POWER SYSTEM STUDY FOR OIL AND GAS PLATFORM CONNECTED TO ONSHORE GRID

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (INDUSTRIAL ELECTRONIC AND CONTROL)

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ABSTRACT

Normally for oil and gas offshore platform, the electrical power supply is generated from the generator either using gas turbine generator, gas engine generator and diesel engine generator. The main power supply is backup by diesel engine generator in case emergency or during black start of the platform. As the design of oil and gas platform become complex, the size of generator keeps increasing. A new concept is being explored to mitigate this problem. Oil and gas company is looking to provide power generation from onshore and supplying the electrical power to a substation platform offshore and then distributed it to various platform. Even though the idea is feasible, but there is a challenge technically. One of the technical expect that need to be carefully consider is the Ferranti effect over long transmission line, in this case the submarine cable. Therefore, some study needs to be done to analyze the stability of the power system when a system is connected to long submarine cable. When there is long transmission line, the tendency of Ferranti effect to occur is likely. So, this study is performed to study the magnitude of Ferranti effect on the propose system and how to mitigate this power stability issue. A load flow study is perform using ETAP software to determine the effect of Ferranti Effect on difference length of submarine cable. Shunt reactor is used as the mitigation method to the Ferranti Effect. This study also determined the size of shunt reactor required over the length of submarine cable. Short circuit study was performed to determine the short circuit level at the receiving end for different length of submarine cable. This short circuit level is crucial in determined the rating of switchgear at the offshore.

Key Words: Ferranti Effect, Shunt Reactor,Submarine Cable,Load Flow Study, Short Circuit Study.

[POWER SYSTEM STUDY FOR OIL AND GAS PLATFORM CONNECTED TO ONSHORE GRID]

ABSTRAK

Kebiasaanya sumber kuasa elektrik untuk pelantar minyak dihasilkan oleh janakuasa samaada menggunakan penjanakuasa gas turbin, penjanakuasa gas enjin dan penjanakuasa diesel enjin. Penjanakuasa utama ini akan dibantu oleh penjanakuasa diesel enjin jika berlaku kecemasan atau semasa perngaktifan permulaan pelantar. Disebabkan pelantar minyak sekarang semakin komplek, saiz penjanakuasa menjadi semakin besar. Satu konsep baru sedang diterokai untuk mengatasi masalah ini. Syarikat minyak dan gas sedang melihat peluang untuk menyalurkan kuasa elektrik dari darat ke pelantar minyak ditengah laut dan kemudiannya menyalurkan ke pelantar minyak yang lain. Walaupun konsep itu tidak mustahil, akan tetapi terdapat halangan dari segi teknikal. Salah satu cabaran teknikal yang harus dititik beratkan adalah kesan Ferranti keatas kabel dasat laut yang panjang. Oleh yang demikian, satu kajian harus dijalankan untuk menganalisis kestabilan system elektrik apabila dihubungkan melalui kabel dasar laut yang panjang. Kesan Ferranti selalunya akan wujud apabila sistem elektrik dihubungkan melalui kabel yang Panjang. Jadi, analisis ini dijalankan untuk mengkaji tahap kesan Ferranti terhadap sistem elektrik dan bagaimana untuk mengatasi masalah kestabilan sistem. Satu kajian aliran kuasa dilaksanakan mengunakan perisian ETAP. Reaktor penarik arus elektrik digunakan sebagai satu cara untuk mengatasi masalah ini. Kajian ini juga mengkaji saiz reaktor penarik arus elektrik yang diperlukan untuk kabel dasar laut yang berbeza. Kajian litar pintas juga dijalankan untuk menganalisa tahap litar pintas untuk saiz kabel dasar laut yang berbeza. Kajian ini penting untuk menentukan spesifikasi alatan di atas pelantar.

Kata Kunci: Kesan Ferranti, Reaktor penarik Arus,Kabel Dasar Laut,Analisa Aliran Arus, Analisa Litar Pintas.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	:	Ampere
AC	:	Alternating Current
CAPEX	:	Capital Expenditure
DVR	:	Dynamic Voltage Restorer
FACTS	:	Flexible AC Transmission System
kVA	:	kilo Volt Ampere
kW	:	kilo Watt
kVar	:	kilo Volt Ampere Reactive
kA	:	kilo Ampere
kV	:	kilo Volt
LV	:	Low Voltage
OPEX	:	Operational Expenditure
SVC	:	Static VAR Compensator
SSSC	:	Static Synchronous Series Compensator
STATCOM	:	Static Synchronous Compensator
UPS	:	Uninterrupted Power Supply
VAR	:	Volt Ampere Reactive
V	:	Volt
VSD	:	Variable Speed Drive

CHAPTER 1: INTRODUCTION

1.1 Background

Oil and gas industry are the biggest industry in Malaysia. The demand for oil and gas increase every year. Normally for oil and gas offshore platform, the electrical power supply is generated from the generator either using gas turbine generator, gas engine generator and diesel engine generator. The main power supply is backup by diesel engine generator in case emergency or during black start of the platform. This power generation is then further distributed down to the load demand on the platform for the production or utility purposes. As the design of oil and gas platform become complex, the total power consumption increases hence the size of generator become bigger. This method required regular maintenance to the generator in order to ensure the oil and gas platform will not loss power generation which can contribute to the loss of production. Besides that, every oil and gas platform required engineer or technician to be onboard in order to monitor the operation of the oil and gas platform. The cost of maintenance and hiring personnel to be on board is high every year.

As the size of generator keep increasing and cost of maintenance and operation increase, a new concept is being explored to mitigate this problem. Oil and gas company is looking to provide power generation from onshore and supplying the electrical power to a substation platform offshore and then distributed it to various platform. This will reduce the cost of maintenance as the gas turbine generator is no longer required. Every platform doesn't have their own power generation anymore. Even though, capital expenditure (CAPEX) is high to install submarine cable but over the year the maintenance cost and operational cost (OPEX) is reducing.

The idea of supplying power from onshore connected to existing power grid is not a new idea but due to some limitation especially on the installation of submarine cable it never been considered before. Nowadays, as technology is growing, the idea is become feasible. Even though the idea is feasible, but there is a challenge technically. One of the technical expect that need to be carefully consider when supplying power over long transmission line is Ferranti Effect as simulated by H.Amreiz, A.Janbey, M.Darwish(2019). There are studied done on transmitting power supply over submarine cable however the study was transmitting power supply from offshore to the onshore using wind turbine farm (Antunes,dos Reis Antunes, Costa Santos, Pires,2018).

1.2 Problem Statement

When a power generation is supplied over a long-distance transmission line, there will be a situation where a phenomenon called the Ferranti effect might happen. The Ferranti effect exit when the receiving end of very long transmission voltage increase if there is no load or small load connected. This cause power stability issue to the overall power system. So, this study is performed to study the magnitude of Ferranti effect on the proposed system and how to mitigate this power stability issue.

1.3 Objectives

The main aim of this project is to perform power system study to achieve the following objective:

- To study power system stability in term of voltage level.
- To study the Ferranti effect on downstream system over long transmission line
- To propose solution on how to mitigate power stability issue.
- To study short circuit level on the system with submarine cable as transmission line.

1.4 Scope of research

This scope of this work can be divided as below

1. Modelling the power system using ETAP software. The study is focus on the power system at the downstream/offshore platform. The main power generation from onshore will be model as power grid only.
2. To run few scenarios of load flow study and analyses the stability of the system due to Ferranti effect.
3. To study short circuit level of the power system. The short circuit level will determine the sizing of the main equipment such as switchgear bus bar rating.

1.5 Research project outline

This report is divided into five (5) chapters as per following:

Chapter 1: Introduction – In this chapter, the overview of the research background and the research objectives and scope are described.

Chapter 2: Literature Review - In this chapter, relevant research materials would be reviewed and discussed.

Chapter 3 – Methodology - In this chapter, the technique of simulation being modeled in ETAP software is explained. Standard generic equipment parameter required for the simulation will be shown and the scenarios of the simulations performed for each study will be explained.

Chapter 4: Results & Discussions – In this chapter, the results obtained from the studies will be discussed.

Chapter 5: Conclusion – In this chapter, the overall research will be concluded.

CHAPTER 2: LITERATURE REVIEW

As mention in the chapter 1, the important technical expect need to be consider in this study is the Ferranti Effect. Worth to note that this study considers submarine cable as the transmission line likewise normally transmission line is overhead or underground transmission line. Various study has been done to study the effect of Ferranti Effect but mostly on overhead transmission line. One particular study has been done on Ferranti Effect over submarine cable (Antunes,dos Reis Antunes,da Costa Santos,Pires2018) but the system is different where there are transmitting power supply from wind turbine offshore to the onshore power grid through submarine cable. Likewise, this study is focusing transmitting power supply from onshore power grid to the offshore platform through submarine cable.

There are three aspect to be consider in this study, the Ferranti Effect, the transmission line model and the method to mitigate the Ferranti Effect.

2.1 Ferranti Effect

The Ferranti effect is a phenomenon where the voltage at the receiving end voltage over long transmission line increase when there is small load or no load connected. In practical, the receiving end voltage should be lower than sending end voltage because of voltage drop in transmission line, therefore current is supplied to the end load. In the year of 1890, Sir S.Z Ferranti, discover the receiving end voltage often increase above the sending end voltage in the case of medium or long-distance transmission line is lightly loading or no-load loading operation. It happened due to capacitive charging current flowing in the transmission line through the inductance and causing the voltage increase relative to the transmission line length increase (Deb,2012).

The nominal π model of the line is the best to explain the Ferranti Effect. Figure 2.1 shows the phasor diagram of the π model. The receiving end voltage, Vr, is represented in OE axis while the current Ic1 through the capacitor C/2 is presented in OH axis. The voltage drop across the resistance R is represented in EF axis while the Ic1X is the voltage drop across X. The phasor FG leads the phasor Ic1R by 90°. Under no-load condition, the sending end voltage VS is represented by phasor OG. It can be seen that Vs<Vr based on the phasor diagram below.

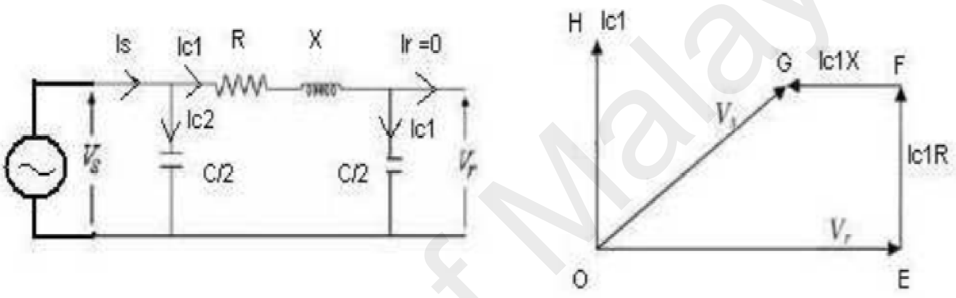

Figure 2.1: Nominal π model and phasor diagram

This can be proven from the equation below:

$$\mathrm{Vs} = \left(1 + \frac{ZY}{2}\right)Vr + ZIr \qquad (2.1)$$

At no load, Ir=0

$$\mathrm{Vs} = \left(1 + \frac{ZY}{2}\right)Vr \qquad (2.2)$$

$$\mathrm{Vs} - \mathrm{Vr} = \left(\frac{ZY}{2}\right)Vr \qquad (2.3)$$

$$Z = (r + j\omega l)S \tag{2.4}$$

$$Y = (j\omega c)S \tag{2.5}$$

Neglecting the transmission line resistance,

$$Z = j\omega lS \tag{2.6}$$

and

$$Vs - Vr = \frac{1}{2}(j\omega lS)(j\omega S)Vr = -\frac{1}{2}(\omega^2 s^2)lc\,Vr \tag{2.7}$$

This equation shows that the sending end voltage is negative which mean the receiving end voltage is higher when there is not load connected. This is Ferranti effect which is expected to occur in the model and will be analyzed.

There is various study relating Ferranti effect over long transmission line. A case study has been done on Ferranti effect and overvoltage of 500kV transmission line in Thailand(Petcharaks,Yu,Panprommin,1999). The transmission line length is 223km. Base on the study, two (2) shunt reactor required at both end of transmission line in order to overcome the Ferranti Effect.

There is other study done on Ferranti effect and the fault over long transmission line however this study is using MATLAB as simulation tools (Mali,Aglaue,Mane,Shakya,2016). This study is done over 400km long transmission line. It is observed the Ferranti Effect increase as the length of transmission line increase.

2.2 Transmission Line Model

Power system performance will depend on transmission line performance. Transmission line performance depends on series inductance L and resistance R, conductance G and shunt capacitance C. The inductance L exist because a force of the magnetic lines appearing around the conductor surrounds the conductor carrying current. Because every conductor has an opposition to the current flow the resistance R exist. The shunt conductance G exist because there is a current leakage over the insulator surface. The capacitance C exist because the carrying current conductor with the earth would form a capacitor (H.Amreiz, A.Janbey,M.Darwish,2019).

In general, the transmission line can be classified into the following types in terms of its physical length (Kiran,Laxmi,2011):

- Short line (< 80km)
- Medium length line (80km < L <120 km)
- Long line (> 120 km)

The transmission line model can be different base on the physical length of the line. For short line, the series parameter is only being consider, ignoring the shunt parameter.

The parasitic capacitance becomes significant for medium length transmission line which impact the receiving voltage and sending voltage and current. Therefore, the shunt component is including in the equivalent line model.

In the long transmission line, the distributed effect of parameter becomes significant and the line has to be represented by the equivalent circuit of π. The line can also represent smaller cascaded sections, where each section is represented by a smaller equivalent π circuit with a medium length line.

2.3 Method to Mitigate Ferranti Effect

The Ferranti effect if not mitigated will be harmful to the system. On prolong condition the life span of the electrical equipment will be deteriorate due to frequent operating at high voltage level. In order to overcome this problem some mitigation method has been suggested. Many studies have been performed to suggest the method to overcome this phenomenon.

Series and Shunt Volt Ampere Reactive (VAR) compensation are used to change the electrical characteristic of electrical power system. Series compensator change the reactance parameter while shunt compensation changes the load impedance of the transmission line (Kiran,Laxmi,2011). Shunt compensation use shunt capacitor during peak load to produce lagging VAR at the receiving end and shunt reactors during low load to absorb line generated VAR to avoid instability.

The Ferranti Effect can be overcome by connecting shunt reactor busbar of the distribution switchgear or directly to the submarine cable. The function of shunt reactor is to consume the excess reactive power generated by the submarine cable under low-load condition and stabilized the system voltage. The shunt reactor is basically same as the transformer, but it has only one winding per phase as compare to transformer.

The selection of shunt compensation reactor is also important to take into consideration. During load rejection or minimal load condition, a resonance phenomenon is highly potent due to capacitive effect of the line. A case study has been done (Samimi,Ahmad-Joneidi,Majzoobi,Golshannavaz,2018) to suggest the appropriate selection of shunt compensation reactor.

In modern world, Flexible AC Transmission system (FACTS) controller is used to mitigate the steady state control issue of the power system. They are various type of FACTS devices nowadays, however the device that provide shunt compensator is static synchronous compensator (STATCOM) and Static VAR Compensator (SVC)(Mohanty,Barik,2018). The SVC operate to control particular parameters by changing the capacitive or inductive current. It can improve the transmission capacity and efficiency. However, SVC have harmonic interference when the voltage drops and severe compensating capacity shortage. This effectively solved by STATCOM. STATCOM is designed to control the inductive or capacitive output current thus improve the power system stability.

As the SVC and STATCOM are shunt compensator, there are study done using different method and devices which is series compensator. One of series compensator devices is Dynamic Voltage Restorer (DVR) and has been used as one of the methods to overcome Ferranti Effect (Tarannum,Singh,2017). Basically, DVR will inject a required magnitude frequency and voltage to restore the load side voltage to the desired amplitude. The advantages using DVR is small size and efficient operation. Figure 2.2 shows the circuit inside the DVR.

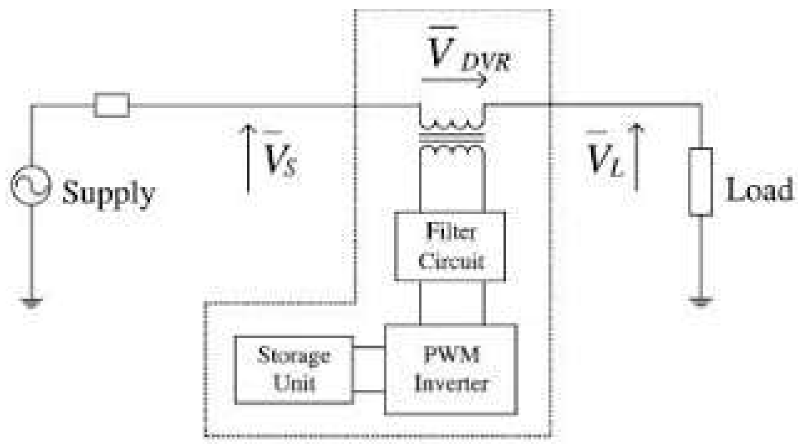

Figure 2.2: Dynamic voltage restorer

Beside DVR, there is study using static synchronous series compensator in mitigating Ferranti Effect (Chavan,Archarya,Bhattacharya,Ds,Inam,2016). Static Synchronous Series Compensator (SSSC) is a type of FACTS series voltage controller based on an inverter. The SSSC function is to monitor the active power flow over transmission line by injects controllable voltage in series. The SSSC should increase the voltage across the transmission line and thus increases the current and transmitted power of the line. The SSSC can be increase or decrease the power flow by altering the polarity of AC voltage injection. Figure 2.3 describe the schematic and connection of SSSC to the transmission line.

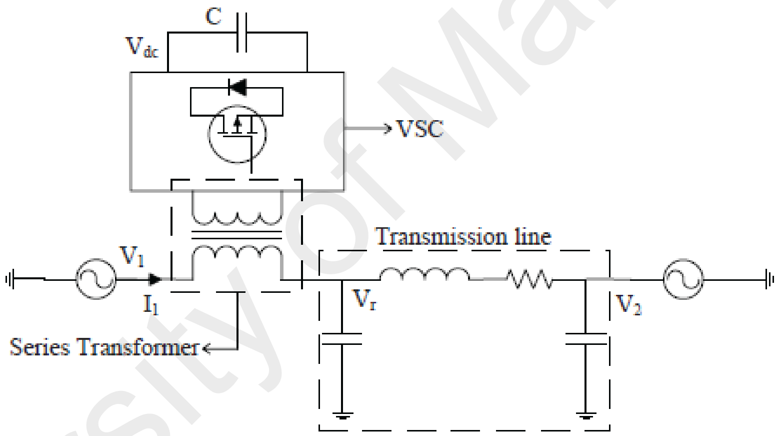

Figure 2.3: Static Synchronous Series Compensator

CHAPTER 3: METHODOLOGY

Normally in offshore platform the power generation is generated from gas turbine or diesel engine generator. The highest voltage level for offshore installation is 11kV and stepped further down to low voltage 400V. Figure 3.1 show the typical overall key line diagram of offshore power system.

As mentioned in chapter 1, the new idea is to eliminate the offshore generator and connected the offshore power system with the power supply from onshore power grid. To implement this idea, the power supply from onshore grid shall be in higher voltage before stepped down to 11kV due to voltage drop along the transmission line. Therefore, a new 230kV switchgear shall be introduced as the power receiving point from the transmission line, in this case the submarine cable. So, for this project, the power system analysis will be studied starting from the 230kV switchgear to the downstream system.

The power system study will be performed using ETAP software. The first part of this study is to model the power system in the ETAP software. After modelling the power system is done then two study will be performed, load flow and short circuit study.

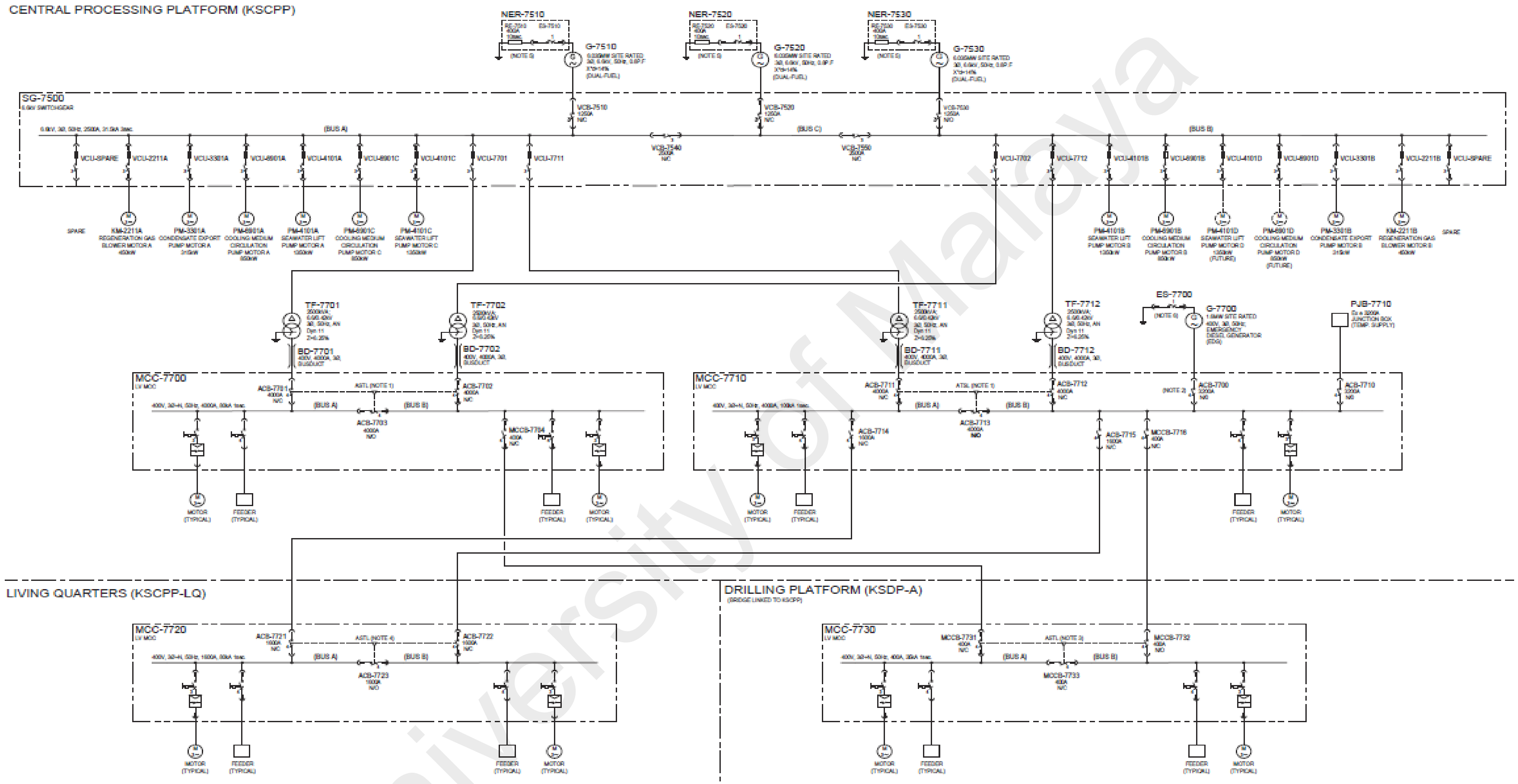

Figure 3.1: Typical Overall Key line Diagram

3.1 ETAP Modelling

Once the overall power system has been defined, the single line diagram will be model in the power system analysis software. The ETAP software version 16 is used for this project. The power system is model base on the load list as per Table 3.1. As the purpose of study, all the modelling data is based on the existing platform as reference. The existing platform is located somewhere in Arab Gulf. All the parameters as much possible as based on the actual data at the existing platform.

3.1.1 Simulation Methodology

Computer simulation software ETAP version 16.2.0 is used to simulate the load flow analysis. The power flow in power generation and distribution system is calculated using Newton-Raphson Algorithm with a maximum iteration is limited to 1000 and a tolerance of 0.01MVA.

3.1.2 Power System Modelling

The system is modelled based on the Overall Key Single Line Diagram as per Appendix A. Generally, where possible, data for all electrical equipment shall be based on the actual manufacturer’s data. However, where manufacturer’s data is not available, an assumed value based on ETAP’s library data is being used for study purposes, which are as per IEC standard. Sub-sections below summarize the data used for power system modelling.

Table 3.1: Load List

Item	CONSUMER / EQUIPMENT DETAILS							CONSUMED LOAD SUMMARY DETAILS										
	Tag No.	LOAD DESCRIPTION	Manufacturer/ Specification/ Notes	Source Bus	Connected Load / Nameplate Rating		Power Factor (cosΦ)	Duty C/I/S	Demand Factor	DEMAND LOAD								
										Continuous (100%)			Intermittent (30%)			Stand-By (10%)		
					kVA	kW	p.u		%	kW	kVAR	kVA	kW	kVAR	kVA	kW	kVAR	kVA
		230KV SWITCHGEAR SG-701 BUS-A																
1		SWITCHGEAR SG-301 BUS-A	-	SG-701 BUS-A	43971.62	41773.04	0.95	C	72.4%	30231.76	14783.34	33801.86						
2		ZTPS-3	-	SG-701 BUS-A	25063.16	23810.00	0.95	S	47.4%							11295.46	3712.64	11889.96
3			-															
4			-															
5		**230KV SWITCHGEAR SG-701 BUS-B**	-															
6		SWITCHGEAR SG-301 BUS-B	-	SG-701 BUS-B	52672.06	50038.45	0.95	C	45.4%	22725.65	7469.56	23921.74						
7		ZTPS-4	-	SG-701 BUS-B	28473.68	27050.00	0.95	S	47.4%							12832.52	4217.85	13507.92
			SUB-TOTAL LOAD		150180.52	142671.50	0.95			52957.41	22252.90	57723.60						
		TOTAL DEMAND LOAD								**52957.41**	**22252.90**	**57723.60**						

Item	CONSUMER / EQUIPMENT DETAILS							CONSUMED LOAD SUMMARY DETAILS										
	Tag No.	LOAD DESCRIPTION	Manufacturer/ Specification/ Notes	Source Bus	Connected Load / Nameplate Rating		Power Factor (cosΦ)	Duty C/I/S	Demand Factor	DEMAND LOAD								
										Continuous (100%)			Intermittent (30%)			Stand-By (10%)		
		SG-301 BUS-A			kVA	kW	p.u		%	kW	kVAR	kVA	kW	kVAR	kVA	kW	kVAR	kVA
1		ZTP-6	-	SG-301 BUS-A	**545.00**	**463.25**	0.85	C	72.4%	335.39	207.86	394.58						
2		ZULF 531/539	-	SG-301 BUS-A	**3696.09**	**3511.29**	0.95	C	40.7%	1428.00	469.36	1503.16						
3		ZULF 51/56	-	SG-301 BUS-A	**3201.09**	**3041.04**	0.95	C	40.8%	1241.78	408.15	1307.13						
4		ZULF 380/388	-	SG-301 BUS-A	**3201.09**	**3041.04**	0.95	C	40.8%	1241.78	408.15	1307.13						
5		ZULF 246/251	-	SG-301 BUS-A	**3696.09**	**3511.29**	0.95	C	40.7%	1428.00	469.36	1503.16						
6		ZULF 390/399	-	SG-301 BUS-A	**3696.09**	**3511.29**	0.95	C	40.7%	1428.00	469.36	1503.16						
7		ZULF 234/239	-	SG-301 BUS-A	**3696.09**	**3511.29**	0.95	C	40.7%	1428.00	469.36	1503.16						
8		ZULF 440/449	-	SG-301 BUS-A	**3696.09**	**3511.29**	0.95	C	40.7%	1428.00	469.36	1503.16						
9		ZULF 350/359	-	SG-301 BUS-A	**5181.09**	**4922.04**	0.95	C	40.4%	1986.66	652.98	2091.22						
10		ZULF 258/263, 303/304	-	SG-301 BUS-A	**2942.65**	**2795.51**	0.95	C	100.0%	3025.11	1718.86	3479.40						
11		ZULF 421/429	-	SG-301 BUS-A	**2992.25**	**2842.63**	0.95	C	100.0%	3118.39	1776.67	3589.15						
12		ZULF 430/439	-	SG-301 BUS-A	**2206.98**	**2096.63**	0.95	C	100.0%	2278.05	1300.43	2623.24						
13		ZULF 400/409	-	SG-301 BUS-A	**3384.88**	**3215.63**	0.95	C	100.0%	3538.56	2014.79	4072.10						
14		ZULF 410/419	-	SG-301 BUS-A	**2599.61**	**2469.63**	0.95	C	100.0%	2698.22	1538.55	3106.19						
15		ZULF 470/479	-	SG-301 BUS-A	**3123.01**	**2966.86**	0.95	C	100.0%	3113.18	1786.90	3590.42						
16		SG-001 BUS-A	-	SG-301 BUS-A	**354.58**	**336.85**	0.95	C	100.0%	2278.05	1300.43	2623.24						
		SUB-TOTAL LOAD			43971.62	41773.04	0.95		72.4%	30231.76	14783.34	33801.86						
		TOTAL DEMAND LOAD								30231.76	14783.34	33801.86						

Item	CONSUMER / EQUIPMENT DETAILS							CONSUMED LOAD SUMMARY DETAILS										
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										Continuous (100%)			Intermittent (30%)			Stand-By (10%)		
		SG-301 BUS-B			kVA	kW	p.u		%	kW	kVAR	kVA	kW	kVAR	kVA	kW	kVAR	kVA
1		SG-001 BUS-B	-	SG-301 BUS-B	365.84	347.55	0.95	C	51.4%	178.62	58.71	188.02						
2		ZULF 450/459	-	SG-301 BUS-B	2206.98	2096.63	0.95	C	108.6%	2276.30	748.18	2396.11						
3		ZULF 63/68	-	SG-301 BUS-B	3201.09	3041.04	0.95	C	40.8%	1241.78	408.15	1307.13						
4		ZULF 198/203	-	SG-301 BUS-B	3201.09	3041.04	0.95	C	40.8%	1241.78	408.15	1307.13						
5		ZULF 81/86	-	SG-301 BUS-B	3201.09	3041.04	0.95	C	40.8%	1241.78	408.15	1307.13						
6		ZULF 87,254	-	SG-301 BUS-B	2706.09	2570.79	0.95	C	41.1%	1055.56	346.94	1111.11						
7		ZULF 57/62	-	SG-301 BUS-B	3201.09	3041.04	0.95	C	40.8%	1241.78	408.15	1307.13						
8		ZULF 104/109	-	SG-301 BUS-B	3201.09	3041.04	0.95	C	40.8%	1241.78	408.15	1307.13						
9		ZULF 660/669	-	SG-301 BUS-B	4191.09	3981.54	0.95	C	40.5%	1614.22	530.57	1699.18						
10		ZULF 710/719	-	SG-301 BUS-B	4191.09	3981.54	0.95	C	40.5%	1614.22	530.57	1699.18						
11		ZULF 1280/1289	-	SG-301 BUS-B	4551.09	4323.54	0.95	C	43.0%	1860.43	611.49	1958.34						
12		ZULF 1290/1299	-	SG-301 BUS-B	4551.09	4323.54	0.95	C	43.0%	1860.43	611.49	1958.34						
13		ZULF 1450/1459	-	SG-301 BUS-B	4551.09	4323.54	0.95	C	43.0%	1860.43	611.49	1958.34						
14		ZULF 1460/1469	-	SG-301 BUS-B	4551.09	4323.54	0.95	C	43.0%	1860.43	611.49	1958.34						
15		ZULF 1440/1449	-	SG-301 BUS-B	3471.09	3297.54	0.95	C	43.3%	1426.43	468.84	1501.50						
14		WI TP-3	-	SG-301 BUS-B	1330.00	1263.50	0.95	C	72.0%	909.72	299.01	957.60						
15																		
16																		
		SUB-TOTAL LOAD			52672.06	50038.45	0.95		45.4%	22725.65	7469.56	23921.74						
		TOTAL DEMAND LOAD								22725.65	7469.56	23921.74						

Item	CONSUMER / EQUIPMENT DETAILS							CONSUMED LOAD SUMMARY DETAILS												
	Tag No.	LOAD DESCRIPTION	Manufacturer/ Specification/ Notes	Source Bus	Connected Load / Nameplate Rating		Power Factor (cosΦ)	Duty C/I/S	Demand Factor	DEMAND LOAD										
										Continuous (100%)			Intermittent (30%)			Stand-By (10%)				
					kVA	kW	p.u		%	kW	kVAR	kVA	kW	kVAR	kVA	kW	kVAR	kVA		
		<u>480 VAC SWITCHGEAR</u>																		
1		MOTOR CONTROL CENTERS -1			354.58	336.85	0.95	C	97.7%	329.04	108.15	346.36								
2		MOTOR CONTROL CENTERS -2			365.84	347.55	0.95	C	51.4%	178.62	58.71	188.02								
		SUB-TOTAL LOAD			720.42	684.40	0.95		74.17%	507.65	166.86	534.37								
		TOTAL DEMAND LOAD								507.65	166.86	534.37								

3.1.3 Power Transformer Modelling

The transformer parameters used are as shown in the Table 3.2 below. The transformer data are based on the actual nameplate rating of the existing transformer on the platform.

Table 3.2: Transformer Modelling Data

TRANSFORMER		ELECTRICAL CHARACTERISTICS				
	Rating (MVA)	Voltage Ratio (V)	Impedance (%)		X/R Ratio	Tapping
			Z1	Z0		
408-IL-XFR(T)-701	80	230/13.8	11.00	11.00	11.00	+/-5% at step of 2.5%
408-IL-XFR(T)-702	80	230/13.8	11.00	11.00	11.00	
408-IL-XFRT(T)-301	1	13.8/0.480	5.75	5.75	5.75	
408-IL-XFRT(T)-302	1	13.8/0.480	5.75	5.75	5.75	

3.1.4 Electrical Load Modelling

For the individually modelled motor ratings, motor efficiency, power factor, locked rotor current and absorbed load are based on Electrical Load on the Electrical Load List. Total platform load is based on Electrical Peak Load as per Electrical Load List.

All MV motors and largest LV motors are modelled individually while other loads are lumped into either Lumped Motor Loads or Lumped Static Loads. The Tables 3.1 show the overall load list for the platform.

3.1.5 Cable and Busduct Modelling

Table 3.3 show the reactance value of the submarine cable used in the model. The submarine cable reactance value is based on the vendor data as per Appendix A.

Table 3.3: Submarine Cable Data

	Voltage Rating (V)	Length (m)	Cable Size (mm^2)	Cable resistance (ohm/km)	Cable Reactance (ohm/km)	Cable Capacitance (µF/km)
BODP-D	23000	37300	3Cx630mm^2	0.071	0.160	0.000063

3.2 Load flow studies

The load flow was simulated using ETAP power system software. All power system components have been modeled as per available data and respective standard model formats available in the ETAP.

At all loads running under steady state operating conditions, the following criteria shall be met;

1. No overloading for electrical on the generator.
2. Nominal voltage variation at all loads shall not exceed ±5 % under normal running condition.

For this study, Newton-Raphson Method is chosen to perform the iterations up to 99 times and with a precision (convergence) of 0.0001.

To study the system stability and the Ferranti effect, load flow study shall be performed. There are few scenarios will be performed to cover every angle of the study objective. On each scenario, the voltage level at the main switchgear at offshore, receiving end, was determined. The total power consumption was also determined.

Table 3.4 summarize the scenario to be performed on load flow study.

Table 3.4: Load Flow Scenario

	Without shunt reactor	With shunt reactor
Short distant submarine cable	SCENARIO 1	SCENARIO 2
Medium distant submarine cable	SCENARIO 3	SCENARIO 4
Long distant submarine cable	SCENARIO 5	SCENARIO 6

As mention in chapter 2.2, the transmission line is categorized in three (3) category as stated by (Irinjil,Jaya,2011). The location of offshore platform can also vary from short to long distance, hence the scenarios are selected based on 3 categories to cover all possibility of platform location. Based on table above, all scenario is performed with all the downstream loads are disconnected. Due to the definition of Ferranti Effect, this is to determine the voltage level at the switchgear that the voltage level at the receiving end will be higher when there is a minimum or no-load condition.

The scenario 1, scenario 3 and scenario 5 was performed to determine the voltage level at receiving end when the submarine cable distance was increasing. This scenario was performed without the mitigation method, a shunt reactor, being taken place. This scenario will show how the system react to the capacitance on the transmission line which is submarine cable. This will show Ferranti Effect happened in this system.

The scenario 2, scenario 4 and scenario 6 was performed to show how the system react when a mitigation method is conducted. This also will determine the size of shunt reactor required in order to stabilize the system. This scenario also will determine the impact of increasing the submarine length onto the size of shunt reactor required in order to stabilize the system.

3.3 Short Circuit Study

Apart from the study of load flow, short circuit study also needs to be performed to determine the short circuit level when a system fault occurred. The short circuit level determination is crucial in selecting the electrical equipment such as the busbar rating of the switchgear and the selection of protective device.

For this study, 3 scenarios shall be simulated to analyst the short circuit level. The 3 scenarios are based on the length of submarine cable as suggested in load flow study. The 3 scenarios are required to determine the short circuit level when the length of submarine cable increase. The short circuit level will determine the rating of equipment such as busbar rating of switchgear and the breaking capacity of the circuit breaker.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter will explain the result and discussion on the result obtain from the study and analysis done. The result will be discussed base on the scenario defined in the previous chapter.

4.1 Load flow studies

4.1.1 Results of load flow scenario 1

In this scenario the load flow analysis is performed to determine the voltage level at the receiving end, in this case the switchgear SG-701. The submarine cable distance is 37.7km. The load flow analysis is performed with the load at the receiving end is not connected.

Figure 4.1 and 4.2 show the result of the load flow study for scenario 1. The sending end point is from Bus 4 which the sending voltage is at 99.37% of nominal current. This is due to voltage drop happened. The receiving end voltage is from SG-701. The receiving end voltage is 101.8%. It can be observed that the voltage level switchgear SG-701 is 2.4% higher than sending voltage and 1.8% higher than nominal voltage. Supposedly the voltage at the receiving end should be lower than sending end as there will be voltage drop along the cable.

However, the voltage is increase. The voltage increase is due to the Ferranti Effect on the submarine cable when the load is minimal or no load at the receiving end side. Even though the voltage increase is still within the allowable limit +/-5% but the amount of reactive power flow back into the system is high 128.7Mvar. Therefore, the reactive power produce by the submarine cable is 128.7Mvar which need to be compensated by the shunt reactor. The simulation result of this scenario as per Appendix A.

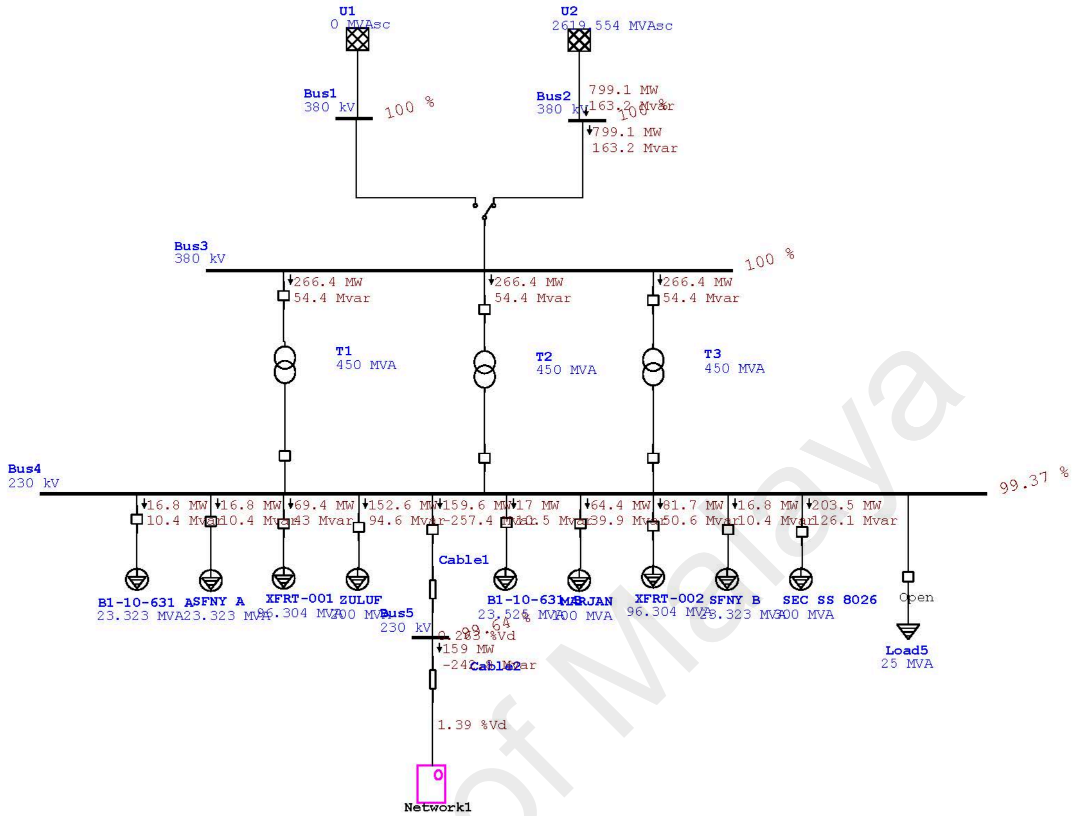

Figure 4.1: Scenario 1 Result (a)

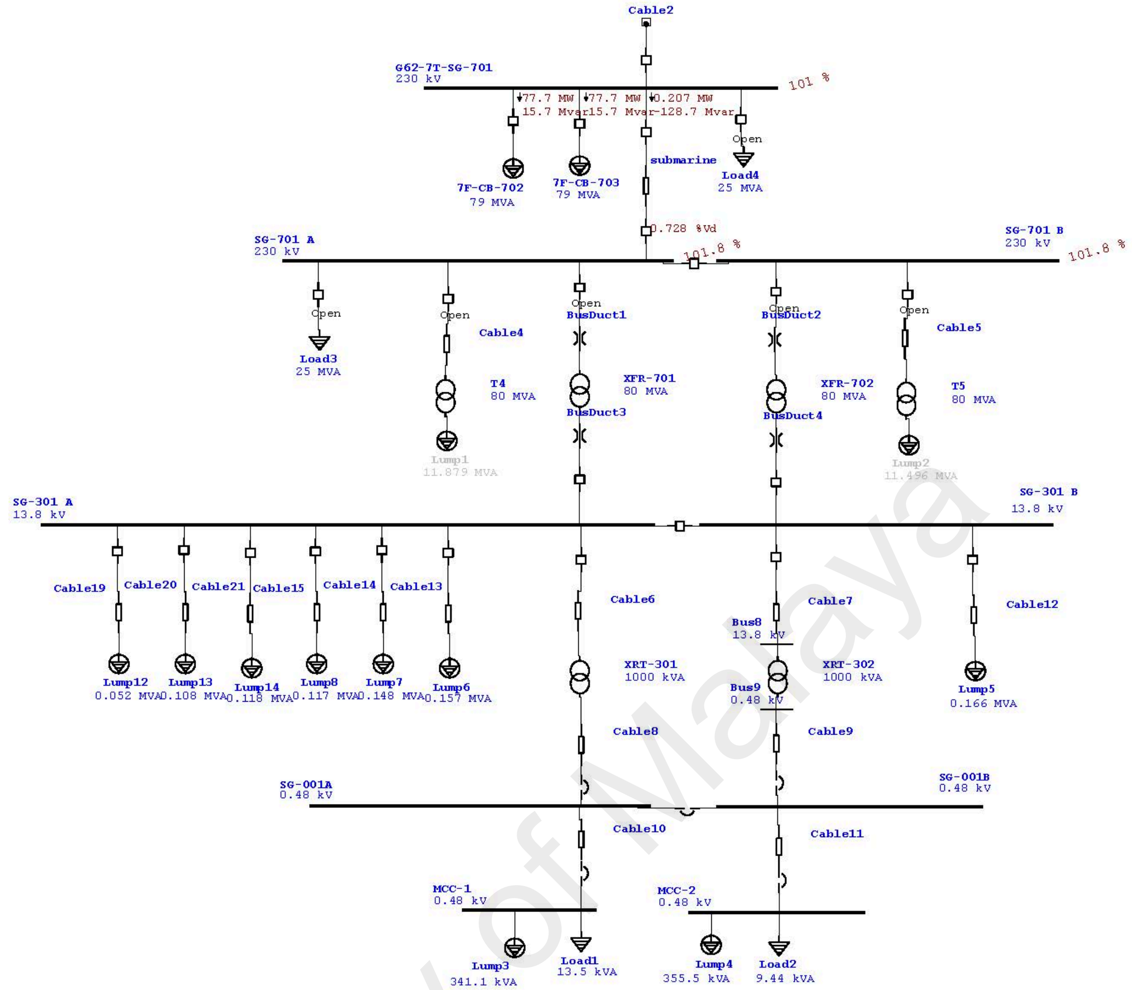

Figure 4.2: Scenario 1 Result (b)

4.1.2 Results of load flow scenario 2

Based on scenario 1, to mitigate the Ferranti effect is to introduce inductive load into the system. Based on the result below, 25Mvar load is enough to stabilize the system. Two 25Mvar shunt reactor is place in between the submarine cable so that it can compensate at both sides.

Figure 4.3 and 4.4 show the result for scenario 2. Base on the result, the two-shunt reactor 25Mvar each manage to compensate the capacitance in the submarine cable during no load scenario. The voltage level at the receiving end now has reduce to 100%

of nominal voltage. The reactive power flow backward is also reduced. The simulation result of this scenario as per Appendix B.

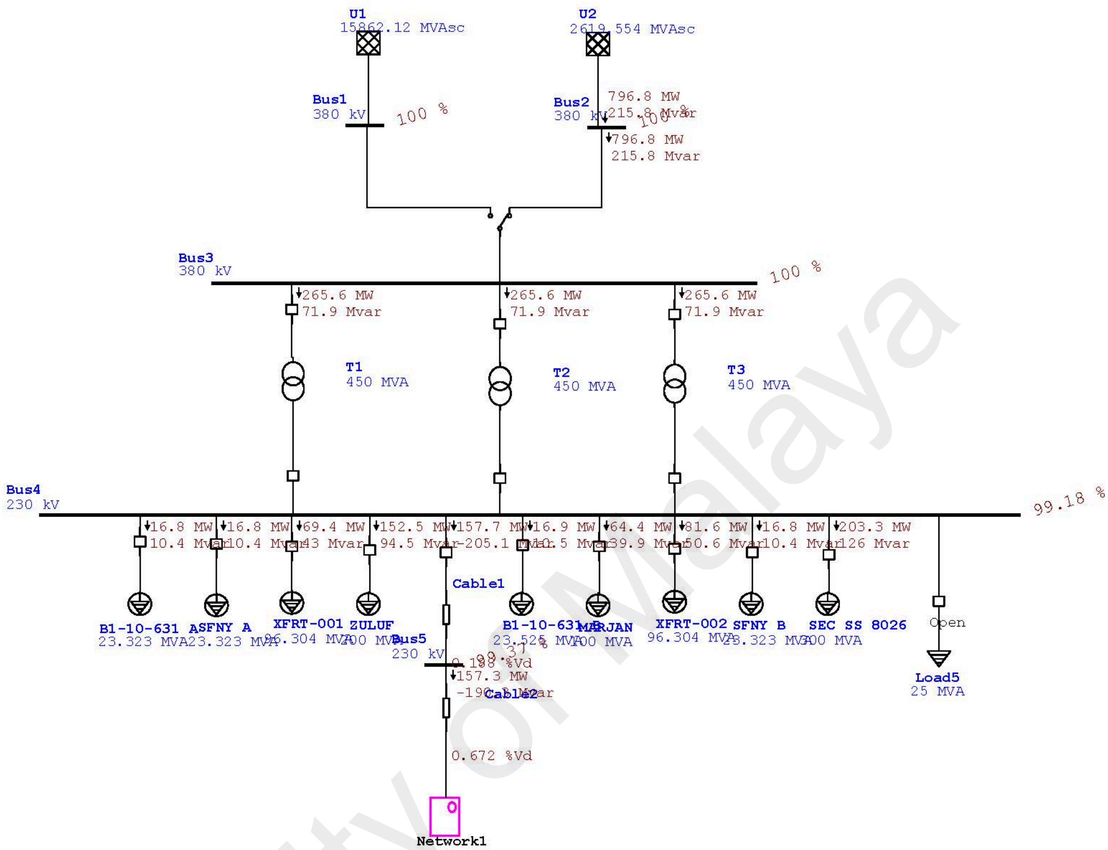

Figure 4.3: Scenario 2 Result (a)

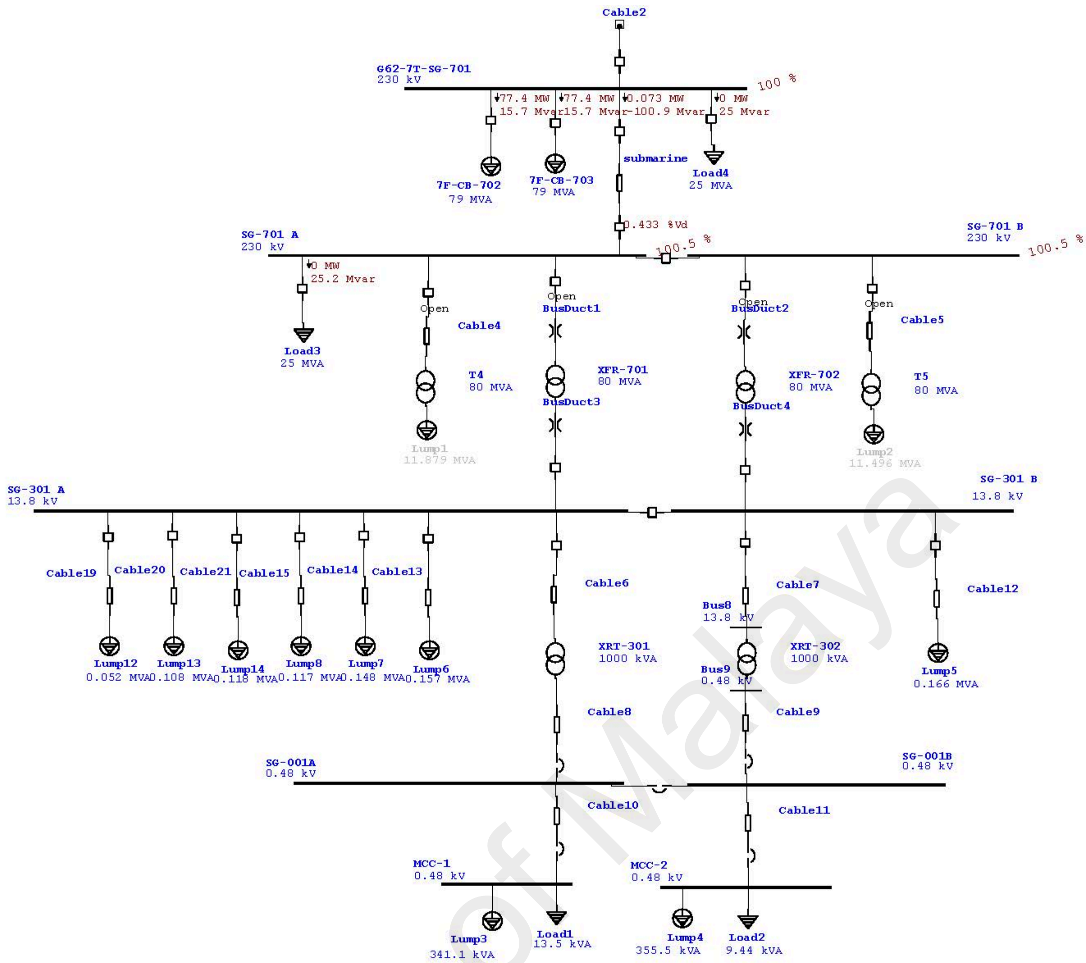

Figure 4.4: Scenario 2 Result (b)

4.1.3 Results of load flow scenario 3

In the scenario 3, the analysis done by increasing the length of submarine cable to the medium distance, 80km as discuss in the chapter 2. The other parameters maintained as previous case.

Based on the result in Figure 4.5 and 4.6, without the shunt reactor the receiving end voltage at SG-701 increase to 107% from nominal voltage when the load is minimal or no-load condition. This has increase over the limit of allowable voltage variance which is -/+ 5%. This is not acceptable, and the system will not be stable. Equipment with prolong operating in high overvoltage will decrease its life span. The amount of reactive power flow back to system at the sending end is 293Mvar. This is the reactive power produce by the submarine cable that need to be compensated by shunt reactor. The simulation result of this scenario as per Appendix C.

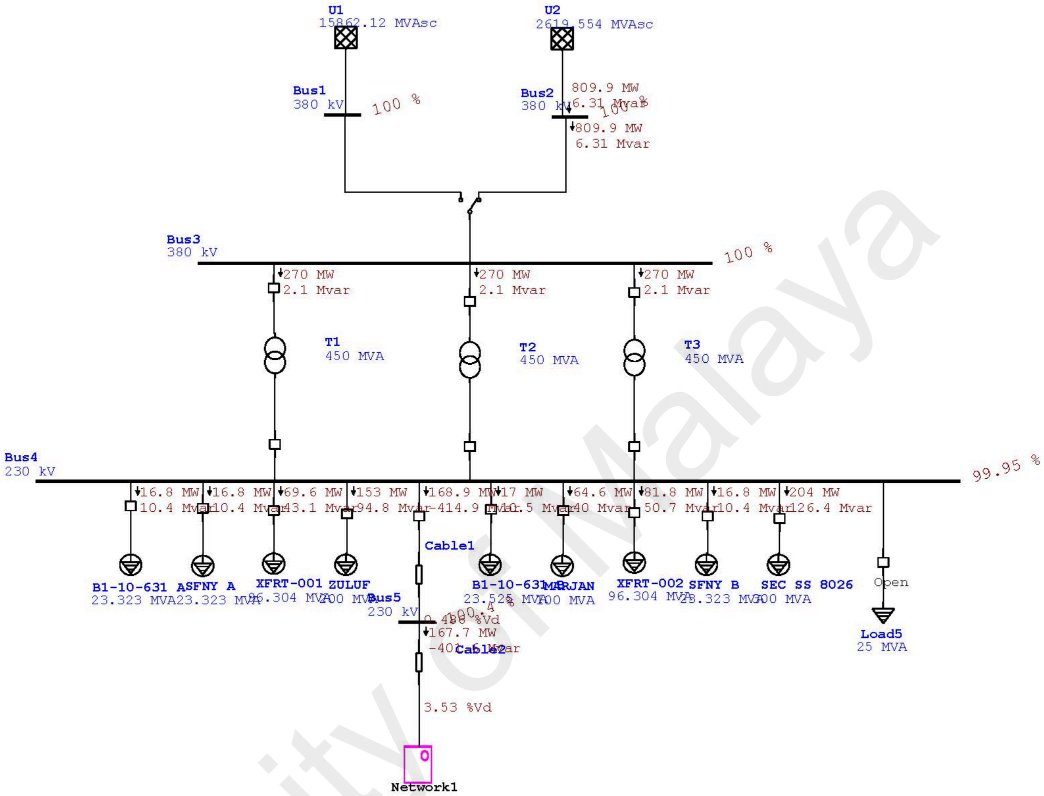

Figure 4.5: Scenario 3 Result (a)

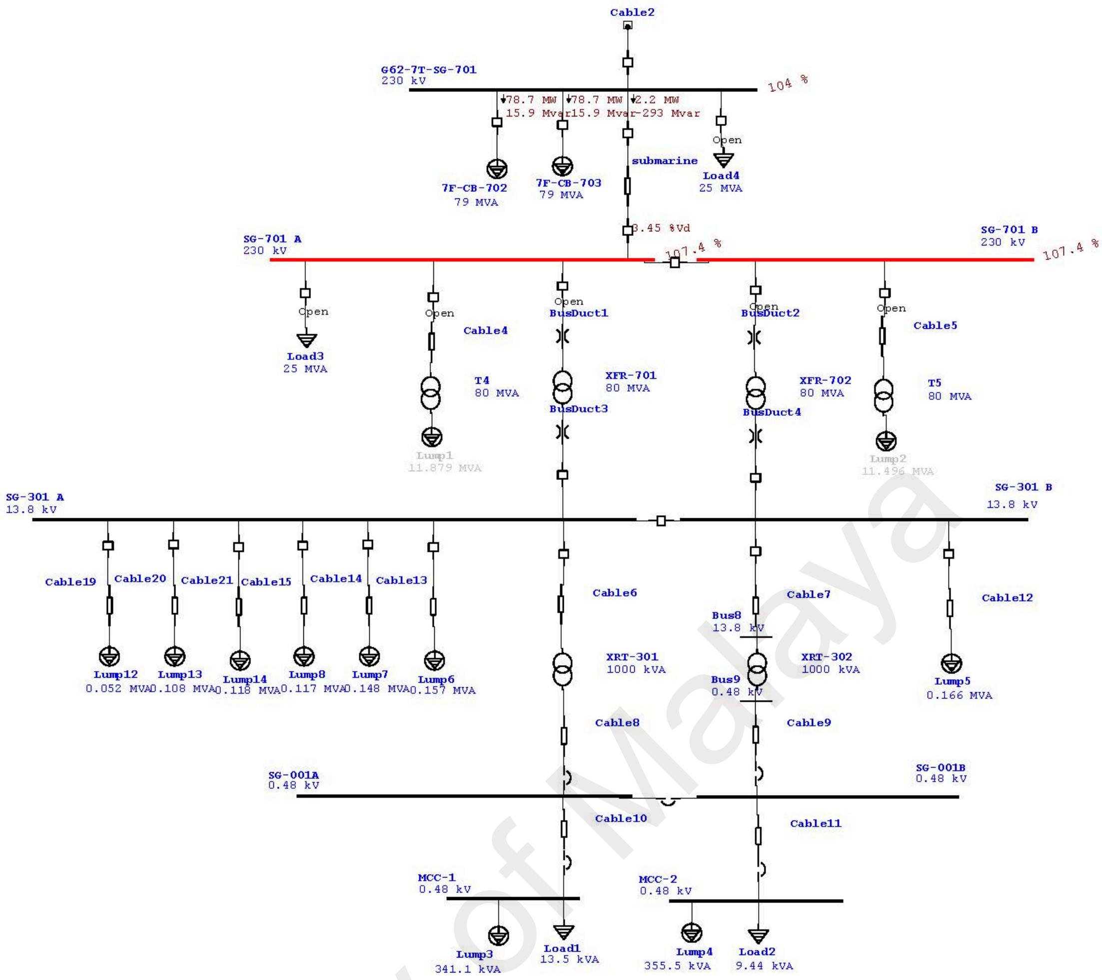

Figure 4.6: Scenario 3 Result (b)

4.1.4 Results of load flow scenario 4

Based on the scenario 3, since the receiving end voltage and the amount of reactive power flow back to the system is increasing due to increase of submarine length, the size of shunt reactor required to mitigate this problem is also increasing.

From the scenario 4 result in Figure 4.7, the size of shunt reactor required is 100Mvar each at sending end and receiving end point. With two shunt reactors implemented, the receiving end voltage manage to reduce to 100.7% of nominal voltage. this will stabilize the voltage of the system. The simulation result of this scenario as per Appendix D.

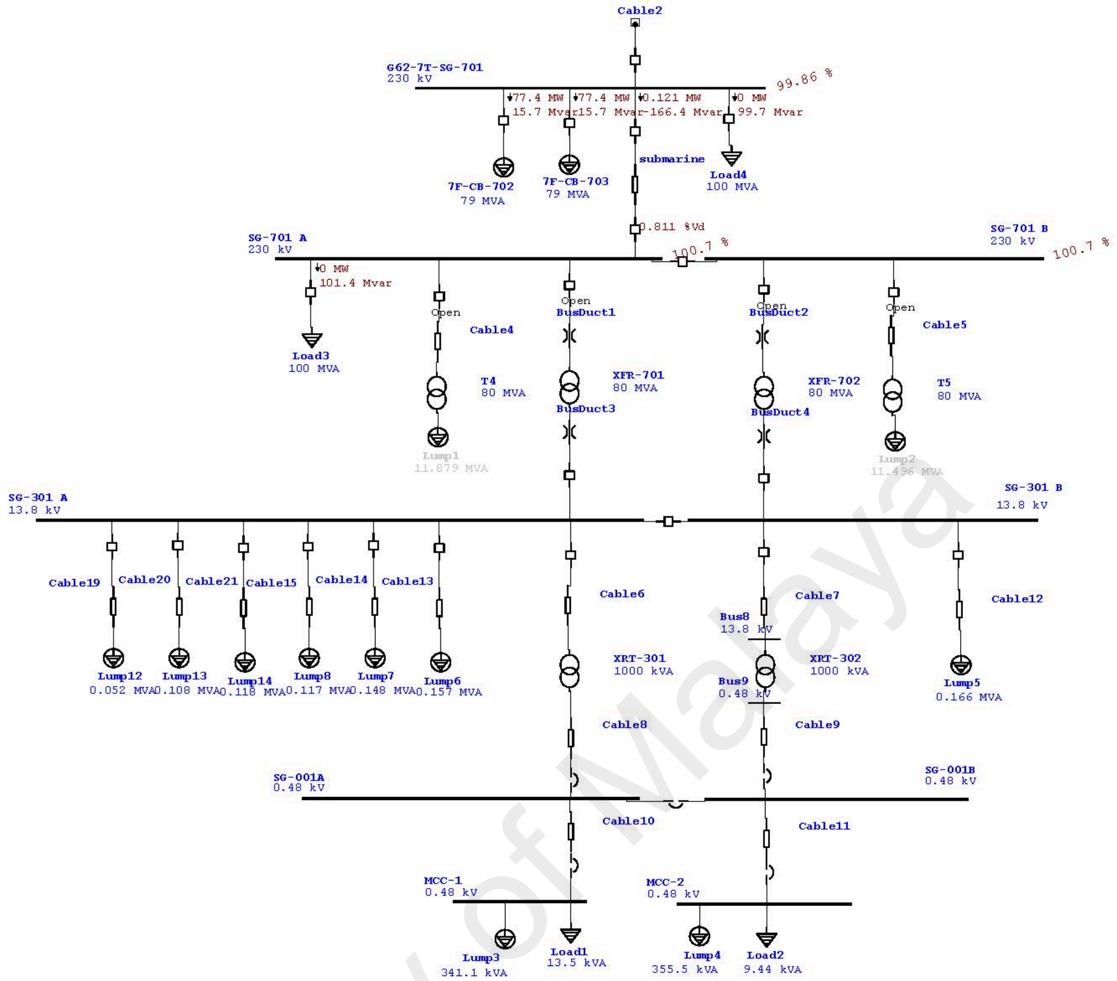

Figure 4.7: Scenario 4 Result

4.1.5 Results of load flow scenario 5

In this scenario, the length of submarine cable is increased to 120km. This is considering a long-distance transmission line. The other parameter is maintained as previous scenario.

Figure 4.8 and 4.9 shows the result for scenario 5. Referring to Figure 4.9, the voltage level at receiving end is higher at 115.3% of nominal voltage when the submarine length increase. This voltage is 15.3% higher than the sending end voltage. This voltage increase happened when there is no load connected at receiving site. In normal cases the receiving end voltage should be less than sending end voltage due to voltage drop in transmission line.

However, the voltage received is higher. This is due to capacitance effect on the submarine cable which called the Ferranti effect. The reactive power that flow back to the system at the sending end point is 475.7Mvar. This is the reactive power produce by the submarine cable due to capacitance charging. This reactive power needs to be compensated by the shunt reactor. The simulation result of this scenario as per Appendix E.

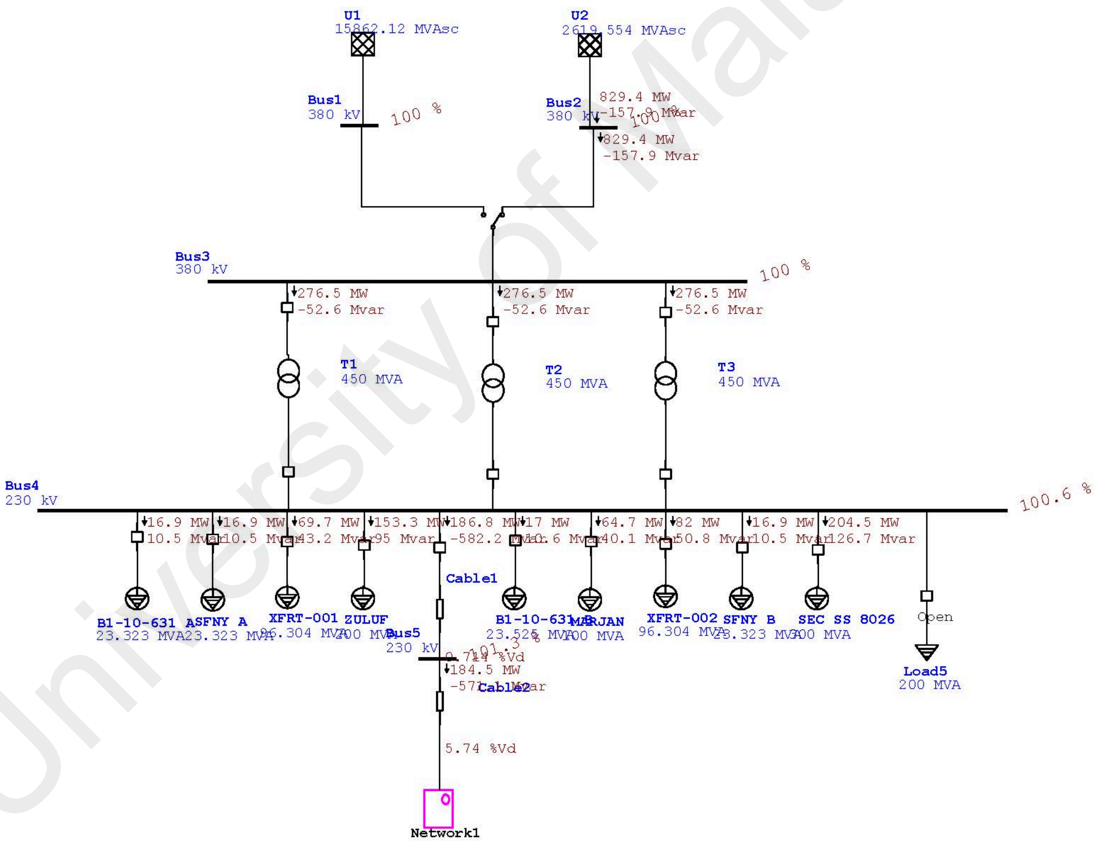

Figure 4.8: Scenario 5 Result (a)

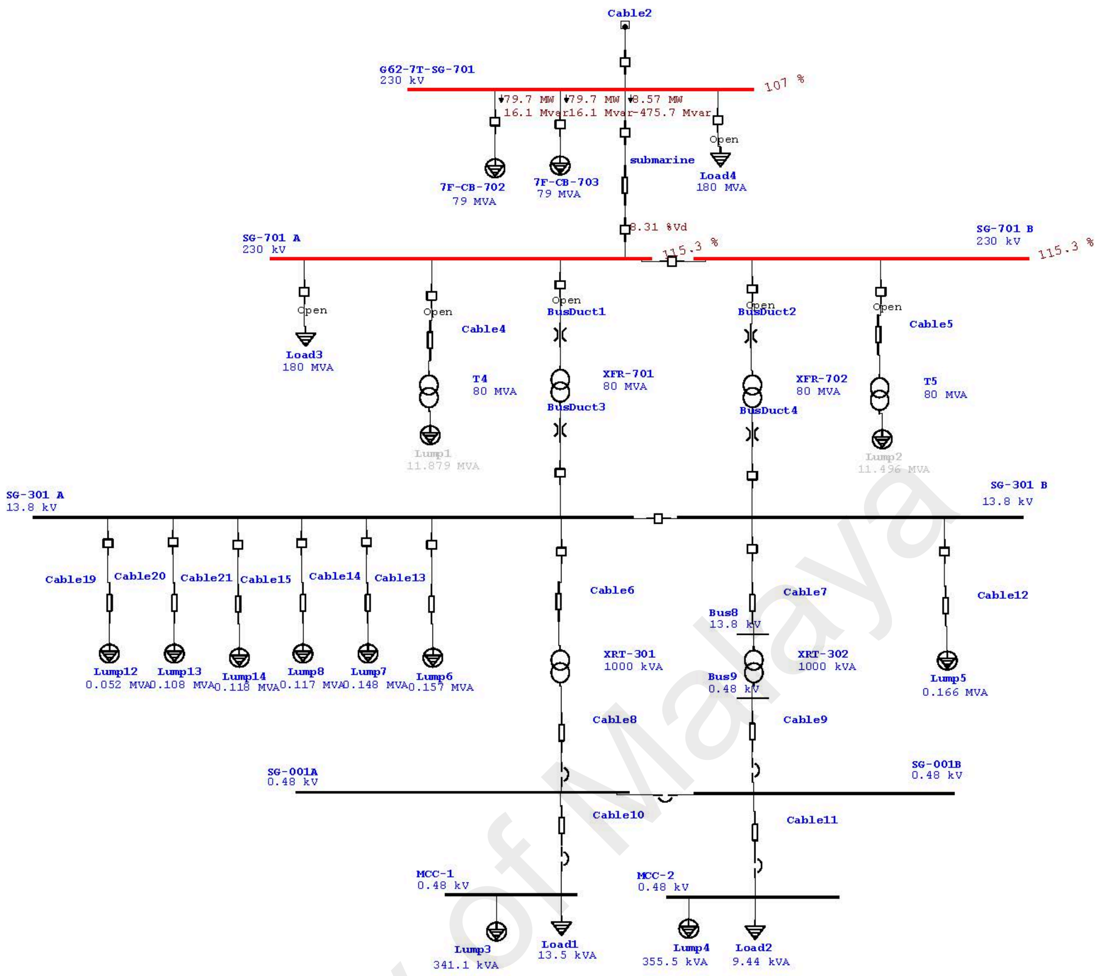

Figure 4.9: Scenario 5 Result (b)

4.1.6 Results of load flow scenario 6

This scenario studied on what will be the size of shunt reactor required to mitigate the voltage problem.

Based the result Figure 4.10, it required 180Mvar of shunt reactor each to mitigate the capacitance effect of submarine cable. The voltage at receiving end manage to be reduce to 100% of nominal voltage. The reactance power flowing back to the system is also reducing from 475.7Mvar to 217.2Mvar. Even though the shunt reactor helps to mitigate the Ferranti effect in this scenario, however the size of shunt reactor required is big in the real implementation. The large shunt reactor in the system will create another problem such as harmonic. The simulation result of this scenario as per Appendix F.

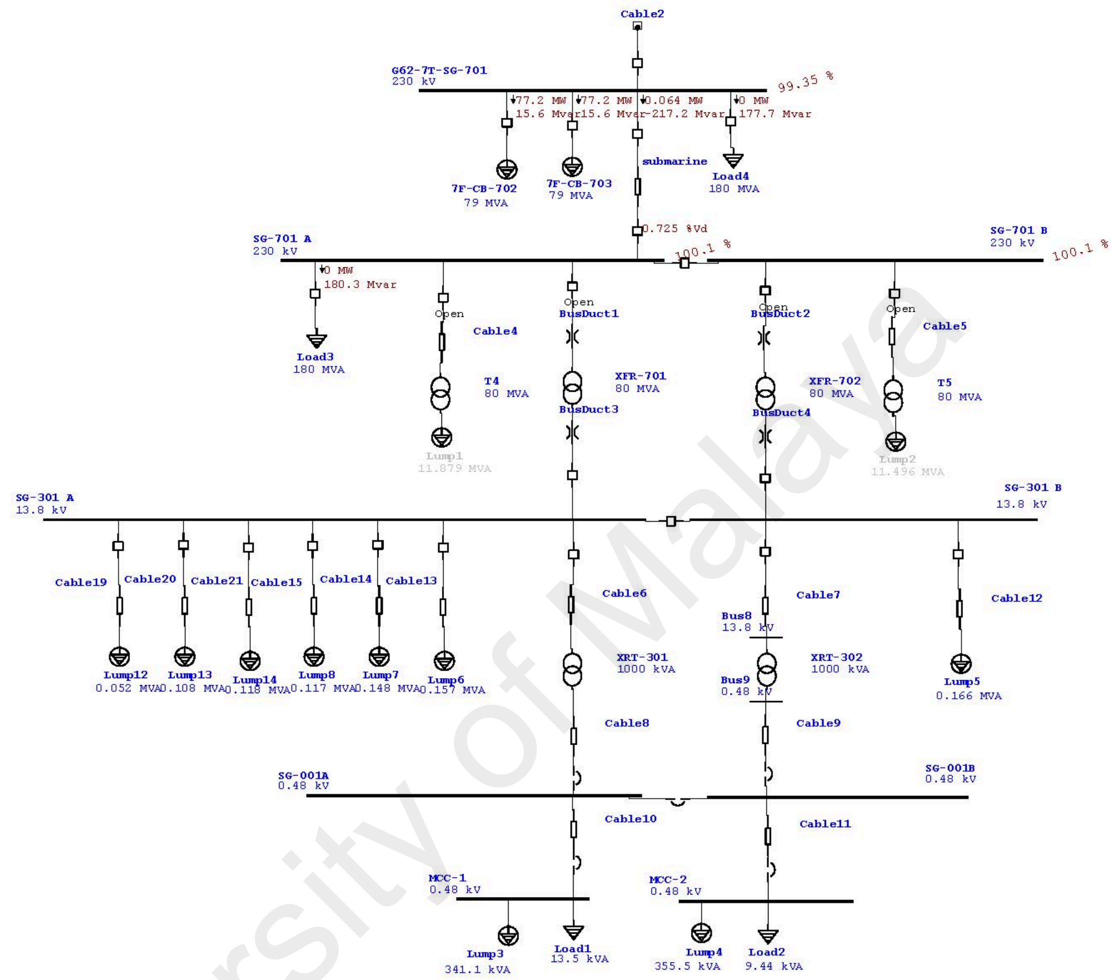

Figure 4.10: Scenario 6 Result

4.1.7 Discussion

The result for load flow study in scenario 1,3 and 5 above shows that when there is no load or minimum load at the receiving end, the voltage level at the receiving end is higher than the sending end. Supposedly, the voltage at the receiving end should be lower than the sending end due to voltage drop along the transmission line or in this case the submarine cable. However, this is not the case as shown in the result. This effect is due to the voltage drop across the line inductance being in phase with the sending end voltage because of charging current. Despite the voltage drop effecting the transmitting end voltage, the receiving end voltage is increased. The submarines cable's characteristic parameters are series inductance due to the magnetic field around the conductor and shunt capacitance due to earth's electrostatic effect. Both the inductance and the capacitance are distributed along the submarine cable length. When the submarine cable is loaded, there is voltage drop along the cable due to the series inductance and the series resistance. When the submarine cable is powered, the voltage drops along the cable due to the inductance series and the resistance series. This is called the Ferranti Effect as stated in (Deb,2012).

Based on the result in above section, shows that the size of shunt reactor is lesser than the reactive power produce by the submarine cable that need to be compensated. If the size of shunt reactor is selected to totally compensate the reactive power produce by submarine cable, the voltage level will be below 100% due to voltage drop on submarine cable resistance. By selecting smaller shunt reactive, the voltage drop due to submarine cable resistance is also compensated.

The Ferranti effect become more obvious the longer the transmission line. The Figure 4.11 shows that when the submarine cable length increases the receiving end voltage, when there is no load, is also increase. This shows that the capacitance of charging current flowing along the submarine cable increase when the length of cable increase and resulting in higher voltage level at the receiving end.

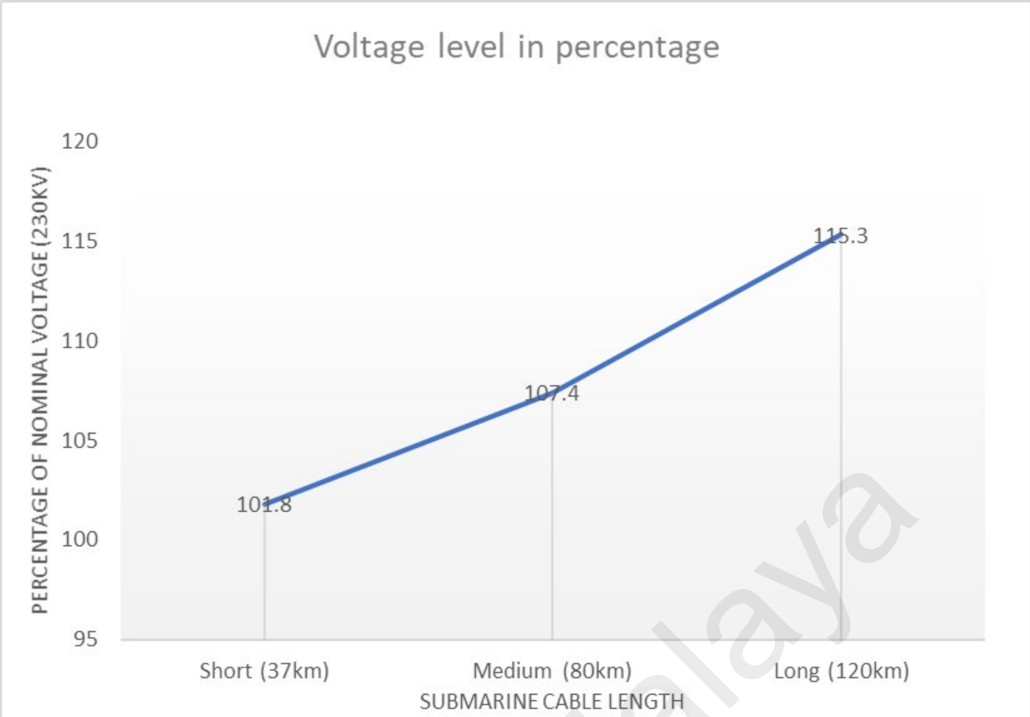

Figure 4.11: Voltage Level in Percentage

The voltage increase due to Ferranti Effect is not good for the stability of the power system. This phenomenon must be overcome. One of the mitigation methods is to install a shunt reactor to compensate the reactive power consume from the submarine cable. Based on the analysis in scenario 2, 4 and 6, two shunt reactors required to be installed, one at the sending end point and one at the receiving end point. The result shows that after the receiving end voltage after installing shunt reactor decreased. The shunt reactor manages to compensate the capacitance of charging current along the submarine cable.

The result also shows that the size of shunt reactor required increase when the length of submarine cable increase as the charging current along the submarine cable also increase. The higher size of shunt reactor is required on order to compensate higher voltage increase at the receiving end. The Figure 4.12 show the comparison of shunt reactor size to the length of submarine cable.

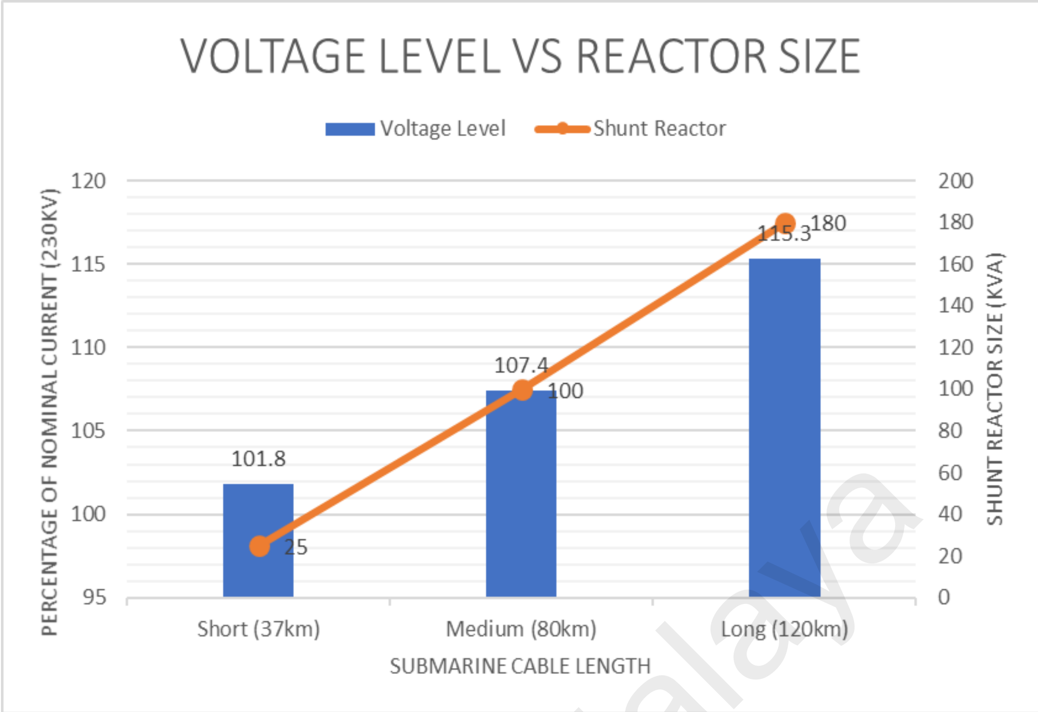

Figure 4.12: Voltage Level Vs Reactor Size

During full loading, even though the shunt reactor is connected the voltage level remain the same. This because the reactive power consume from the downstream load is only 1.44Mvar base on the Table 3.1. This reactive power consume is small to give an impact to the voltage level. However, authors in Nashawati, Fischer, Le and Taylor (2011) suggest, the system loading will lead to elevated voltage level. If the reactive power consume from the system loading is higher, the voltage level at the receiving end will be reduce if the shunt reactor is connected.

Therefore, to overcome this issue, modern Flexible AC transmission (FACTS) devices is opted nowadays as explain by Mohanty and Barik(2018). This device is flexible where the shunt reactor can be switch on or connected when the load is light or no load and switch off or disconnected when the load is normal at full load. But switching on and off the shunt reactor may have other issue such as transient stability. This transient stability has been analysis by Hutahaean, Sianipar (2011) and H. Abdul Hamid, N.Harid, A.Haddad (2009).

4.2 Short Circuit Study

The short circuit study is performed using ETAP software and IEC standard. The short circuit study is analysis base on 3 scenarios.

4.2.1 Result of Short Circuit Study scenario 1

The short circuit analysis was done base on scenario 1 and 2 of load flow analysis. The submarine length is 37km while the load is fully connected. The result of short circuit study shown in Figure 4.13.

Based on the result in Figure 4.13, the short circuit level at SG-701 is 8.696kA. this value is still acceptable and consider low enough. It is below the rated of SG-701 busbar short circuit rating which is 31.5kA. The simulation result of this scenario as per Appendix G.

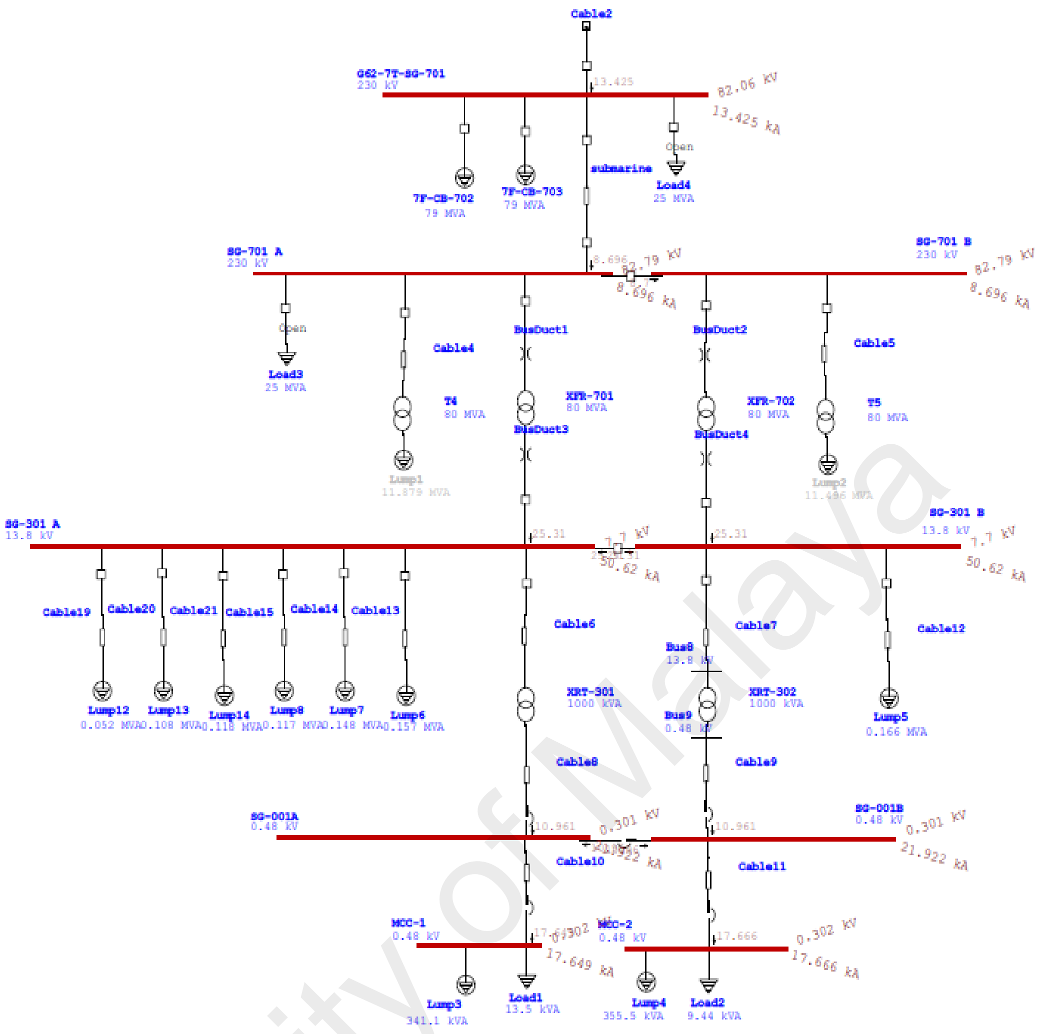

Figure 4.13: SC Scenario 1 Result

4.2.2 Result of Short Circuit Study scenario 2

In this medium distance scenario, the short circuit study was done base on scenario 3 and 4 of load flow study. The submarine cable distance was 80km. The downstream load is fully connected. The result of the short circuit study is as per Figure 4.14.

Based on the result in Figure 4.14, the short circuit level at SG-701 is 6.193kA. This figure is a little lower compare to previous scenario. This is due to higher resistance level over long submarine cable cause current lost during transmission. The simulation result of this scenario as per Appendix H.

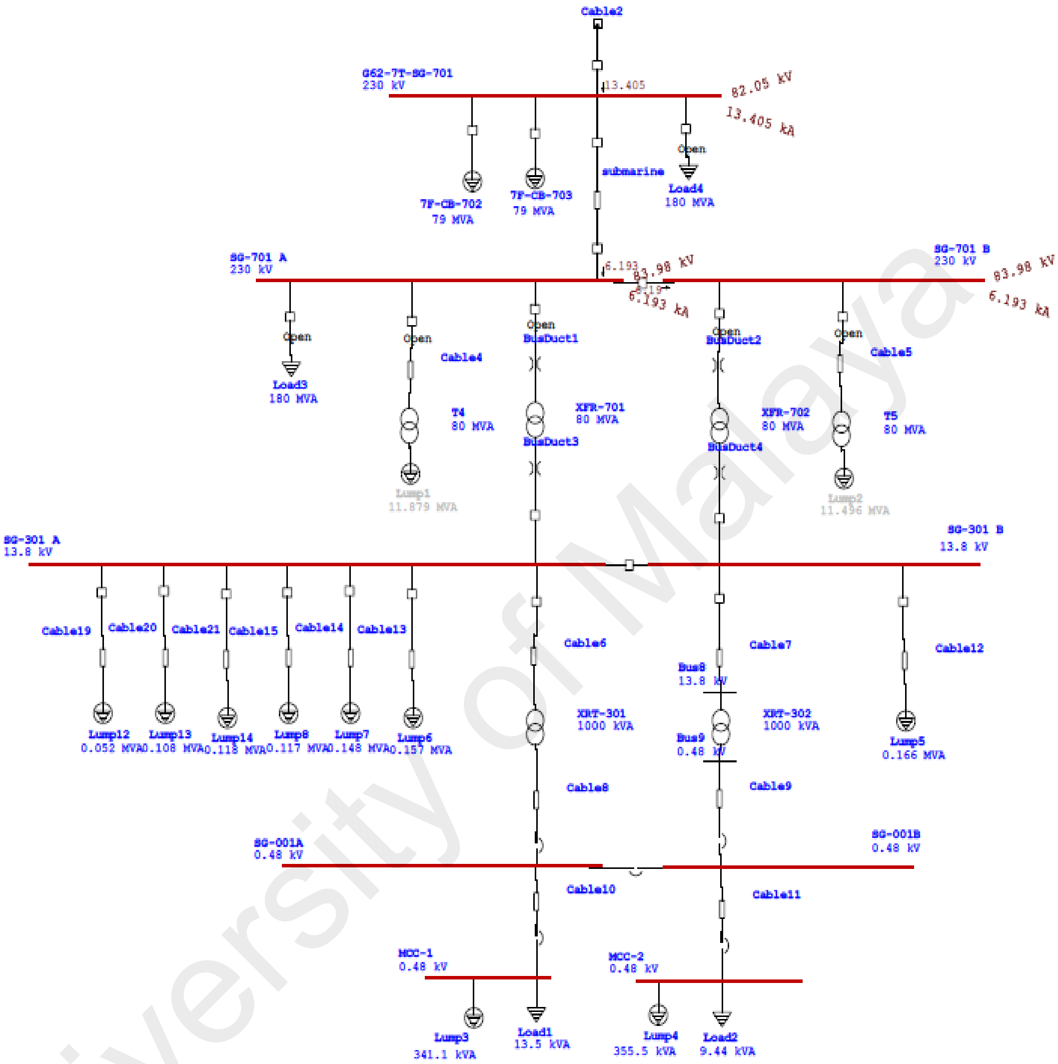

Figure 4.14: SC Scenario 2 Result

4.2.3 Result of Short Circuit Study scenario 3

For this scenario, the submarine cable length was set at 120km away. The other setting was the same as scenario 5 and 6. The Figure 4.15 below show the short circuit study result for scenario 3.

Based on the result Figure 4.15, the short circuit level at SG-701 is even lower from the previous scenario. The short circuit current was at 4.868kA. his is due to higher resistance level over long submarine cable cause current lost during transmission. The simulation result of this scenario as per Appendix I.

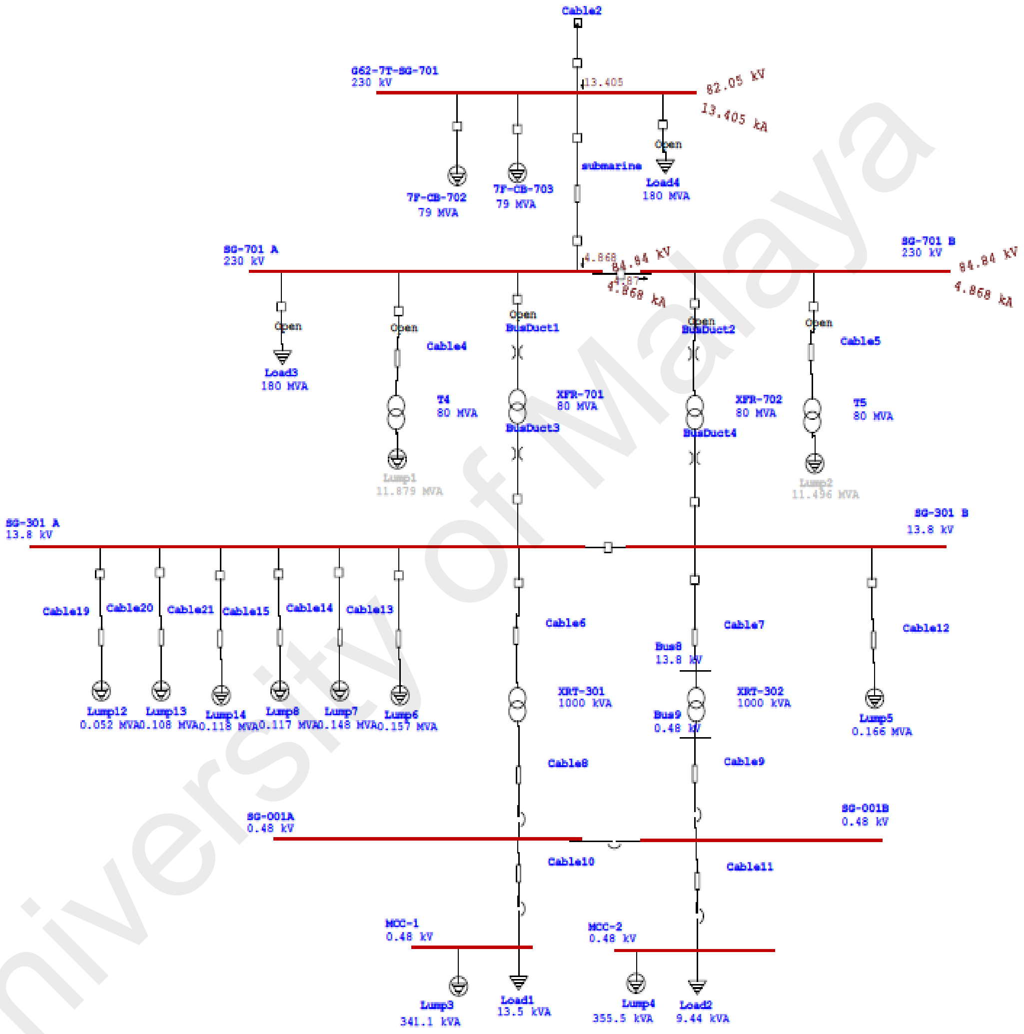

Figure 4.15: SC Scenario 3 Result

4.2.4 Discussion

The result from 3 scenarios above shows that the short circuit level decrease when the length of submarine cable increase. This is due to the resistance across the submarine increase when the length is increase. Figure 4.16 show the comparison of short circuit level between scenarios.

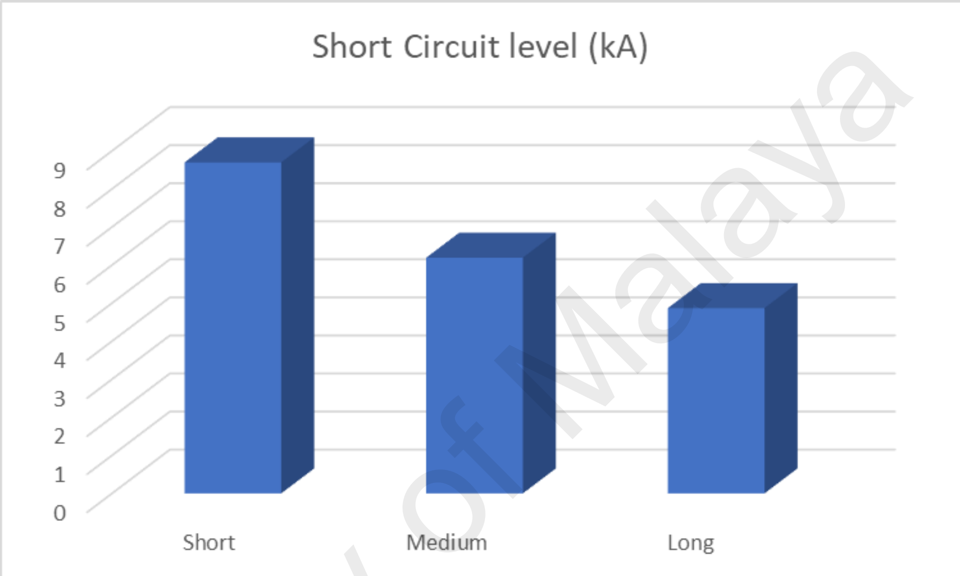

Figure 4.16: Short Circuit Level

Based on the Figure 4.16, the short circuit level for all 3 scenarios are below 10kA. This is considered low and acceptable. The busbar rating of switchgear SG-700 is rated at 31.5kA.

CHAPTER 5: CONCLUSION AND FUTURE WORKS

The idea of supplying power from onshore to the offshore seems possible with few condition and restriction. However, before the idea being implemented, there are few things need to be consider based on this study. In term of system stability, the voltage level, as predicted there is Ferranti effect occur in the system over long transmission line. However, this problem can be overcome by introducing shunt reactor to the system. The system can be stabilized after that. But there is restriction in term of implementation the solution. The transmission line, submarine cable length shall be limited to the short range only which is below 80km. The reason is, when the submarine cable length is more than 80km, the shunt reactor required to compensate the Ferranti effect is too big. This is not practical for offshore installation. The space required to place the entire shunt reactor is big.

As per result of study in chapter 4, the study proves there is voltage instability in the system due Ferranti Effect over long submarine cable. The level of voltage instability was determined over different length of submarine cable. The study also proves the mitigation method proposed able to stabilize the voltage level to the normal. For the short circuit level study, the study prove that the short circuit level is manageable and acceptable. The short circuit level is low due to high resistance over the submarine cable.

It can be concluded that all the objective of this study as specified in section 1.3 has been achieved. The power system study can be useful for future reference in implementing power supply from onshore to the offshore platform over long submarine cable. One of the areas that can improve from this study is the parameter of submarine cable reactance value. Good submarine cable reactance value might reduce the capacitance effect over the long submarine cable thus reduce the voltage rise at the receiving end when there is no load.

5.1 Future Works

As for future study, one area needs to further verify is the total harmonic of the system. As shunt reactor was implemented, there is harmonic introduce in the system. This harmonic study can lead to the limitation of shunt reactor size that is feasible for different length of transmission line. The major harmonic contribution in power system on the offshore platform are uninterrupted power supply (UPS) and Variable Speed Drive (VSD). The platform may have different size and number of UPS and VSD requirement. Therefore, the shunt reactor size limitation might be different for every platform power system.

The other area that might study further is the transient stability study of the power system. As discuss in section 4.1.7, one of the mitigation plans is using FACTS where the shunt reactor can be switch on or connected when the load is light or no load and switch off or disconnected when the load is normal. The switching on and off the shunt reactor may have transient stability issue. This are can be study further to better understanding on implementation of this idea.

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