DESIGN SUBSEA POWER GENERATION SYSTEM

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Mechanical Engineering
Universiti Teknologi PETRONAS
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Mohammad Faizal B. Abdul Kadir

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Abstract

Subsea technologies are now moving further where the operation now done by using latest subsea equipment that are more efficient and cost effective. The main issue is that these equipment powered by the power supplied from the platform which causes the power losses due to the cable distance and friction inside the cable. The main objective of this study is to design subsea power generation system that can overcome the stated issue in order to reduce the cable length that lead to power losses. In order to conduct this research, a structured mechanical systems design was adopted. The concept generation for an alternative power generation was made by using the morphological chart. Subsequently, concept selection was done by using the weighted score matrix. Then, in the assembly drawing, the system configuration shows how the part are related and connected to other parts of the assembly. Mathematical modeling was produced using the governing equation gathered from the literature. Using the data from the mathematical modeling, the detail design was produced using the AUTOCAD and CATIA softwares. The deliverables of the project are assembly drawing and the design specification needed to operate a Remote Operated Vehicle (ROV).

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Chapter 1

Introduction

1.1 Background study

Subsea technologies are now moving toward a new era for oil and gas industry which operated using latest subsea equipment that give more efficient as well as cost effective[1]. These subsea equipment need power to operate it. Before further research about subsea power generation system can be done, the subsea equipment power requirement need to be study. Remote operated vehicle (ROV) was selected as a reference to the subsea equipment power requirement.

Gas power turbine distributed system was chosen as a datum for this projects. The physical decomposition of this system was made in order to understand the power generation system. After that, further research about alternative deepwater power generation system was done. Three power generation unit was selected from various choices available in the market, manufacturer or research paper. Based on the power generation unit chosen, new power generation system was being design by referring the datum.

1.2 Problem Statement

The issue with power supplied from platform is the power losses due to the cable distance and friction inside the cable. The power generation capability may not be available on the host and the host payload may be limited, therefore additional facilities particularly needed if it is in deepwater.

1.3 Objective

The main objective of this study is to design subsea power generation system as an alternative to the conventional top-side power generation facility on an oil platform or floater.

1.4 Scope of study

The scope of study will be focusing in designing the power generation system by using 3 available type of power generation unit which can produce electricity directly in the deepwater by referring to the datum. The purposed design is to be used for Remote Operated Vehicle (ROV) power requirement.

Chapter 2

Literature review

They are many power generating unit available in the market. The solution to the problem occurs are by harvest the energy or power under the water itself. By doing this, the losses due to the long cable can be minimize. The power generating unit that available which can harvest underwater are linear generator and rotech tidal turbine (using movement of water).

2.1 Subsea equipment

Subsea is a general term frequently used to refer to equipment, technology, and methods employed in marine biology, undersea geology, offshore oil and gas developments, underwater mining, and offshore wind power industries[2]. A subsea production system consists of a subsea completed well, seabed wellhead, subsea production tree, subsea tie-in to flow line system, and subsea equipment and control facilities to operate the well[3].

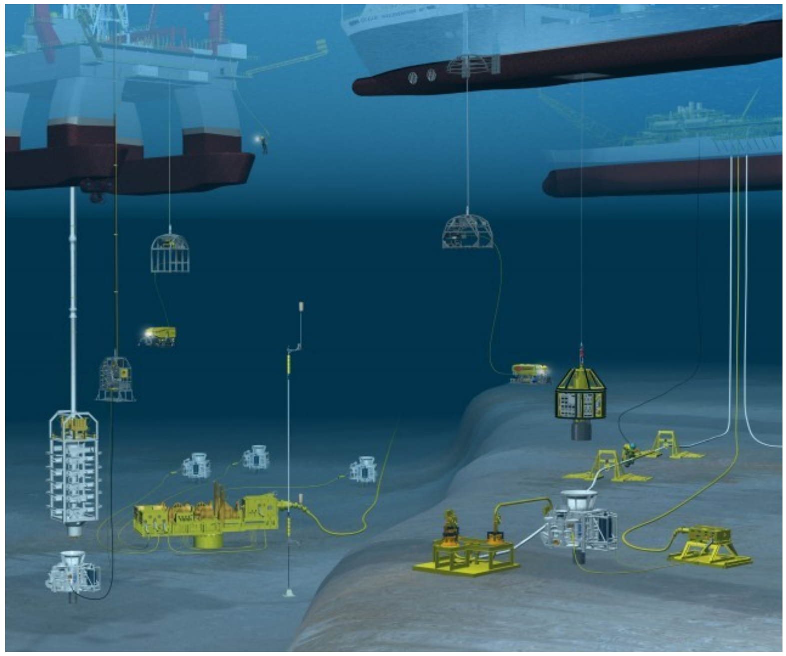

Figure 1 Subsea field layout [4]

Figure 1 shows the layout for subsea field layout that mostly used in the oil gas industry for deepwater.

The subsea production system consists of the following components:

1. Subsea drilling systems
2. Subsea Christmas trees and wellhead systems
3. Umbilical and riser systems
4. Subsea manifolds and jumper systems
5. Tie-in and flow line systems
6. Control systems
7. subsea installation.
8. Remote operated vehicle (ROV)

Most of the subsea production system use power to operate. 10kW to 10MW are the range of power required for the subsea equipment[3]. Remote operated vehicle was selected as the power guideline to design power generation system. Power required for operating the remote operated vehicle is 500HP(≈373kW) for trenching n burial class[5].

2.2 Power generation Unit

2.2.1 Linear Generator

Figure 2 and Figure 3 show that the linear generator have three part, namely :

1. stator
2. rotor
3. buoy

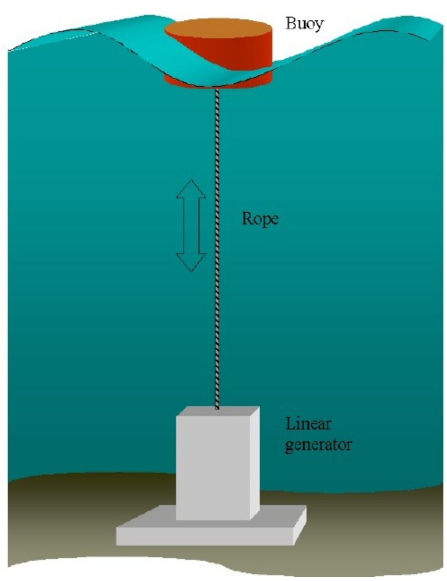

Figure 2 Working principle of linear generator[6]

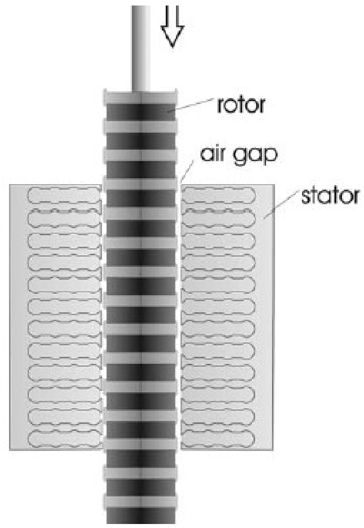

Figure 3 Main parts of a linear generator[6]

As shown in Figure 4, stator consists of magnets and pole shoes. For the rotor part consist of coil windings and stator steel show in Figure 5.

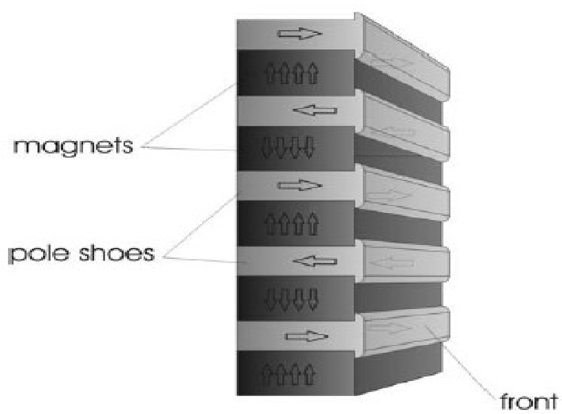

Figure 4 Stator Part [6]

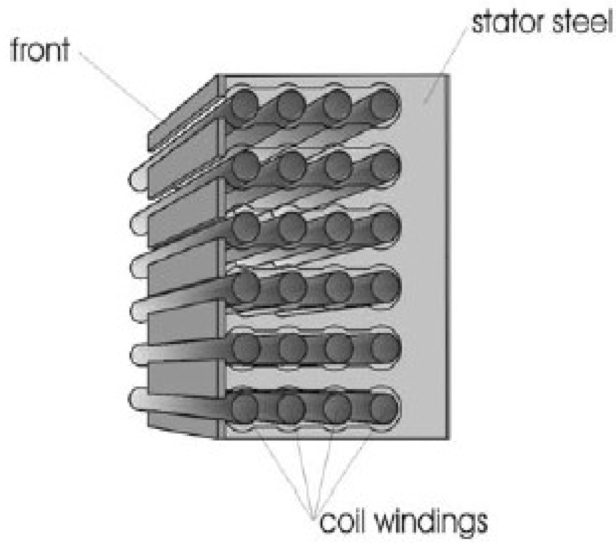

Figure 5 Rotor Part[6]

The pressure can be calculated by using equation 1. The pressure is calculated to determined the pressure acting on the linear generator. This is required for selection the of the material needed for the body of the linear generator.

$$P = \frac{1}{2}\rho v^2 + \rho g H \text{ [7]} \qquad \text{equation 1}$$

Where : P = pressure

ρ = density of water

v = velocity of water

g = gravity

H = height

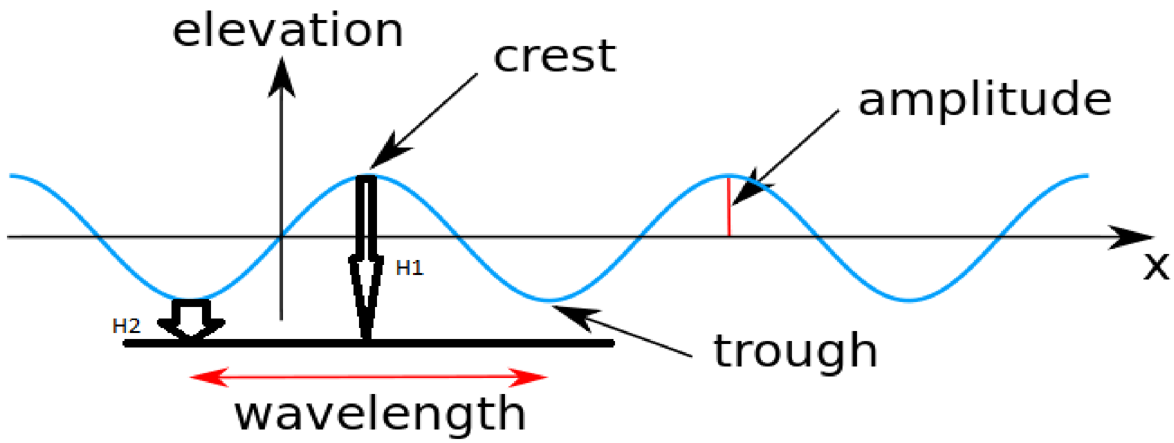

Figure 6 wave propagation [7]

From the Figure 6 above, shows that at crest, the amplitude is H1 and at trough, the amplitude is H2. From this, we can conclude that P1>P2 because H1>H2. Other than that the moving piston have connection with the buoyancy force and the pressure produce from the wave. The buoyancy can be calculated from equation 2. The calculation for buoyancy is for requirement of the buoy which needs to be attached to the linear generator.

$$F_B = \rho g V \quad [8] \qquad \text{equation 2}$$

Where : F_B = Buoyancy Force

ρ = density of water

g = gravity of water

V = volume of body

The buoyancy force throughout the movement of the wave will be the same. Therefore to make the piston to actuate, the value of $P2 < F_B/A < P1$. The induction of electromotance can be calculated by using equation 3.

$$e = 2fwNl\hat{\beta}cos2\pi ft \text{ [6]} \qquad \text{equation 3}$$

Where : e = induced electromotance

f = frequency

w = pole width

l = side length of a coil

β = maximum magnetic induction

N = number of turn

t = the linked flux at the time

Therefore, the effective electromotance can be calculate by using the equation 3 divided by square root of 2

$$E = \frac{\hat{e}}{\sqrt{2}} = \sqrt{2}fwlN\hat{\beta} \text{ [6]} \qquad \text{equation 4}$$

Where : E = effective electromotance

ê = maximum induced electromotance

f = frequency

w = pole width

l = side length of a coil

β = maximum magnetic induction

N = number of turn

From the all the equations given, there are several ways to increase the induction of voltage:

1. By increasing the frequency of oscillation in a period of time. To increase the frequency of the oscillation, using spring at the stator to give external forces to oscillate.
2. Increasing the number of turn of coil that wrap the rotor part.

2.2.2 Rotech Tidal Turbine

Rotech Tidal Turbine use the motion of the sea as forces to rotate the blade. Rotech, a specialist in tools for the oil gas, geothermal, subsea and renewable energy markets, developed the bi-directional Rotech Tidal Turbine (RTT) that has been "Each one megawatt unit has a turbine diameter of 11.5m and a fully ballasted weight in excess of 2500 tons[9].

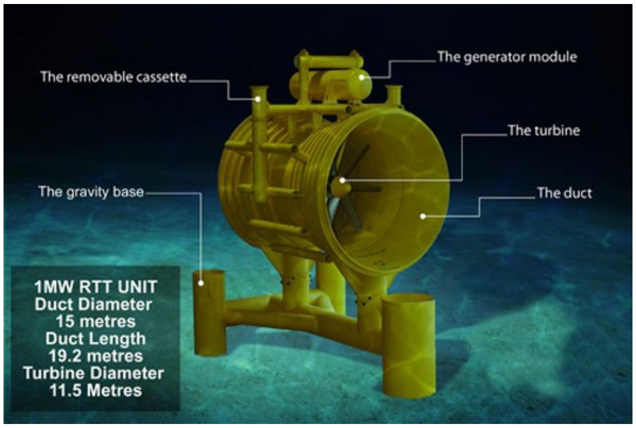

Figure 7 Prototype of RTT[9]

RTT is a gravity based venturi with a central cassette containing the generator, hydraulic pump, brake and motors which can be remove for operational and maintenance purposes. RTT is a horizontal-axis turbine in a double ended duct-diffuser.

RTT drive by generator via two hydraulic swash motors in an efficient closed-loop system. The design is robust and invisible while in use on the sea bed, the venturi captures the tidal flow energy very efficiently so its performance is competitive with wind energy and considerably less controversial in visual terms. The impellers are mounted on a central shaft within the cassette that incorporates an in-line fixed displacement hydraulic pump and the Wichita brake, all within a sealed pod. In order to maximize the flow efficiency through the turbine the electricity generating motor is mounted outboard of the flow tube. The hydraulic pump drives the generator via two hydraulic swash motors in an efficient closed-loop system.

The power available that can be produced by RTT can be calculated using equation 5.

$$P = \frac{1}{2}\rho A V^3 C_p \quad [10] \qquad \text{equation 5}$$

Where : P = power produced

ρ = density of water

A = sweep area

V = speed of water

C_p = coefficient of power

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor[10]. To this day, this is known as the Betz Limit or Betz' Law. The theoretical maximum power efficiency of *any* design of wind turbine is 0.59[10].

From equation 5, the power can be maximized as follows:

1. Increase the velocity of water
2. Increase the sweep area of the blade.

The RTT is the same principal as the linear generator. The difference between RTT and linear generator is the rotor part. The movement of RTT rotor part is rotation while linear generator rotor part move linearly.

2.2.3 Thermoelectric generator

The temperature difference between the produced oil and the surrounding sea water can be converted into electric energy by low power thermoelectric generators based on the Seebeck effect or in the rankine cycle[11]. A thermocouple circuit is formed when two dissimilar metals are joined at both ends and there is a difference in temperature between the two ends[12]. The combination of two metal is known as peltier element.

Some basic requirements need to be considered to design the thermoelectric generator. For the starter, the disturbance of the crude oil flow must be reduced to a minimum, so that any modification of the internal cross section of the oil duct should be avoided. This requirement imposes a generator with a circular geometry, with the same internal diameter as the crude oil duct. Thus the Peltier elements, of plane geometry, must be adapted to the cylindrical geometry of the tube by means of a fixation interface with high thermal conductivity. The exposure to the high external pressure and corrosion of the structure are also features of fundamental importance in the generator design.

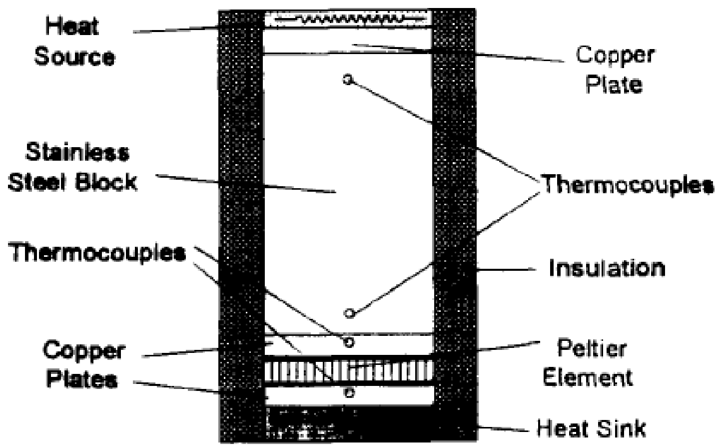

Figure 8 Peltier Element [11]

The total temperature drop ΔT from the crude to the water is distributed along the different elements of the generator. The sequences of drop that place many stages, at first drop from the inner to the outer part is due to the convective thermal resistance of the oil-tube interface. Then followed by a small decrease due to the finite thermal conductivity of the oil duct, a more important temperature drop ΔT_p Over the Peltier element, and a another small decrease at the copper plate. A final drop occurs at the copper-water interface, due to its convective thermal resistance.

Under Steady state condition, the voltage produced through any section of a pipe can be determined from equation 6.

$$V = S(T_i - T_o) \quad [13] \qquad \text{equation 6}$$

Where : $V = voltage$

S = seebeck constant

To=Temperature final

Ti= Temperature inital

2.3 Energy storage unit

Energy storage is accomplished by devices or physical media that store energy to perform useful operation at a later time[14]. Some technologies provide only short-term energy storage, and others can be very long-term. Uninterrupted power supply (UPS) by using the delta conversion or double conversion.

2.3.1 Delta conversion

The delta-conversion configuration consists of two bidirectional converters, a battery bank, a static switch and a series transformer [15]. The configuration of delta conversion as Figure 9.

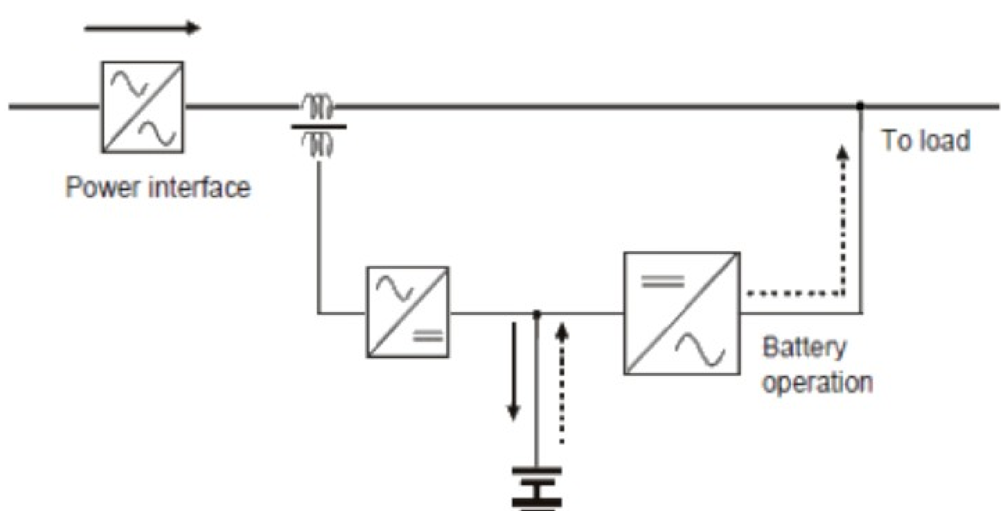

Figure 9 Configuration of delta conversion [15]

Special Transformer used in delta-conversion UPSs as interface between the load utility power, with a "delta" inverter in the transformer secondary to regulate input current and power. While controlling the voltage at the load, the UPS can regulate the magnitude, wave shape, and power factor of the current supplied at the UPS input which result in effective power factor. UPS output is dependent of input supply frequency variations.

2.3.2 Double Conversion

Online or double-conversion UPSs are the most commonly used static UPSs because they are capable of completely isolating sensitive IT loads from unconditioned utility power[15]. The configuration of double conversion is shown in Figure 10.

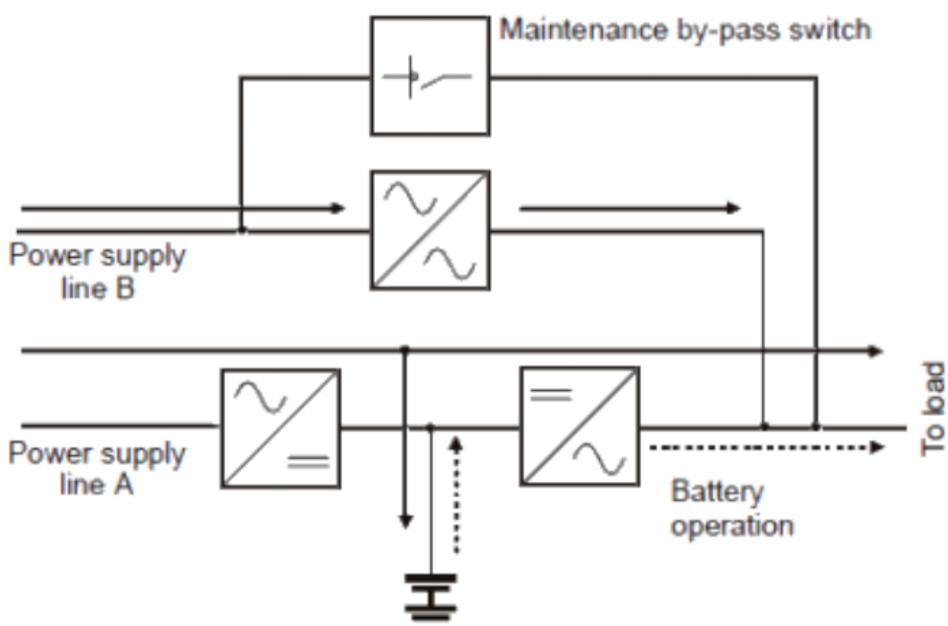

Figure 10 Configuration of double conversion [15]

Double-conversion UPSs always provide the load with a high quality, conditioned AC signal, even during normal operation when utility power is available. For this reason, double-conversion UPSs are more common in high availability, high-power mission critical applications such as industrial facilities, data centers and medical applications. Typical output power ratings for these types of UPSs range from 10 to over 1.000 kVA[15].

2.4 Distribution

Distribution system is important for power generation system in order to distribute the energy produced by the power generation unit to the subsea equipment. Distribution used for regulate power required for each subsea system. The distribution that applicable for deepwater system are electro hydraulic multiplex system and all electric system.

2.4.1 Electro hydraulic multiplex system

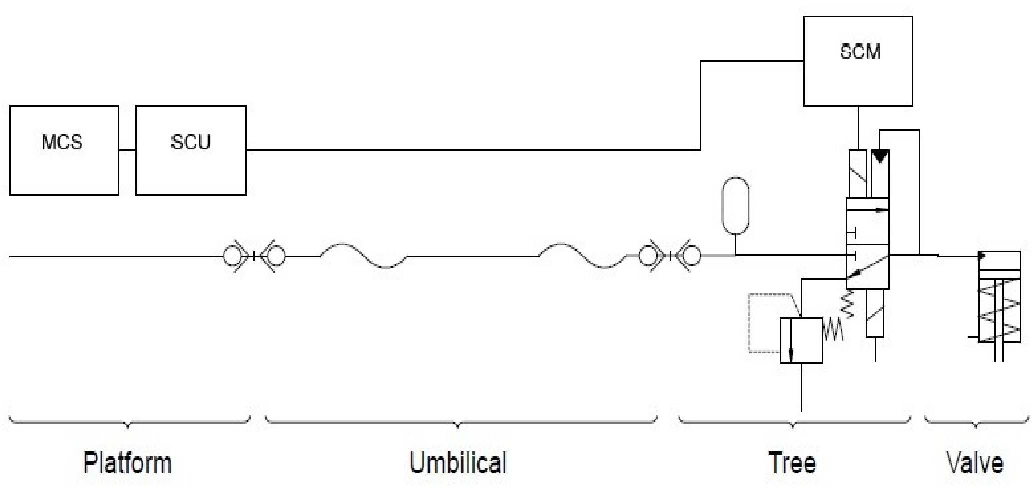

Figure 11 Configuration of electro hydraulic multiplex system [16]

Table 1 Abbreviation for electro hydraulic multiplex system

Abbreviation		Explanation
MCS	Master control station	Dedicated system that controls and retrieve data from subsea equipment on the ocean floor [17].
SCU	Subsea control unit	provides a standard communications interface and facilitates control and monitoring of the subsea environment. [18].
SCM	Subsea control module	provides advanced multiplex electro-hydraulic functions to control and monitor subsea control systems[18].

2.4.2 All electric system

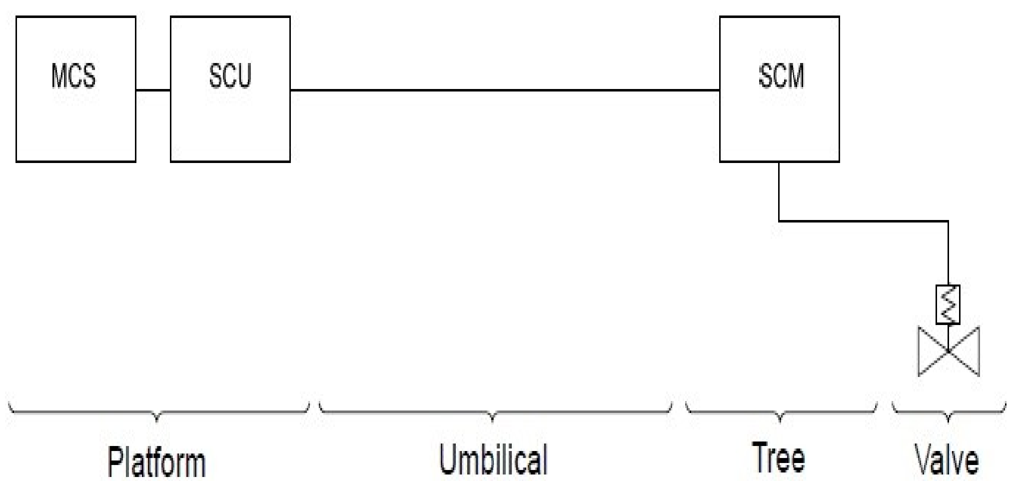

Figure 12 Configuration of all electric system distribution[16]

Table 2 Abbreviation for all electric system distribution

Abbreviation		Explanation
MCS	Master control station	Dedicated system that controls and retrieve data from subsea equipment on the ocean floor [17]
SCU	Subsea control unit	provides a standard communications interface and facilitates control and monitoring of the subsea environment.[18]
SCM	Subsea control module	provides advanced multiplex electro-hydraulic functions to control and monitor subsea control systems[18]

2.5 Cable

Cable is one of the requirement in the power generation system. Cable use for transporting power that produce from power generation unit to the energy storage unit, energy storage unit to distribution and distribution to the subsea equipment. The cable that can be use for the deepwater are shown as bellow :

1. HVAC subsea cable
2. HVDC subsea cable

2.5.1 HVAC subsea cable

Subsea cables using XLPE insulation are currently available in three phase three core designs up to 225kV and in single core designs up to 400kV[19].

Figure 13 HVAC subsea cable insulated with XLPE[19]

2.5.2 HVDC subsea cable

For HVDC transmission, the very high power schemes (>300MW) are catered for by HVDC Classic, however this type of HVDC requires large expensive converter stations and is not easily integrated for multi-terminal operation.

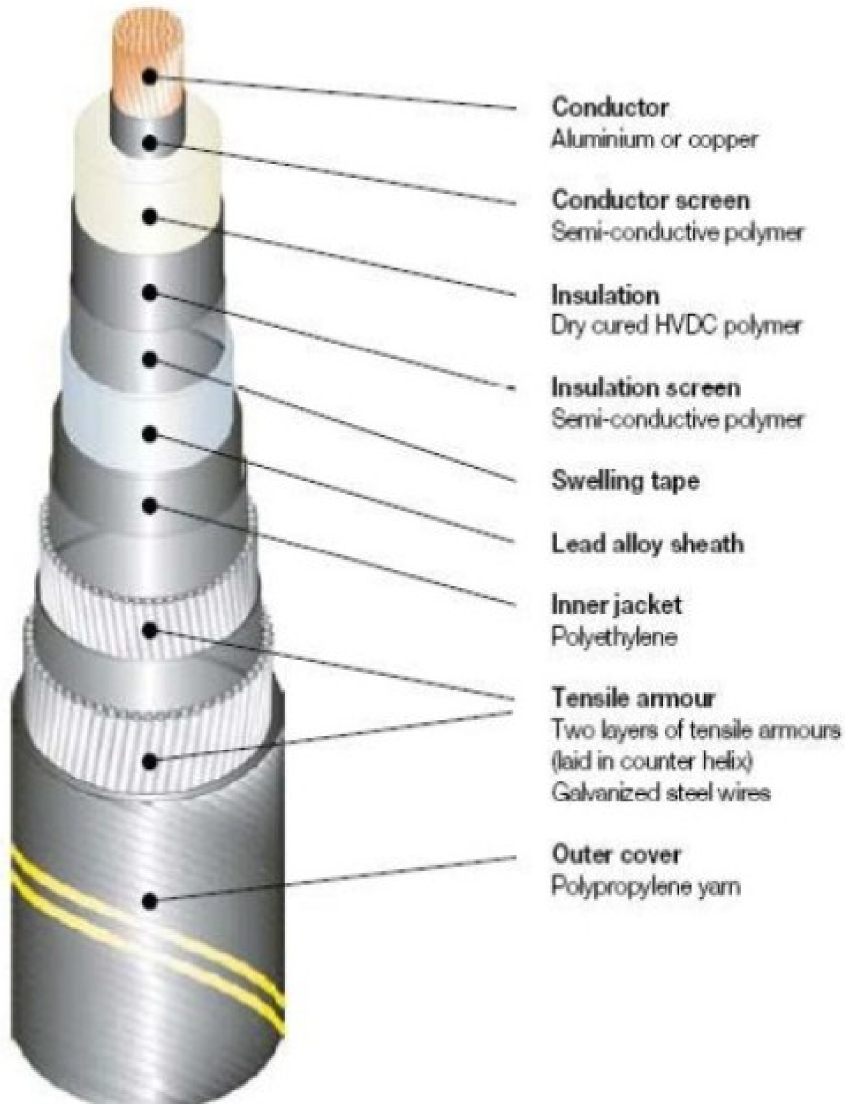

Figure 14 HVDC subsea cable insulated with polypropylene yarn[19]

Both cable used in the power generation system. The HVDC subsea cable used for transmitting power from power generation unit to the energy storage unit and energy storage unit to distribution. For HVAC subsea cable used for distribution to subsea equipment.

2.6 Connector

Underwater-mateable connectors, also known as “wet-mate connectors”, have been around since the 1960’s[20]. Since that time, there already have many product and supplier providing choices. It can be categorized according to the current diversity into generic groups of underwater-mateable products. All of these products (listed in approximate order of increasing unit cost) have been extensively qualified and tested and are in operational use. Types of underwater mateable connector are as follow[20] :

1. Miniature rubber molded electrical Wet-mate connector
2. Rubber molded electrical Wet-mate connector
3. Metal Shell Electrical Wet-Mate Connectors
4. Pressure Balanced Electrical CO-Axial Wet-Mate connectors
5. Pressure Balanced Electrical Wet-Mate connectors

Chapter 3

Methodology

3.1 Research methodology

The methodologies for conducting this research analysis project divided into several categories as follow.

1. Problem definition
2. Information gathering
3. Concept generation
4. Concept selection
5. Assembly design
6. Mathematical modeling
7. Detail design

3.1.1 Problem definition

Due to the power generation unit located at the platform, the higher power needed to accommodate the losses caused from transportation of power to the seabed and the cost will be higher because longer cable is need.

3.1.2 Information gathering

Information gathered from various sources:

1. Internet
2. Books
3. research paper
4. journal

3.1.3 Concept generation

Starting from physical decomposition of the power generation system, follow by morphological approach. From the morphological approach, each element was being selected to form one complete system.

3.1.4 Concept selection

The selection of the concept being done using the weighted score matrix.

3.1.5 Assembly drawing

From the chosen power generation system, the position of the element was shown in the assembly drawing.

3.1.6 Mathematical modeling and calculation

Based on the governing equation, the power produced being calculated with variation of sweep area and velocity of water.

3.1.7 Detail design

Modeling the power generation unit using AUTOCAD software and CATIA based on the calculation get from the mathematical modeling.

3.2 Flow chart

In order to fulfill the objective, the flow of the project shown as Figure 15

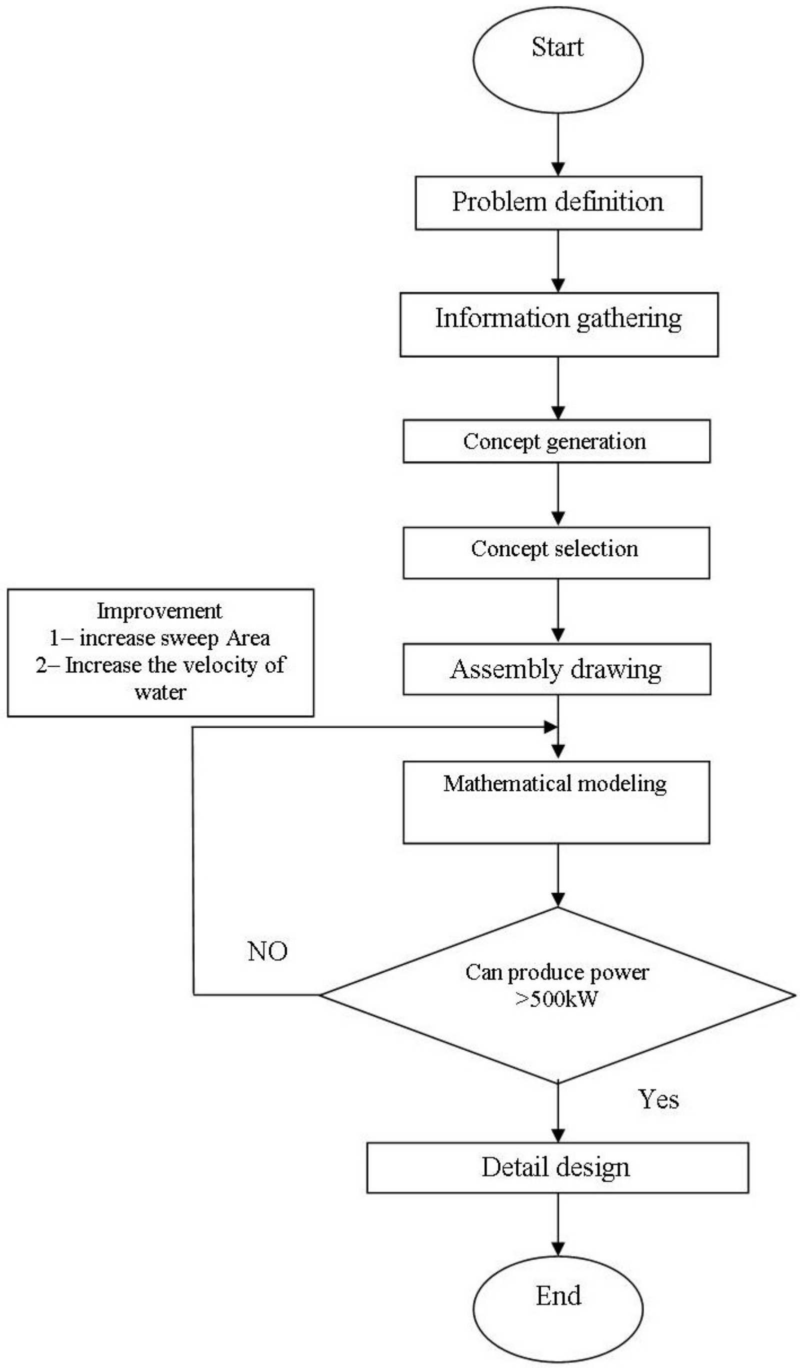

Figure 15 Flow chart

3.3 Gantt chart

Table 3 Gantt chart

week / Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
problem definition																	Semester																	
Information gathering																																		
Concept generation																																		
Assembly drawing																																		
Mathematical modeling and calculation																																		
Detail design																																		

Legend	
green	FYP 1
Blue	FYP 2
	keymilestone

Chapter 4

Result

4.1 System decomposition

The power generation system is decomposed as follows.

1. Power generation unit
2. Energy storage unit
3. cable
4. connector
5. Distribution

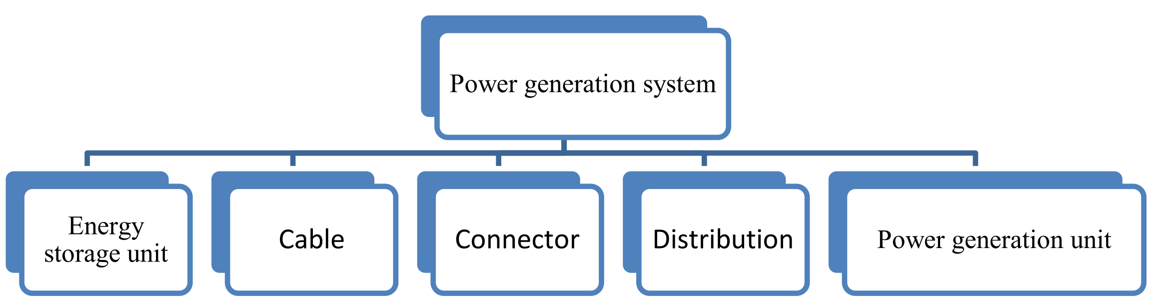

Figure 16 Physical decomposition of power generation system

4.2 Morphology chart

Table 4 Morphology chart

Morphology chart					
Energy storage unit	Delta Conversion	Double conversion			
Cable	HVAC	HVDC			
Connector	Miniature rubber molded electrical Wet-mate connector	Rubber molded electrical Wet-mate connector	Metal Shell Electrical Wet-Mate Connectors	Pressure Balanced Electrical CO-Axial Wet-Mate connectors	Pressure Balanced Electrical Wet-Mate connectors
Distribution	Electro hydraulics multiplex system	All electric system			
Power Generation unit	Linear generator	RTT	Thermoelectric		

4.3 Concept generation

4.3.1 Concept A

Table 5 Concept A configuration data

Element	**Components**
Energy storage unit	Delta conversion UPS
Cable	HVAC,HVDC
Connector	Rubber molded electrical Wet-mate connector
Distribution	All electric system
Power generation unit	RTT

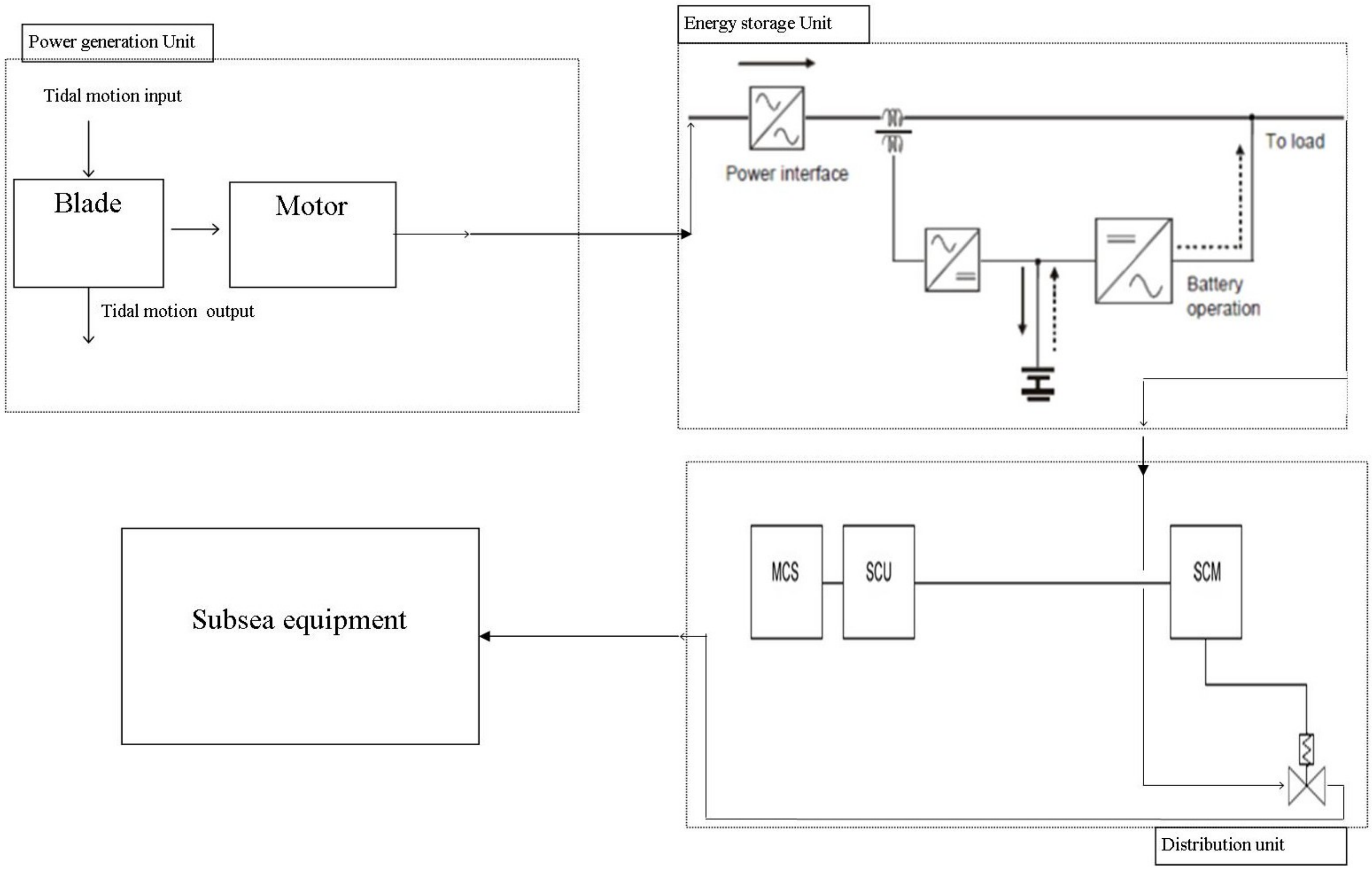

Figure 17 Concept A configuration

4.3.1 Concept B

Table 6 Concept B configuration data

Element	**Components**
Energy storage unit	Delta conversion UPS
Cable	HVAC,HVDC
Connector	Pressure Balanced Electrical CO-Axial Wet-Mate connectors
Distribution	Electro hydraulics multiplex system
Power generation unit	Linear generator

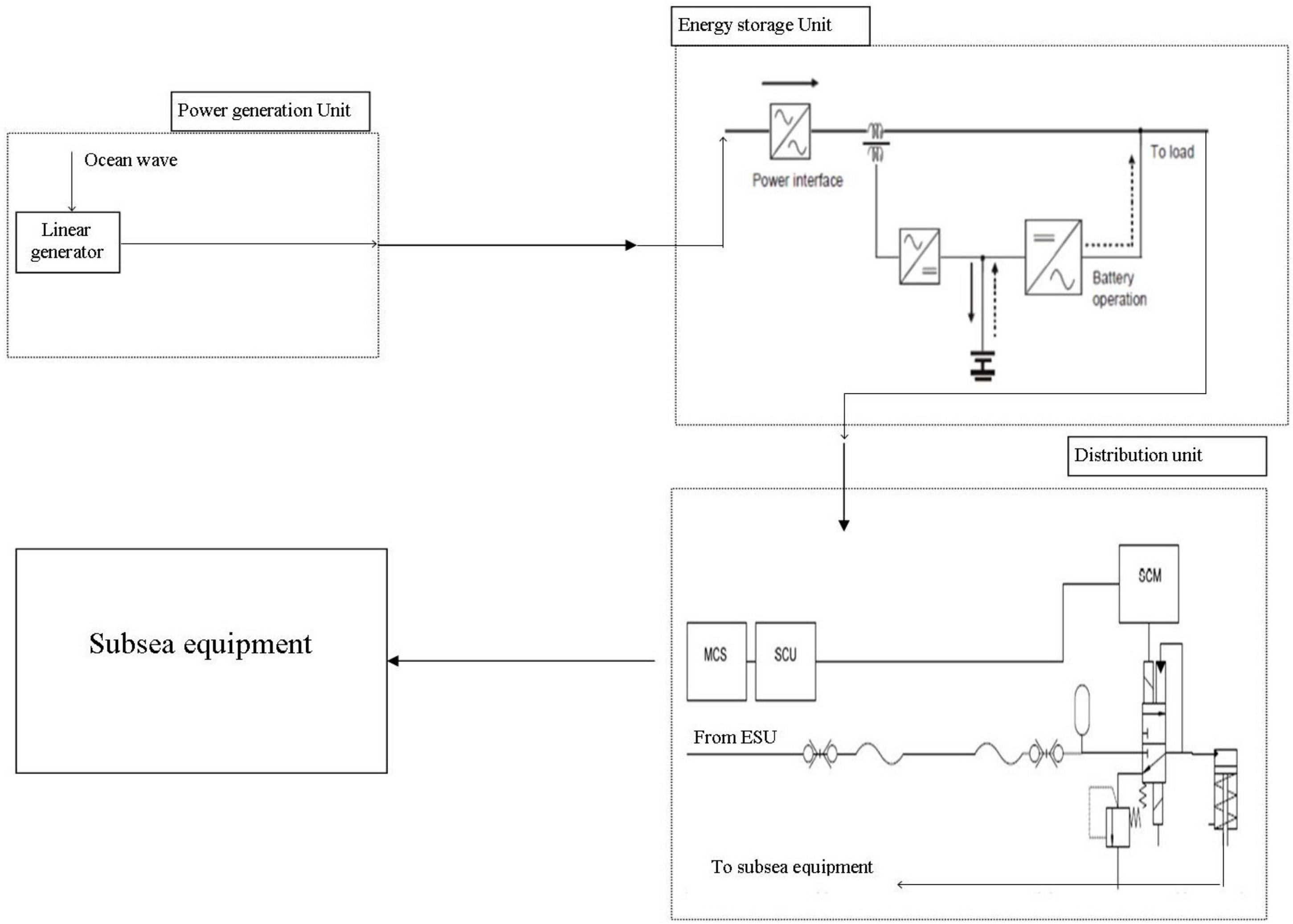

Figure 18 Concept B configuration

4.3.1 Concept C

Table 7 Concept C configuration data

Element	**Components**
Energy storage unit	Delta conversion UPS
Cable	HVAC,HVDC
Connector	Miniature rubber molded electrical Wet-mate connector
Distribution	Electro hydraulics multiplex system
Power generation unit	Thermoelectric

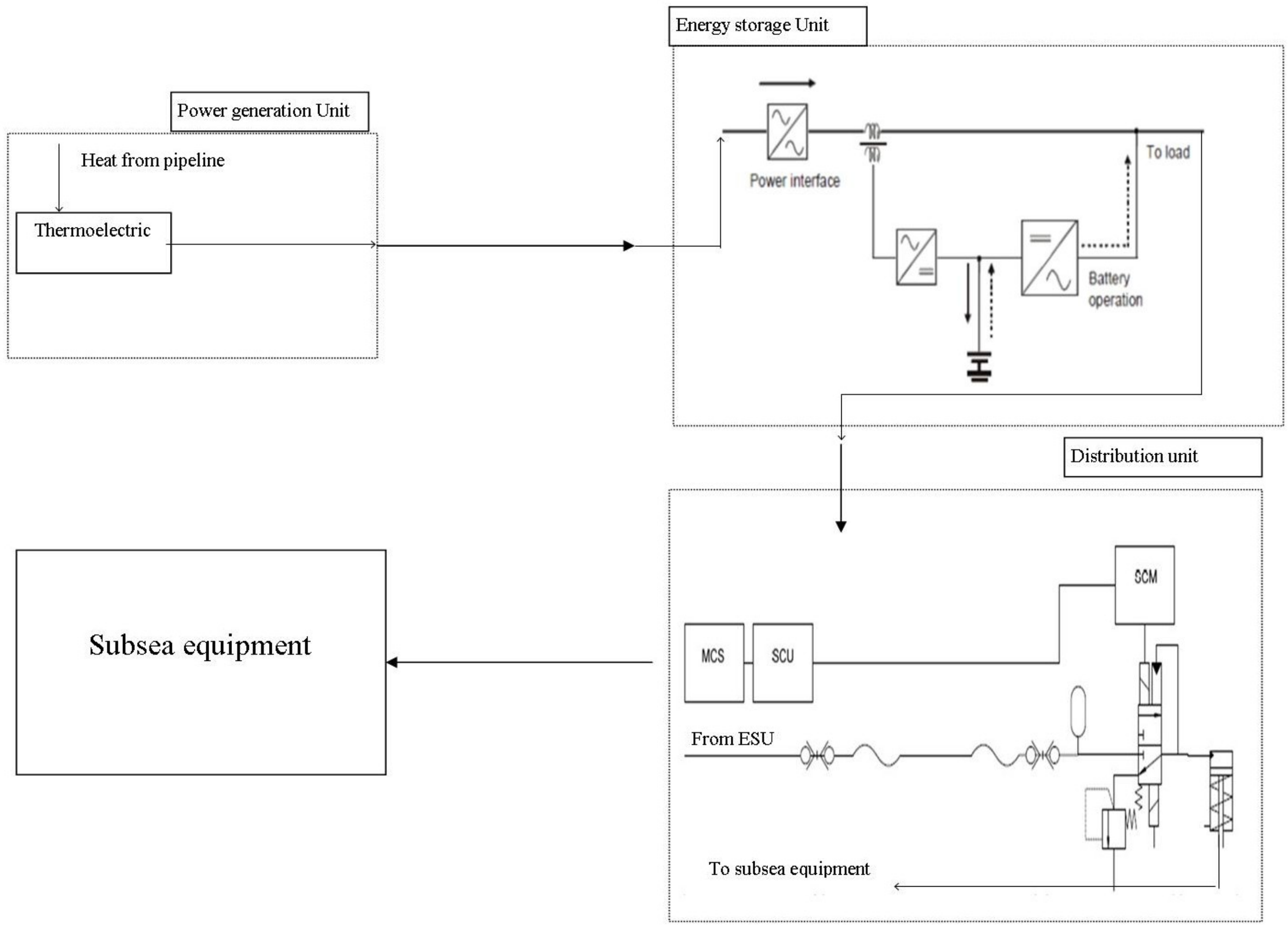

Figure 19 Concept C configuration

4.4 Concept selection

Weighted score matrix was used as concept generation selection. Figure 20 below show objective tree which show weigh factor to be used in weighted scored matrix. All the concept using the weighted scoring with 10 point scale. The criteria are derived from objective tree which classified the criteria into two major category namely performance and sustainability of the system.

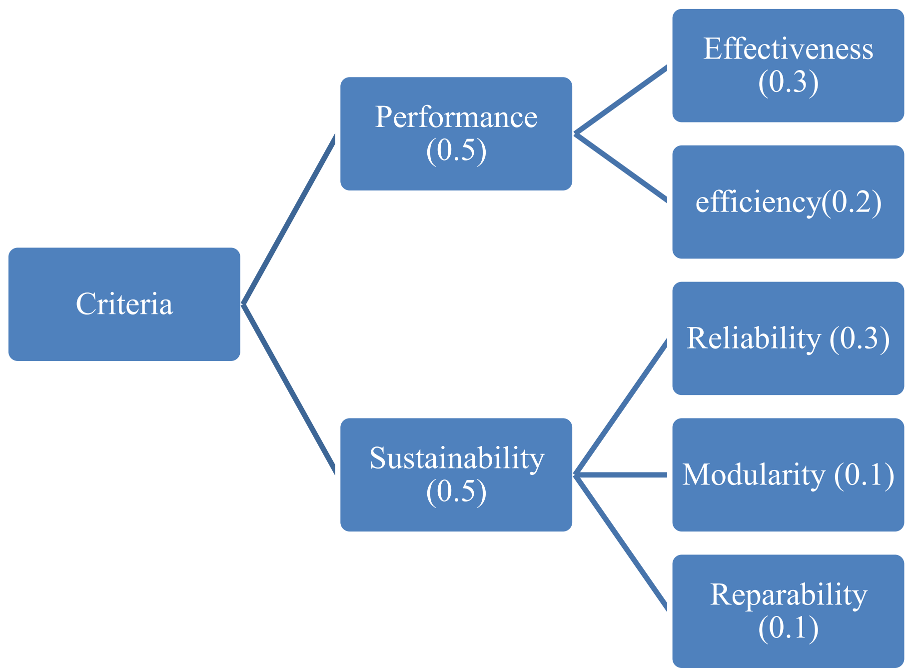

Figure 20 Objective Tree

The performance and sustainability divided by half of weight factor. This is to enhance stability on both performance and sustainability. As shown in Figure 20, the performance divided by two which are efficiency(0.2) and effectiveness (0.3). The sustainability divided by three part, which are modularity (0.1), reparability (0.1) and reliability (0.3).

The specification of the criteria are :

1. Reliability

   The function of equipment over time. This is to ensure the equipment cannot breakdown easily.
2. Efficiency

   The efficiency of the system for converting power from the source.
3. Effectiveness

   The effectiveness of the system to do its intended function completely and accordingly.
4. Modularity

   The criteria stress on the installation and assemble or disassemble of the system.
5. Reparability

   Stress on the availability of the system to be repaired in case of breakdown or problem.

Table 8 Weighted score matrix

Selection Criteria	Weight factor	A		B		C	
		Score	Rating	Score	Rating	Score	Rating
Effectiveness	0.3	8	2.4	8	2.4	6	1.8
Efficiency	0.2	6	1.2	8	1.6	4	0.8
Reliability	0.3	8	2.4	5	1.5	6	1.8
Modularity	0.1	9	0.9	8	0.8	8	0.8
reparability	0.1	3	0.3	5	0.5	3	0.3
Total Rating			6.6		6.2		6.4

The concept generation A was choose because it has higher rating, 6.6 compare with the concept B, 6.2 and concept C, 6.4.

4.6 Mathematical modeling

Governing equation

$$P = \frac{1}{2}\rho A_2 V_2^3 C_p$$

where : P = power produced

ρ = density of water

A_2 = sweep area

V_2 = speed of water

C_p = coefficient of power

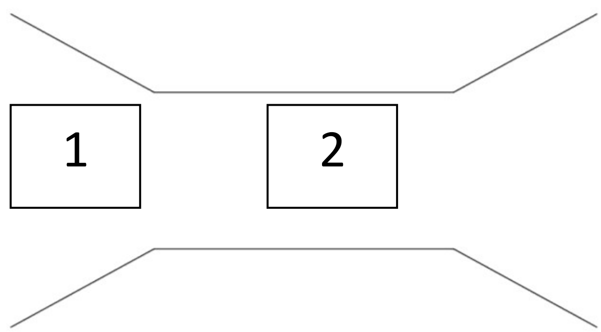

Figure 21 Duct system for power generating unit

From Figure 22, the ducting system was made like that because to increase the velocity at the region number 2. From the calculation of flow rate state that, the flow of water will be the same through the duct. Therefore to increase the velocity which low velocity at the part 1, the sweep area must be small compared to the catchment area. This can be validated by the following calculation.

The flow rate 1 = 2

$$Q_1 = Q_2$$

$$A_1V_1 = A_2V_2$$

The catchment area, $A_1 = 4\ A_2$, this is to reduce the cost of manufacture.

velocity at the region number 2,

$$V_2 = 4\ V_1$$

The speed of water at the seabed was assumed at 2m/s.

Therefore maximum power can be harvest by using the RTT shown in the Table 9.

Table 9 Power produced from constant velocity of water at the seabed

V1(m/s)	A1(m^2)	r1(m)	Q(m^3/s)	A2(m^2)	r2(m)	V2(m/s)	Power (watt)
2	1	0.564153	2	0.25	0.282077	8	37760
2	2	0.797833	4	0.5	0.398916	8	75520
2	3	0.977142	6	0.75	0.488571	8	113280
2	4	1.128306	8	1	0.564153	8	151040
2	5	1.261484	10	1.25	0.630742	8	188800
2	6	1.381887	12	1.5	0.690944	8	226560
2	7	1.492609	14	1.75	0.746304	8	264320
2	8	1.595666	16	2	0.797833	8	302080
2	9	1.692459	18	2.25	0.84623	8	339840
2	10	1.784008	20	2.5	0.892004	8	377600
2	11	1.871084	22	2.75	0.935542	8	415360
2	12	1.954283	24	3	0.977142	8	453120
2	13	2.034083	26	3.25	1.017041	8	490880
2	14	2.110867	28	3.5	1.055434	8	528640

Therefore the sizing of the duct required are as Table 10

Table 10 Sizing of duct system

	Size
Radius of catchment	2.1m
Radius of sweep	1.06m

Therefore, the catchment area needed to produced 500kW power approximate to $14m^2$. Meanwhile the sweep area needed is $3.5m^2$.

Chapter 5

Conclusion & Recommendation

5.1 Conclusion

The main objective of this study is to design subsea power generation system as an alternative to the conventional top-side power generation facility on an oil platform or floater. The subsea power generation system using the RTT power generation unit which can produce 500 kW power and thus can operate the remote operated vehicle. The power receive RTT is much more higher compared to the power generation system at the platform. This is because the uses of cable at the platform is 3000m(deepwater) while for the RTT only uses not more than 100m. The longer the cable, the more power will be loss. Therefore, the power need to produced RTT is much lower compare with the power generation system at the platform because need to compensate the losses due to the longer cable.

5.2 Recommendation

The RTT power generation system is good to be used for the oil and gas industry. There a few recommendation need to be focused for the next project.

1. Suitable duct system. Find the best design for the duct system to minimize the turbulent and increase the laminar flow. In addition, laminar flow will help to increase the propeller lifetime.
2. Propeller design. The suitable design for propeller which can maximize the power produced.

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