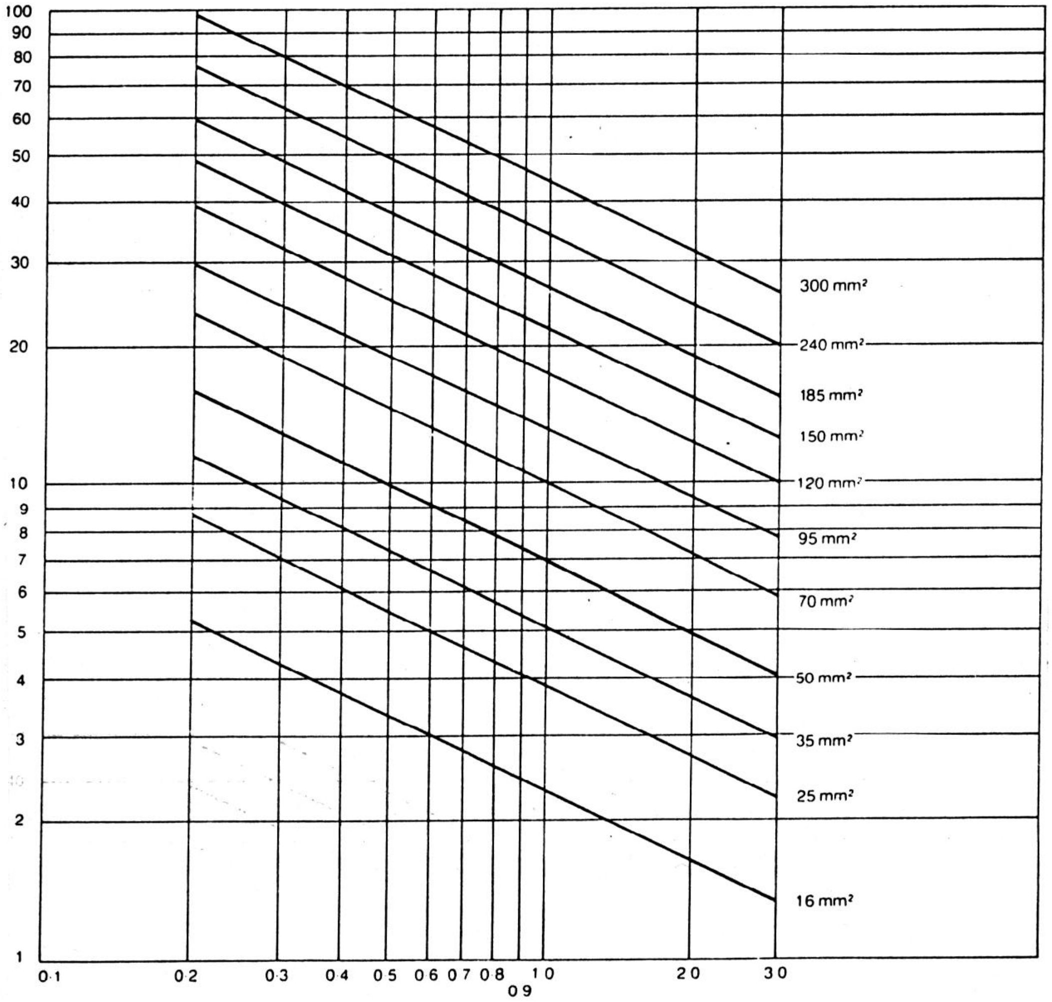


Figure 2.3: short circuit ratings of copper conductor and XLPE insulated cables (kA-Second)[8]

Voltage drops in cables

For single-phase system:

$$\Delta v\% = \frac{\Delta V}{V_N} x100\% = \frac{2.I.1.(R_{L.}Cos\phi + X_{L.}Sin\phi)}{V_N} \times 100\%$$

For three-phase system:

$$\Delta v\% = \frac{\Delta V}{V_N} x100\% = \frac{\sqrt{3}.I.1.(R_{L.}Cos\phi + X_{L.}Sin\phi)}{V_N} \times 100\%$$

Where

Δv% : Percent voltage drop (%)
ΔV : Absolute value of voltage drop (V)
VN : System rated voltage (V)
I : Line or cable current (A)
l : Line or cable length (Km)
RL : Line or cable resistance at operating temperature (ohm/km)
XL : Line or cable reactance (ohm/Km)
Cosφ : Load power factor

If the voltage drop is lower that allowable voltage drop which has been defined in the project requirement, the cable cross section is acceptable. Otherwise the cable conductor size shall be increased.

HINT: Motor power factors differ in normal operation from starting status, so while voltage drop during starting is calculated right power factor must be selected. Please see appendix D.

Static design of the system

3

In the previous Chapter, the design criteria and the load list were defined and it was also noted that they were necessary to know before the design of the electrical system. In this Chapter, the proper single line diagram is designed for feeding the loads based on the criteria defined in Chapter 2. To achieve this, manual calculations of the required power should first be performed to assist us in selection of equipments and bus bars. Then, these calculations are checked by two main studies as Load Flow Study and Short Circuit Current Study which is conducted by ETAP software.

3.1 Preliminary single line diagram

After preparing load list(s) and understanding the demand, we need to design a stable network to supply our required power. During the design, feeding type mentioned in the load list and voltage level should be taken into account so that we would get general idea how to feed the loads. Normal loads are fed from the normal bus bar and essential loads such as emergency lightings are fed from the emergency bus bar.

Vital loads such as Emergency shutdown (ESD) systems are fed from UPS.
After conducting our detailed calculation, the final single line diagram would be different from the primary one as shown in the figure 3.1. Consequently, when the final single line is shown, the modification process can be found.

As it is shown in the following, this unit of the refinery is supplied by two 20kV incomings and the 12.5 MVA transformers provide the 6.3kV output voltage. They must work as a backup of each other so that one transformer can create enough capacity to feed all the loads in case of any possible failure in another one. Of what was discussed in the above, it can be concluded that each transformer in the normal function is loaded by half of the total load.

Although each of these two normal transformers are able to feed all the loads in the normal function, however, another 20kV line has also been considered for the emergency load purposes in order to ascertain the availability of power supply during any faulty condition in the system. On the other hand, “automatic change over system” has been designed for the purpose of feeding the emergency loads in case of missing the normal bus bars.

The vital loads are fed by UPS and the source of these loads is the batteries which are charged during normal operation. Moreover, emergency operation is also used in case of having none of the normal or emergency supplies.

The sizing of transformers, bus bars, and circuit breakers should be performed by load balance study as well as software simulations which is mentioned in this and next chapters.

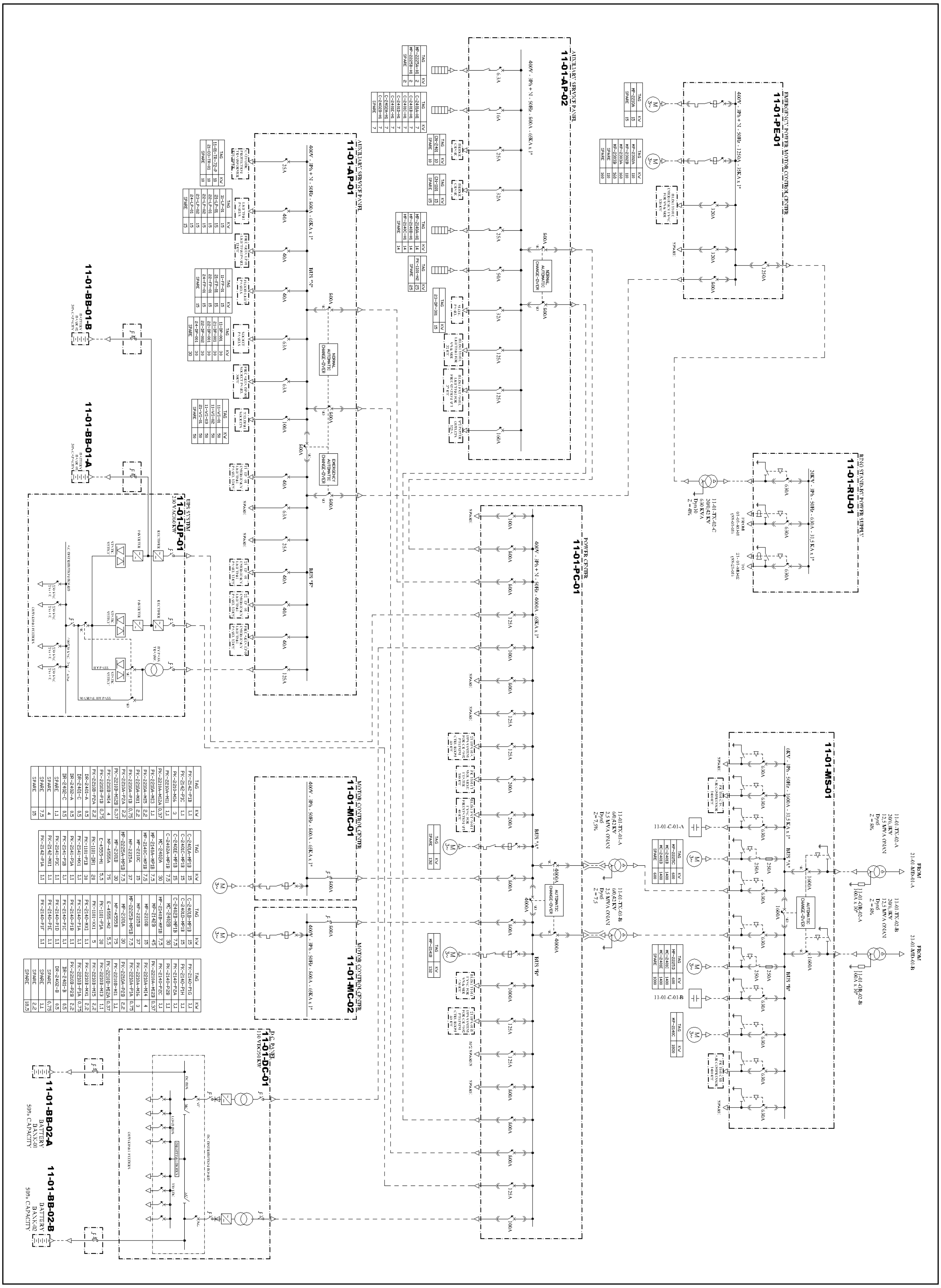


Figure 3.1: Overall single line diagram

3.2 Load Balance Study

While single line diagrams are prepared, the load balance studies shall simultaneously be done to calculate the required power supply, transformer sizing and bus bars sizing. In addition, active power, reactive power and power factor for each bus and entire system is calculated. The base of the calculation is to obtain a sum of the active and reactive powers considering load factor from downstream (loads) to upstream (generator). In the table 3.1 the last stage of calculation has been presented and it can be seen that on MV bus bars the appearance power is 10217kVA so, the12500kVA upstream transformer is a proper choice. In addition, the power factor is 0.889 but it should be realized that capacitor bank sizing should be based on this calculation with considering cables reactance that may have major impact on voltage drops of the bus bars.

Table 3.1: Load balance calculation-Panel No. 11-01-MS-01

Item tag	**Equipment name**	**type**	**Absorbed Power**	**Rated Power**	**Demand Factor**	**Eff @ demand**	**PF @ demand**	**Consumed Load**				
								Duty	**POWER**		**FLA**	**LRC**
			kW	kW				C S I	kW	kVAr	A	A
11-01-MS-01-B - LC[Run] 982.75 A / PF[Run] 0.889 - LC[Peak] 1305.71 A / PF[Peak] 0.889												
PK-1101-C1B	AIR COMPRESSOR	M	1500	1800	0.83	0.9	0.88	C	1564	810	203	1221
MP-2225 D	MACHINERY COOLING WATER PUMP	M	496	600	0.83	0.9	0.85	S	527.7	314	71	429
MP-2140 C	HP BFW PUMPS	M	1579	1800	0.88	0.9	0.89	S	1645.4	829	202	1213
MC-2401 E	AIR COMPRESSOR	M	1083	1400	0.77	0.9	0.88	I	1131.7	607	160	959
MC-2401 C	AIR COMPRESSOR	M	1083	1400	0.77	0.9	0.88	C	1131.7	607	160	959
11-01-TX-03-B	TRANSFORMER (11-01-PC-01 INCOMMING)	T							1552.2	716	-	-

11-01-MS-01-A -LC[Run] 982.75 A / PF[Run] 0.889 - LC[Peak] 1305.71 A / PF[Peak] 0.889												
PK-1101-C1A	AIR COMPRESSOR	M	1500	1800	0.83	0.9	0.88	C	1564.1	810	203	1221
MP-2225 C	MACHINERY COOLING WATER PUMP	M	496	600	0.83	0.9	0.85	S	527.7	314	71	429
MC-2401 D	AIR COMPRESSOR	M	1083	1400	0.77	0.9	0.88	C	1131.7	607	160	959
MC-2401 B	AIR COMPRESSOR	M	1083	1400	0.77	0.9	0.88	C	1131.7	607	160	959
11-01-TX-03-A	TRANSFORMER (11-01-PC-01 INCOMMING)	T						C	1552.2	716	-	-

PDB Summary Data, PDB name: 11-01-MS-01

Voltage: 6 kV

Maximum of normal running load:

9079.4	kW
4686.9	kVAR
10217.8	kVA
0.889	P.F.

Peak load:

12063.1	kW
6225.4	kVAR
13574.7	kVA
0.889	P.F.

3.3 Load flow studies

Load flow studies are carried out in order to calculate all bus voltages, branch power factors, currents and power flows throughout the plant electrical system. The load flow reports shall tabulate the magnitude of active (real) power and reactive power which have been supplied by each generator, transformer, feeder and bus bar with the total connected plant load. Load flow diagrams shall be prepared for both main and essential systems and shall indicate MW, MVAr figures, bus bar volts and voltage phase angles.

- The load flow studies should include the preparation of calculations and diagrams showing the distribution of loads under predicted abnormal operating conditions, such as loss of one generator, feeder or transformer due to fault or maintenance conditions. System losses shall also be determined and indicated on the diagrams.
- Voltage drop and voltage regulation calculations shall be carried out as part of the load flow studies. These calculations shall determine the voltage profile of the network under full load and light/no load conditions.

The results of the above load flow studies shall be used to check the following:

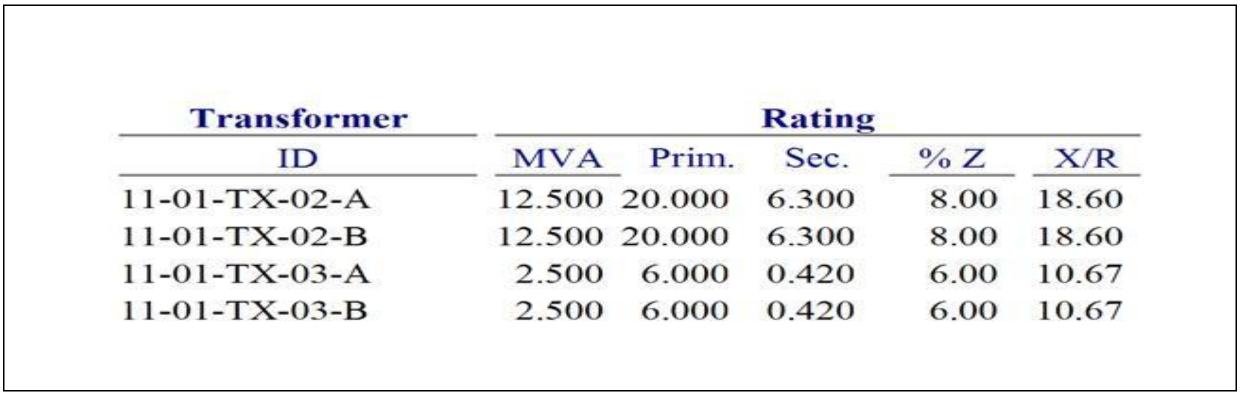
- System voltage profile and phase angles
- Transformer ratings/loadings
- Power losses
- Transformer taps settings/ratings

3.3.1 Load flow report of software

Load flow should be done under the normal condition when bus tie is open. According to design criteria 5 percentage tolerance on each bus is allowed.

By studying the reports, it can be concluded that voltage drops are acceptable. The transformer sizing is perfect, and spare capacity of 20 % is met on all transformers.

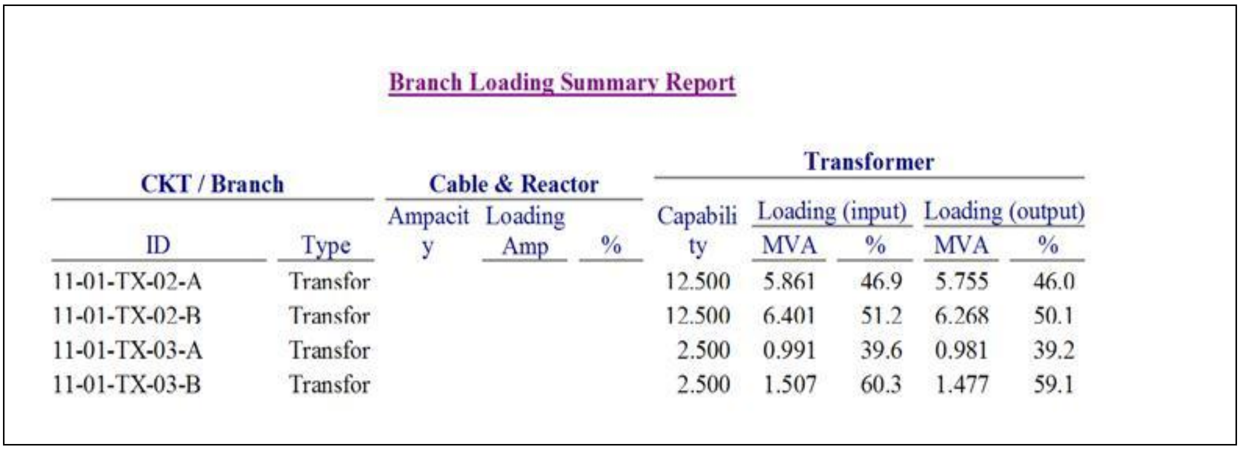
Table 3.2: Load Flow Study-Transformers input data



Transformer	Rating				
ID	MVA	Prim.	Sec.	% Z	X/R
11-01-TX-02-A	12.500	20.000	6.300	8.00	18.60
11-01-TX-02-B	12.500	20.000	6.300	8.00	18.60
11-01-TX-03-A	2.500	6.000	0.420	6.00	10.67
11-01-TX-03-B	2.500	6.000	0.420	6.00	10.67

The transformers input data are shown in the table 3.2 the short circuit impedance have been discussed in section 2.2.5.

Table 3.3: Load Flow Study-Branch loading summary

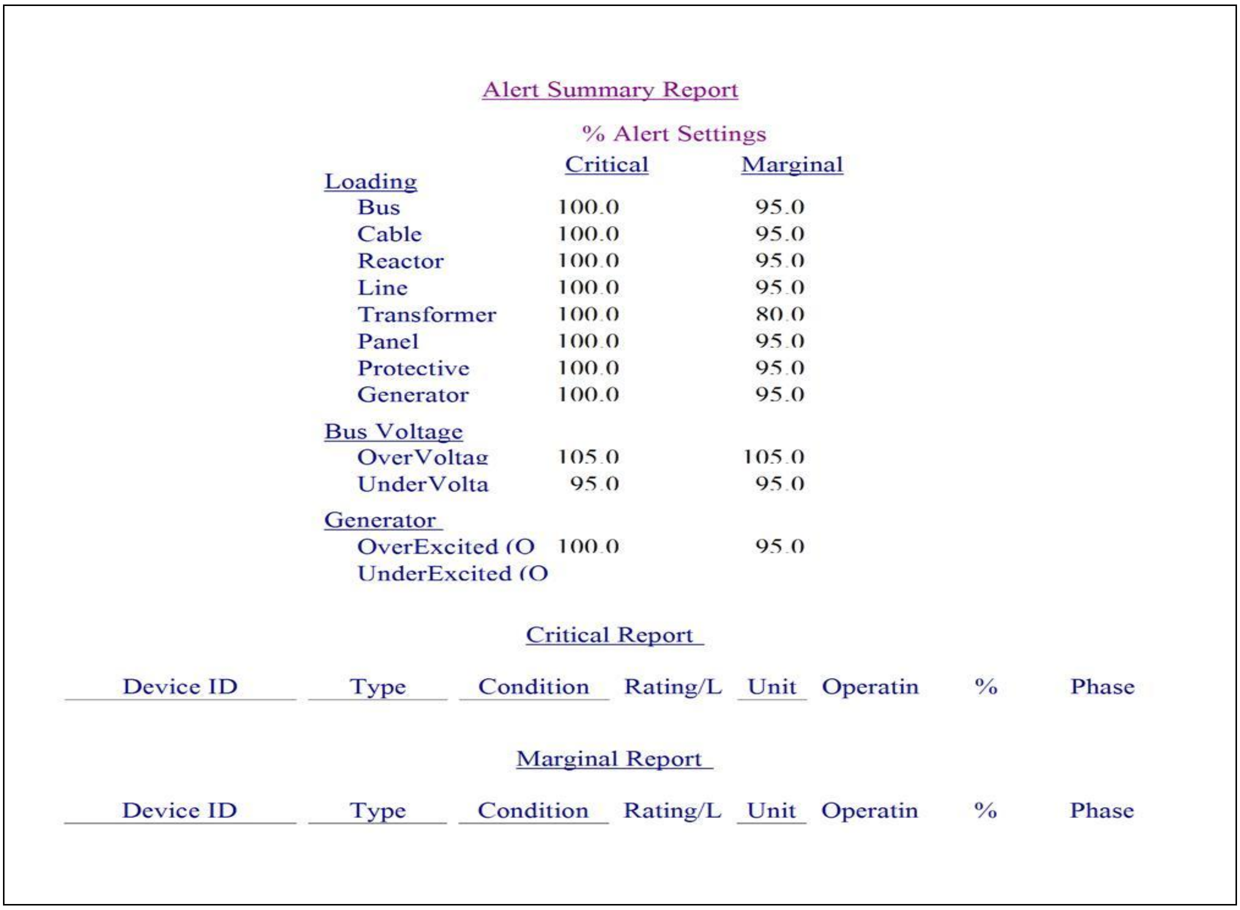


Branch Loading Summary Report

CKT / Branch		Cable & Reactor			Transformer				
		Ampacity	Loading		Capability	Loading (input)		Loading (output)	
ID	Type		Amp	%		MVA	%	MVA	%
11-01-TX-02-A	Transfor				12.500	5.861	46.9	5.755	46.0
11-01-TX-02-B	Transfor				12.500	6.401	51.2	6.268	50.1
11-01-TX-03-A	Transfor				2.500	0.991	39.6	0.981	39.2
11-01-TX-03-B	Transfor				2.500	1.507	60.3	1.477	59.1

In the above table, the loading on each transformer is shown. The most important point is that the two transformers connected to the bus bars with common bus tie should have capacity to withstand another transformer loads.

Table 3.4: Load Flow Study-Alert Summary Report



Alert Summary Report

	% Alert Settings	
	Critical	Marginal
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	80.0
Panel	100.0	95.0
Protective	100.0	95.0
Generator	100.0	95.0
Bus Voltage		
OverVoltag	105.0	105.0
UnderVolta	95.0	95.0
Generator		
OverExcited (O	100.0	95.0
UnderExcited (O		

Critical Report

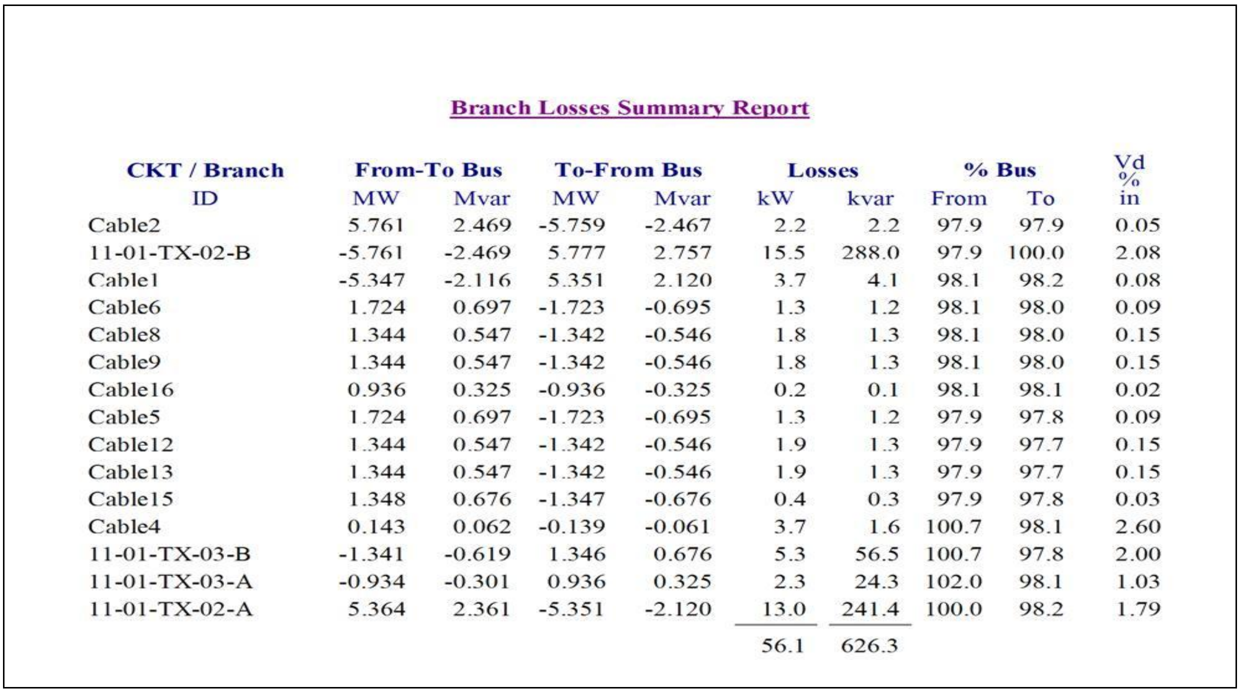
Device ID	Type	Condition	Rating/L	Unit	Operatin	%	Phase

Marginal Report

Device ID	Type	Condition	Rating/L	Unit	Operatin	%	Phase

In this table by defining the limits, the system is checked and in case of wrong sizing of equipments it will be appeared in the Marginal section or Critical section.

Table 3.5: Load Flow Study-Branch Losses Summary Report



Branch Losses Summary Report

CKT / Branch	From-To Bus		To-From Bus		Losses		% Bus		Vd %
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in
Cable2	5.761	2.469	-5.759	-2.467	2.2	2.2	97.9	97.9	0.05
11-01-TX-02-B	-5.761	-2.469	5.777	2.757	15.5	288.0	97.9	100.0	2.08
Cable1	-5.347	-2.116	5.351	2.120	3.7	4.1	98.1	98.2	0.08
Cable6	1.724	0.697	-1.723	-0.695	1.3	1.2	98.1	98.0	0.09
Cable8	1.344	0.547	-1.342	-0.546	1.8	1.3	98.1	98.0	0.15
Cable9	1.344	0.547	-1.342	-0.546	1.8	1.3	98.1	98.0	0.15
Cable16	0.936	0.325	-0.936	-0.325	0.2	0.1	98.1	98.1	0.02
Cable5	1.724	0.697	-1.723	-0.695	1.3	1.2	97.9	97.8	0.09
Cable12	1.344	0.547	-1.342	-0.546	1.9	1.3	97.9	97.7	0.15
Cable13	1.344	0.547	-1.342	-0.546	1.9	1.3	97.9	97.7	0.15
Cable15	1.348	0.676	-1.347	-0.676	0.4	0.3	97.9	97.8	0.03
Cable4	0.143	0.062	-0.139	-0.061	3.7	1.6	100.7	98.1	2.60
11-01-TX-03-B	-1.341	-0.619	1.346	0.676	5.3	56.5	100.7	97.8	2.00
11-01-TX-03-A	-0.934	-0.301	0.936	0.325	2.3	24.3	102.0	98.1	1.03
11-01-TX-02-A	5.364	2.361	-5.351	-2.120	13.0	241.4	100.0	98.2	1.79
					56.1	626.3			

In Table 3.5, the losses of equipment and voltage drops are presented. The voltage drops are acceptable. The losses of transformers are very important and during purchasing this matter should be checked to be compatible with design criteria.

3.4 Short circuit calculations

Short-circuit calculations shall be executed using the following criteria:

- The method of IEC 60909 shall be adopted for calculating short-circuits currents.[3]
- IEC tolerances shall be used for transformer and generator impedances
- Both resistance and reactance shall be taken into account for all impedances
- The DC component of the asymmetric short-circuit current shall be shown to have decayed sufficiently by the time that the circuit breaker contacts open to enable the arc to extinguish.

The results of the short-circuit study shall be used to confirm the following:

- Bus bar Ratings
- Switchgear and Distribution Equipment Ratings
- Cable Ratings
- Bus-duct Ratings
- Protective Earthing Systems

Hereunder ABB method [9] for calculation of short circuit as a reference is reviewed:

3.4.1 Data necessary for the calculation

Some general indications regarding the typical parameters characterizing the main components of an installation are given hereunder. Knowledge of the following parameters is fundamental to carry out a thorough analysis of the installation.

3.4.1.1 Distribution networks:

The network short-circuits powers according to standard IEC 60076-5. [4]

Table 3.6: Network short circuit power

Distribution network voltage [kV]	Short circuit apparent power [MVA]
7.2-12-17.5-24	500
36	1500
52-72.5	5000

3.4.1.2 Synchronous generator

Vn and Sn are known data.

- The synchronous reactance (direct axis Xd): under steady state condition
- Transient and sub transient reactance (X'd, X"d): under transitory conditions when the load suddenly varies.

The evolution of these parameters in per unit:

$$X\% = \frac{\sqrt{3}\text{In}\times X}{Vn}\times 100$$

Where:
X is the real value in ohm of the considered reactance;
In is the rated current of the machine;
Vn is the rated voltage of the machine

The following values can be indicated as order of quantity for the various reactances:

- Sub transient reactance: the values vary from 10% to 20% in turbo-alternators (isotropic machines with Smooth rotor) and from 15% to 30% in machines with salient pole rotor (anisotropic);
- Transient reactance: from 15% to 30% in turbo-alternators (isotropic machines with smooth rotor) and from 30% to 40% in machines with salient pole rotor (anisotropic);

3.4.1.3 Transformer

In delta-star transformers following data should be found:

- rated apparent power S_n [kVA]
- primary rated voltage V_{1n} [V]
- secondary rated voltage V_{2n} [V]
- short-circuit voltage in percent V_K% according IEC 60076-5.[4]

Table 3.7: Transformer short circuit impedance ratings

Rated apparent power Sn [kVA]	Short-circuit impedance vk%
≤ 630	4
630 < Sn ≤ 1250	5
1250 < Sn ≤ 2500	6
2500 < Sn ≤ 6300	7
6300 < Sn ≤ 25000	8

Table 3.8: Transformer operating capacity under overload

Multiple of the rated current of the transformer	**Time [s]**
25	2
11.3	10
6.3	30
4.75	60
3	300
2	1800

3.4.1.4 Asynchronous motor

The rated active power in kW, the rated voltage Vn, the rated current in, efficiency and power factors are available. In the short circuit condition these kinds of motors functions as generator with X"d 20% to 25% .Consequently motor contribution can be considered 4 or 5 times of rated current.

3.4.2 How to calculate resistance and reactance

As we know transformation ratio K:

K $=V_1/V_2$ in accordance with the following relationship: $Z_2 = Z_1/K^2$

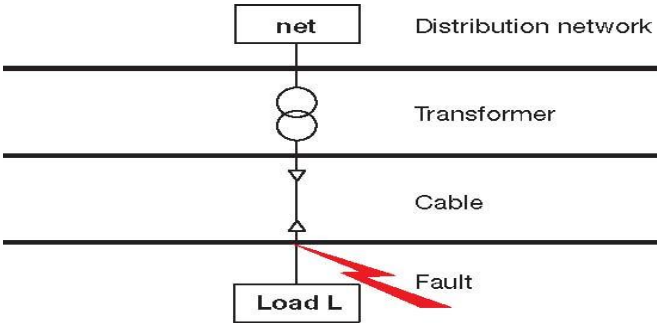


Figure 3.2: Schematic drawing of a network

By knowing the equivalent impedance seen from the fault point and V_{EQ} the short circuit current can be calculated.

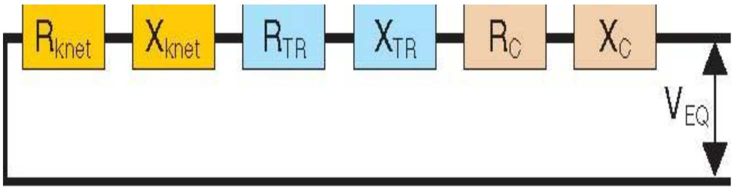


Figure 3.3: Equivalent impedance seen from fault point

$$V_{EQ} = \frac{C.Vn}{\sqrt{3}}$$

The factor “C” depends on the system voltage variation and the loads

3.4.2.1 Supply network (net)

$Z_{knet} = \frac{{v_{net}}^2}{S_{knet}}$ Then

$R_{knet} = 0.1\ X_{knet}$

$X_{knet} = 0.995\ Z_{knet}$

3.4.2.2 Transformer

$$Z_{TR} = \frac{V_K \times {V_{2n}}^2}{100 S_{nTR}} \quad R_{TR} = \frac{P_{PTR}}{3 \times {I^2}_{2n}}$$

Where

P_{PTR} is the total losses related to the rated current (I_{2n})

The reactive component

$$X_{TR} = \sqrt{({Z^2}_{TR} - {R^2}_{TR})}$$

3.4.2.3 Overhead cables and lines

The cable resistance (at temperature of 20°C) and reactance are usually can be found on manufactures manuals

For different operation temperature following formula can be used.

$r_\theta = [1 + (\alpha - 20)]\ r_{20}$

Where:

α is the temperature coefficient (for copper it is 3.95×10^{-3}).

3.4.2.4 Short circuit total impedance

The short-circuit total resistance $R_{Tk} = \Sigma R$ and The short-circuit total reactance $X_{Tk} = \Sigma X$

Then the short-circuit total impedance value is, $Z_{TK} = \sqrt{({ZR^2}_{TK} - {X^2}_{TK})}$

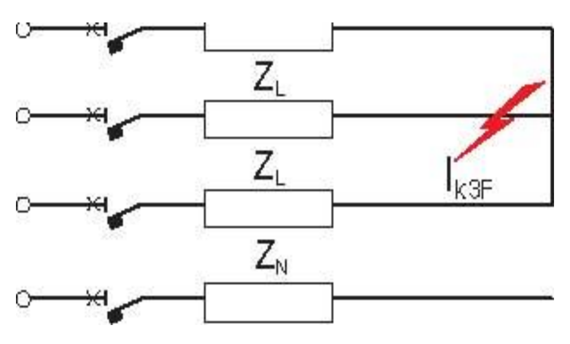


Figure 3.4: Scheme of Short circuit total impedance

$$I_{K3F} = \frac{C.V_n}{\sqrt{3}.Z_{TK}}$$

The voltage factor “c” is to simulate the effect of network phenomena such as voltage variations, changes of transformer taps or the sub transient reactances of motors or generators.

This current is generally considered as the fault which generates the highest currents without considering the motors contribution or when their action has decreased, usually it is called the steady state short-circuit current and is taken as reference to determine the breaking capacity of the protection device.

3.4.3 Calculation of motor contribution

In case of short-circuit, the motor begins to function as a generator and feeds the fault for a limited time by knowing sub transient reactance “X”, it is possible to calculate the numerical value of the motor contribution. But since this datum is not easy to find; For MV motors it can be estimated the motor contribution current as 4 to 6 times of rated current.

For a LV motor, if the sum of the rated currents of the motors directly connected to the network is not bigger than the short circuit current that has occurred the motor contribution can be neglected according to the Standard IEC 60909. [3]

3.4.4 Calculation of the peak current value

In order to define the breaking capacity (the circuit breaker is opened in fault condition) and making capacity (The circuit breaker is closed in fault condition) of circuit breakers we need to obtain the symmetrical component and pick current value of short circuit current respectively. The pick current value is related to symmetrical Component (i_s) that is sinusoidal waveform and unidirectional component (i_u) that has exponential curve due to presence of resistance(R) and inductance (L) of the circuit upstream of the fault point with time constant of L/R.

$i_S = \sqrt{2}.I_k \sin^{-1}(\omega.t - \varphi_k)$ and $i_U = \sqrt{2}.I_k \sin^{-1}\varphi_k \, .e^{-\frac{R.t}{L}}$

The value of the first current peak may vary from $\sqrt{2\, I_K}$ $to\ 2\sqrt{2}\, I_K$

Where I_K is rms value of symmetrical current: $I_K = \frac{V}{\sqrt{R^2+X^2}}$

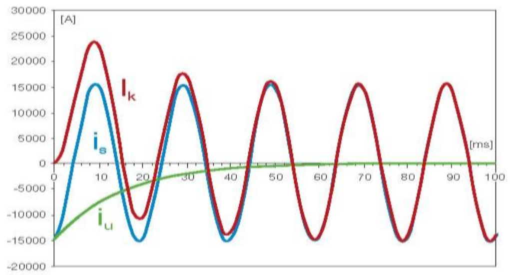


Figure 3.5: sinusoidal waveform and unidirectional

The Standard IEC 60909 [3] guides using this formula

$i_P = K.\sqrt{2}.I_K$

Where the value of “k” related to following formula can be estimated by utilizing Figure 3.6:

$K = 1.02 + 0.98.e^{-3\frac{R}{X}}$

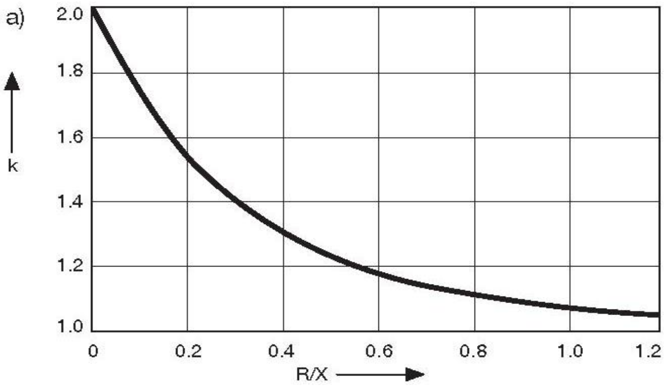


Figure 3.6: Value of k related to ratio of X and R

As above mentioned the short circuit peak current decides making capacity of circuit breaker. In the IEC 60947-2 [1] the ratio between breaking capacity and making capacity of circuit breaker has been defined but it should be noted that the making capacity should not be lower than the calculated peak value. Otherwise, the higher range of circuit breaker must be selected. Here an example from ABB is explanatory.

Example:

Suppose that an rms value of the sysmetrical component equals to IK=33 KA ,and the power factor under short circuit is 0.15.

How would be the circuit breaker making capacity and breaking capacity?

By having power factor ($\cos\varphi_k$ =0.15) ,the ratio of X/R is 6.6 and through the above graph the value of K =1.64 can be found consequently Ip would be 76.6 kA.

Considering IK=33kA the circuit breaker with breaking capacity of 36 kA seems to be proper and also by referring to the Standard IEC 60947-2 [1] the ratio of making capacity to breaking capacity would be 2.1.So the making capacity is 36 multiply by 2.1 that is 75.6.

But as above mentioned the making capacity must be higher than short circuit peak current value so the next range of circuit breaker with breaking capacity of 50kA and making capacity of 50*2.1= 105kA should be selected.

3.4.5 Manual short circuit calculation

In this section the manual calculation on the MV bus bar is done. The calculation should be done on the worst condition when one of the incomings is open and bus tie is closed.

These results can be compared with the software results which present in the Table 3.9 and both results must be according to section 2.2.3.

VR= 20kV → I_K=500000/(20/1.73)=14.4 kA

RATIO TRANSFORMER : K=20kV /6.3kV=10/3=3.174, Z_{net} =1.1*20K / (√3*14.4KA) =0.88, $Z_{KNET6.3KV}$ =0.88/$(3.174)^2$ =0.0873

$X_{NET6.3K}$ =0.995$_{ZNET6.3K}$ =0.995*0.0873 =0.0869, $R_{NET6.3K}$ = O.1X_{net} =0,00869Ω

Network:

S_K = 500 MVA, R_{Cable} = 0.004, X_{Cable} = 0.0042

Transformer:

S_{Ntr} =12.5 MVA , VK%= 8% ,

$Z_{TR} = V_{2n}^2$ * VK% /(100 S_{ntr})= 6300^2 * 8 /(100*12.5*$10^{6)}$= 0.254

I_{2n}=12.5MVA/(√3*6300)= 1145.569 A

For calculation of R_{tr} we can refer to load flow report to see transformer losses:

As it can be seen P_{TR} of transformer No.11-01-TX-02B equals 15.5kW while I= 51% * I_{2n} =584.2 A →

$R_{TR} = P_{TR}/(3I_{2n}^2)$= 0.015Ω, X_{TR}= $\sqrt{(Z_{TR}^2 - R_{TR}^2)}$= 0.253 Ω, $R_{TOTAL} = R_{NET6.3K} + R_{Cable} + R_{TR}$ =0.0276 Ω

$X_{TOTAL} = X_{NET6.3K} + X_{Cable} + X_{TR}$= 0.344 → $Z_{TOTAL} = \sqrt{(R_{TOTAL}^2 + X_{TOTAL}^2)}$= 0.345 Ω

I_{k3F} =C. V_n/ (√3 Z_{TOTAL}) = 1.1*6300/ (√3 * 0.345) = 11.6 KA

The next stage is calculation of motor contribution:

As above mentioned the best estimation for motor contribution in short circuit is to consider 6 times of rated current.

As we know rated current can be calculated by these formula I_r= POWER/(√3*P.F*EFFICIENCY)

So by Referring to IPS table P.F= 0.87 , EFFICIENCY = 0.96 rated current for 6kV motors are as follow:

For motors 1800 kW , I_r = 1800/(√3*0.87*0.96)= 202.7 → Motor contribution current in S.C equals 6* I_r=1.2 KA

For motors 1400 kW , $I_r = 1400/(\sqrt{3}*0.87*0.96)= 157.7$ → Motor contribution current in S.C equals 6* I_r=0.94 KA

And LV motors are negligible.

Estimation of total motor contribution = 4*0.94 KA + 2* 1.2 KA = 6.16 KA

IK"= 11.6 KA +6.16 KA= 17.8 KA

As it can be seen in the software short circuit report (Table 3.9) IK and IK" are as follow:

IK= 12.55 KA and IK"= 20.07 KA

Regarding some estimations for motor contribution manual calculation is acceptable

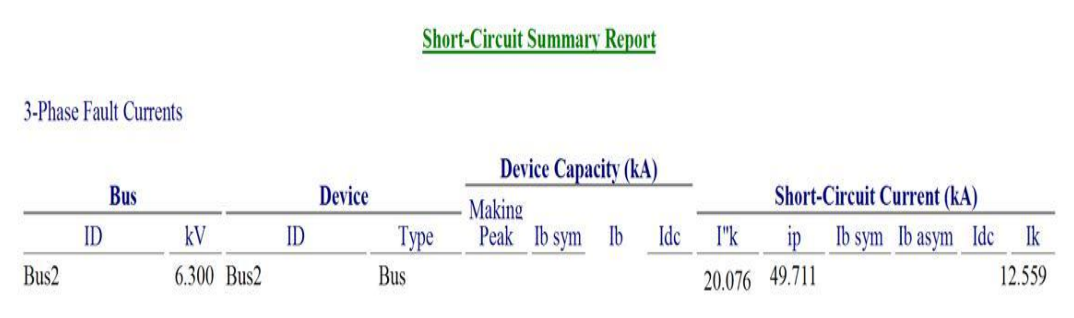
Since IK" meets the criteria (less than 25KA) short circuit impedance of 12.5 MVA transformers are suitable.

3.4.6 Short circuit Report of software

In this section, the results of software on short circuit study are presented.

3.4.6.1Short circuit on MV bus bar

Table 3.9: Short circuit current on MV bus bar



Short-Circuit Summary Report

3-Phase Fault Currents

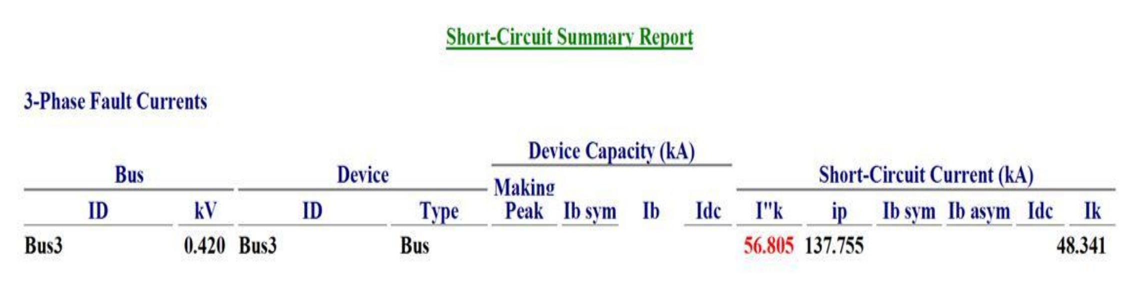
Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
ID	kV	ID	Type	Making Peak	Ib sym	Ib	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus2	6.300	Bus2	Bus					20.076	49.711				12.559

As shown in the above table (3.9) I"K= 20.07 kA and it complies with the design criteria.

3.4.6.2 Short circuit on LV bus bar with 6kV/0.42kV transformer short circuit impedance of 6%

Now the short circuit on the low voltage bus bar is investigated and similar to calculation on MV bus bar the bus tie is closed and only the bus bar is fed by one of the incomings. As it was mentioned before the short circuit impedance of 6kV/0.42kV transformer is 6%.

Table 3.10: Short circuit current on LV bus bar (V_k=6%)



Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
ID	kV	ID	Type	Making Peak	Ib sym	Ib	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus3	0.420	Bus3	Bus					56.805	137.755				48.341

Referring to section 2.2.3 the result is not proper.

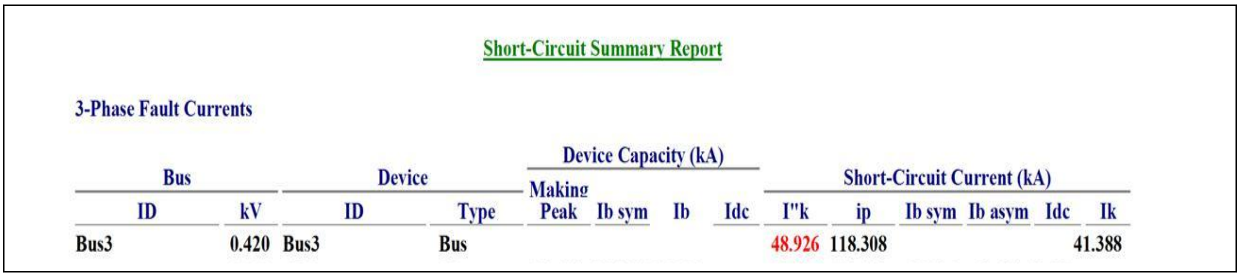
3.4.6.3 Short circuit on LV bus bar with 6kV/0.42kV transformer short circuit impedance of 7.5%

As it can be observed in the Table 3.10 I''K=56.8 kA however, this value should not exceed 50 kA according to IEC standard [1]. So, by increasing short circuit impedance of 6kV/0.42kV transformers, the desirable result will be obtained.

By trial and error, it is observed that the short circuit impedance of 7.5% is suitable so the short circuit impedance of the transformers must change from 6% to 7.5%. By increasing the transformer short circuit impedance, the symmetrical short circuit current would be I''K=48.86kA and lower than 50KA which can be found in software report (in Table 3.11).

It should however be noted that since the short circuit impedance of the mentioned transformers have changed, the load flow study must be repeated to check the voltage profiles again. In this case, the bus voltages have not been much affected**.**

Table 3.11: Short circuit current on LV bus bar (V_k=7.5%)



Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
ID	kV	ID	Type	Making Peak	Ib sym	Ib	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus3	0.420	Bus3	Bus					48.926	118.308				41.388

As it was discussed, by adjusting short circuit impedance of transformers, the short circuit current value can be controlled.

Dynamic Performance of the Electrical System

4

In Chapter 3, all the voltage behavior especially voltage drops were checked in the static status. In this Chapter, Transient situation will be investigated. The most common checking of the system in the transient condition is the Motor Starting which is important in two aspects as follows; first, it should be checked if the biggest motor can start up when all other motors are running normally. Second, the impact of this starting on other motors should be noticed. In other words, the biggest motor should be able to start up by itself and this starting up should not cause the running motors to stall.

4.1 Motor starting study

A motor starting study shall be carried out in order to determine the voltage profile of the system while starting under minimum supply conditions. This happens when the rest of the plant is operating at full load so that the largest rated motor connected to the main system can check the stability of the other running motors and system.

In this stage, the final review and modification on sizing shall be performed as it was explained earlier in "the balance between short circuit impedance of transformer and short circuit level" and is adjusted during short circuit and load flow study. In this stage, if transient voltage violated what has been determined during basic and standard, there would then be some solutions to correct the voltage drop as follows;

- By increasing the size of cables: if the voltage drop is not comprehensive, this method can be considered useful and best way
- By adjusting the tap changer
- By using compensators such as capacitor banks
- By increasing the size of transformer and increasing allowable short circuit withstand level of bus bar and equipment. As shown in the following formula, when it increases $S_{n,}$ the Z_{TR} will be reduced while V_k% is constant. By changing S_n and $Z_{TR,}$ the desirable results for load flow, short circuit and motor starting can respectively be obtained.

$$Z_{TR} = \frac{V_K . V_{2n}}{100 S_{nTR}}$$

4.1.1 Report of software

To perform the motor starting, the bus tie and one of the incomings are closed. Here, the biggest motor is 1800 kW which is connected to the 6.3kV bus bar.
As illustrated in Figure 4.3, the transient voltage drops on bus bar are less than 15% and for the same reason they meet the project requirements on transient condition. In addition, other motors keep running during voltage drop on the bus bar. Please see the reports.

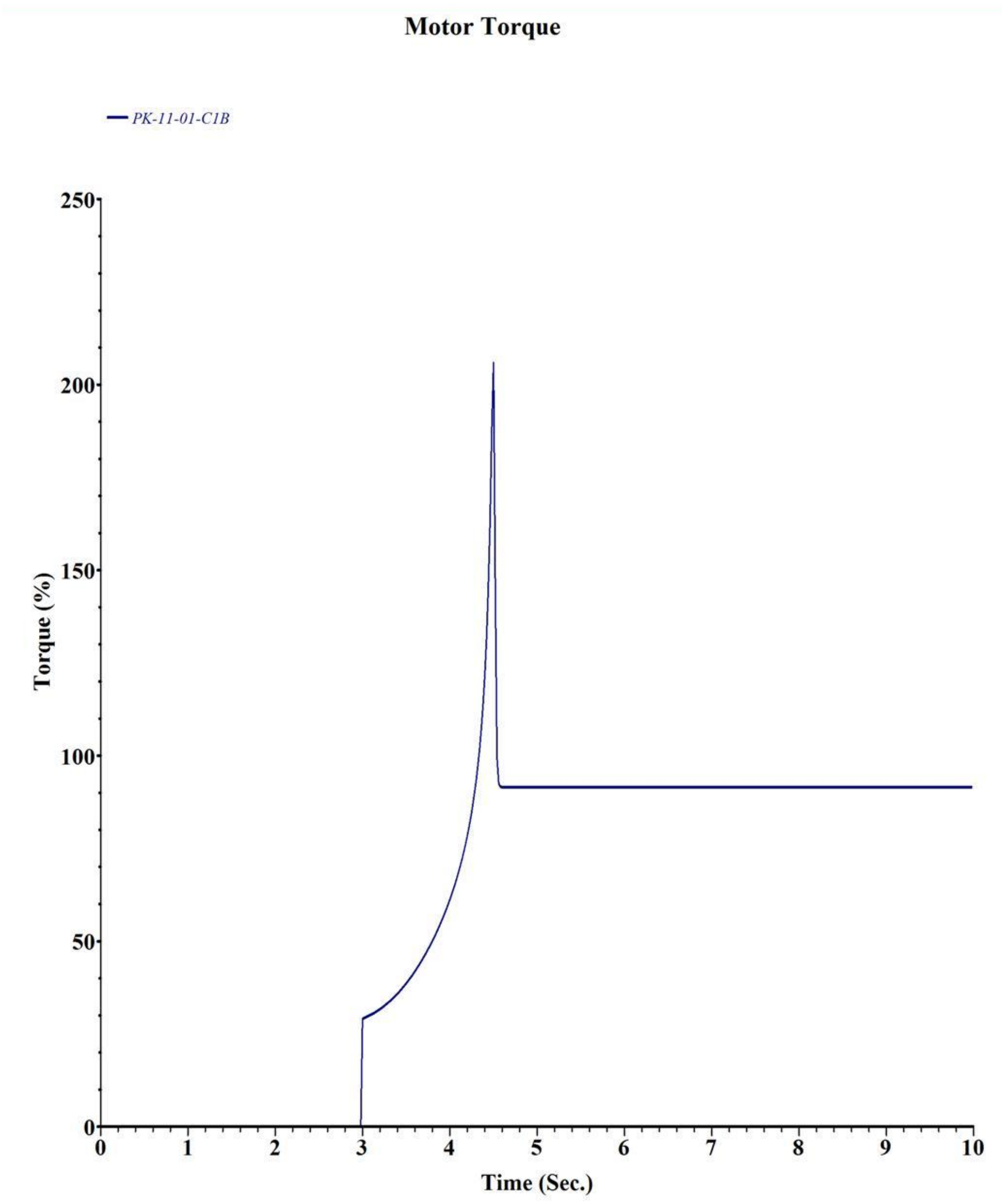


Figure 4.1: Motor Torque curve

To be certain about motor's ability to run, the "motor torque" must be higher than "load torque". This can be observed in the Figure 4.1 that the motor torque can reach more than two times of the load torque in only one second.

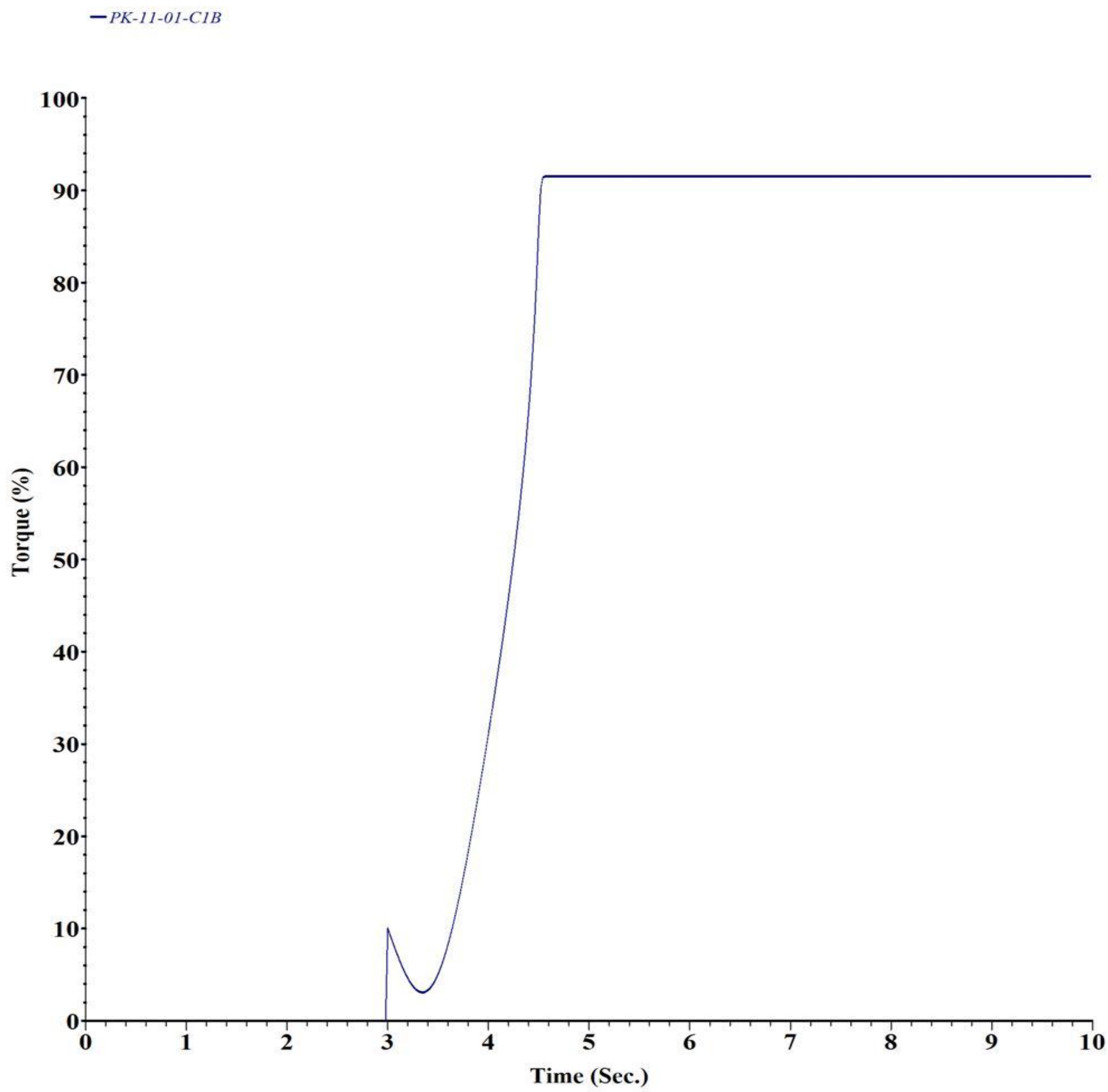


Figure 4.2: Load torque curve

In figure 4.2, the load torque (pump torque) is presented. As in the above explained, the motor torque must be selected so that it can start.

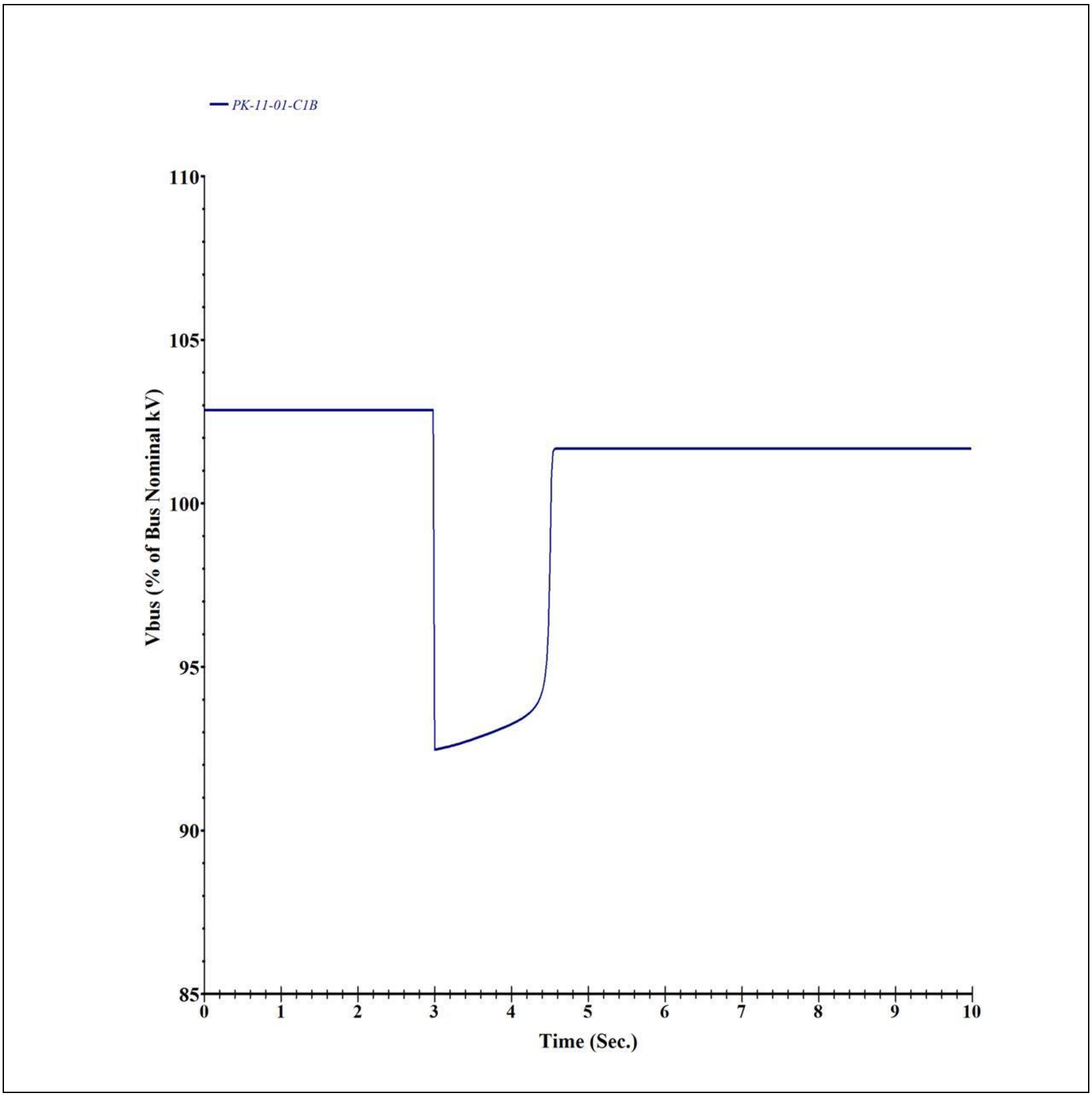


Figure 4.3: Voltage dip during motor starting

As shown in figure 4.3, the duration of startup is only one second and the voltage dip is only 10 percent which meets the design criteria in motor starting status.

4.2 Analysis of running motors during voltage dip

Influence of Transient voltage drop on running motors

As we know, when a big industrial motor starts up, it will automatically cause a voltage drop on feeding bus bar and the voltage drop may lead to stall the other parts of running motors which are fed by the same bus bars. This happens for following reasons;

- Motor Torque is insufficient and it should be taken into the consideration that the torque is proportional to square of the voltage. So, the voltage drop on running motor leads to torque reduction and as long as motor torque operating curve is higher than the load torque curve, the motor will run.

- Voltage drop causes to increase the slip and the current to compensate required flux (flux is proportional to v/f) to provide desired torque. This means lower efficiency due to thermal losses so that long time running on the reduced voltage can result in burning the wires of the motor. In order to avoid the above issue, the thermal relay trips the circuit. Consequently, in order to avoid stalling running motors due to thermal losses, motor starting duration should be as short as possible. To achieve all the above electrical parameters of the motor, resistance, inductance and the mechanical parameters like "inertia" must be well selected. More details are illustrated in the following pictures;

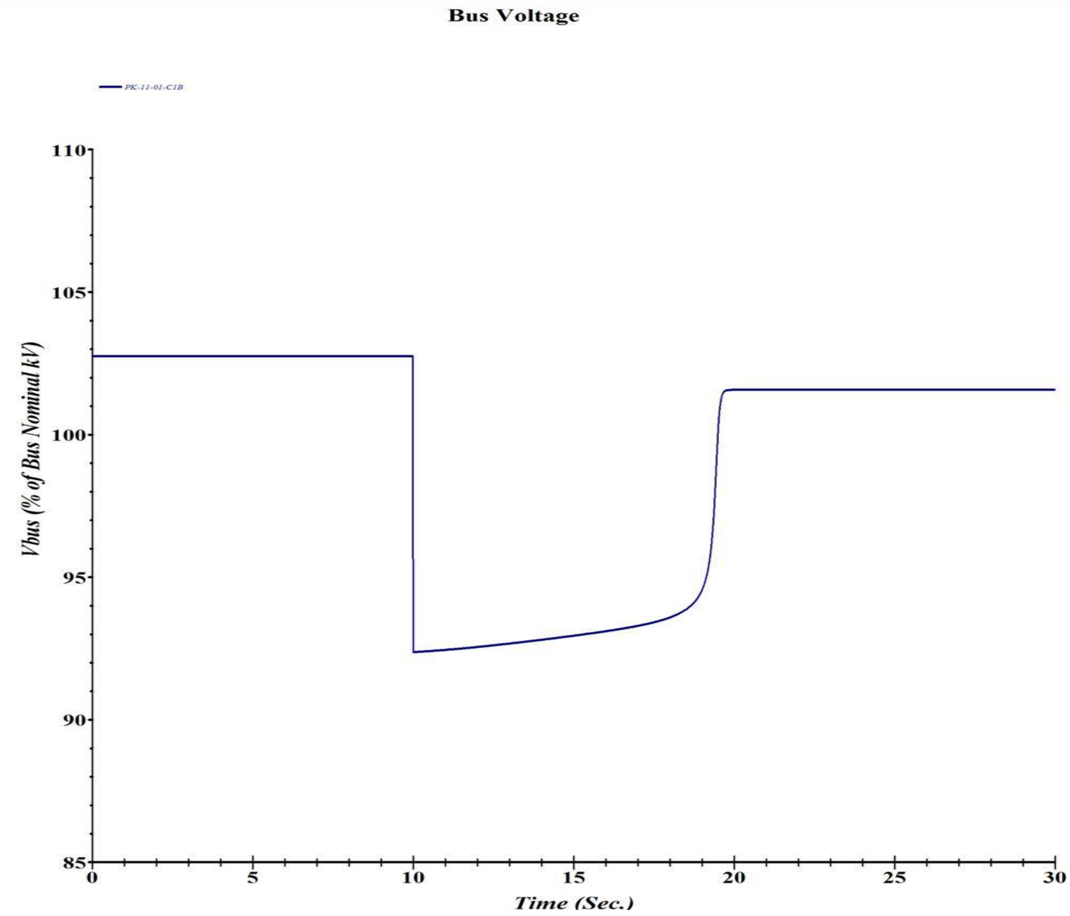


Figure 4.4: 10% voltage dip for 10 second on the bus bar feeding running motor

In 4.1, the startup time of the biggest motor was only one second. However, in order to see the effect of the startup time, a longer duration has been selected (by adjusting the torques). In Figure 4.4, the bus bar experiences almost 9% of voltage drop for a duration of 10 second due to startup of the biggest motor. The influences of this starting on another motor (Mtr4) has been presented in the following;

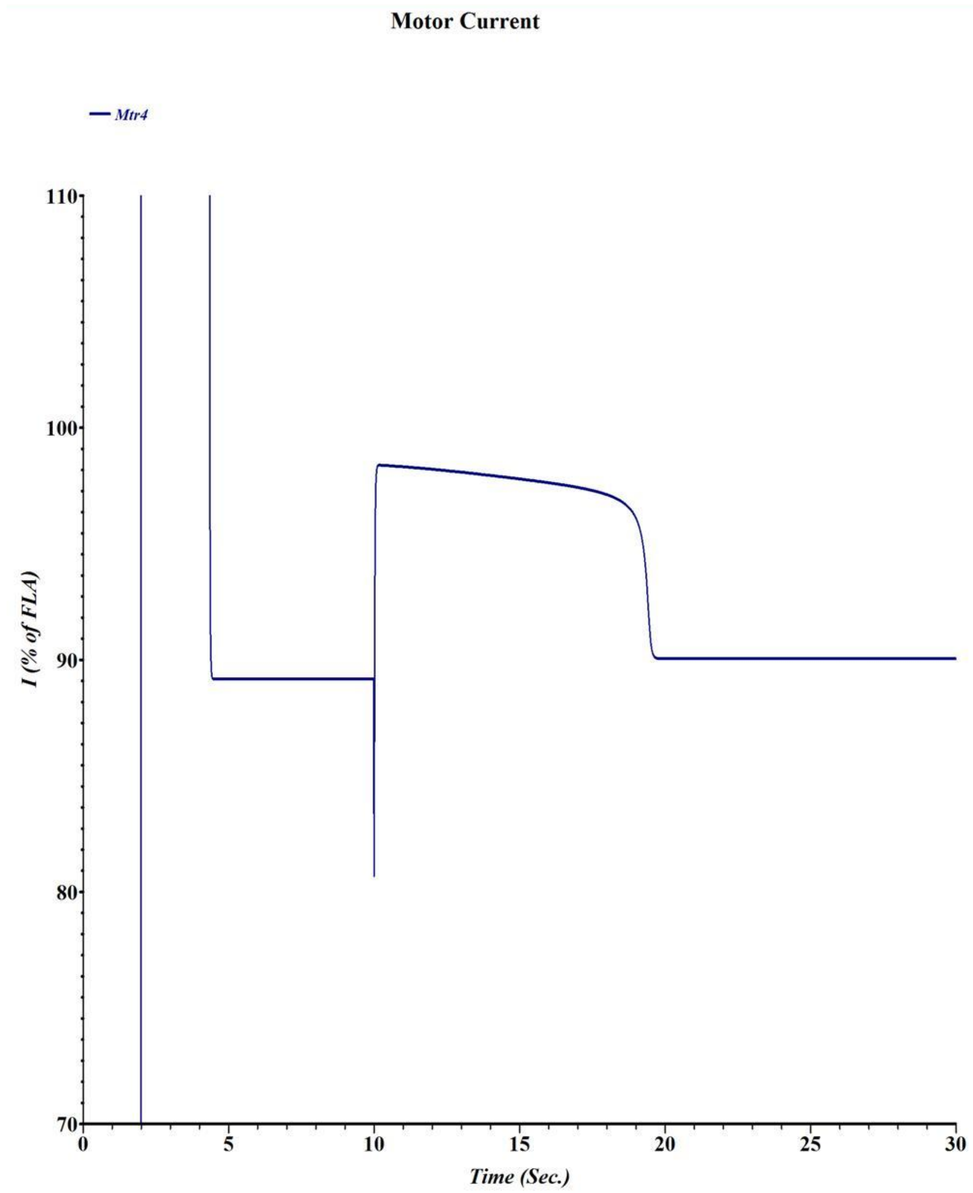


Figure 4.5: Increase of motor current during voltage dip

In figure 4.5, the motor is running on the normal operation before second 10 and at this time, another motor starts up. As illustrated, the start up takes 10 second and the motor current suddenly increases.

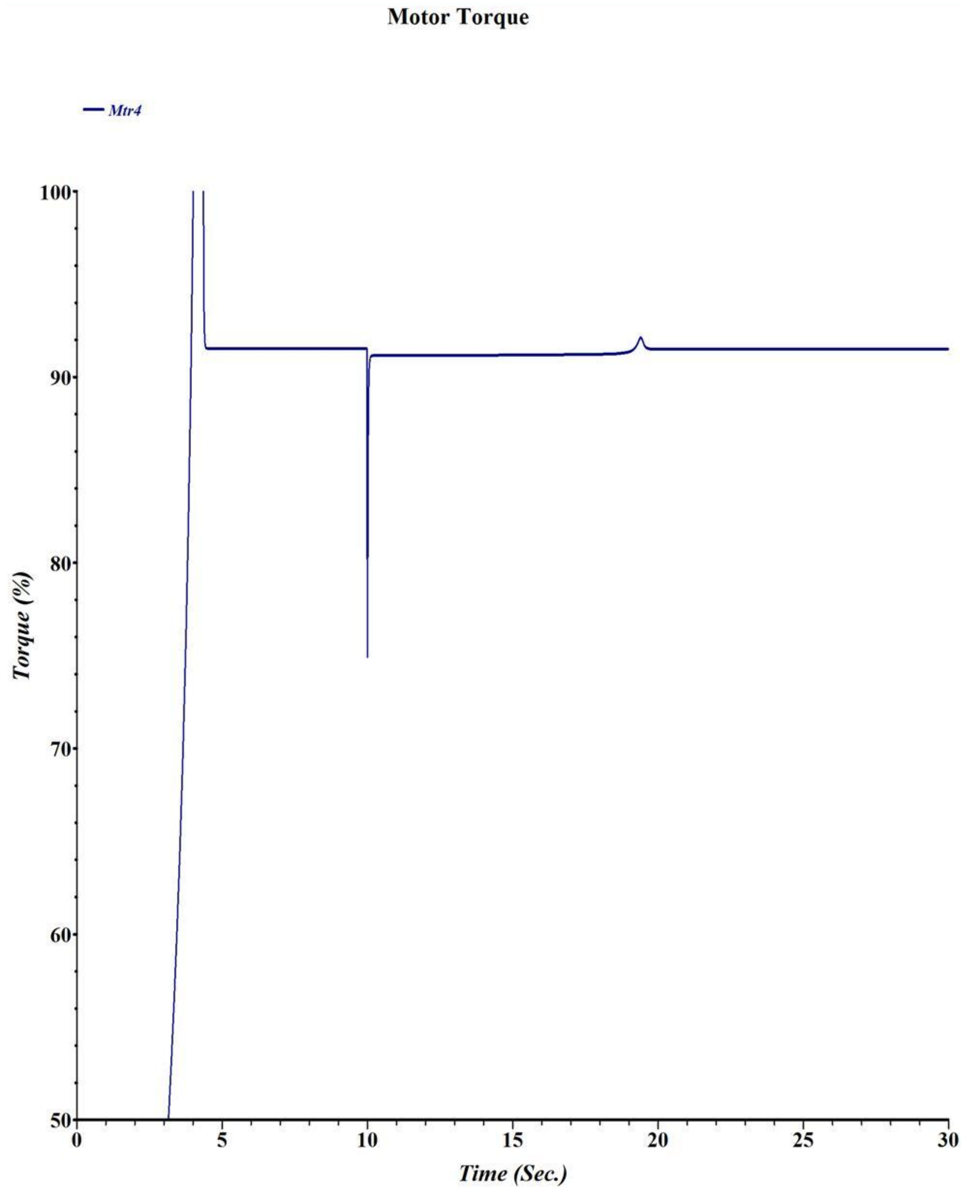


Figure 4.6: Motor Torque drop

As we know, Torque of motor is proportional to square of Voltage. So, when motor receives 9 percent voltage drop, the torque drop should almost be 19%. But the motor torque here should not be lower than load torque and one can easily see that the torque is compensated by increasing of the current and slip. Practically, it can be said that the operating point on motor torque curve is changing and despite of the motor’s capability of running against load, it consumes more current in lower speed which means lower efficiency of the motor. Long time start up may eventually lead to burning of wires.

Protections of the Electrical System

5

The Electrical system should be safe for personnel and equipments. Here, three main important considerations are presented to assure the safety of the system. First of all, the selection of circuit breakers is discussed which explains how to select the right circuit breaker in different voltage levels. The next important matter is the right selection of relays in order to keep our system safe in possible faulty conditions. And finally, selection of the electrical equipments in the hazardous areas where explosive gas and other dangerous materials exist will be presented due to importance of safety in the Oil and Gas industry.

5.1 CIRCUIT BREAKER SELECTION

In this industry, the majority of motors which rated below 150 kW are considered as LV motors and the ones rated above 150 kW are considered as MV motors and their upstream panels should respectively be proper for these loads. Utilizing different types of switching devices are discussed in the following. Although this subject undoubtedly depends on different manufacturers' products but the following categorizing is almost applicable for most of the current products of vendors.

5.1.1 LV switchgears

5.1.1.1 Different types of incoming circuits

Incoming components or devices of low voltage switchgears could be molded case circuit breaker (MCCB), air circuit breaker (ACB), on load isolator switch, on load isolator switch with fuse or fuse base. The selection of any one of these components should be in accordance to the design of distribution networks. The application of MCCB and ACB of this table shall be limited to the case that we need for local protection as well as the upstream back up protection. The rated current of different types of switches has been indicated in Table 5.1.

5.1.1.2 Different types of outgoing circuits

- The outgoing circuits with rated currents, smaller or equal to 25A could be categorized in one group and might be fed from a branched bus bar. In this case, installation of on load isolator switch would not be necessary for each outgoing circuits, and we can control each group of loads only with one on load isolator switch.
- Fuse and combination of fuse and switch can only be used for outgoing feeders with rated currents up to 630A or smaller.
- The moulded case circuit breaker (MCCB) can be used only in outgoing feeders with rated currents up to 800A.
- The air circuit breaker (ACB) may be used for outgoing feeders with rated currents up to 800A and for currents above 800A.
- The miniature circuit breaker (MCB) shall be used for outgoing feeders with rated currents up to 40A.

5.1.2 MV switchgears

Motor starter installed in medium voltage switchgear are intended to control 3 phase 6kV electrical motors. 6Kv motors rated 150 kW to 1000 kW can be controlled by contactor type motor starters and 6Kv motors rated above 1000 kW shall be controlled by circuit breakers. The circuit breaker ratings are presented in Table 5.2.

Table 5.1: Rating currents of different low voltage Switchgears

ITEM NO	SWITCHING DEVICE	RATED CURRENT (A)		SWITCHGEAR FEEDING EQUIPMENT
		MIN	MAX	
1	ACB	630	4000	By Transformer or Generator
2	MCCB	100	1250	By Transformer or Generator or low voltage switchgear which is installed in a remote position and needs a local protection
3	On load Isolator switch	25	1250	By a low voltage switchgear which protect circuit with cartridge fuse, ACB or MCCB
4	On load Isolator switch with cartridge fuse	25	1250	By a low voltage switchgear which needs a local protection
5	Cartridge fuse without Switch	25	250	By a low voltage switchgear which is near this panel.

Table 5.2: Rating voltage, rating current, breaking capacity and dielectric test data for medium voltage Switchgears

Rated Voltage kV	**Dielectric test**		**Breaking capacity kA rms**	**RATED CONTINUOUS SERVICE CURRENT**							
	IMPULSE kV	50 HZ kVrms		400	630	800	1250	1600	2000	2500	3150
7.2	60	20	16	×	×	×	×	×			
			20		×	×	×	×			
			25		×	×	×	×	×	×	
			31.5		×	×	×	×	×	×	
			40				×	×	×	×	×
			50				×	×	×	×	×
12	75	28	16	×	×	×	×	×			
			20	×	×	×	×	×			
			25		×	×	×	×	×	×	
			31.5		×	×	×	×	×	×	×
			40			×	×	×	×	×	×
24	125	50	12.5	×	×	×	×	×			
			16	×	×	×	×	×			
			20		×	×	×	×	×	×	×
			25		×	×	×	×	×	×	×
36	170	70	12.5	×	×	×	×				
			16		×	×	×	×			
			20			×	×	×	×	×	×
			25			×	×	×	×	×	×

Hint: For making and breaking study please refer to chapter 3.4.4.

5.2 Relay selection

Selection of proper relay is one of the most important stages to have a reliable network. In this report, selection of relay for incoming and outgoing feeders for LV switchgear and MV switchgear up to 33kV has been discussed. The relay selected for this project is illustrated by figures in this Chapter and overall views of diagrams are shown in appendixes B and C.

5.2.1 *Low voltage switchgears*

5.2.1.1 *Downstream switchgear of power distribution transformers.*

A) Incoming feeder:

The minimum protections for incoming feeders of these switchgears are as follows:

- Instantaneous over-current (ANSI CODE-50)
- Time over-current (ANSI CODE-51)
- Time earth fault (ANSI CODE-51N)

The tripping commands of Bochholtez relay and oil temperature of power transformer shall be applied to opening mechanism of incoming circuit breaker. The rated current of current transformers shall be sized in according to the rated current of power transformer. The under-voltage (27) and restricted earth fault protections (REF-64) shall be considered (if these functions were mentioned in design criteria of project). In case the transformer neutral point get isolated from the earth, insulation monitoring or residual voltage protections shall be substituted instead of time earth fault (51 N) protection. In figure 5.1, the relays selected for LV panels and transformers are presented.

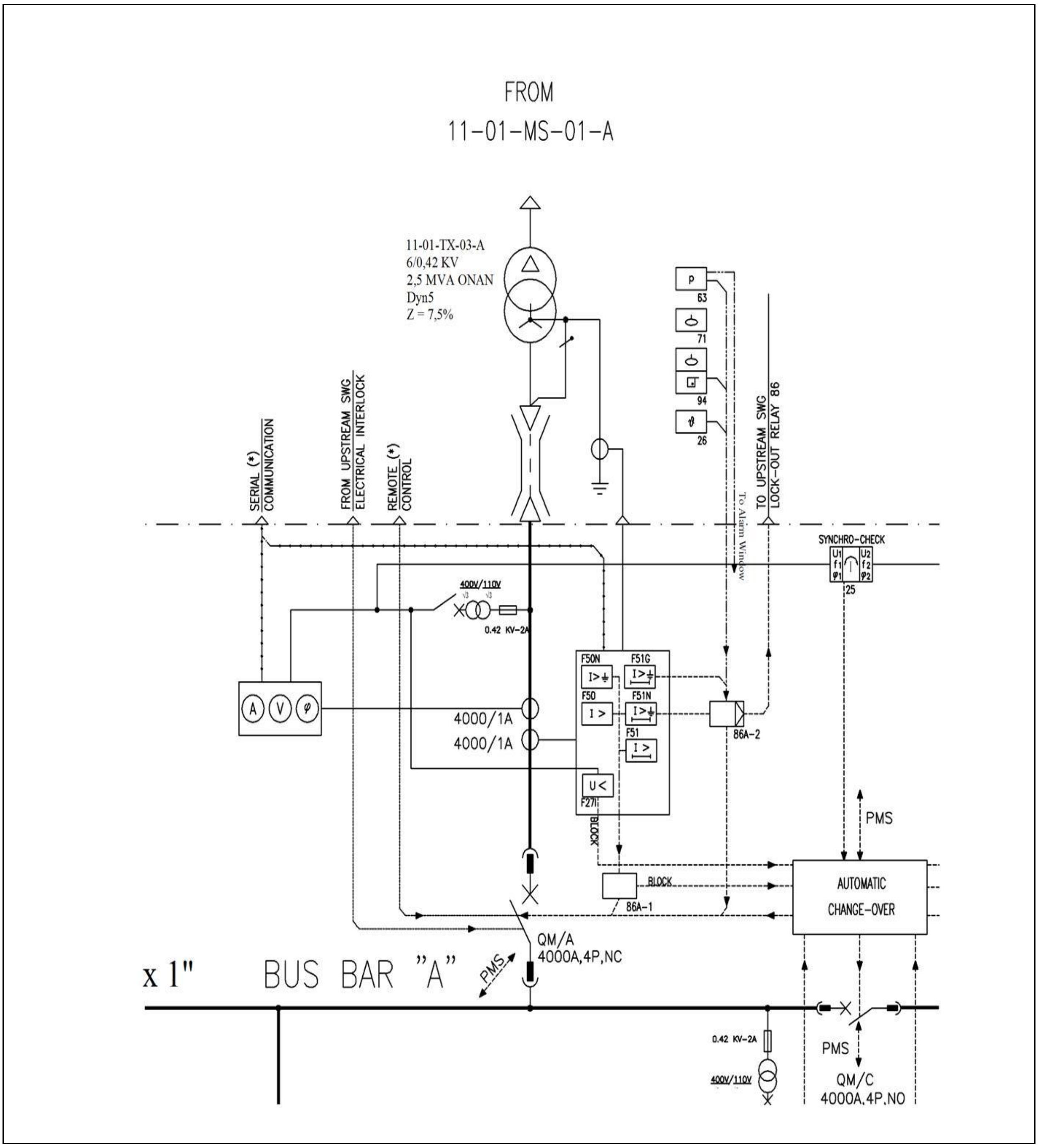


Figure 5.1: LV incoming feeders' protections

B) Outgoing feeders:

For protection of outgoing feeders, the instantaneous over-current protection (50) should generally be considered. The nominal current of protection device (molded case circuit breaker or HRC fuse) shall be coordinated according to technical specification of outgoing cable.

If the outgoing feeders should feed the panels and they are installed in hazardous or fire risk area the explosion proof panels must be used. In addition to the above mentioned protection, the time earth fault protection (51N) with sensitivity of 300 mA needs to be added as well.

5.2.1.2 Motor control center switchgears

A) Incoming feeders:

If the nominal current of feeder is equal or greater than 630A, the necessary protections of incoming circuit breaker should be instantaneous and time over current (ANSI-50, 51). But in case the above mentioned protections have been foreseen in upstream feeder (i.e.; outgoing feeder of power distribution center which feeds the motor control center switchgear) or where the nominal current of circuit breaker exists with less than 630A, then the upstream protections could be considered for incoming feeder. For protection of control transformer, the required protections shall be GL type with fuses in primary side and MCCB switches in secondary side of control transformer.

It should be noted that, most of the control circuits are generally isolated from the earth and in order to prevent double earth fault, the installation of insulation monitoring relay with alarm signal are recommended in secondary side of control transformers.

B) Motor type feeders:

Minimum protections of feeders which feed directly the electrical motors are as follows:

- Short circuit or instantaneous over current protection (50) which can be provided by HRC (High Rupture Capacity) fuses or by magnetic releases of molded case circuit breakers (MCCB).
- Over current protection could be provided by thermal overload relay (bi-metal) or with thermal release of the motor protection circuit breaker (MPCB). Selection of the type of protection devices should be based on basic design of the project. If the method of motor start up is a “direct on line” (D.O.L), but the mechanical load has large inertia with long starting times (more than 15-20 sec.) then the type of overload relay (Bi-metal) should be long starting time.

There are different ways/methods for protection against phase failure as follows;

- The first one is to use sensitive phase sequence voltage relay
- The second method is to use new thermal overload relays (bimetals) with phase failure function (this method is considered very cost effective and reasonable economically)
- The third method is to use HRC fuse type feeders with fuse-failure contacts against short circuits. Fuse failure contact in control circuits is applied in order to open the power circuits
- Finally, installing miniature circuit breaker with a rating of lower than the rating of power fuses in parallel with fuses is recommended.

In the last case above, three phases MCB shall have auxiliary contacts in order to apply in control circuit for opening the main contactor of motor starter. When one of the power fuses is failed, a large current will pass through one phase of parallel MCB’s and since the rating of MCB is much lower than the nominal current of power circuit, the MCB will consequently trip and its auxiliary contact will open the power circuit of motor starter. Meanwhile, it should be noted that the short circuit capacity of selected MCB must be coordinated with the short circuit current of the network at the point of installation of MCB.

Nowadays, using of MPCB which has integrated functions of the overload, short circuit and phase fault protection is common.

Thermal protection of stator windings and bearings temperature of motors with rated output power of 100 kW should be anticipated if the above mentioned protections are predicted in the basic design documents or in client standards. The method of detection and indication of over temperature of motor windings and bearings here is based on RTD sensors. The protection relay should have sufficient input channels for all windings and bearings RTD’s as well as having sufficient protection of motor windings with small output power. For sufficient protection, we must install more sensitive sensors and PTC inside the motor windings. This type of protection is usually used for motors with independent separate windings (multi speed motors) where the protection of motor windings could not be provided by single thermal overload relay. The faulty contacts of PTC or RTD type relays should de-energize the control circuit of motor starter in main contactor coil. In the figure 5.2 protections of LV motors is shown.

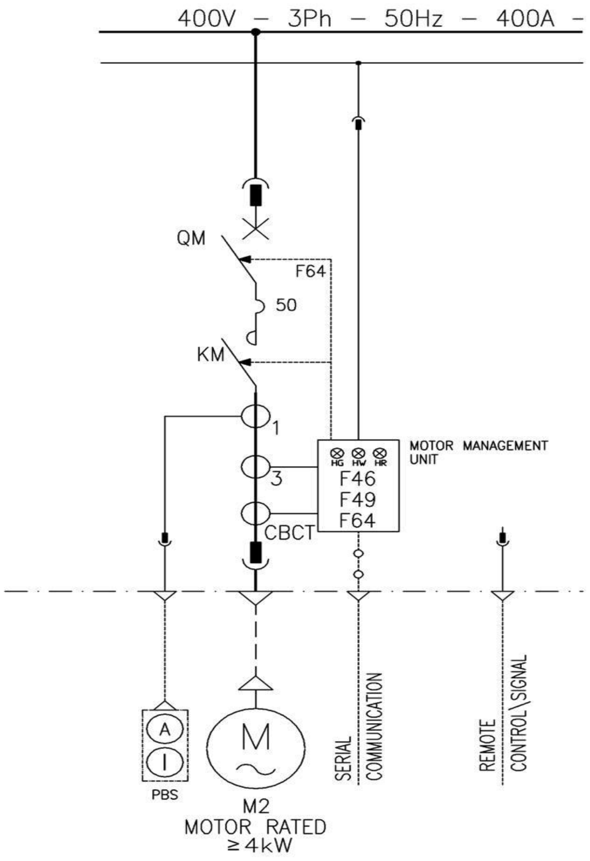


Figure 5.2: LV motors' protections

5.2.2 *Medium voltage switchgears*

5.2.2.1 Distribution feeders:

The following protections are generally considered for medium voltage outgoing feeders which feed the downstream medium voltage switchgears:

- Instantaneous over-current (ANSI CODE-50)
- Time over-current (ANSI CODE-51)
- Time earth fault (ANSI CODE-51N)

It is important to note that since the neutral point of distribution transformer networks

(HV / MV) are grounded by neutral grounding resistors (considering that amplitude of ground fault current is lower than the symmetrical three phase or phase to phase fault), therefore, the time earth fault (51N) protection could generally be used and the relay setting can be implemented with better coordination. In some certain conditions, for better reliability and continuation of electric power source, the outgoing feeders should be operated in parallel configuration and for the same purpose, it is necessary to install directional over current protection in addition to the above mentioned protections. Meanwhile, for incoming feeders of medium voltage distribution switchgears, the under-voltage protection (27) should be predicted in order to apply trip command to outgoing feeders.
In addition, as shown in Figure 5.3, the trip circuit supervision, Relay 74, must be provided to assure continuity of circuit.

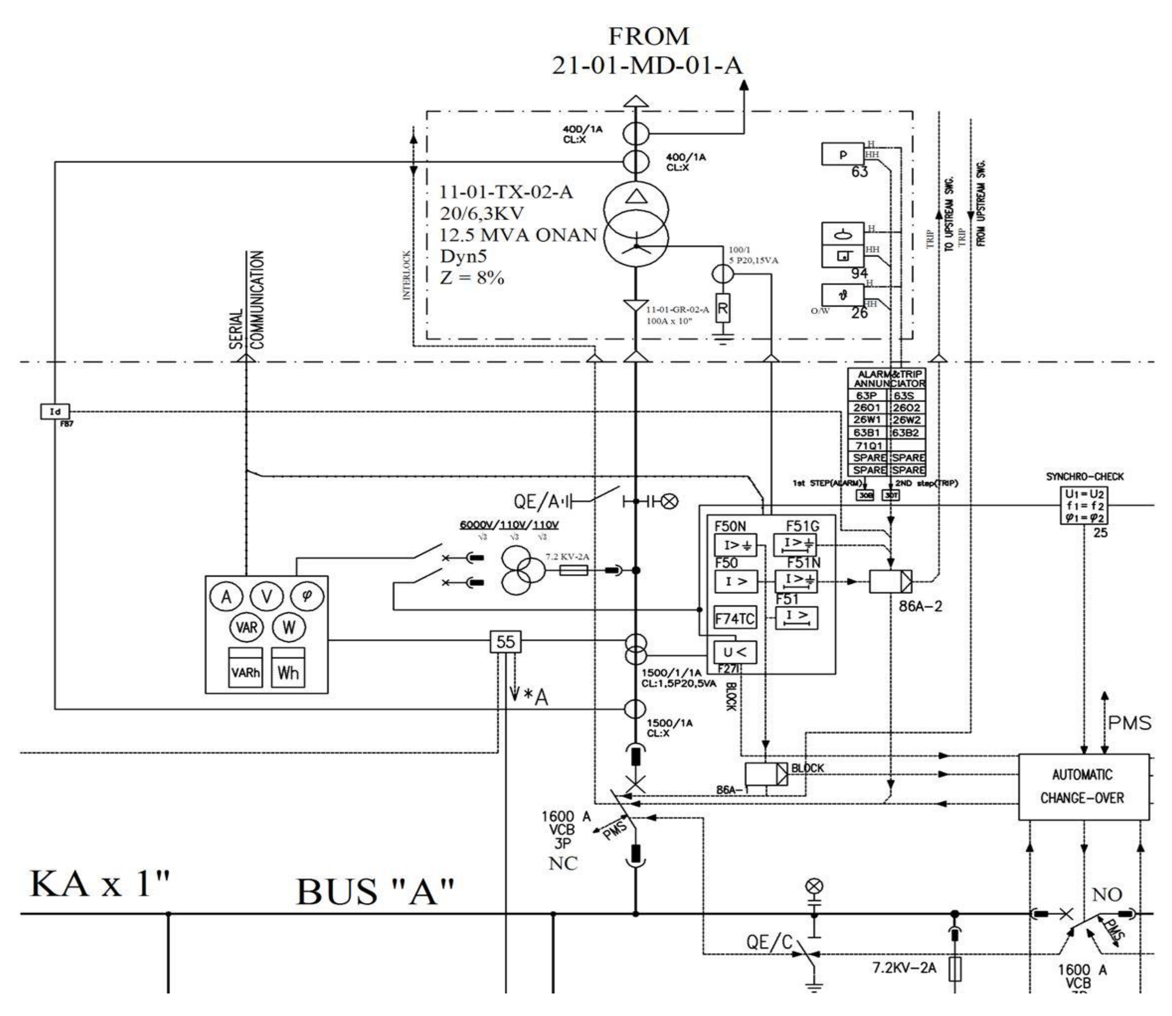


Figure 5.3: MV incoming feeders' protections

5.2.2.2 *Transformer feeders:*

The following protections should be foreseen for the above mentioned feeders;

- Protection of primary windings of transformer against short circuit fault with instantaneous over-current relay (ANSI-50) or medium voltage fuses for all outgoing transformer feeder.
- Protection of primary windings of transformer against over-current fault with time over-current relay (ANSI-51) and time earth fault relay (ANSI-51N) for power distribution transformers with output rating of greater than 630kVA.

- Protection of transformer windings against over temperature by using oil type thermometer for power transformers with a rating greater than 400kVA.
- Protection of transformer windings against internal fault (electric arch between windings and winding with core or body of transformer) by Bochholtz relay for power transformer with rating equal or greater than 400kVA.
- Restricted earth fault protections (ANSI-64) for transformers with ratings from 2500kVA up to 8000kVA must be considered.
- Differential protection (ANSI-87) for power transformers with ratings equal or greater than 10000kVA must be provided as well.
- Internal overpressure protection is needed for transformers without oil expansion tank or power transformers with output rating equal to or greater than 10000kVA.
- Tap changer protections is necessary for transformers which are equipped with on-load voltage regulator (OLTC) in according to vendor recommendations.

Please see Figure 5.4 for some relays selected for this project

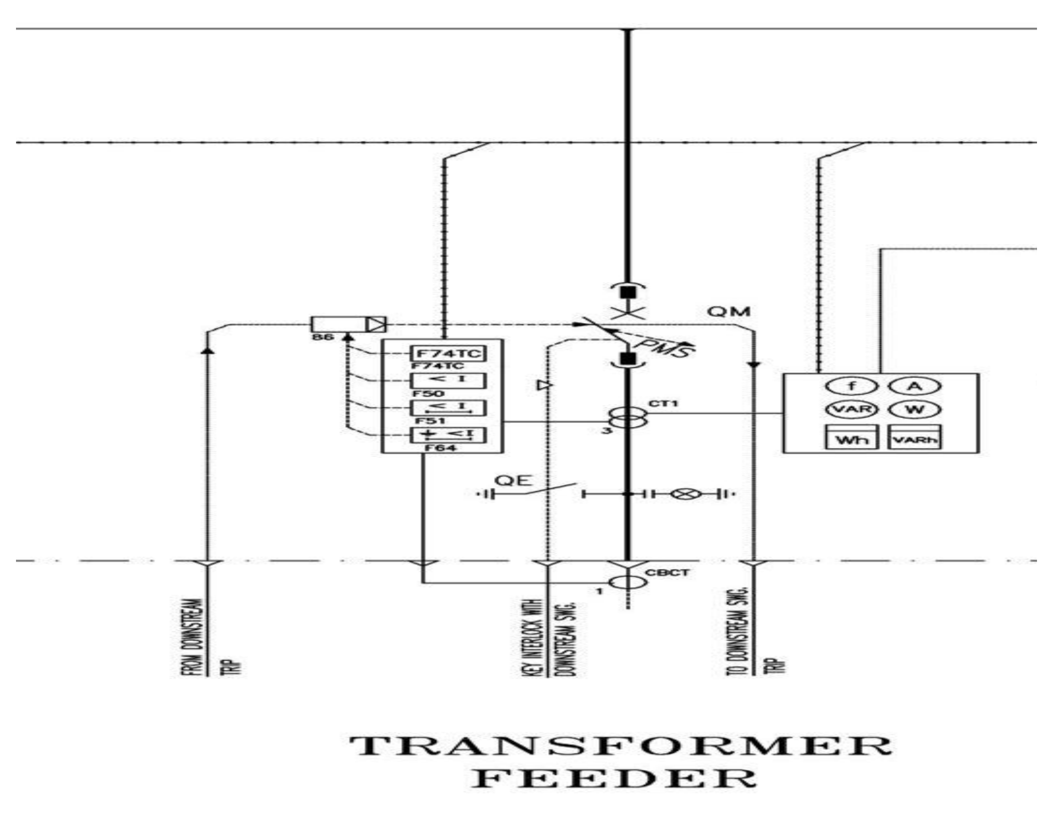


Figure 5.4: MV Transformers' protections

5.2.2.3 Medium voltage motor protections:

Protections of induction motors (squirrel cage or wound rotor), which are generally used in energy industry are as follows;

- Over temperature protection of windings and bearings of motors by RTD sensors and temperature monitor relay for motors with an output power equal or greater than 250 kW.

- It should be noted that installation of this protection for motors with an output power between 150 kW up to 250 kW is optional based on each project requirements.
- Protection against short circuit faults by installation of instantaneous over current relay for all motors.
- Protection against overload faults by relay 49 (thermal relay) with facilities to limit number of starts in a period of time in order to reduce the cumulative heat effects on motor windings. The modern microprocessor multi function relays, usually has all necessary functions for motor protections and the function 49 which is the most important protection of the motors, hence the instantaneous over current protection (51) would not be essential for motor protection.
- Protection of motors against rotor temperature rise which is caused by negative sequence current with circulating speed of two times nominal frequency (with respect to rotor). Eddy currents heat should be protected by 46 relay (reverse phase or phase balance).
- In “wound rotor type motors”, if any fault happens in rotor systems, (i.e., circulation of electrolyte or any other problem in rotor contacts with windings), according to motor manufacturer’s specific design, the motor start up command will be blocked and the relay with function (51LR) shall be used to protect motor. In case of any rotor failure during normal running, this relay must trip the motor feeder as well.
- Protection against earth fault (51N) by using core balance CT or digital relays that sum up secondary currents of CTs on each phase.
- Protection against bearings vibration for motors with rated power greater than 1500 kW shall be provided with vibration monitoring relay.
- It is advisable to use lock out relay for medium voltage transformer and motor type feeders in order to block the closing command of breaker before fault removal**.**

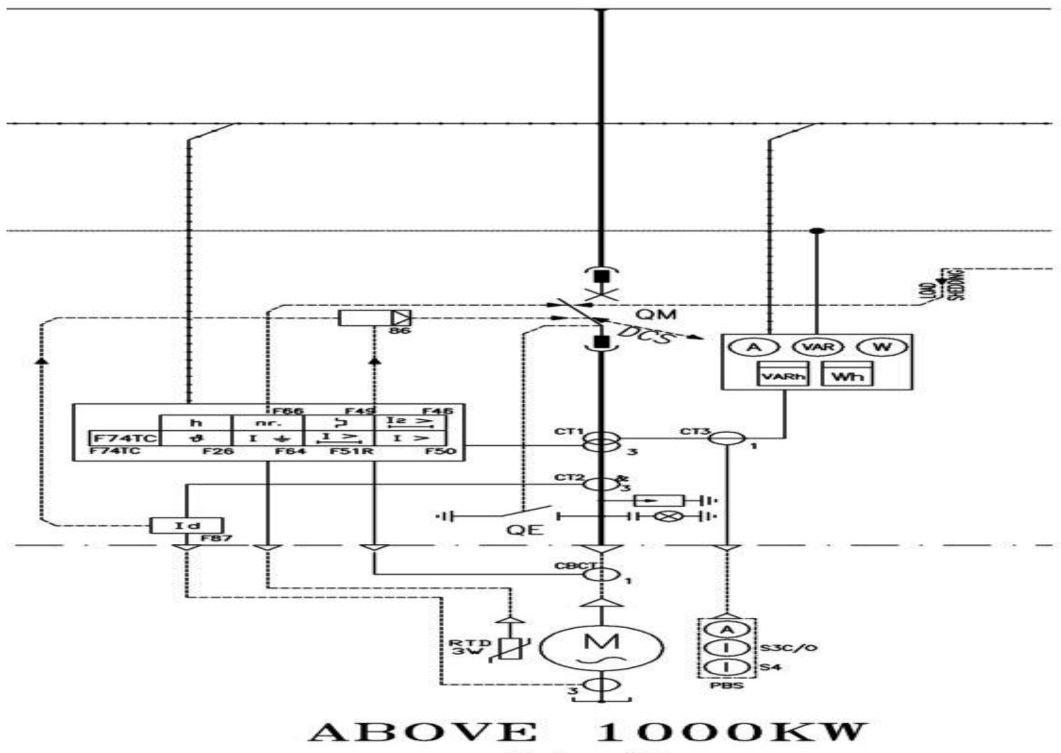


Figure 5.5: MV motors' protections

5.3 Equipment protection in hazardous area

Oil & gas refineries are usually not safe places in terms of existences of flammable gases or liquids. Consequently, for selection of electrical equipments special measurements should be considered. Different methods of equipments' selection as well as their major definitions are explained briefly in the following;

5.3.1 Hazardous area zones

Hazardous areas are divided into three zones, namely [6]:

Zone 0

Zone 0 is a location in which ignitable concentrations of flammable gases or vapours are present either continuously or for a long period of time.

Zone 1

Zone 1 is a location in which ignitable concentrations of flammable gases or vapors are likely to exist under normal operating conditions or exist frequently because of repairs of pumps or compressor stations.

Zone 2

Zone 2 is a location in which ignitable concentrations of flammable gases or vapors are not likely to occur in normal operations except for a short period of time.

The extent of a zone is three dimensional and is defined as the distance in any directions (i.e., vertical and horizontal) from the source of release to the point where the flammable mixture has been sufficiently diluted by air to a level below the lower explosive level (LEL) of the mixture.

An area is considered to be unclassified or non-hazardous if the location is not classified as a Zone 0, Zone1 or Zone 2 area.

Refer to Table below for cross referencing of Zones with other Classification methods.

Table 5.3: Hazardous Classification Cross Reference Table

Standards	**Classified Area**		
IEC 60079-10 CENELEC	Zone 0	Zone 1	Zone 2
API RP 500A or NFPA 70 or NEC 500.5 to NEC 500.7	Class 1 Division 1		Class 1 Division 2

5.3.2 Gas Groups

Flammable liquids, gases and vapours can be divided into the basic gas groups as follows:

IIA – Propane
IIB – Ethylene
IIC – Hydrogen
IID – Acetylene

Definitions

According to IEC [7], hazardous areas are the zones in which explosive or ignitable gas (or vapors) atmosphere are or may be present among the products above mentioned.

Table 5.4: IEC Gas Groups versus EN and NEC/UL Codes

IEC 60079-12	**EN 50.014**	**NEC/UL 1604**		
Gas Group	Gas Group	Class	Division	Group
I	I	I	I or 2	D
IIA	11A			
IIB	IIB	I	I or 2	C or B
IIC	IIC	I	1 or 2	A or B

5.3.3 Temperature Class

Flammable mixtures of gas, vapours or mists with air have a minimum ignition temperature under normal conditions. The maximum surface temperature of electrical equipment which is to be installed in the hazardous area has to be lower than the minimum ignition temperature of the gas mixture during normal operation or during an expected overload.

Surface temperatures were determined for various electrical equipments for use in hazardous areas. They are designed to operate with a maximum surface temperature as outlined in the following temperature classes:

T1- Maximum surface temperature of 450°C
T2- Maximum surface temperature of 300°C
T3- Maximum surface temperature of 200°C
T4- Maximum surface temperature of 135°C
T5- Maximum surface temperature of 100°C
T6- Maximum surface temperature of 85°C

Table 5.5: Protective equipment type in hazardous area

Zone	**Letter Designation of Protection**	**Type of Protection**
Zone 0	Ia	Intrinsically Safe – Apparatus is incapable of releasing enough energy to cause an explosion
Zone 1	M	Encapsulation – Arcing device is enclosed in resin
	D	Flameproof - Enclosure can contain an internal explosion
	E	Increased Safety – Enclosure does not allow the ingress of hazardous gases
	Ib	Intrinsically Safe – Apparatus is incapable of releasing enough energy to cause an explosion
	O	Oil Immersion – Arcing device is enclosed in oil
	Q	Powder Filling – Arcing device is enclosed in finely ground power
	P	Purged/pressurized enclosure – Pressure is higher than the area surrounding the enclosure
Zone 2	NC	Non-incendive – Hermetically sealed
	NA	Non- Sparking Device
	NR	Restricted Breathing – Enclosure restricts the ingress of hazardous gases.

5.3.4 Protection Methods

Table 5.5 provides examples of the method of equipment protection which is suitable for use in the related zones.

Conclusion

6

As mentioned in the previous chapters, the purpose of this study is to design the stable electrical system in refineries. Considering the following items are important key measurements that ascertain a safe, stable and continuous power supply:

1. Precise load list in terms of required power, load factors, load type and relevant feeding type assures a reliable system. Since the main purpose of electrical network is to energize electrical loads, the better understanding of loads, the better design of the network.

2. Taking normal feeding, emergency feeding and vital feeding (for relevant loads) into consideration are crucially important.

3. Reliable protections including relays and circuit breakers to protect equipment and personnel in faulty situation must be paid attention to.

   In addition, right connection of electrical protection and relays with other instrumentation systems such as fire & gas protection system, distribution control system, emergency shutdown system will assure safe refinery.

4. Main studies including load flow, short circuit and transient study assist us to confirm stability of system. Furthermore, it should be noted that any modifications to each study will influence on the results of other studies and in the final stages, entire studies' results should be checked in order to approve all desired results.

5. Cable sizing is important in many aspects such as cost, voltage drop and reactive power losses. Wrong cable sizing can adversely affect on the system by leading to faulty conditions as well as huge costs of detecting the fault and replacing the cable which can be costly and time consuming.

6. Although in this project the power factor was acceptable according to design criteria, but capacitor bank is recommended for improving power factor for the purpose of having lower reactive losses, better control on voltage drops and lower size of cable. Selecting smaller cable cross section can be more economical.

7. By adjusting short circuit impedance of transformer, it is possible to control short circuit current. But the higher short circuit impedance, the higher losses. That is why utilizing transformers with higher sizes are sometimes recommended. Considering the tap changer for transformer can assure the required voltage level at site.

8. Right equipment selection for hazardous areas of refineries can avoid explosion and any possible disaster.

9. To ascertain the ability of the motors to start up the required torque must be provided and also start up time is an important factor that should be as short as possible.

References and Appendixes

7

References:

[1] IEC 60947-2: Low-Voltage Switchgear and Control gear Part 2: Circuit-Breakers Second Edition; Corrigendum-1997; Amendment 1-1997

[2] IEC 60502: Extruded Solid Dielectric Insulated Power Cables for Rated Voltages from 1 kV up to 30 kV First Edition

[3] IEC 60909: Short-Circuit Current Calculation in Three-Phase A.C. Systems First Edition

[4] IEC 60076-5: Power Transformers Part 5: Ability to Withstand Short Circuit First Edition; (Amendment 2-1994)

[5] IEC 60056: High-Voltage Alternating-Current Circuit-Breakers Fourth Edition; Corrigendum-04/1989; Amendment 1-1992; Amendment 2-1995; Amendment 3-1996

[6] IEC 60079-10: Electrical Apparatus for Explosive Gas Atmospheres Part 10: Classification of Hazardous Areas Third Edition; Corrigendum-1996

[7] IEC 60079-12: Electrical Apparatus for Explosive Gas Atmospheres Part 12: Classification of Mixtures of Gases or Vapours with Air According to Their Maximum Experimental Safe Gaps and Minimum Igniting Currents First Edition

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[9] ABB Technical application paper Volume 2: MV/LV transformer substations, theory and an example of short circuit calculation, February 2008, 1SDC007101G0202

[10] ABB Electrical installation hand book, second edition Published by ABB SACE via Baioni, 35 - 24123 Bergamo (Italy)

Appendixes:

Appendix A: OVERAL SINGLE LINE DIAGRAM

Appendix B: MV SINGLE LINE DIAGRAM AND PROTECTIONS

Appendix C: LV SINGLE LINE DIAGRAMS AND PROTECTIONS

Appendix D: LOW AND MEDIUM VOLTAGE MOTORS WITH CONVENTIONAL RATINGS AND CHARACTERISTICS ACCORDING TO IPS-E-EL-100

APPENDIX A

OVERAL SINGLE LINE DIAGRAM

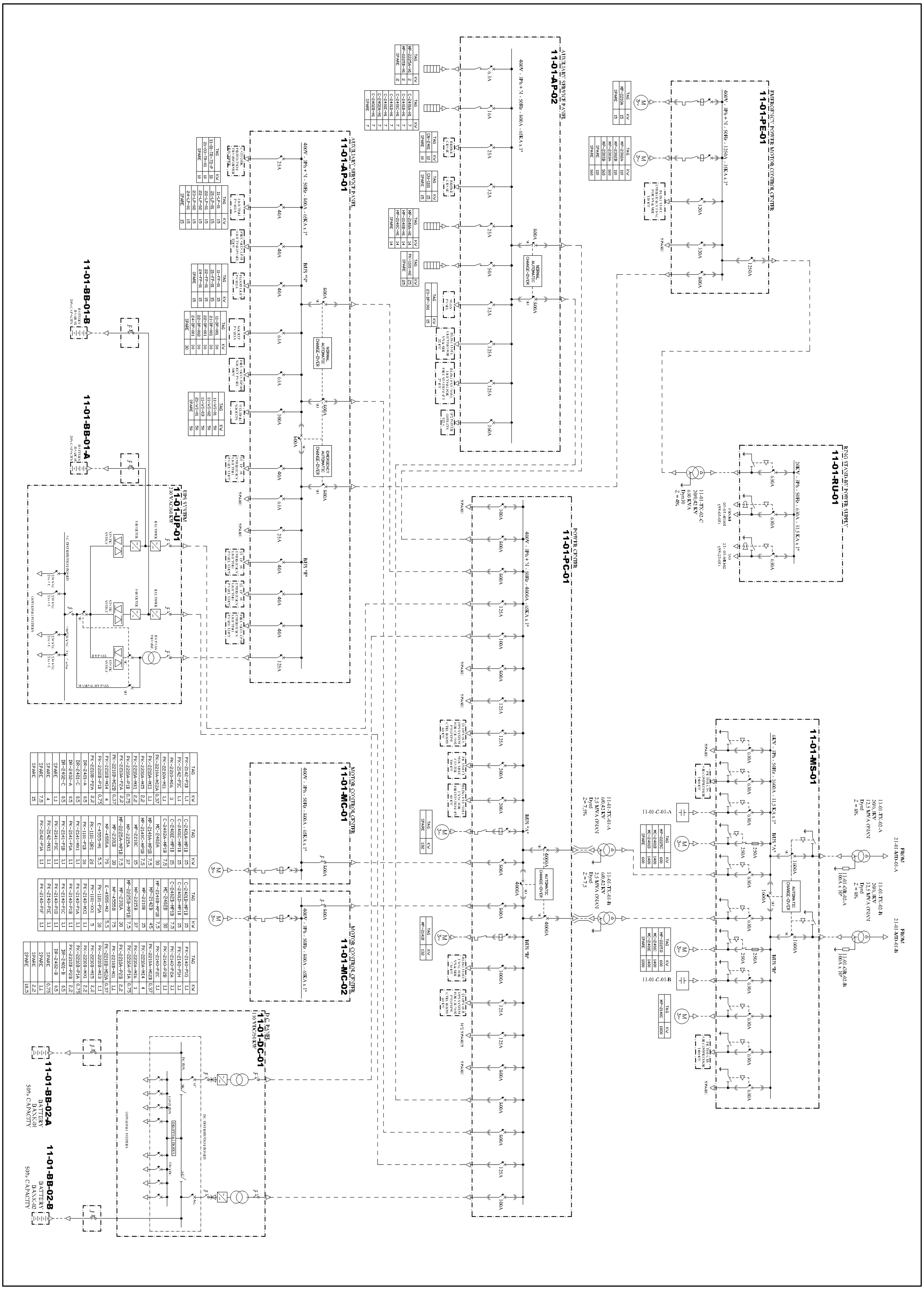


Figure 7.1: Overall Single Line Diagram

APPENDIX B:

MV SINGLE LINE DIAGRAM AND PROTECTIONS

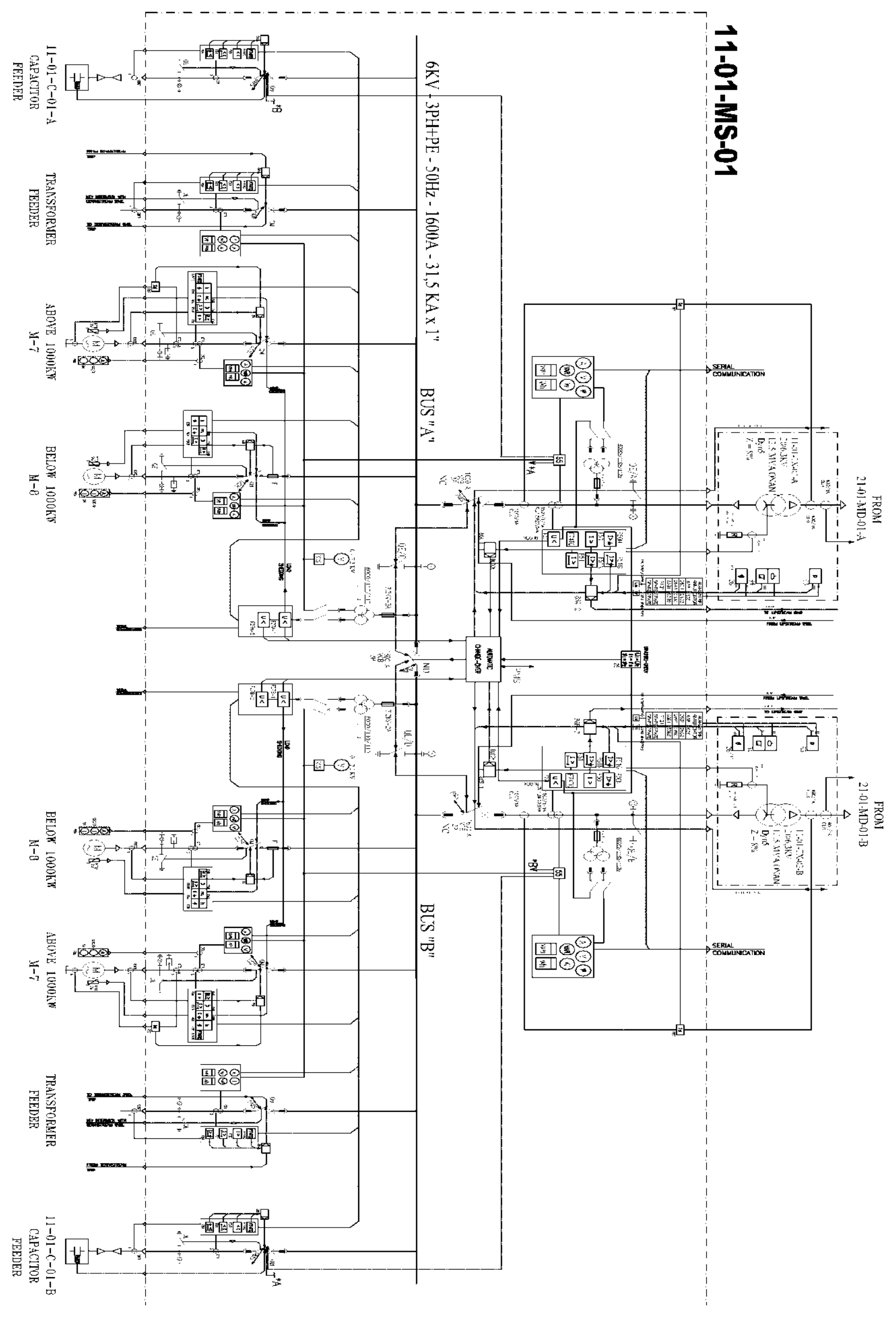


Figure 7.2: MV Single Line Diagram and Protections

APPENDIX C:

LV SINGLE LINE DIAGRAMS AND PROTECTIONS

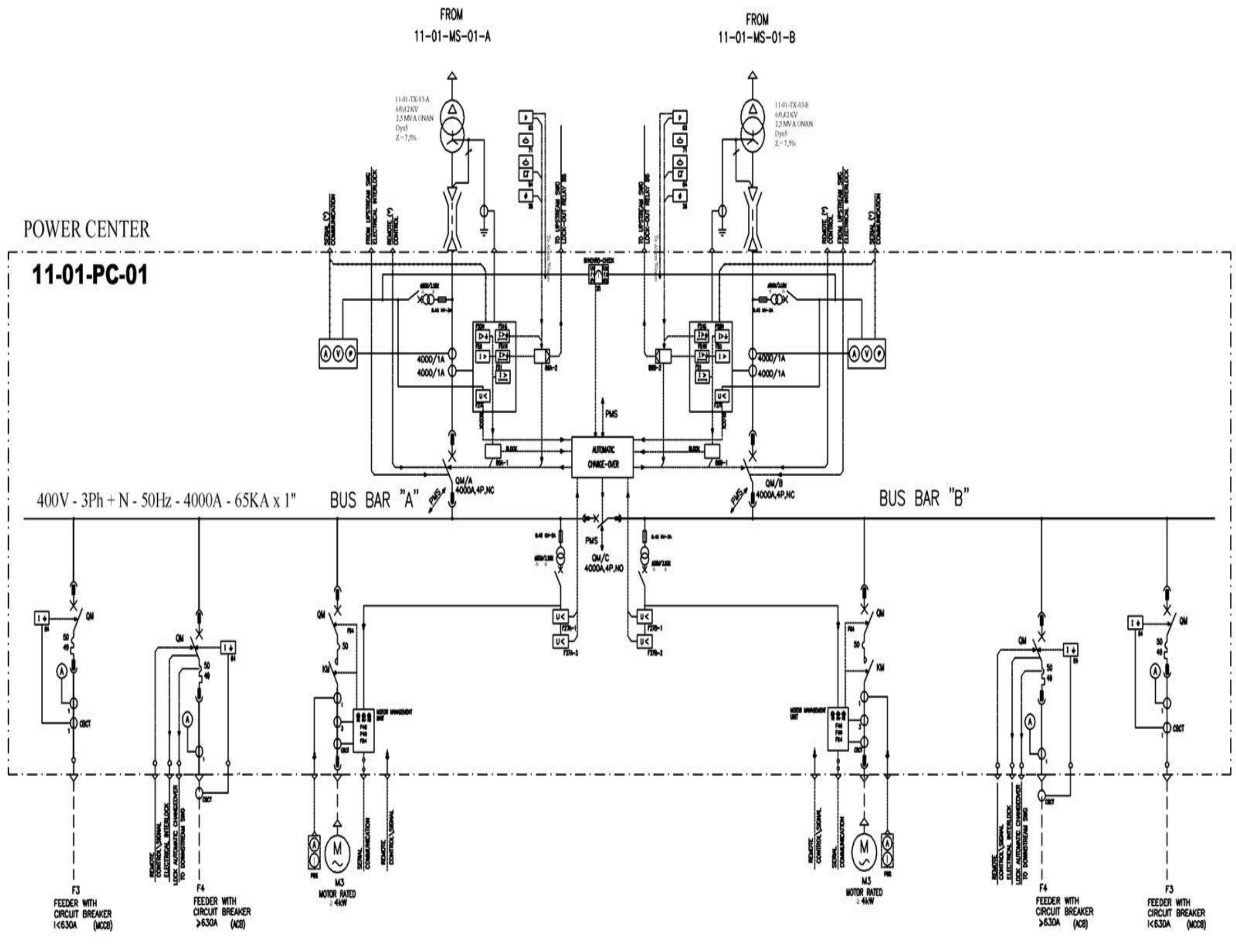


Figure 7.3: Low voltage single line diagram and protection –Power Center

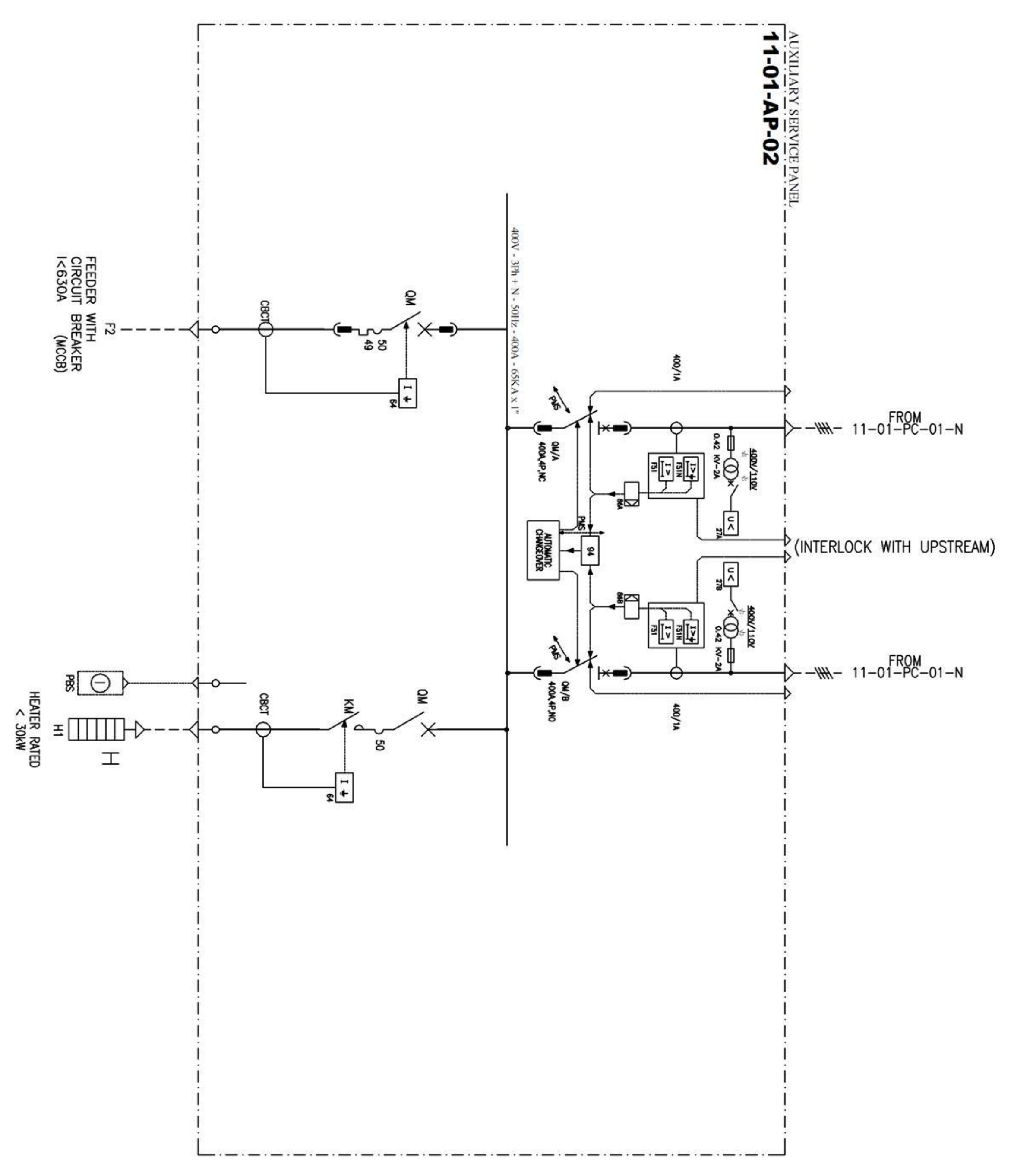


Figure 7.4: Low voltage single line diagram and protection –Auxiliary Panel

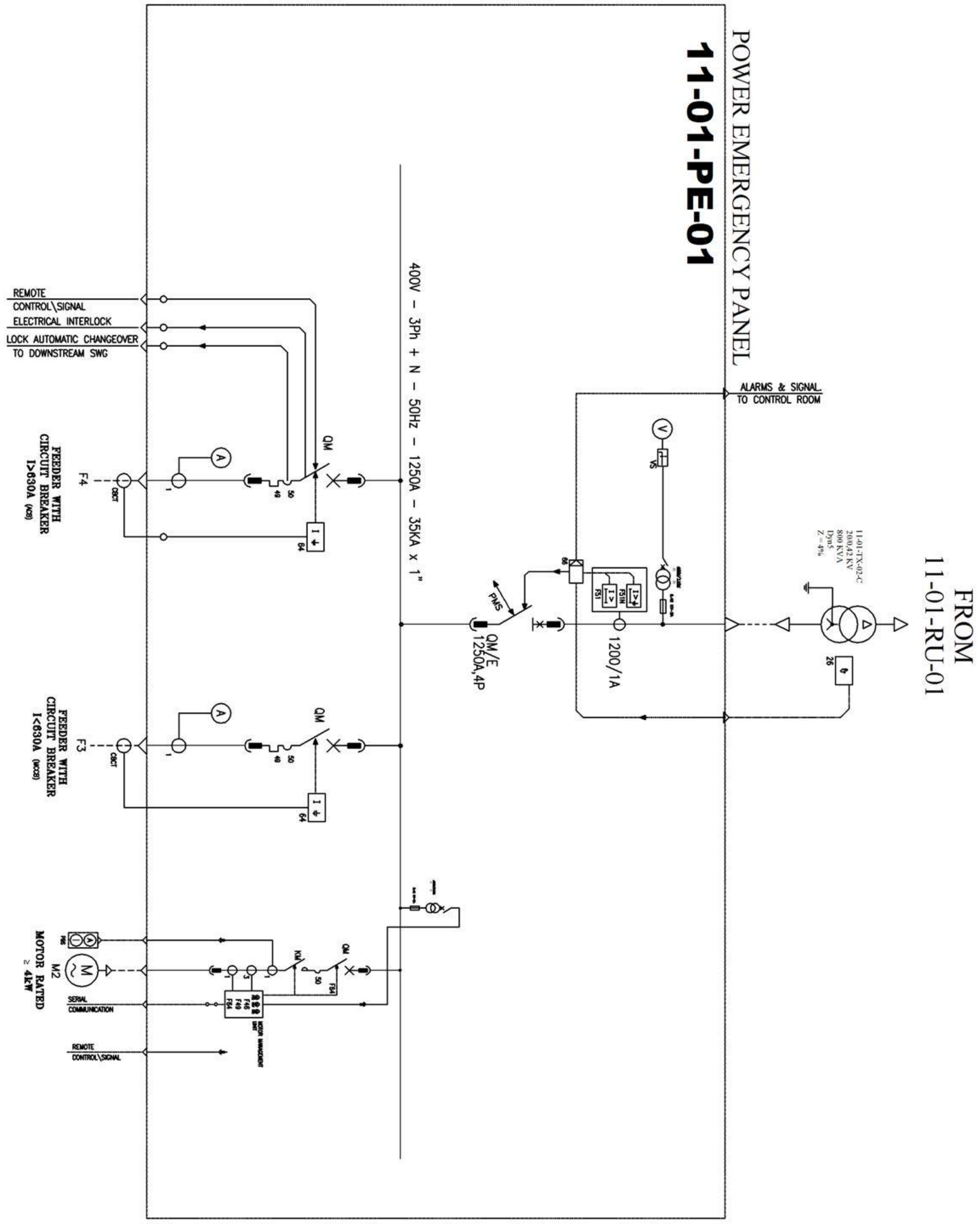


Figure 7.5: Low voltage single line diagram and protection –Power Emergency Panel

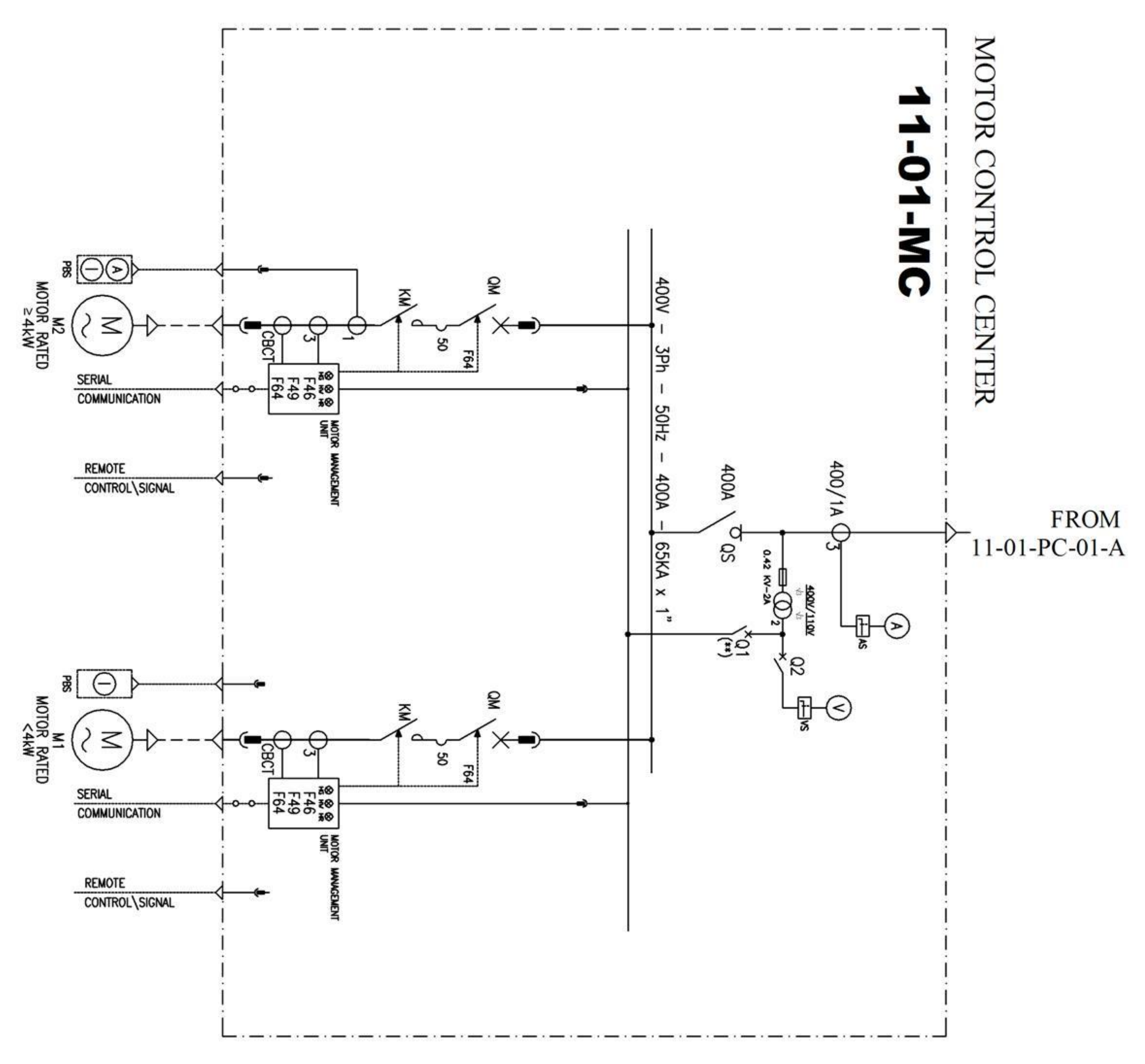
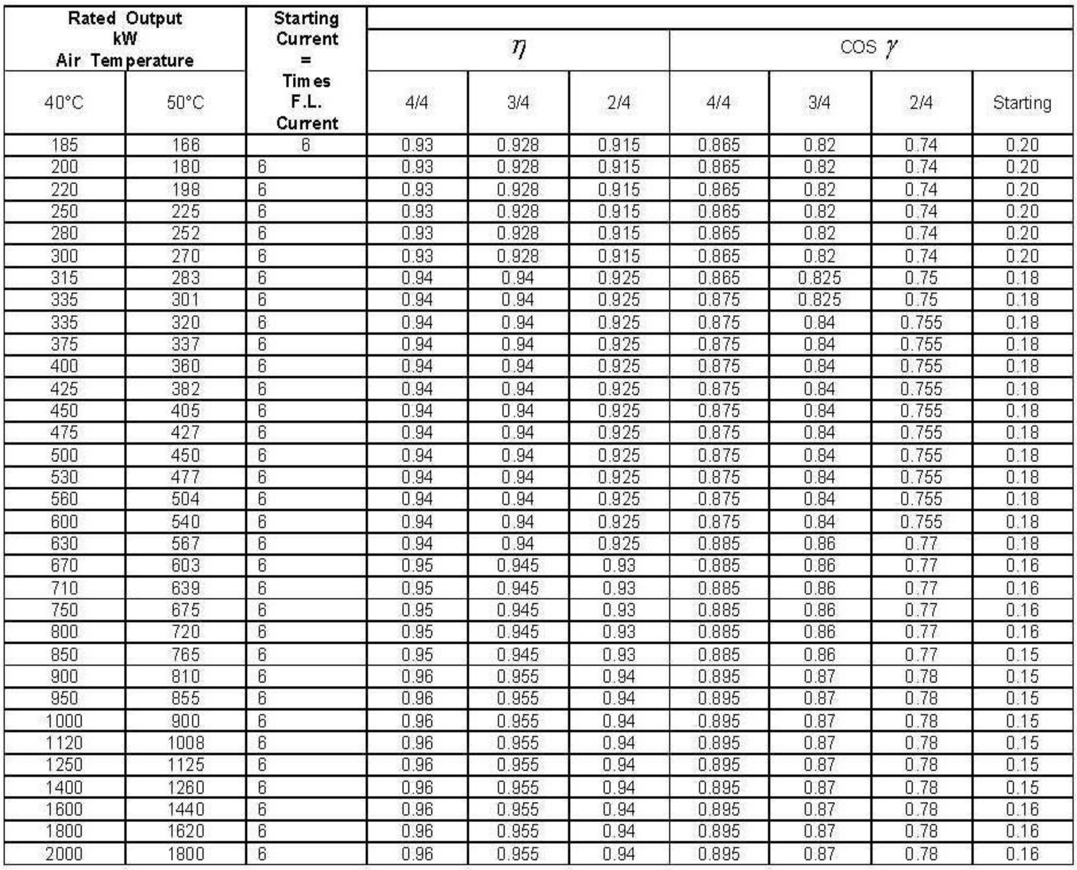


Figure 7.6: Low voltage single line diagram and protection –Motor Control Center

APPENDIX D:

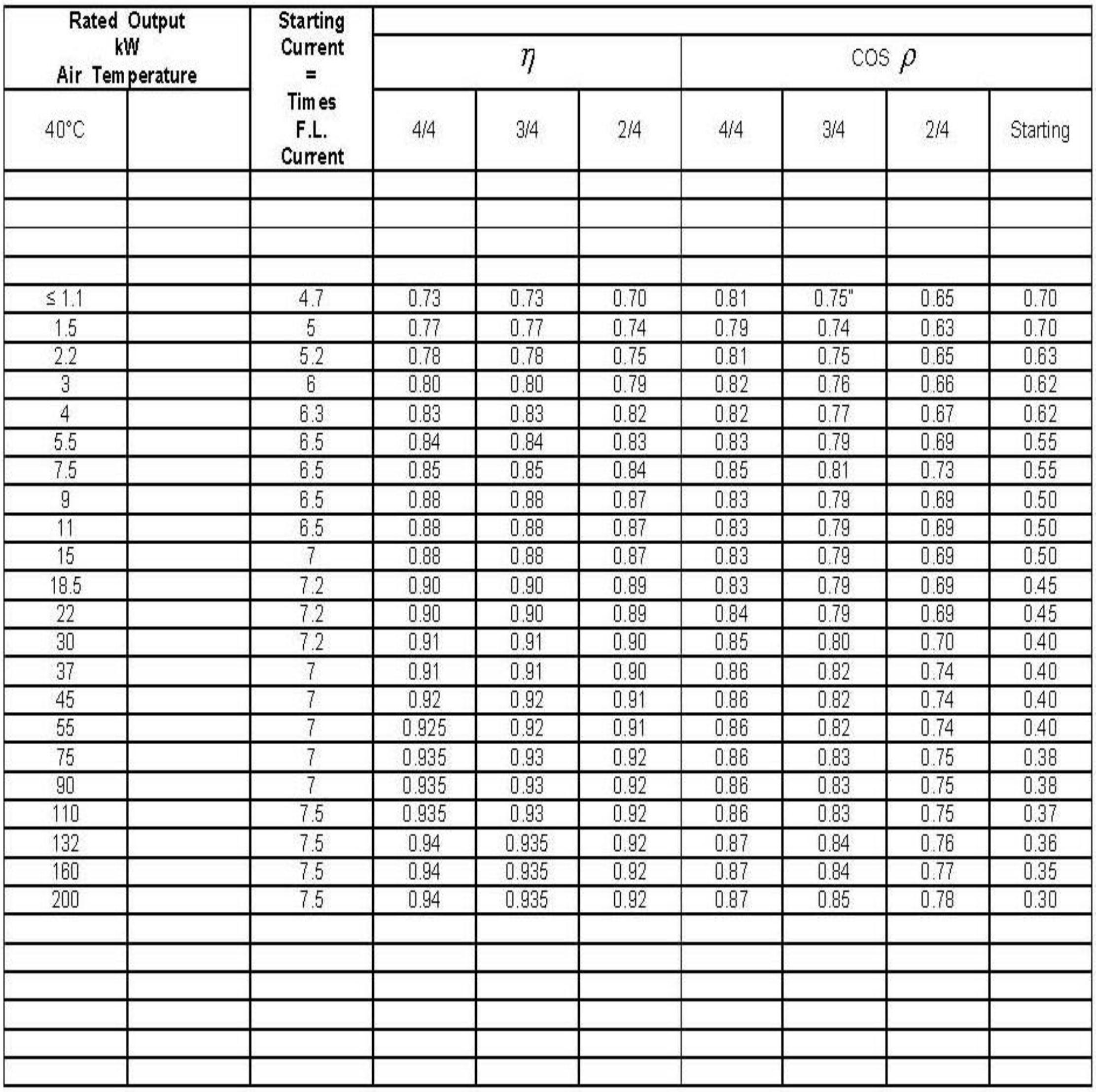
LOW AND MEDIUM VOLTAGE MOTORS WITH CONVENTIONAL RATINGS AND CHARACTERISTICS ACCORDING TO IPS-E-EL-100

Table 7.1: Medium Voltage Motors Ratings



Rated Output kW Air Temperature		Starting Current = Times F.L. Current	η			COS γ			
40°C	50°C		4/4	3/4	2/4	4/4	3/4	2/4	Starting
185	166	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
200	180	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
220	198	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
250	225	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
280	252	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
300	270	6	0.93	0.928	0.915	0.865	0.82	0.74	0.20
315	283	6	0.94	0.94	0.925	0.865	0.825	0.75	0.18
335	301	6	0.94	0.94	0.925	0.875	0.825	0.75	0.18
335	320	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
375	337	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
400	360	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
425	382	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
450	405	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
475	427	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
500	450	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
530	477	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
560	504	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
600	540	6	0.94	0.94	0.925	0.875	0.84	0.755	0.18
630	567	6	0.94	0.94	0.925	0.885	0.86	0.77	0.18
670	603	6	0.95	0.945	0.93	0.885	0.86	0.77	0.16
710	639	6	0.95	0.945	0.93	0.885	0.86	0.77	0.16
750	675	6	0.95	0.945	0.93	0.885	0.86	0.77	0.16
800	720	6	0.95	0.945	0.93	0.885	0.86	0.77	0.16
850	765	6	0.95	0.945	0.93	0.885	0.86	0.77	0.15
900	810	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
950	855	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
1000	900	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
1120	1008	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
1250	1125	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
1400	1260	6	0.96	0.955	0.94	0.895	0.87	0.78	0.15
1600	1440	6	0.96	0.955	0.94	0.895	0.87	0.78	0.16
1800	1620	6	0.96	0.955	0.94	0.895	0.87	0.78	0.16
2000	1800	6	0.96	0.955	0.94	0.895	0.87	0.78	0.16

Table 7.2: Low Voltage Motors Ratings



Rated Output kW Air Temperature		Starting Current = Times F.L. Current	η			COS ρ			
40°C			4/4	3/4	2/4	4/4	3/4	2/4	Starting
≤ 1.1		4.7	0.73	0.73	0.70	0.81	0.75"	0.65	0.70
1.5		5	0.77	0.77	0.74	0.79	0.74	0.63	0.70
2.2		5.2	0.78	0.78	0.75	0.81	0.75	0.65	0.63
3		6	0.80	0.80	0.79	0.82	0.76	0.66	0.62
4		6.3	0.83	0.83	0.82	0.82	0.77	0.67	0.62
5.5		6.5	0.84	0.84	0.83	0.83	0.79	0.69	0.55
7.5		6.5	0.85	0.85	0.84	0.85	0.81	0.73	0.55
9		6.5	0.88	0.88	0.87	0.83	0.79	0.69	0.50
11		6.5	0.88	0.88	0.87	0.83	0.79	0.69	0.50
15		7	0.88	0.88	0.87	0.83	0.79	0.69	0.50
18.5		7.2	0.90	0.90	0.89	0.83	0.79	0.69	0.45
22		7.2	0.90	0.90	0.89	0.84	0.79	0.69	0.45
30		7.2	0.91	0.91	0.90	0.85	0.80	0.70	0.40
37		7	0.91	0.91	0.90	0.86	0.82	0.74	0.40
45		7	0.92	0.92	0.91	0.86	0.82	0.74	0.40
55		7	0.925	0.92	0.91	0.86	0.82	0.74	0.40
75		7	0.935	0.93	0.92	0.86	0.83	0.75	0.38
90		7	0.935	0.93	0.92	0.86	0.83	0.75	0.38
110		7.5	0.935	0.93	0.92	0.86	0.83	0.75	0.37
132		7.5	0.94	0.935	0.92	0.87	0.84	0.76	0.36
160		7.5	0.94	0.935	0.92	0.87	0.84	0.77	0.35
200		7.5	0.94	0.935	0.92	0.87	0.85	0.78	0.30