EXTRACTION OF WAVE ENERGY BY SYNCHRONOUS GENERATOR: DESIGN AND PERFORMANCE ANALYSIS

DISSERTATION/THESIS

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Submitted by:

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I, Ankita Pandey, Roll No. 2K20/PSY/04 student of M.Tech. (Power System), hereby declare that the project Dissertation titled "EXTRACTION OF WAVE ENERGY BY SYNCHRONOUS GENERATOR: DESIGN AND PERFORMANCE ANALYSIS" which is submitted by me to the Department of Electrical Engineering Department, Delhi Technological University, Delhi in fulfillment of the requirement for the award of the degree of Master of Technology/Bachelor of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I, Ankita Pandey, Roll No. 2k20/PSY/04 student of M. Tech. (Power System), hereby declare that the dissertation/project titled "EXTRACTION OF WAVE ENERGY BY SYNCHRONOUS GENERATOR: DESIGN AND PERFORMANCE ANALYSIS" under the supervision of Prof. Jitendra Nath Rai of Electrical Engineering Department Delhi Technological University in fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

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ABSTRACT

Due to the intricate nature of the technique necessary to harvest energy from waves in the ocean, its usage in commercial applications has been rendered impossible. Throughout the course of this research, a variety of cutting-edge strategies for harvesting wave energy have been developed. This project utilizes a one-of-a-kind topology that is designed to eliminate the limitations of conventional linear generators and increase the amount of continuous power supply. Additionally, this project utilizes a straightforward design that consists of uniquely shaped floaters that are mounted on land. The primary objectives of this project were to conduct an investigation into a cutting-edge technological system that has the potential to reduce the costs associated with the construction and operation of an ocean wave energy (OWE) power plant that is connected to the grid, while simultaneously improving operational efficacy and expanding business opportunities. These objectives were designed to be accomplished by: Floaters may be attached to the coastline or anything else that is made artificially; as a consequence, its installation along the coast is simple, as are the requirements for its maintenance and its accessibility. A synchronous machine is what we make use of here at this facility in order to produce electricity. In spite of the fact that it is forecasted that the height of the waves in the ocean would be relatively modest, with an average height of 0.5 meters, the ocean is still capable of generating and

transmitting electricity with a high voltage and current value. For the purpose of output analysis, Python code is used, whilst SCADA and MATLAB tools are utilized for the purpose of physically illustrating the project. In this section of the research, in addition to electrical generators, the emphasis is on hydraulic motors.

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NOMENCLATURE

OWE - Oceanic Wave Energy

WEIA - World Energy Information Administration

WEC- Wave Energy Converter

LG - Linear Generator

SPLEG - Single Port Linear Electrical Generator

PTO - Power take off

FSPMLG - Flux-switching permanent magnet linear generator

CHAPTER - 1

INTRODUCTION

1.1 Renewable Energy Sources :

Up until this point, the whoIe world's need for electricity has been fulfilled through the use of non-renewable resources such as coal and petroleum[4]. In India, the nation's need for energy is satisfied by non-renewable sources to the tune of around 82% of total consumption. The following are the natural energy reserves that might be guaranteed as of the year 2006: Natural gas: 245 billion cubic feet, mineral oil, shale, and liquid gas: 239 billion cubic feet, natural uranium: 36 billion cu ft, and equivalent tonnes of coal: 748 billion. These are all expressed in billion tonnes per Equiv[9]. The World Energy Information Administration (WEIA) is the source of these data, and we can examine that the world has already surpassed the projected usage rate of non-renewables in recent years, and there are shortages of these resources to produce electricity. We can also see that the world has already surpassed the projected usage rate of non-renewables in recent years. Additionally, we are able to observe that the global utilisation rate of non-renewable resources in recent years has already exceeded the projections that were made[5].

1.2 Expansion in Non-Renewable Energy Production :

According to the findings of the study, by the year 2028, electricity generated from renewable sources would account for 54.6 percent of the total. The Central Power Authority (CEA) has developed certain forecasts that indicate that the percentage of electricity that is generated by renewable sources would increase from its current level of 18.5 percent to 45 percent by the year 2029-2030[4]. Prospective locations have been found in the regions of Khambhat and Kutch, in addition to huge backwaters where barrage technology may be used. The overall estimated potential for tidal energy in India is around 12455 MW, and this potential has been assessed. The full theoretical potential of wave emergy is estimated to be somewhere around 40,000 MW, according to some estimations[7].

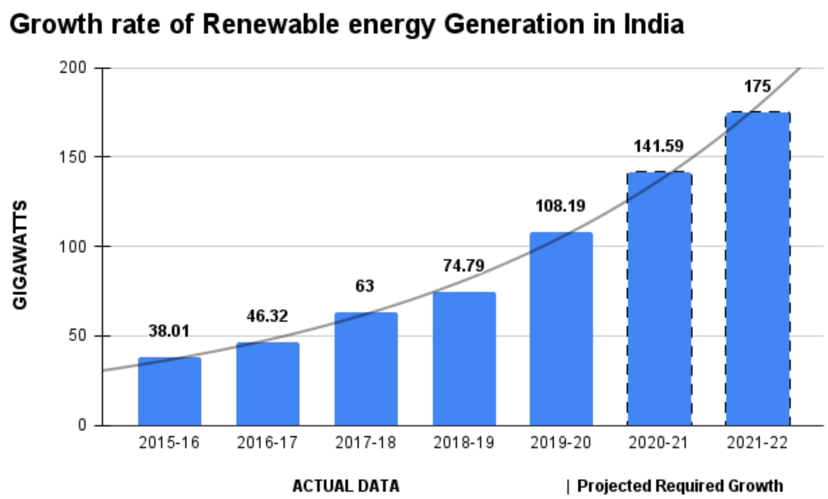

Figure 1.1: Growth rate of Renewable energy Generation in India
(Source: Ministry of Renewables and Press Information Bureau, GOI.)

The amount of power or energy that may be taken from waves is often determined by the height and velocity of the wave, in addition to the wave's time period. This is in addition to the wave's length. It is believed that the energy from sea waves throughout the coast of India varies from around 5.5-15.5 MW/m, whilst the theoretical estimations of the same come out to approximately 41-61 GW [10]. According to the findings of a study conducted by IITM and CRISIL, the capacity utilisation factor of the energy produced by waves in India ranges from 15.5-20.5 percent, and it is estimated that the potential for energy production along the western coast is greater in comparison to that along the eastern coast. Following is research that reveals that there has been a considerable rise in the quantity of energy that has been created by making use of the wave energy that is contained within the ocean[5].

1.3 Oceanic Waveenergy :

Wave energy is the process of harnessing the kinetic energy of ocean waves to do beneficial labor, such as the production of electricity, the desalination of water, or the pumping of water[8]. A wave energy converter is any device that draws electricity from the ocean's waves (WEC)[1].

Waues are produced when wind bIows over the surface of the water of a body of water[4]. As long as the speed of the waves just above the water is lower than the speed of the wind just above the water, there will be a conversion of emergy from the wind to the waves[8]. The development of waves is caused by a combination of factors, including changes in air pressure between the vpwind and the Iee side of a waue crest and friction on the water surface caused by the wind. This combination leads the water to enter a shear stress state[1].

Wave power is not the same as tidal power, which uses the energy of the current created by the Sun and the Moon's gravitational pull to generate electricity[5]. Wave power is generated by the ocean's waves. Ocean currents are different from waves and tides because they are driven by other factors, such as breaking waves, wind, the Coriolis effect, cabbeling, and changes in temperature and salinity[6]. Waves and tides are not to be confused with ocean currents.

In contrast to other well-established forms of renewable energy, such as wind power, hydropower, and solar power, the production of electricity from waves is not a commercial technique that is extensively used[7]. Despite this, efforts to exploit this source of energy date back to at least 1890[2] mostly owing to the great power density it has. As a point of comparison, the power density of photovoltaic panels is 1 kW/m2 when they are receiving the maximum amount of solar insolation, and the power density of the wind is also 1 kW/m2 when it is blowing at 12 meters per second[9]. However, the power density of the waves along the coast of San Francisco is an average of 25 kW/m2 per year[6].

This energy might be completely harnessed by India thanks to its vast coastline, which has estuaries and gulfs that can be utilized to their maximum potential[7]. The harnessing of tidal streams and ocean currents to generate massive amounts of power requires comparatively little negative effects on the surrounding ecosystem, despite the fact that these resources are vast and almost limitless[9].

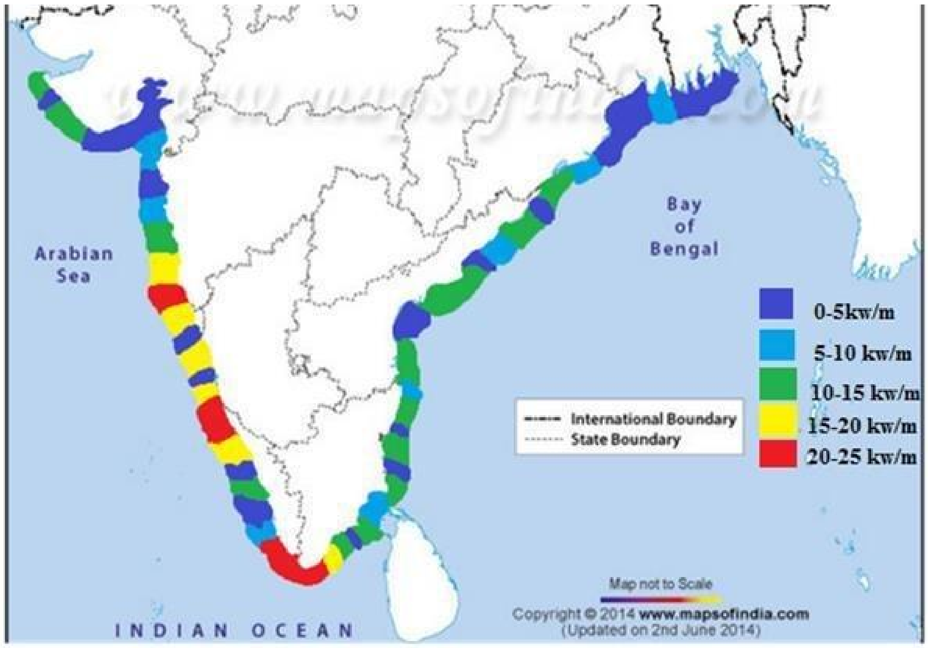

Figure 1.2: Wave energy Potential in India

(Reference: Ocean Energy For Electricity Generation And Its Potential In India**)**

Basic research and development is being handled by the National institute of Ocean Technology in Chennai, which is part of the Ministry of Earth Sciences; however, additional contributions from other prestigious institutions will assist us in better comprehending and developing the technologies more quickly[2].

1.4 Why Use Wave Power?:

More than half of the world's population lives within 93 miles (150 kilometers) of a coastline, and in many parts of the globe, people have access to the power of the ocean's waves throughout the clock[3]. In 2005, a piece of study that explored its relevance and came to the conclusion that mor+e than 10% of the world's energy originates from water was published. This illustrates that the use of wave energy is continuously expanding because of the fact that it has a favorable influence on the environment that it is located in[9].

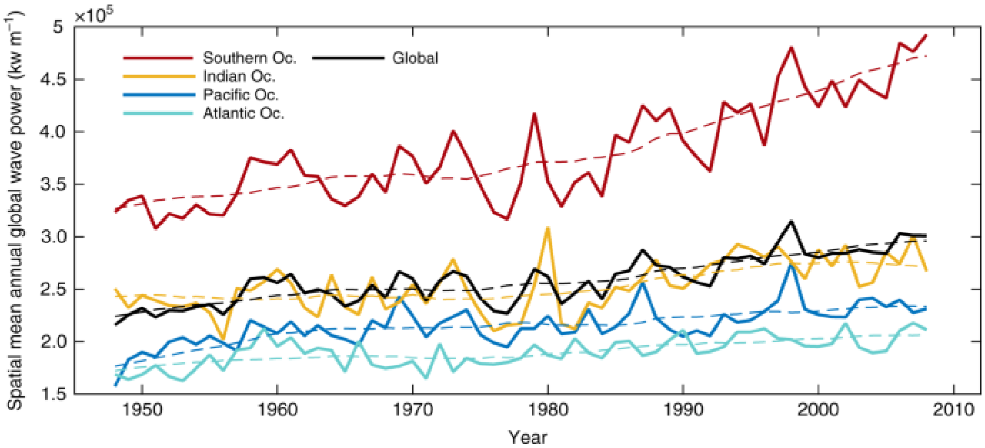

Figure 1.3: Growth rate of Wave energy Generation in World[6]

Wave energy has the ability to create an amount of power that is sufficient to produce an amount of electricity that is comparable to creating twice the amount of electricity that is now generated around the globe, according to estimations that were supplied by the Globe Energy Council[3]. As a result, the objective of this project is to provide an alternative technique of producing energy that has the potential to be reliable, to have a low impact on the natural environment, and to be accessible at all hours of the day and night[4].

1.5 Conversion of Wave Energy :

According to an earlier approach, in order to collect the energy from waves and transfer it into kinetic energy[Brooke 2003], it is needed to employ an interface device such as a floating structure since it acts as a conduit between the two forms of energy. The WEC is the name that has been given to this floating structure[Brooke]. The conversion process begins with this stage, which is the most crucial one. During the secondary conversion process, the kinetic energy that was there is converted into a different kind of useful energy.

Wave energy converters, or WECs for short, are machines that take the kinetic and potential energy that is connected with moving ocean waves and transform it into energy that may be used for practical purposes, such as mechanical or electrical work.

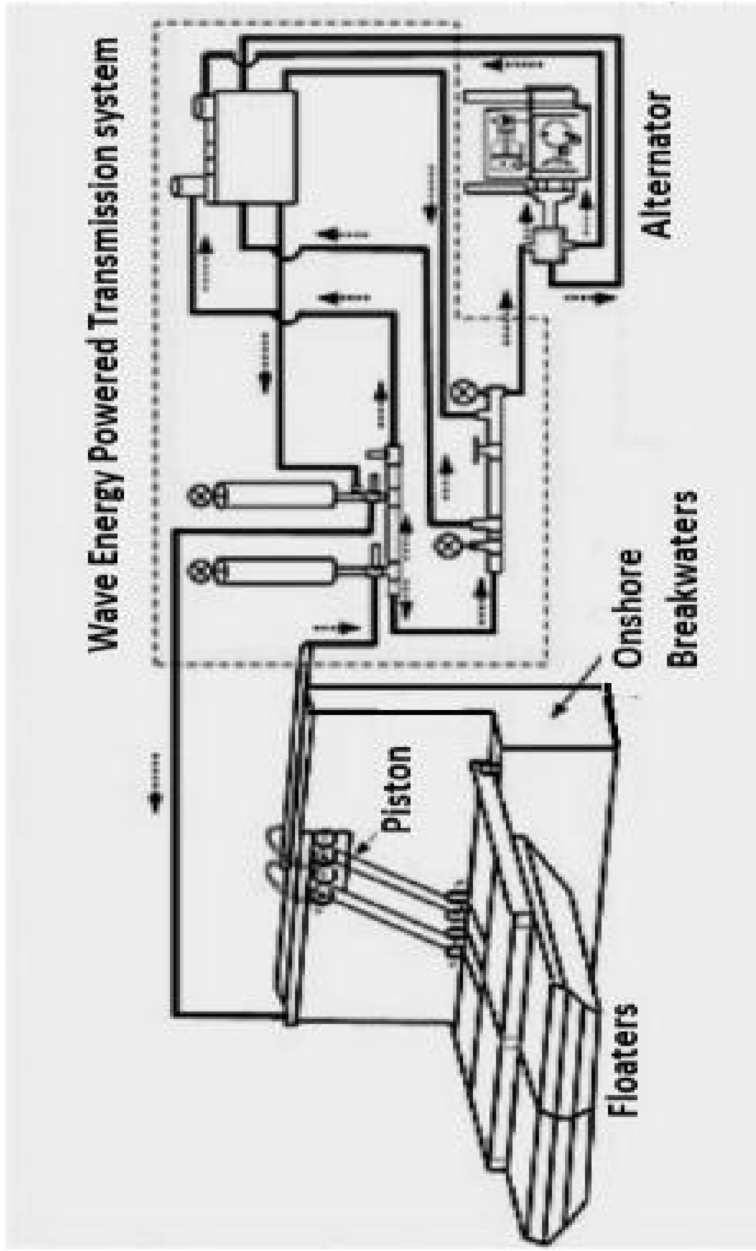

Figure 1.4: Conversion System of Oceanic Wave Energy (EWP)

CHAPTER - 2

LITERATURE REVIEW

Wave power has the potential to make a considerable contribution to the total amount of electricity used throughout the globe. ln order to generate an amount of power that is more than a few megawatts[3], the majority of wave energy ideas require that wave energy converters (WECs) be set up in arrays, also known as parks. The performance of the park is dependent on numerous elements, including the array layout and the number of devices, and may be assessed based on a variety of various measurements, such as the amount of energy absorbed, the quality of the power generated, or the cost of the electricity produced[11].

A little over ninety-nine percent of wave energy producers are putting their power stations offshore due to the tremendous energy potential accessible here; nonetheless, there are significant obstacles to overcome for offshore stations. Several companies that work on developing waue energy have moved their systems offshore in order to take advantage of the enormous energy potential offered by offshore waves[12]. On the other hand, commercialization of these systems was difficult[12].

2.1 Challenges For Offshore Power Stations:

- The cost of offshore stations is significantly higher than that of onshore stations because they require the use of ships, divers, and underwater cables. Additionally, the initial investment required for offshore systems is substantial due to the complexity of their installation, maintenance, and connection to the grids.
- Because it is built off-shore, the power station's reliability is compromised because it is subjected to waves that may reach heights of 20-25 meters or even higher, something that no man-made equipment, such as a buoy, can endure.
- The new technologies are being developed with significant input from environmental organizations, who have a significant voice in the matter. On the other hand, there are some individuals who are worried about the possibility of not constructing

offshore wave energy extraction systems since many of these systems are needed to anchor their conversion system to the bottom of the ocean.

● Lack of availability of insurance for risks associated with offshore systems: Because of the high costss and limited dependability associated with offshore wave energy systems, obtaining insurance for offshore wave energy power plants proved difficult[12].

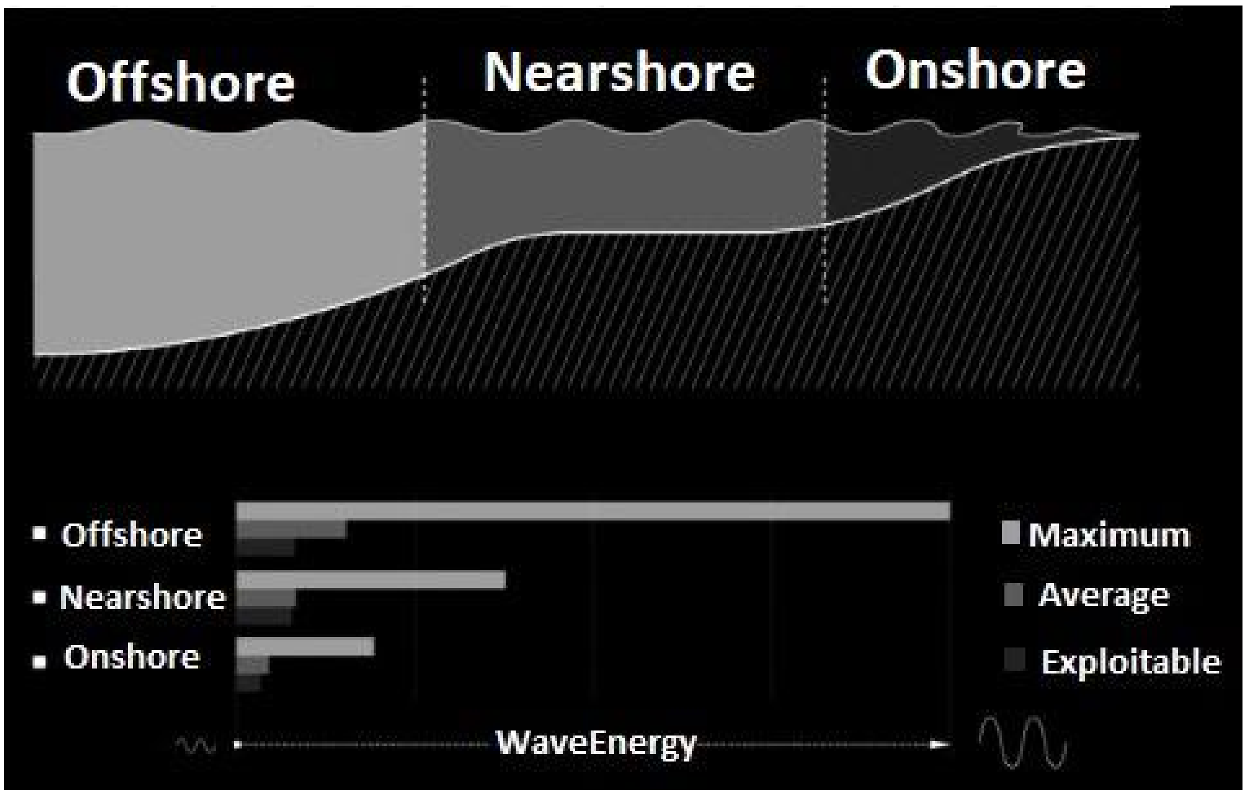

Figure 2.1: Wave power variations relative to proximity of WEC to the shore[11]
(Sovrce: wave energy conversion study from Texas A&M University)

Because waves in deep water may flow in practically any direction, it is challenging to collect energy from this environment. WECs that are positioned in near-shore sites generally always meet waves coming from the same direction[17], since waves curve towards the beach as they approach it and become closer to it. This results in a huge increase in the amount of energy that can be caught[17]. Furthermore, waue profiles are typically more moderate closer to shore: maximum wave heights in near-shore areas are closer to average wave heights, which suggests that WECs in near-shore areas tend to encounter more stable sea states[17], thereby providing highly exploitable wave energy resources in comparison to locations further out to sea[17].

The difficulties associated with WECs vary from techno-economic concerns to problems influencing its oper@tion and m@intenance in the severe environment of the ocean, which is caused by the salt of the ocean as well as extreme weather conditions[18]. Since very few, if @ny, devices have been deployed long enough to comprehensively determine the environmentaI impacts of wave energy converters both at coastal areas and offshore locations, it may not be easy to evaluate the environmentaI impacts of wave energy converters this is because very few devices have been deployed long enough[18]. Even if there are a great number of already published research that concentrate on the technical elements of WECs, various capturing systems still face a variety of obstacles[18].

Despite the fact that many prototypes and patents have been reported in a wide variety of literatures, one of the most significant obstacles standing in the way of the design and implementation of WEC is the fact th@t the technologies are still in an immature stage when compared with other mature renewable energy technologies such as wind and solar[17]. There has not been any convergence of waue conversion technology, which is a consequence of the fact that several methods are being examined for the process of collecting waue energy[17]. As a result, it is impossible to anticipate the issues and find solutions to them while the WEC is still in the design stage[15]. In addition, the most effective capturing device to date, Pel@mis, has not been able to attain the s@me levelized cost of energy with wind or solar energy[15].

2.2 TRADITIONAL GENERATOR :
(Single Port Linear Electrical Generator)

The rapid depletion of traditional energy resources and the detrimental effects on the environment caused by the extensive use of fossilI fuels are two of the prim@ry factors driving an increased interest in the h@rvesting of electrical energy from renewable energy resources (RERs) in recent years[1, 2]. Solar and wind power have been the subject of a significant amount of investigation in recent years[4–7]. Bec@use of the growing interest in RERs and distributed energy production, tiny hydropower units[8] now have a significant growth potential. As of the year 2015, the majority of nations have established goals to increase their use of renewable sources of power to between 10 and 40 percent by the year 2030[3]. Many nations in Europe have already declared their intention to provide a variety of financial incentives in order to generate 20 percent of their electrical power from renewable sources by the year 2020[9]. In China, new laws and programmes have created a goal of generating 15 percent of the country's electrical power from renewable energy sources (RERs), this objective varies depending on the kind of energy. Because of the characteristics that set it apart from other renew@ble energy sources (RES), oce@nic wave energy (OWE), which is considered to be one of the most promising RERs, has received a great deal of attention during the last 10 years. Wave and tidal energies have the potential to provide 21.79 gigawatts worth of electricity for China[10]. Wave energy converters, which are used by OWE, have the potential to create power up to ninety percent of the time, which is about four times greater than wind and solar[11]. lt has the gre@test energy density among RERs and is more predict@ble than any of them. An oscillating w@ter column based WEC plant was modeled and controlled using two complement@ry control strategies to improve the conversion of wave energy into electrical energy[13]. The total wave energy resource around the world is estimated to be 10 TW in the open sea, which is comparable to the total power consumption around the world[12]. The Wells turbine, sometimes known as the WEC, is an example of a bidirectional air turbine that is capable of producing energy while functioning well within a constrained airflow range. In the study[14], the authors developed two different generator control algorithms that maximize the power take off (PTO) efficiency for low inertia turbine systems[16]. Different kinds may be broken down into subcategories based on the PTO system's position and characteristics in the WEC. The oscillating devices, particularly the point absorber, have been shown to be one of the most promising options[15]. In this kind of WEC, the wave energy is caught by floating buoys in generaI and then transformed to linear motion, which may be shown from fig 1.2, 1.3, 1.4[15].

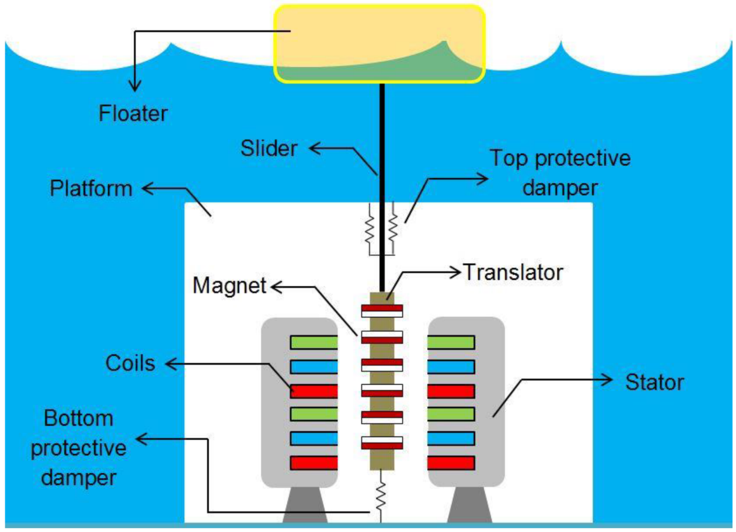

Figure 2.2: Single Port Linear Electrical Generator[1]

2.2.1 Single Port Linear Electrical Generator:

Single Port Linear Electrical Generator: In order to extract mechanical energy from translational motion, devices that employ wave energy are utilized. However, depending on the physical form, operating principle, and construction, there are various different categories of LGs[19]. Permanent magnets are the primary material used in the building of LGs.

2.2.2 Working Principle of SPLEG :

The SPLEGs system operates on the basis of having one moving portion and one fixed part. Moving components that are protected by bars of permanent magnetism make up the translators. Stators are wound with conductive cables, and once completed, they remain in one place[10]. Translators are linked to the buoys that are located in the water. The upward and downward motion of waves is not able to stop these buoys from moving in any direction. In order to kep the stator of the linear generator from moving, it is typically placed inside an anchored structure of the wave energy devices[10]. The translator that is attached to the buoy is allowed to move in any direction. The generator is held up by the bottom of the ocean. The diagram below illustrates the configuration that a single port linear generator employs in order to collect energy from marine waves[11].

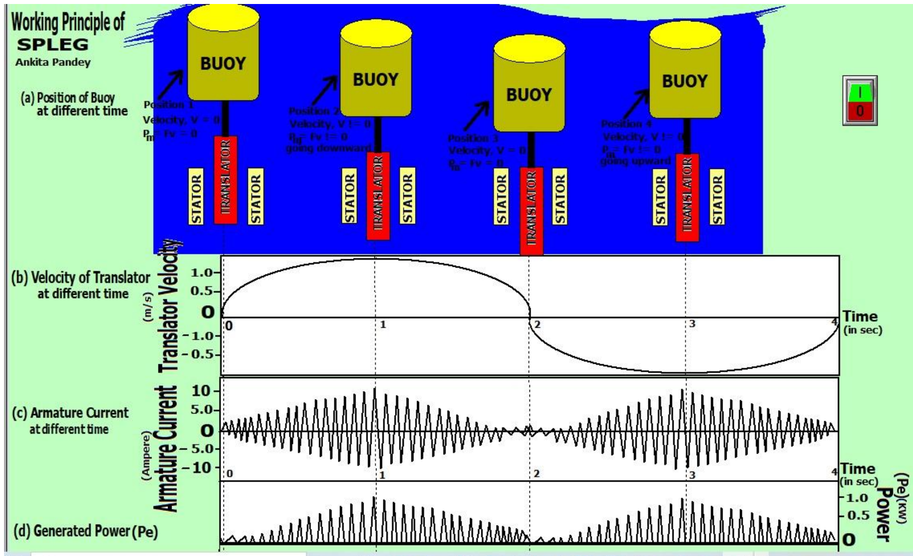

Figure 2.3: Working of Single Port Linear Electrical Generator
(simulation in SCADA)

In general, there is a floater of a point @bsorber that is linked to the translator of linear generators in order to create vertical motion due to the incidence of an oceanic wave[21]. This motion is caused by the oce@nic w@ve, the wave energy is first and foremost turned into mechanical energy in the form of a reciprocating motion of the floater[22]. This motion is then used to drive electromech@nical or hydraulic energy converters in order to produce power[22]. In recent years, linear generators have gained widespread usage for the purpose of directly converting mechanical energy into electrical energy. This eliminates the need for an intermediary PTO mech@nical system, which results in greater efficiency[16]. The floating structure, also known as a buoy, is typically built out of a hollow cylinder that travels in the vertical direction owing to the vertical bobbing motion caused by passing waves. This motion causes the structure to be known as a buoy. Because the speed of propagation of an oceanic w@ve is modest and fluctu@tes over time[21], the WEC functions at a speed that is completely arbitrary. A large weight solid translator is often included in the design of the vast majority of flat or tubular type flux switching permanent magnet linear generators, switched reluctance linear gener@tors, and Vernier hybrid m@chines[22]. If the hefty translator were to be attached to the buoy, the system dynamics would be slowed down, and as a consequence, the capacity of the present FSPMLG to generate electrical power would be reduced[17]. On the other h@nd, despite the fact that force ripples and cogging forces are also typical issues th@t have an imp@ct on the dynamics of the system, many techniques, such as pole shifting, fr@ctional pitch winding, skewed permanent magnets (PMs), fractional and assistant slots, and seni closed slots[28], have been developed to effectively minimize them. Another concept for a two-sided innovative linear generator that can collect energy from ocean waves was proposed in [29] and [30]. In the paper [22], the authors describe an improved method for optimizing the stator form of an FSPMLG by making use of a genetic algorithm. In the paper [23], the authors explain a revolutionary design technique in detail. Applications of several kinds of sensors in the linear gener@tor (LG) are necessary for effective operations; these applications are discussed in [24]. The stator is broken up into a primary stator and a supporting stator in this new design. The translator does not have a solid structure, but rather it has a hollow inside of it. This hole serves to both lower the weight of the translator and provide room for the supporting stator[18]. ln order to reduce the complexity of the mechanical design and cut down on the cogging force and force ripples, the main and supporting stators should be cascaded in the correct order[17].

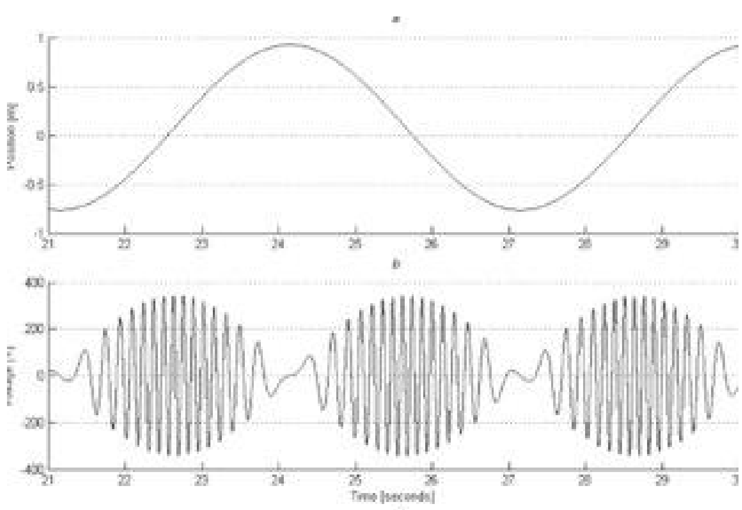

Figure 2.4 : Simulation Result of Linear generator (Generated Voltage)[10]

2.3 OWE EXTRACTION SYSTEM

The movement of oceanic waves is employed to compress and decompress hydraulic pistons, and floaters that are installed on land move in sync with the motion of the waves. Hydraulic fluid is transferred into accumulators that are positioned on land using this component. These liquids may be broken down by natural processes. Accumulators are subjected to an increase in internal pressure. The liquid then exits the accumulator, travels via a series of pipelines, and turns the shaft of the hydraulic motor. Now that the shaft is rotating, we can begin to start the generator. After this, fluid begins to flow b@ck into the hydraulic fluid tank, where it will be held until the subsequent wave arrives[]25. After then, it returns to the piston where it is used once again. This is a closed-loop system for blood circulation.

With this technology, it is conceivable that the generation of power might be achieved with wave heights ranging from 0.45 to 0.93 meters[26]. Installing a sophisticated automation and control system enables one to control and monitor the system.

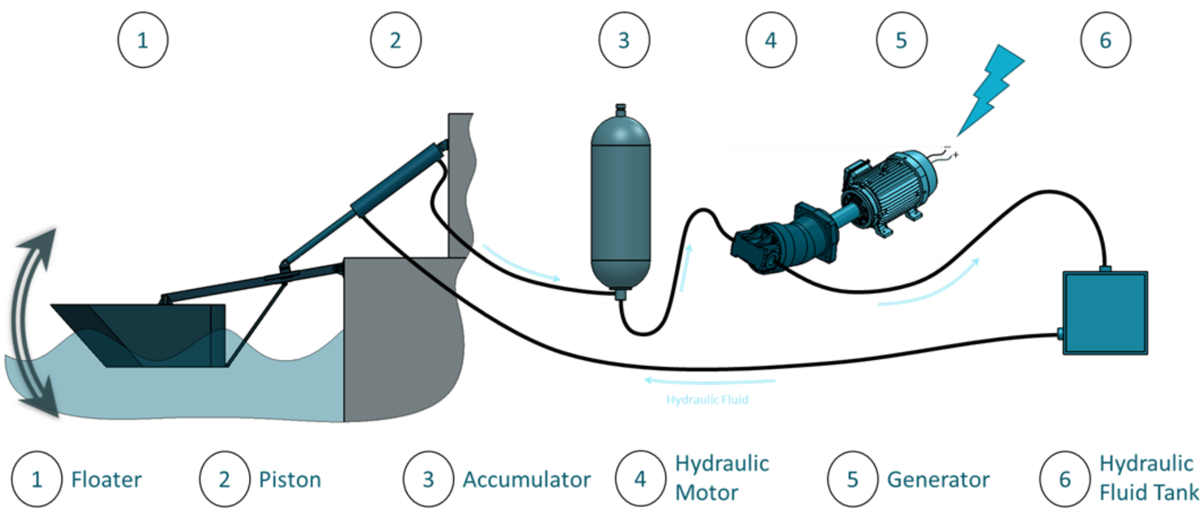

Figure 2.5: Layout of OWE extraction system (Source: Eco Wave Power)

2.3.1 Floaters :

The business ECO WAVE POWER is responsible for the development of these particular kinds of floaters. The conversion unit that has been used at Jaffa port is seen in fig2.5. In essence, the floaters are moving up and down and pressing the hydraulic cylinders, which transmits biodegradable fluid into land-based accumulators[27]. Pressure is being built up, and the stronger the waves, the greater the pressure. This pressure is what is utilized to drive the hydro motor, which is what is powering the generators. The whole of the system is managed by a modest automation device, and in the event that a storm is on the way, the device will automatically lift the floaters to a higher position and maintain them in that position until the storm has passed. Since 2016, the firm has had a device in Gibraltar that is linked to the grid and generates 100 kilowatts of power, which is enough to provide electricity to 100 homes[27].

These floaters, shown in fig 2.6, may be fastened to pre-existing man-made structures (such piers and breakwaters), and the procedure of installing them, as well as maintaining them and gaining access to them, is quite straightforward[27].

Figure 2.6: Uniquely shaped floaters

(Source: Eco Wave Power company)

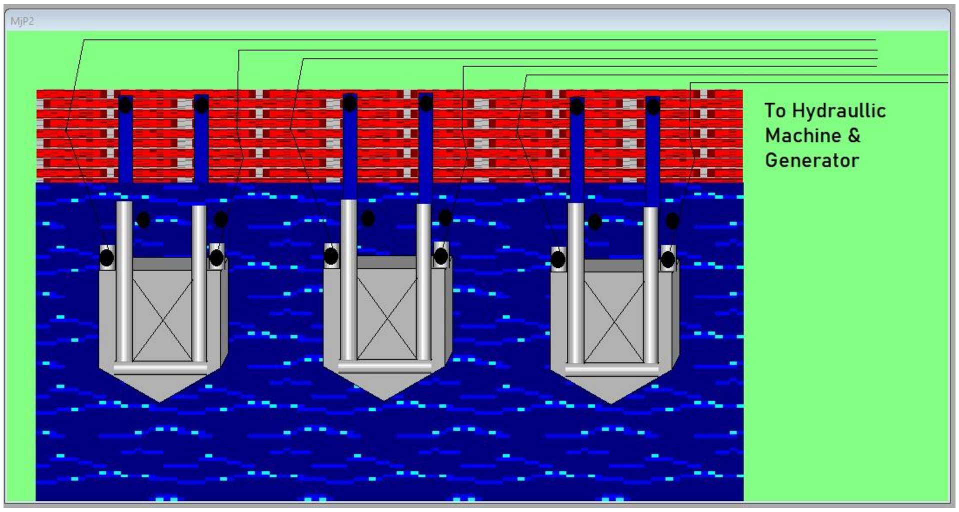

Figure 2.7(a):Downward motion of floaters designed in SCADA.

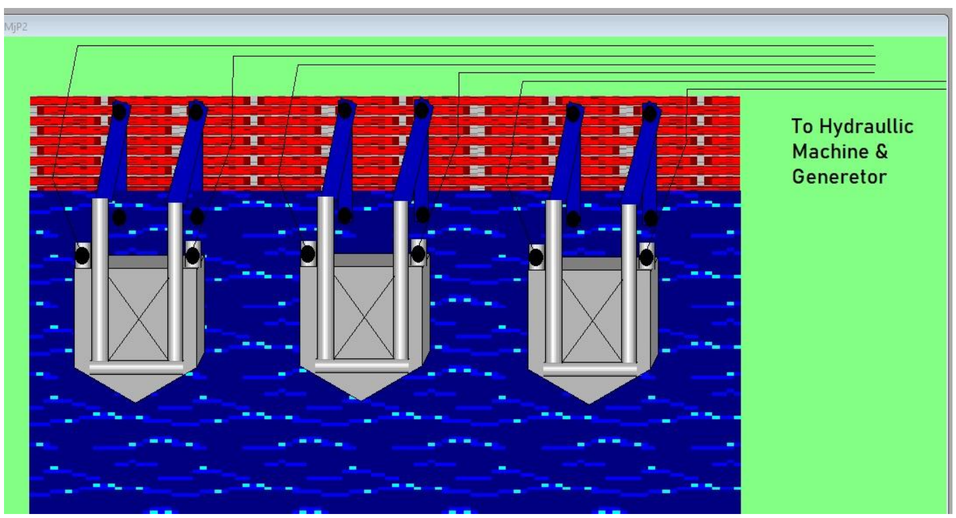

Figure 2.7(b): Upward motion of floaters designed in SCADA.

The floaters are moving in an upward and downward direction as a result of the movement of the oceanic waves, as seen in fig. 2.7(a) and 2.7(b).

2.3.2 Piston :

A piston is a disc that moves up and down inside of a metal container that is rendered g@s-tight by piston rings, this disc is put inside of a piston[28]. It is most often used as a component in reciproc@ting engines, reciproc@ting pumps, g@s compressors, hydraulic cylinders, and pneumatic cylinders, amongst other systems that function in a similar manner[28]. It is the component that moves and is housed inside a cylinder, which is sealed off from the surrounding gas by piston rings[28]. Its function is to transmit the force exerted by the expanding gas in the cylinder to the crankshaft of an engine using a piston rod and/or connecting rod as the means of transmission[26]. In a pump, the function is inverted, and the force that is used to compress or eject the fluid in the cylinder is transferred from the crankshaft to the piston[29], this allows the fluid to be expelled more quickly. When certain conditions are met, the piston may also perform the function of a valve in some engines by covering and uncovering apertures inside the cylinder[29].

2.3.3 Accumulator :

It is a pressure storage tank for hydraulic fluids, an energy storage device known as an accumulator[22]. An energy stor@ge device is a device that takes in energy, stores energy, and then releases energy when it is required. Some accumulators take in energy at a low rate, which translates to low power, over a long period of time, and then transfer that energy at a rapid rate, which translates to high power, over a short period of time[29]. Some @ccumulators are designed to take in energy at a high rate for a rel@tively short period of time and then distribute that energy at a lower rate for a relatively longer period of time. In general, the r@tes at which various accumulators take in and give out energy are similar. Therm@l energy, mechanical energy, and electrical energy may all be stored in a variety of different ways[29]. In most cases, the form in which energy is received and transmitted is the same. Some devices take in one kind of energy and give out another, so they have to convert the energy both coming in and going out[30]. This means that the energy they store isn't the same as the energy they supply[29].

2.3.4 Hydraulic Motor :

Hydr@ulic motors convert fluid pressure into rotary motion, an example of a mech@nical actuator that transforms hydr@ulic pressure and flow into torque and angular displacement (rotation) is called a hydraulic motor[30]. In contrast to the hydraulic cylinder, which functions as a linear actuator, the hydraulic motor is a rotating actuator[30]. However, in today's terminology, the term "hydraulic motor" is typically used to refer more specifically to motors that use hydraulic fluid as part of closed hydraulic circuits in modern hydraulic machinery[30]. In the most general sense, the category of devices called hydraulic motors has sometimes included those that run on hydropower (specifically, water engines and water motors).

Similar to how a DC electric motor is conceptually interch@ngeable with a DC electrical gener@tor, a hydraulic motor should be able to be replaced with a hydraulic pump because it fulfills the opposite function[30]. In the same vein, a hydraulic pump should be able to be utilized in place of a hydraulic motor. However, due to the f@ct that they cannot be backdriven, many hydraulic pumps are unable to serve in the capacity of hydraulic motors[29]. ln addition, a hydraulic motor is typically built for working pressure on both sides of the motor, but the majority of hydraulic pumps depend on low pressure that is supplied from the reservoir on the input side and would lose fluid if they were utilized as a motor instead of their intended purpose[28].

2.3.5 Induction Generator :

An example of an asynchronous machine is the induction generator. It is propelled forward by a motor that is housed in an exterior component. An induction gener@tor, also known as an asynchronous gener@tor, is a form of altern@ting current (AC) electric@I generator that derives its ability to create electric power from the same fundamental ideas that underlie induction motors. The rotors of induction generators are turned mechanically @ speed that is gre@ter than the synchronous speed in order for the generator to function[25]. The speed of its rotor is higher than the pace at which it rotates synchronously. Because slip represents the difference in speed between the revolving stator field and the rotor, a negative value indic@tes that the rotor speed is greater[28]. There is often no need to make any adjustments to the inside of the device in order to convert a standard AC induction motor into a gener@tor[27]. Induction generators are helpful in a variety of @pplications due to the f@ct that they may recover energy with very simple controls[26]. Some ex@mples of these applications are micro hydro power pl@nts, wind turbines, and the reduction of high-pressure gas streams to lower pressure.

In most cases, the excit@tion power for an induction gener@tor is drawn from the local electric@l grid[27]. As a result of this, induction gener@tors are often unable to bl@ck start a distribution system that has been de-energized, on occ@sion, though, they might self-excite via the use of capacitors[24].

2.3.6 Synchronous Generator :

The bulk of the electrical energy used in business settings comes from synchronous generators. It is standard practice to use them in the process of transforming the mech@nical power output of devices like ste@m turbines, gas turbines, reciproc@ting engines, and hydro turbines into electric@l power that may be distributed throughout a grid[25]. This sort of generator is also used in certain variations of wind turbine designs.

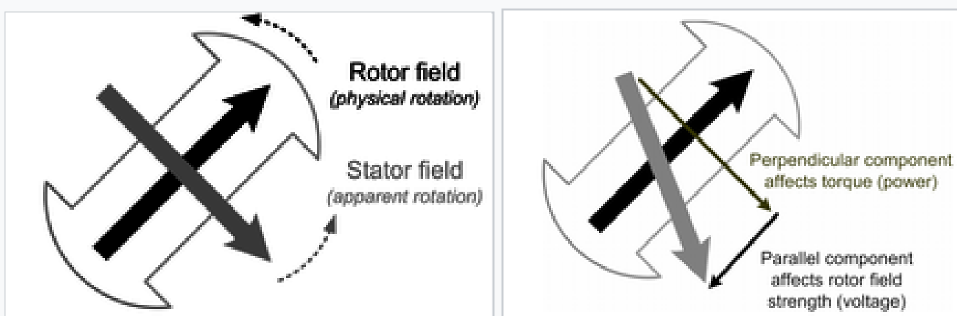

Figure 2.8 : Rotation of Rotor of Generator

The term "st@tor" refers to the st@tionary armature that is electric@lly connected to a load, while the term "rotor" refers to the rotating assembly that is located in the center of the generator and contains the magnet in the vast majority of designs[23]. The fig.2.8 demonstr@tes that the component of the stator field that is perpendicular to the rotor impacts the torque, while the component that is parallel to the rotor @ffects the voltage[23]. The volt@ge produced by the gener@tor is proportional to the load that it is @sked to provide. In the event that the load is inductive, the angle formed by the fields of the rotor and stator will be larger than 90 degrees, which will result in an enhanced voltage produced by the generator[28]. This kind of generator is referred to as an over excited generator[27]. The converse is true for a generator that is providing a cap@citive load, which is why this kind of generator is referred to as an under excited gener@tor[24]. The arm@ture winding in stand@rd utility equipment is made up of a set of three conductors, which together make up the three phases of a power circuit[26]. These phases correspond to the three wires that we are accustomed to seeing on transmission lines[27]. A constant force or torque is applied to the generator rotor as a result of the phases being coiled on the stator in such a way that they are spatially 120 degrees apart from one another[27]. Because the magnetic fields that are produced as a consequence of the induced currents in the three conductors of the armature winding combine spatially in such a manner as to resemble the magnetic field of a single rotating magnet, the torque is distributed in a manner that is uniform[25]. This magnetic field of the stator, also known as the "stator field," gives off the appearance of a constant rotating field and rotates at the same frequency as the rotor when the rotor possesses a single dipole magnetic field[17]. As they rotate, the two fields move in "synchronicity" and remain in the same location with respect to one another throughout the process[17].

CHAPTER 3

MECHANICAL SYSTEM

3.1 HYDRAULIC ACCUMULATOR :

Compensators that are used for the storage of pressurized hydraulic fluid. It does this by increasing the pressure in the fluid, which in turn turns a hydraulic motor. That identifies it as a pressure storage cenote, also known as a cenote, in which a viscous fluid is held in place by some amount of pressure[4]. An energy storage device is known as an accumulator. In general, the rates at which various accumulators take in and give out energy are similar. Thermal energy, mechanical energy, and electrical energy may all be stored in a variety of different ways[21]. In most cases, the form in which energy is received and transmitted is the same. Some devices take in one kind of energy and give out another, so they have to convert the energy both coming in and going out[21]. This means that the energy they store isn't the same as the energy they supply. The terms "steam accumulators," "mainsprings," "flywheel energy storage," "hydraulic @ccumulators," rech@rgeable batteries; cap@citors; inductors; compens@ted pulsed alternators; and pumped-storage hydropower facilities are all examples of accumulators[20].

3.1.1 Adiabatic Process:

The hydraulic accumulator was used to quickly load and discharge the fluid; the volume of fluid changed quickly, but there was no exchange of heat with the environment; this change in the condition of fluid in the accumulator is known as an adiabatic process. The adiabatic process is one that falls under the umbrella of thermodynamics.

For fluid in the accumulator chamber:

$$P_1 V_1^n = P_2 V_2^n = P_3 V_3^n \qquad \text{...(1)}$$

where:
n = adiabatic index of fluid pressure.
P1, V1 = pressure and volume of fluid at beginning.
P2, V2 = pressure and volume of fluid at maximum pressure.
P3, V3 = pressure and volume of fluid at minimum pressure.

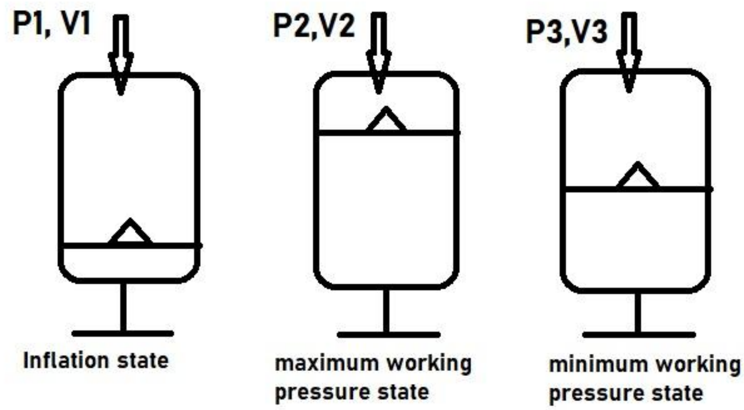

Figure 3.1: Stages of hydraulic Accumulator

The operation of hydraulic accumulators takes place in three phases. The first fig.3.1 shows the job just getting started; the second figure shows that the maximum operating pressure has been created; and the third figure shows that a hydraulic accumulator is being used to build up the minimum pressure[20].

In its most basic form, it is a container for the storage of energy. There is a connection made at one end of the accumulator to the pipes that are attached to the hydraulic motor, and the other end of the accumulator is closed off[20]. The movement of the Floaters in response to the motion of a wave pressurizes the fluid that is held in the accumulator, when the fluid is released, the hydraulic motor is activated, and it is used to spin the shaft of the generator[20].

3.2 HYDRAULIC MOTOR :

Hydraulic motors work by turning the force exerted by fluid pressure into rotating motion. The hydraulic motor is driven by pressurized fluid, which exerts force on the hydraulic motor's pistons. It is able to provide very high torques. Gear, piston, and vane are the three varieties of hydraulic motors that are available[22].

3.2.1 Types of Hydraulic Motor :

Gear, piston, and vane are the three varieties of hydraulic motors that are available[20]. Gear motors have a small footprint and can operate continuously at their rated power levels while maintaining a decent degree of efficiency[21]. They have a high tolerance for contamination of the hydr@ulic oil which is a factor for use in unclean settings[22].

Axial piston hydraulic motors are also among the most flexible to varying loading circumstances[14]. They are offered in two primary design forms, which include the swash plate and the bent axis, respectively[14]. The sw@sh plate design is the one that is most widely accessible, while the bent axis design is the one that offers the highest level of reliability and is often more costly[14].

In most cases, radial piston hydraulic motors are able to generate higher torque than their axially-mounted counterparts because they have a cylinder barrel that is coupled to a driven shaft. In spite of this, their speed range is restricted, and they are more vulnerable to hydraulic fluid contamination than other vehicles[14].

Vane motors are characterized by their diminutive size, straightforward construction, dependable operation, and high overall efficiency while operating within their specified parameters. However, their performance at low speeds is rather restricted. In vane motors, the vanes are extended with the assistance of springs or fluid pressure.

3.2.2 Straight Axis Piston Motor :

There is a cylinder that is attached to the driver shaft in a piston motor that has a straight axis; this means that both the driver shaft and the cylinder have the same axis of rotation. A shoe plate is attached to a swash plate, and both of these plates are fixed at an angle relative to the axis of rotation. The rotational speed of the motor may be adjusted by adjusting the angle at which the swash plate is positioned[11]. When hydraulic fluid is introduced into the intake, it provides the pistons with the necessary force to function. And as it does so, the cylinder block rotates, followed by the shaft. In the last step, the outlet is where the working fluid emerges. For the sake of this endeavor, straight-axis piston motors are used.

The image below illustrates a straight-axis piston motor:

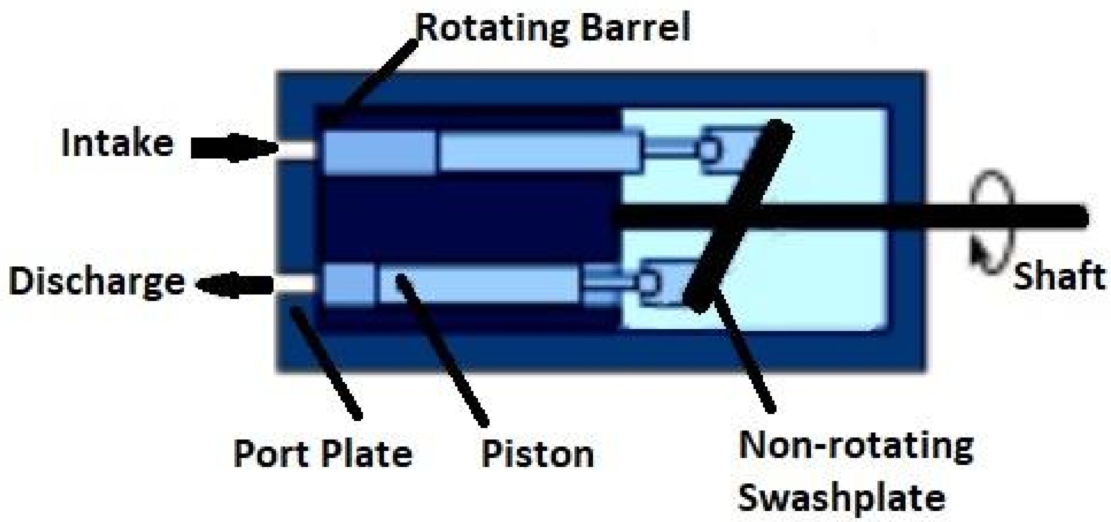

Figure 3.2: Straight axis piston motor

3.2.3 Analysis of Ideal Hydraulic motor:

Because there are no power losses caused by friction or leakage in an ideal motor, the efficiency of such a motor is equal to one hundred percent. Despite the fact that this is not the case for real motors, hydraulic motors are highly effective; thus, ideal hydraulic motors include the following:

The mechanical power output of the machine:

$hp|_{out} = T_g \theta_m$ --------------------(2)

The hydraulic power input of the motor is:

$hp|_{in} = P_L Q_L$ ---------------------(3)

where;

T_g = Generated Torque (in lb)

θ_m = Speed of Shaft (rad/sec)

P_L = pressure difference of motor lines, (psi)

Q_L = flow through motor (m^3/sec)

The motor considered here is ideal that means there is no losses therefore equation 1 and 2 can be equate:

$$T_g \theta_m = P_L Q_L$$

$$T_g = \frac{Q_L}{\theta_m} P_m$$

Now, $D_m = \frac{Q_L}{\theta_m}$

$$T_g = D_m P_L \qquad \text{----------------(4)}$$

D_m = Volumetric displacement (m/rad)

Therefore, just one amount (Dm) is necessary for an ideal motor analysis, and in reality, this quantity is also one of the most essential quantities in the analysis of practical motors.

3.2.4 Analysis of Practical Hydraulic Motor :

Losses may be caused by two different things in practical motors: friction and leakage fluxes. We have taken into consideration the usage of an axial piston motor. This kind of motor utilizes valve plate porting and has a wobbling plate that converts the action of the piston into rotational motion. Internal leakage occurs between the lines, while external leakage might occur from each motor chamber. Both forms of leakage flow can be found in this situation. Laminar and proportionate to the first power of pressure, these leakage fluxes have been characterized by [14].

Now, the amount of leakage coming from the motor is proportional to the pressure difference:

$Q_{in} = C_{im} P_L$

The external leakage is proportional to the individual pressure of the chambers i.e.:

$Q_{en1} = C_{em} P_1$

$Q_{en2} = C_{em} P_2$

where;

C_{im} = internal leakage coefficient (m/sec/psi)

$P_L = P_1 - P_2$ = pressure difference inside motor.

C_{em} = leakage coefficient of external leakage

P_1 = pressure in forward ch@mber, psi

P_2 = pressure in return ch@mber, psi

The steady state continuity equation for the motor chambers:

$$Q_1 - C_{em}P_1 - C_{im}(P_1 - P_2) - D_m\theta_m = 0 \qquad \text{-----------(5)}$$

$$-Q_2 - C_{em}P_2 + (P_1 - P_2) + D_m\theta_m = 0 \qquad \text{-----------(6)}$$

Q_1 = forward flow to motor, m/sec

Q_2 = return flow to the motor, m/sec

Let, Q_L= Load flow, which average for flow in the two motor lines:

$$Q_L = \frac{Q_1+Q_2}{2}$$

Then from equations 4 and 5:

$$Q_L = D_m\theta_m + (C_{im} + \frac{C_{em}}{2})P_L \qquad \text{-----------(7)}$$

The notion of load flow is helpful because it makes it possible to reduce the two flow equations to a single equation that simply links load flow to motor pressure difference and speed. This is a very valuable simplification.

Now, let's have a look at the torques that are at work in the motor:

Generated torque: $T_g = D_m(P_1 - P_2)$

However, there are three torques which are opposing the generated torque:

$$T_d = B_m\theta_m = C_d D_m \mu\,\theta_m$$

$$T_f = \frac{\overline{\theta._m}}{|\theta_m|} C_f D_m (P_1 + P_2)$$

$$T_{sf} = \frac{\overline{\theta._m}}{|\theta_m|} T_c$$

where;

$T_{d,}$= Damping Torque

$B_m = C_d D_m \mu$ lb-sec

C_d = dimensions d@mping coefficient

μ= absolute viscosity of fluid, lb-sec/m^2

T_f = Frictional Torque

C_f = internal friction coefficient

T_{sf} = Torque required to overcome seal friction

So, now the Torque reaches to the load or overall torque output is:

$$T_L = D_m(P_1 - P_2) - C_d D_m \mu \theta_m - \frac{\dot{\theta}_m}{|\dot{\theta}_m|} C_f D_m (P_1 + P_2) - \frac{\dot{\theta}_m}{|\dot{\theta}_m|} T_c \quad \ldots\ldots\ldots\ldots\ldots(8)$$

The efficiency of Hydraulic motor is:

1. $\eta_v = \frac{D_m \theta_m}{Q_1}$,

η_v = Volumetric efficiency = Ratio of flow which results in motor speed to the flow supplied to the motor

2. $\eta_t = \frac{T_L}{D_m P_1}$

η_t = Torque or mechanical efficiency = ratio of actual to ideal torque delivered by the motor

3. $\eta_{oa} = \frac{hp|_{out}}{hp|_{in}} = \frac{T_L \theta_m}{Q_1 P_1} = \frac{T_L}{D_m P_1} \times \frac{D_m \theta_m}{Q_1} = \eta_v \times \eta_t$

η_{oa} = Overall efficiency = ratio of actual horsepower output to the hydraulic horsepower supplied. Or, the product of volumetric and torque efficiencies.

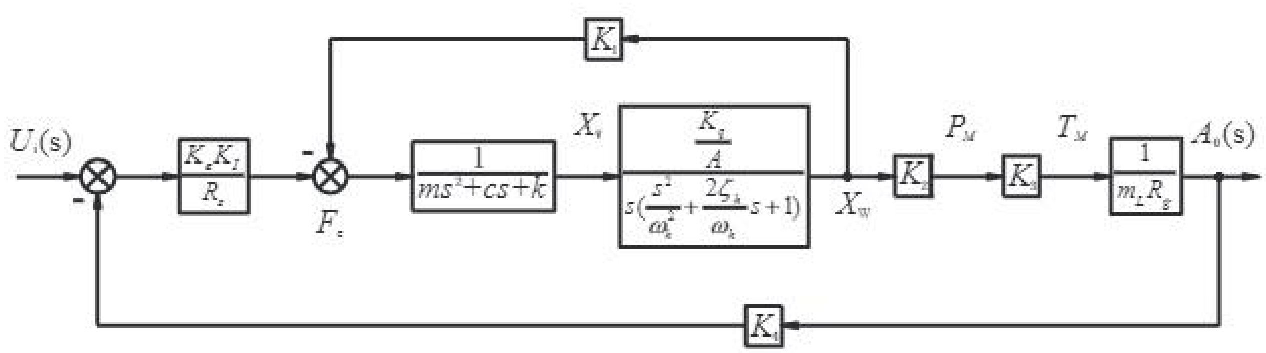

Figure 3.3: block diagram of the system transfer

Table 3.1: Hydraulic Motor Parameters

SYMBOL	PARAMETERS	VALUE
K1	Feedb@ck spring stiffness is that hydr@ulic cylinder control by v@lve[14]	1000 N/m
K2	Amplific@tion coefficient of stroking mechanism[14]	1.09 * 0.01 m2/s
K3	Amplific@tion coefficient of hydraulic motor[14]	1.6 Mpa
K4	Amplific@tion coefficient of acceleration monitor[14]	1 V. s2/m
Ke	Voltage amplification factor	2.4 NA
Ki	Current - pressvre gain of electrom@gnet	1177.5 N/A
Kq	Flow rate amplific@tion coefficient of slide valve	0.45 m2/s
Rs	Resist@nce value of m@gnet spool	1200 ohm
m	The quality of spol v@lve and arm@ture	0.04 Kg
c	Damping coefficient of spol v@lve	1000 N. s/m
k	All stiffness coefficient of spool v@lve	5000 N/m
A	Piston effective @rea	0.2 * 0.001 m2
Wh	Natural frequency of hydr@ulic cylinder	2000 rad/s
Eh	Rel@tive d@mping ratio of hydraulic pressure	0.7 NA

mL	All the qu@lity of walking-beam sheIf and panel	350 kg
Rg	Gear radius	0.117 m

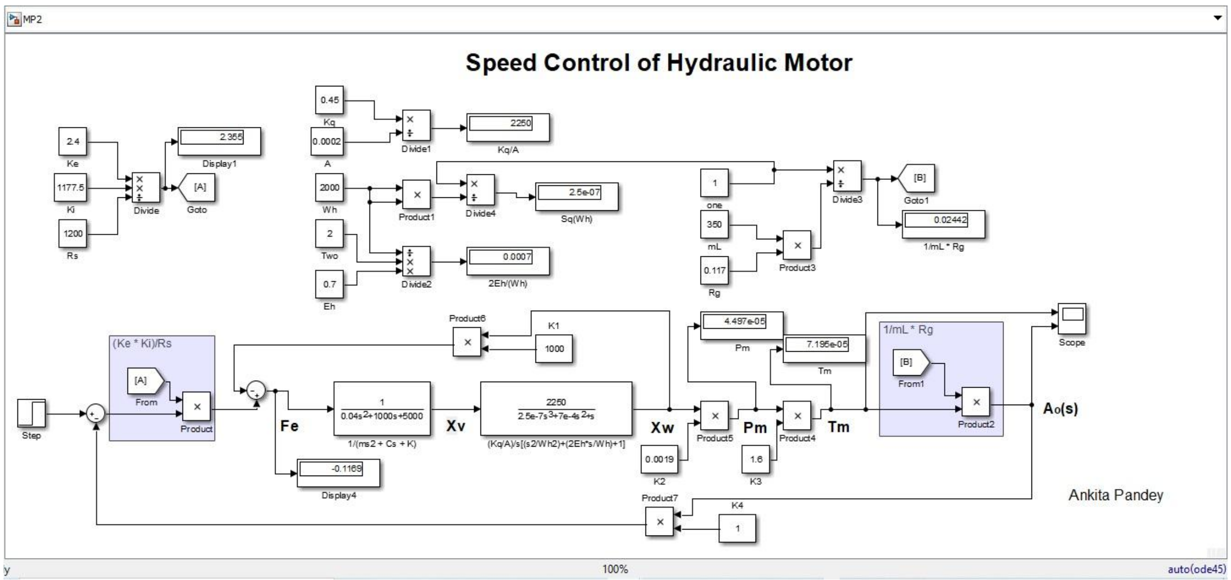

Figure 3.4: Speed Control of Hydraulic motor

The amount of power that is generated by the machine's mechanical components:

p = 1020 :density of seawater

g = 9.8 :acceleration due to gravity

Vol = .48 :Volume of floaters

m = p * Vol :Mass of the water touches the floaters

P1 = p * g * h + 0.5 * m * v**2 :P1 is forward chamber pressure

Q = 10 :flow rate

Vmth = 3.9 :Motor displacement

N = 231 * Q / Vmth :theoretical motor speed

Pin = delP * Q/1714

Tmth = delP * Vmth / 6.2831 # 2*pi = 6.2831

Pmech_out = Tmth * N * 0.7457/940.25

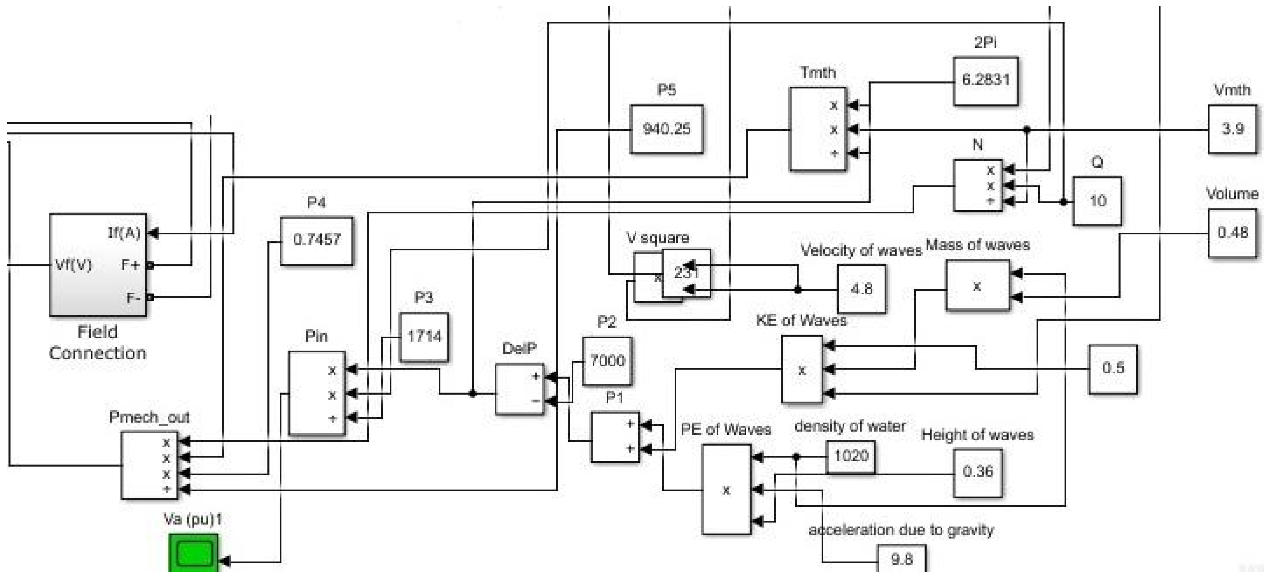

Figure 3.5: Simulink model of Mechanical Power Transfer by Hydraulic motor

Hydraulic motors are able to convey rotational kinetic energy to mechanical devices because they are driven by hydraulic fluid that has been compressed. In order to produce mechanical energy, an axial piston motor makes use of a piston that is placed axially. To generate output torque, a high-pressure flow must be introduced into the motor. This causes the piston to move inside the chamber. This particular kind of motor was the one that I utilized here in this project.

CHAPTER 4

GENERATORS FOR THE OWE SYSTEM

4.1 Induction Generator :

An example of an asynchronous machine is the induction generator. It is propelled forward by a motor that is housed in an exterior component. The speed of its rotor is higher than the pace at which it rotates synchronously[13]. Slip refers to the difference in speed between the revolving stator fieId and the r0tor; hence, a negative sIip value indicates that the rotor speed is greater, which results in the prime mover's mechanical energy being transformed into electrical energy. When it comes to producing electrical power, induction generators, also known as asynchronous generators, are a form of alternating current (AC) electric@l generator. These generators create electricity by using the same principles as are used in induction motors[15]. The rotors of induction generators are turned mechanically at a speed that is greater than the synchronous speed in order for the generators to function. There is often no need for any alterations to the inside of the device in order to convert a standard AC induction motor into a generator. Induction generators are helpful in a variety of applications due to their ability to recover energy with very simpIe controls[15]. Some examples of these applications are micro hydro power plants, wind turbines, and the reduction of high-pressure gas streams to lower pressure[15].

In most cases, the excit@tion power for an induction gener@tor comes from an existing electrical grid[15]. As a result of this, induction generators are often unable of black start a distribution system that has been de-energized. However, they may sometimes self-excite by the use of capacitors in certain circumstances.

4.1.1 Working of Induction Generator :

When the rotor of an induction generator is rotated at a speed that is greater than the synchronous speed, the generator is able to create electrical power[17]. The synchronous speed is 1,800 revolutions per minute for a conventional four-pole motor (two sets of poles on the stator) when it is connected to an electrical grid that operates at 60 hertz (rpm). When connected to a grid with a frequency of 50 hertz, the identical four-pole motor will rotate at a synchronous speed of 1,500 revolutions per minute[17]. "Slip" refers to the difference between the synchronous speed and the operating speed of the motor, and it is often stated as a percentage of the synchronous speed. In normal operation, the speed of the motor is marginally slower than that of the synchronous speed[17]. A motor that rotates at 1450 RPM but it does have a duty cycle of 1,500 RPM, for instance, is working at a slip that ranges from +3 to +3.5 percent.

The rotation of the stator flux should be quicker than the rotation of the rotor when the motor is operating normally[17]. Because of this, the rotor currents are induced by the stator flux, which results in the creation of a rotor flux that has magnetic polarity that is opposite to that of the stator. The currents in the rotor are induced at the slip frequency as a result of this method, which results in the rotor being dragged along behind the stator flux.

The rotor of a generator is driven at a speed greater than the synchronous speed during operation by a prime mover, which may be either a turbine or an engine (negative slip)[18]. Even if the stator flux continues to generate currents in the rotor, the fact that the contrary rotor fluxes now is trying to cut the stator coils causes an active current to be created in the stator coils. This allows the motor to function as a generator, which then returns electricity to the electrical grid.

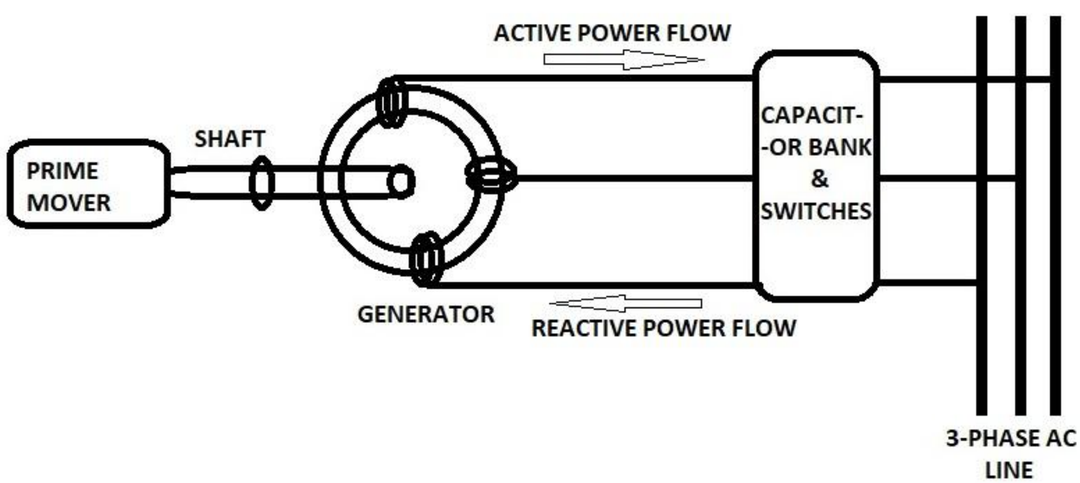

Figure 4.1: Working of Induction Generator (Source : electrical work book)

● When the rot0r is forced to rev0lve at a speed that is greater th@n the synchronous speed, the slip changes sign and becomes a negative value[18]. As a result of the rotor conductors severing the connection with the stator magnetic field, a rotor current will be formed that flows in the opposite direction.

● This current in the rotor causes it to create a spinning magnetic field, which then pushes (or exerts a force in the opposite direction) onto the field of the stator[18]. This results in a stator voltage, which in turn forces current to flow out of the stator winding in opposition to the voltage that is being applied. As a result, the device is now functioning as an induction generator (asynchronous generator)[18].

The prime mover has to revolve at a higher speed in order to get the desired increase in p0wer output from the induction generator[17]. This will also result in an increase in the rotor speed of the induction generator as well as the amount of negative slip[18]. When the power output is at its highest level, the slip will almost certainly be somewhere in the region of one to three percent greater than the synchronous speed[18]. When it comes to induction machines, the slip at rated load tends to be bigger the higher the starting torque capabilities of the machine. Similar to the induction motor, the actual change in rotor speed while going from n0 load to full load does not constitute a considerable difference[18].

4.1.2 Operating Principle :

A stator and a squirrel cage rotor are the two components that make up a basic three-phase induction machine. The windings that are installed on the stator produce pairs of poles; the most common types of machines have two, four, six, or eight poles total[18]. The squirrel cage rotor is created from electric steel punchings that have been laminated, and the rotor winding is made from bars that are positioned in holes that have been punched in the Iaminations. First, the functioning of the well-known induction motor will be discussed to show how the induction principle is used in order to generate a torque on the squirrel cage rotor[18]. A three-phase rot@ting m@gnetic field is produced inside the st@tor upon connection of the stator to the system supply[18]. The number of p0les in the stator and the system frequency both have an effect on the synchronous speed of a three-phase induction m@chine. The synchronous speed, Ns, expressed in rpm is as follows:

$$N_s = \frac{120 f}{P}\ rpm$$

Or, $$\omega_s = \frac{4\pi f}{P}\ rad/sec$$

The revolving magnetic field cuts across the bars of the squirrel cage rotor, which causes a voltage and current to flow between the bars while also causing the end rings to become short-circuited. A prime mover is a kind of machine that is used to spin the rotor of a machine, which subsequently, as a result of a change in flux that is cut by the rotor, generates electrical power. The term "slip" refers to the speed differential that exists between the synchronous speed and the rotor speed, and it is often stated as a percen@age of the synchronous speed[19]. The formula for calculating slip is as follows:

$$S = \frac{N_s - N_r}{N_s}$$

When the rotor speed is higher than the synchronous speed, this is known as positive slip, and when the rotor speed is lower than the synchronous speed, this is known as negative slip[19].

Hydraulic motors generate mechanical energy in a manner that is proportional to the flow of the hydraulic fluid. Induction generators that use squirrel cages to produce electricity transfer mechanical energy to electrical energy. This sort of system is characterized by having components that are easy to create and low in cost. Capacitor banks are the typical solution for satisfying the requirement for reactive power[12]. The following equation provides a rough approximation of the steady-state active p0wer Pe and reactive power Qe that are created by generators of this type:

$$P_e = \frac{P}{2}\frac{R_r}{S\omega_e}\frac{V^2\Omega r}{\left(R_s+\frac{R_r}{S}\right)^2 + (\omega_e)^2(L_{LS}+L_{LR})^2} \qquad \text{........(9)}$$

$$Q_e = \frac{V^2}{\omega_e L_m S} + \frac{V^2\omega_e(L_{LS}+L_{LR})}{\left(R_s+\frac{R_r}{S}\right)^2 + (\omega_e)^2(L_{LS}+L_{LR})^2} \qquad \text{.......(10)}$$

Where;

P = number of poles

Lm = magnetizing inductance

Rr and Rs = rotor and stator side resistance

r = electrical rotor speed

e = line frequency

V = stator voltage

Ls and Lr = leakage inductance

All the electrical quantities are referred to the stator side.

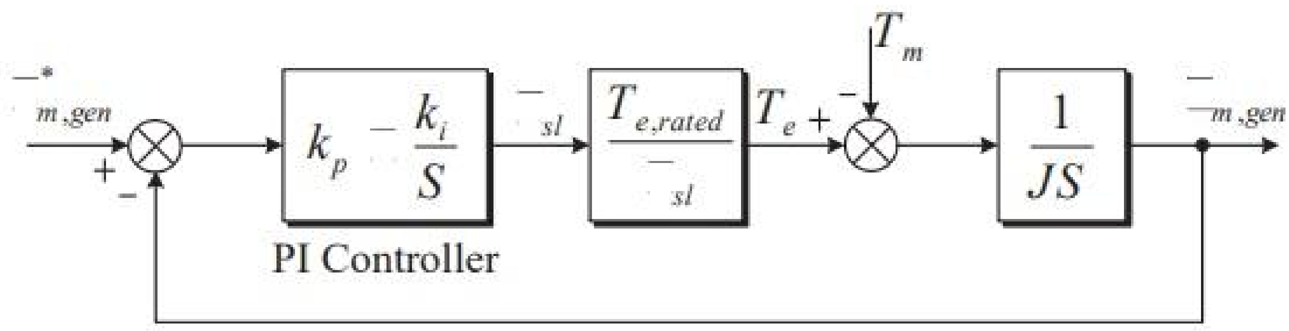

Figure 4.2: Control of Induction Generator

4.2 SYNCHRONOUS GENERATOR :

A synchronous generator is a kind of synchronous machine that, via a process known as electrom@gnetic induction, converts mechanical power into alternating current (AC) electric power[23]. Synchronous gener@tors are an example of synchronous machines, it moves forward thanks to a motor that is contained in a component that is located on the outside[16]. The pace at which the synchronous rotation is taking place is equivalent to the speed at which the rotor is rot@ting. The Faraday principles of electromagnetic induction serve as the synchronous generator's guiding principle of operation[16]. This allows the generator to be driven by the principles. An electromotive force will be created in the arm@ture coil anytime it spins within a magnetic field that is uniform, as stated by the theory of electrom@gnetic induction[16]. Even if the field rotates but the conductor stays in the same place, an electromagnetic field will still be created. Because of this, the conductor is subjected to an electromagnetic field as a direct consequence of the relative motion that exists between the field and itself[16].

The waveform of the induced voltage consistently takes the form of a sinusoidal curve, regardless of the circumstances[16].

4.2.1 CONSTRUCTION OF SYNCHRONOUS GENERATOR :

The alternator is made up of two primary components, namely:

1. STATOR : The section of the alternator that is always in the same place is called the stator. It is responsible for transporting the armature winding, which is where the voltage is produced. The alternator uses the stator as its source for the output it produces.

2. R0TOR : The altern@tor's rotor is the portion of the altern@tor that rot@tes. The m@jority of the field flux is gener@ted by the rotor.

Alternator Construction Utilizing the Stator

● The alternator's stator is composed of a number of components, including the fr@me, the st@tor core, the st@tor or arm@ture windings, and the coling arr@ngement.

● For machines of a smaller size, the stator frame may be built of cast iron, where@s for machines of a larger size, it might be made of welded steeI.

● Laminations of high-grade steel with a silicon content are used in the construction of the stator core. The hysteresis and eddy-current losses in the st@tor core may be reduced thanks to these silicon steel laminations.

● The slots are carved into the innermost portion of the stator core's circumference. These spaces are then filled with a winding for a three-phase armature.

● The alternator has a star connection for the armature winding of the component. The winding for each phase is spread out among a number of different slots. An important sinusoidal spatial distribution of electromagnetic field is generated whenever current is passed via the distributed armature winding.

Alternator Construction Utilizing the Rotor

The field winding of the alternator is carried by the rotor, which receives direct current fr0m a separate DC source through two slip rings[20]. The direct current flows via the field winding (also called exciter). The exciter is often an extremely tiny direct current (DC) shunt generator that is positioned on the shaft of the alternator.

There are two different kinds of rotor constructions that are utilized for alternators: the salient-pole type and the cylindrical rotor type, both of these types are employed[20].

4.2.2 Salient Pole Rotor :

The definition of the word "salient" is "projecting." As a result, the poles that make up a salient pole rotor are those that protrude outward fr0m the surface of the rotor core[22]. According to what is seen in the fig.4.2 this whole assembly is f@stened to the shaft of the altern@tor[22]. When the field winding is energized by the DC exciter, the individual field pole windings are linked in series such that neighboring poles will have opposing polarities when the field winding is energized[22].

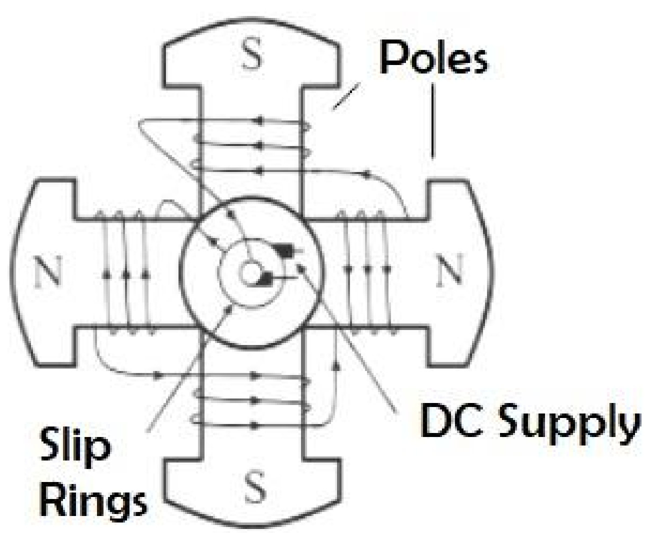

Figure 4.3 : Salient Pole Rotor of Alternator

The alternators that are powered by diesel engines or w@ter turbines employ the salient pole type of rotor because of the following reasons[22]: The salient pole type of rotor is more efficient than other types of rotors at low and medium speeds (ranging from 1,21 to 4,10 RPM).

- It is not possible to build salient pole type rotors with a structure that is robust enough to resist the mechanical loads that may be imposed on them while operating at greater speeds.
- If the s@lient field poIe type rotor were operated at a high speed, then it would result in windage loss and it would h@ve a tendency to make noise.

In order to make room for the poles, the Iow speed rotors of the alternators have a di@meter that is much larger than average. As a direct consequence of this, salient pole type rotors tend to have a very large diameter but a relatively short axial length.

4.2.3 Cylindrical Rotor :

Solid forgings of high-quality nickel-chrome-molybdenum steel are used in the production of the cylindrical rotors[20].

- Because of the way the cylindrical rotor is built, there are no actual poles that can be seen inside of it as there are in the salient pole rotor[22].
- Slots are cut at regular intervals and parallel to the rotor shaft in about two-thirds of the outer perimeter of the cylindrical rotor[22].
- These slots are where the field windings are installed, and the DC supply is used to excite them. A scattered form of winding w@s used for the field.
- The pole faces are formed by the section of the rotor that is not slotted.
- The fig.4.4 of the cylindrical rotor makes it abundantly evident that the poles that

are created are non-salient, which means that they do not extend outward from the surface of the rotor.

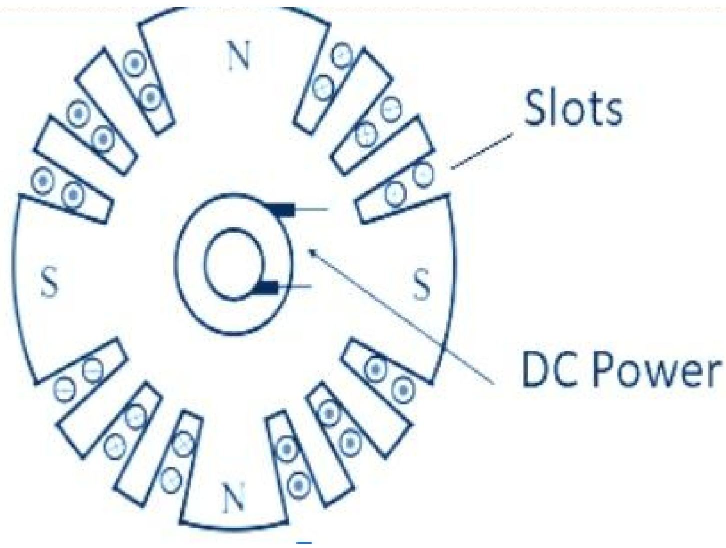

Figure 4.4 : Cylindrical Rotor of Alternator

The cylindrical type rotor structure is employed in high-speed alternators with speeds between 1,512 and 3,031 RPM, such as those operated by steam turbines, for the following reasons:

The cylindrical style of rotor design offers superior mechanical strength and makes it possible to achieve more precise dynamic balancing.

- Because of the consistent air gap, it provides a noiseless operation even while operating at high speeds.

- Because the flux distribution around the rotor's perimeter is very similar to a sine wave, an improved electromagnetic field waveform is produced as a result.

An alternator with a cylindrical rotor typically h@s a relatively narrow diameter and an extended axial length. Alternators with a cylinder-shaped rotor are referred to as turbo-alternators or turbo-generators. Alternators that have cylindrical rotors are always installed in a horizontal orientation[22].

4.2.4 Working Principle and Operation of Alternator :

Alternators and synchronous generators both function according to the concept of electromagnetic induction, which states that an electrom@gnetic field (EMF) is induced in a conductor whenever there is a change in the flux connecting the conductor[26]. Voltage will be created in the alternator's armature winding whenever it is exposed to a revolving magnetic field. This is how the altern@tor produces electricity.

The alternator's rotor develops alternating N and S poIes when the rotor fieId winding is energized by the DC exciter. This results in the rotor h@ving a polarity of N and S[23]. When a prime mover turns the rotor in a direction counter to the direction of clockwise rotation, the magnetic field of the rotor poles cuts through the armature conductors that are mounted on the stator[23]. Because of this, electromagnetic induction causes an induced electric field (EMF) in the conductors of the armature. This particular induced EMF is an alternating one due to the fact that the N and S poles of the rotor alternately travel through the armature conductors[23].

The frequency of the electromagnetic field that is produced may be calculated using Fleming's right rule, which can be used to identify the field's direction.

$$f = \frac{P\ N_s}{120}\ Hz$$

Where,

The synchronous speed in RPM is denoted by Ns.

P denotes the total number of poles on the rotor.

The magnitude of the voltage that is produced is influenced both by the pace at which the rotor is rot@ting and by the DC field exctation current[23]. When the situation is balanced, the voltage that is created in each phase of the winding is the same, but they vary in phase by an electrical degree of 120 degrees[23].

CHAPTER 5

ANALYSIS OF MODEL PROPOSED

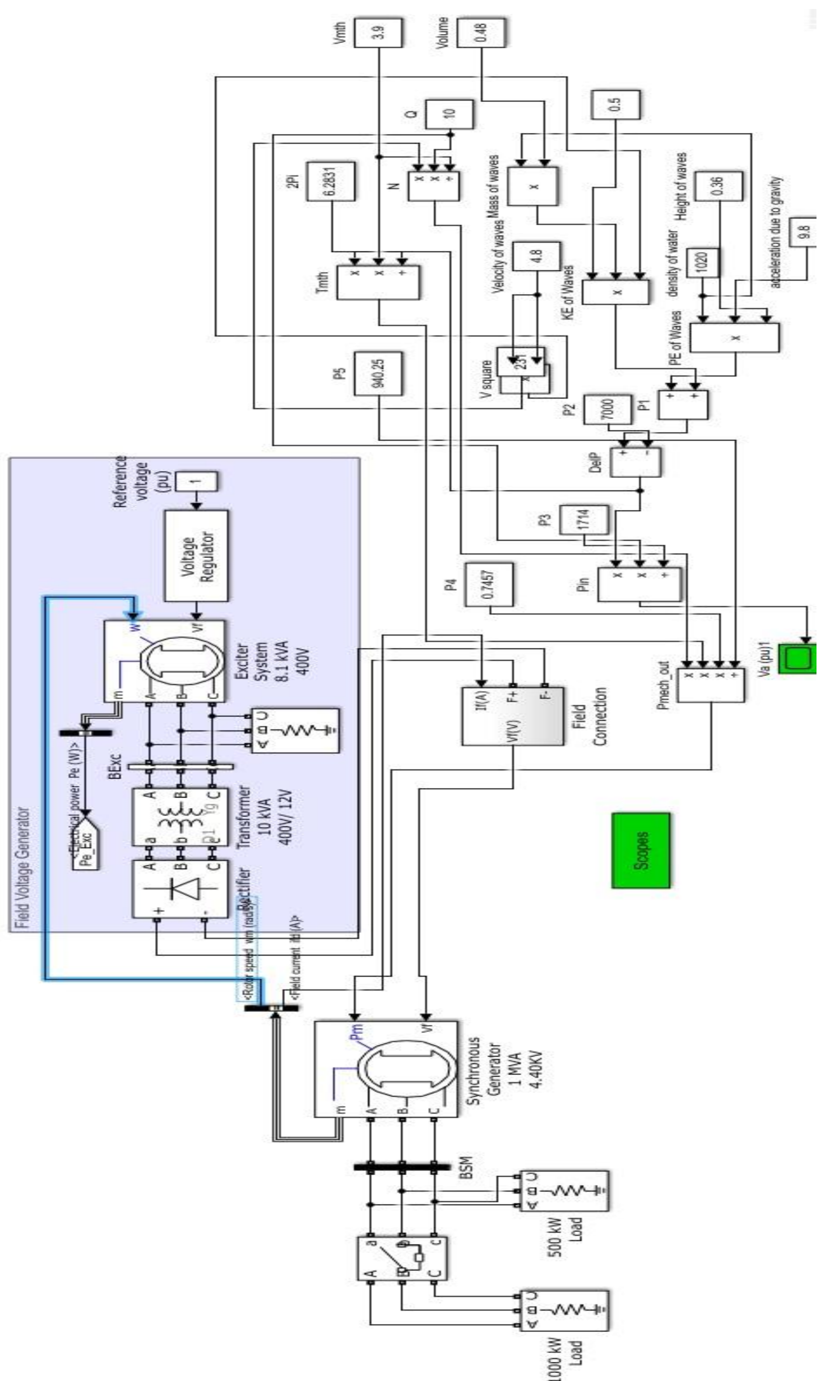

Figure 5.1 : Simulink Model Of Proposed OWE System

5.1 Python Coding :

The amount of power that is generated by the machine's mechanical components:

p = 1020 :density of seawater

g = 9.8 :acceleration due to gravity

Vol = .48 :Volume of floaters

m = p * Vol :Mass of the water touches the floaters

P1 = p * g * h + 0.5 * m * v**2 :P1 is forward chamber pressure

Q = 10 :flow rate

Vmth = 3.9 :Motor displacement

N = 231 * Q / Vmth :theoretical motor speed

Pin = delP * Q/1714

Tmth = delP * Vmth / 6.2831 # 2*pi = 6.2831

Pmech_out = Tmth * N * 0.7457/940.25

The amount of power that is generated by the machine's Electrical components:

pole = 10 :considering the value

flux = 0.48 wb

slots = 96 :coil distribution is full pitched

Z = 16 :conductors per slots

f = pole * N / 120

n =slots/pole :slots per pole

B = 180/n

m = slots/(10*3) :slots per pole per phase

Kd = Sin (m*B/2)/m* Sin (B/2)   :Distribution Factor

kc = 1   :full pitched coil has chorded factor 1

T = slots * Z / (3*2)   :no of turns per phase

Egph = 4.44 * kd * kc * f * phie * T   :per phase generated Emf

Pst = 0.1   :Considering stator losses

Ped = (Pout - Pst)*1000   :Power Developed by the machine

Pfi = 500 KW   :Considering iron and friction and windage losses

Pe_out = (Ped - Pfi)

Xs = 12   :synchronous reactance in ohm

Vt = 5000 V   :terminal voltage

CHAPTER 6

RESULT AND DISCUSSION

Wave energy extraction systems have been researched, and the following are the findings, which include the hydraulic motor and Generator that was used, as well as its settings for the suggested model and the sequence of operation. The suggested model makes use of the SCADA and MATLAB softwares in addition to PYTHON. There are two types of generators: an induction generator and a synchronous generator. And as a direct consequence of this, this is shown in conjunction with the power production curve at various times during the day. Comparative analysis of the two generators' properties is carried out.

6.1 Result :

PYTHON code Results are :

```
velocity of oceanic wave =  4.80 m/sec
height of oceanic waves = 0.36 m
Pressure exerted by oceanic wave =  9238.75 Hp
Theretical Speed of the motor =  592.31 Rpm
Input Power of the Hydraulic Motor = 13.06 Hp
Torque generated by Motor = 1389.62 lbf-in
Output Power of the Hydraulic Motor = 0.65 MW
frequency = 49.36 Hz
Generated Emf per phase = 2583.10 volts
Generated Line Emf = 4474.06 volts
Developed Power by the Machine = 0.55 MW
Output Power of the Machine = 0.55 MW
Torque angle of machine delta = 17.25 degree
Overall Efficiency = 84.45104357773856 %
generated voltage at 8 am = 4.47 KV
generated power at 8 am = 0.97 MW
```

Figure 6.1 : Mechanical and Electrical Power generation at 8 am

```
velocity of oceanic wave =  5.30 m/sec
height of oceanic waves = 0.49 m
Pressure exerted by oceanic wave =  11774.47 Hp
Theretical Speed of the motor =  592.31 Rpm
Input Power of the Hydraulic Motor = 16.19 Hp
Torque generated by Motor = 1722.15 lbf-in
Output Power of the Hydraulic Motor = 0.81 MW
frequency = 49.36 Hz
Generated Emf per phase = 2583.10 volts
Generated Line Emf = 4474.06 volts
Developed Power by the Machine = 0.71 MW
Output Power of the Machine = 0.71 MW
Torque angle of machine delta = 22.35 degree
Overall Efficiency = 87.45337588980871 %
generated voltage at 11 am = 4.47 KV
generated power at 11 am = 1.21 MW
```

Figure 6.2 : Mechanical and Electrical Power generation at 11 am

```
velocity of oceanic wave =  5.40 m/sec
height of oceanic waves = 0.55 m
Pressure exerted by oceanic wave =  12636.17 Hp
Theretical Speed of the motor =  592.31 Rpm
Input Power of the Hydraulic Motor = 15.38 Hp
Torque generated by Motor = 1636.30 lbf-in
Output Power of the Hydraulic Motor = 0.77 MW
frequency = 49.36 Hz
Generated Emf per phase = 2583.10 volts
Generated Line Emf = 4474.06 volts
Developed Power by the Machine = 0.67 MW
Output Power of the Machine = 0.67 MW
Torque angle of machine delta = 21.02 degree
Overall Efficiency = 86.79512941199098 %
generated voltage at 4 pm = 4.47 KV
generated power at 4 pm = 1.15 MW
```

Figure 6.3 : Mechanical and Electrical Power generation at 4 pm

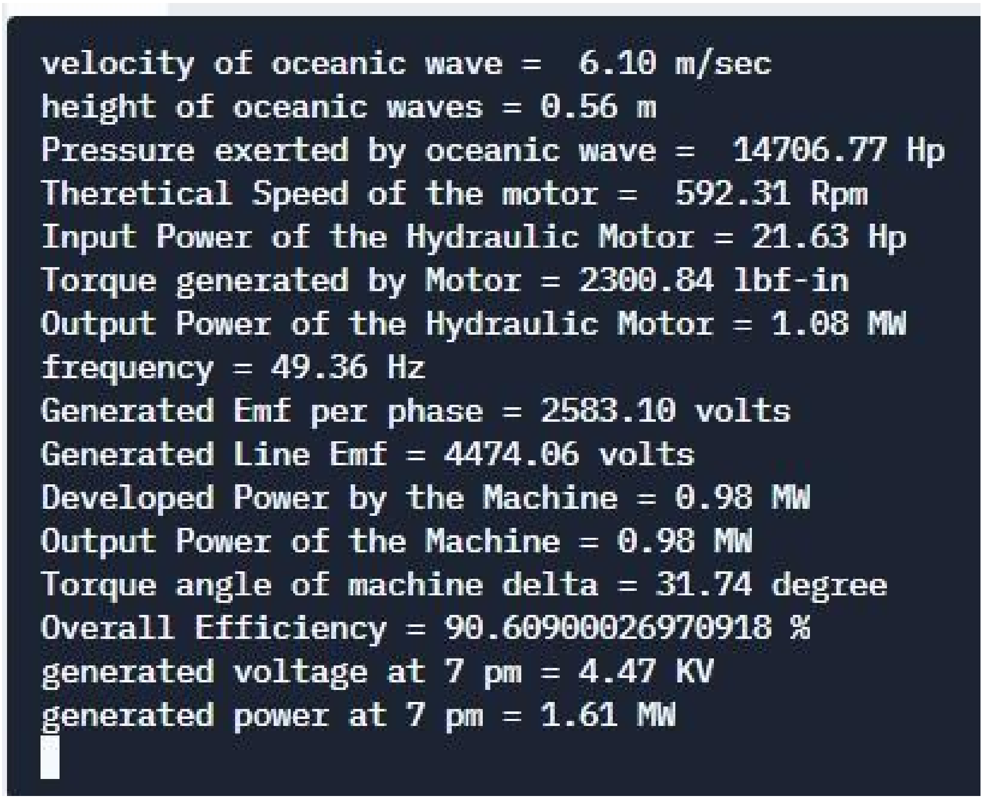

Figure 6.4 : Mechanical and Electrical Power generation at 7 pm

The findings reveal the values of the output power of the synchronous generator and the hydraulic motor at different times throughout the day, such as at four o'clock in the afternoon, seven o'clock in the evening, eight o'clock in the morning, and eleven o'clock in the morning. in addition to an analysis of the power that is generated by the system. It is obvious that the speed of the sea waves and their height are at their peak during the night when compared to other times of the day, which results in a higher quantity of power being generated. Before we can connect the system to the grid, we will need to install inverters so that we can be sure it continues to generate the required quantity of power. Even in this case, the frequency does not remain constant or remain at a rate of 50 hertz, which is the standard that has been decided upon for the India Power Network. Because of this, a frequency converter is used in order to keep the frequency stable, which also necessitates the utilization of certain power electrical components for the goal of accomplishing this task. After this, a transformer only has to be connected so that power may be sent into the grid.

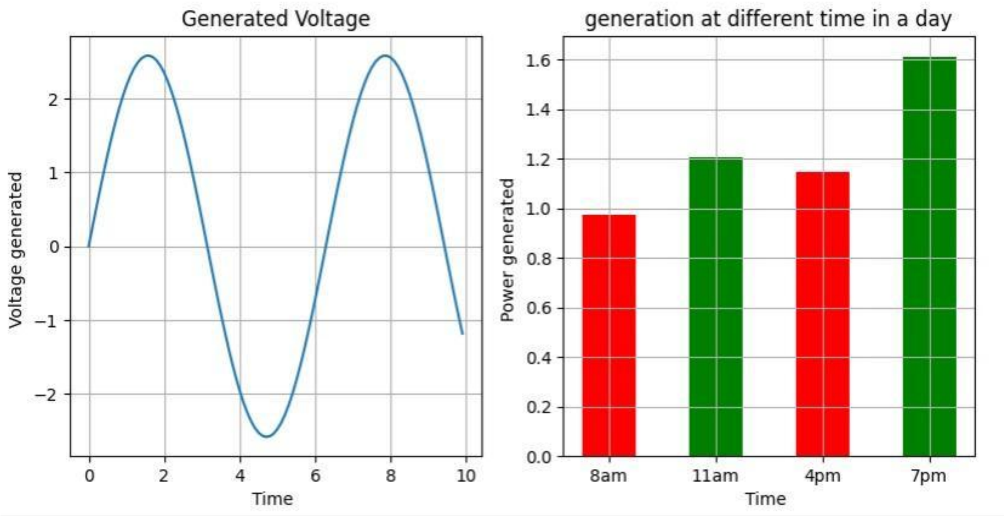

Figure 6.5 : Graph between Voltage and Power generated at different time intervals

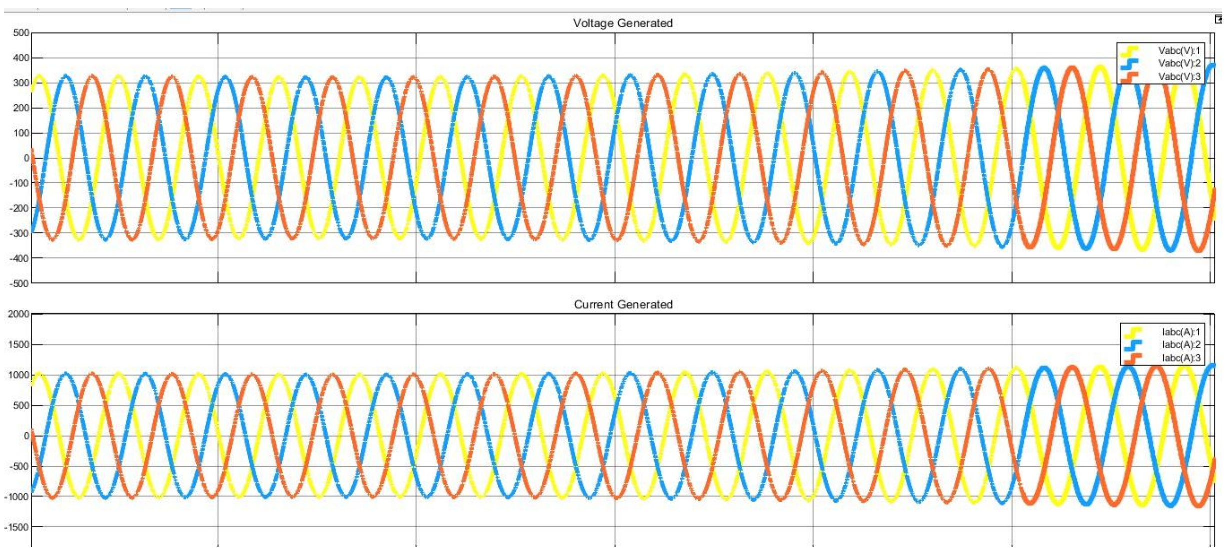

Figure 6.6 : MATLAB Simulation Result of Rotatory generator
(Generated Voltage and Current)

One can see that the Power and Voltage output of the simulated model is compared to results from PYTHON codes. All the values considered are taken from somewhere. The value of height and velocity of the oceanic waves are taken from the ESSO - Indian National Center for Ocean Information Services.

6.2 Comparison with Traditional Generator output :

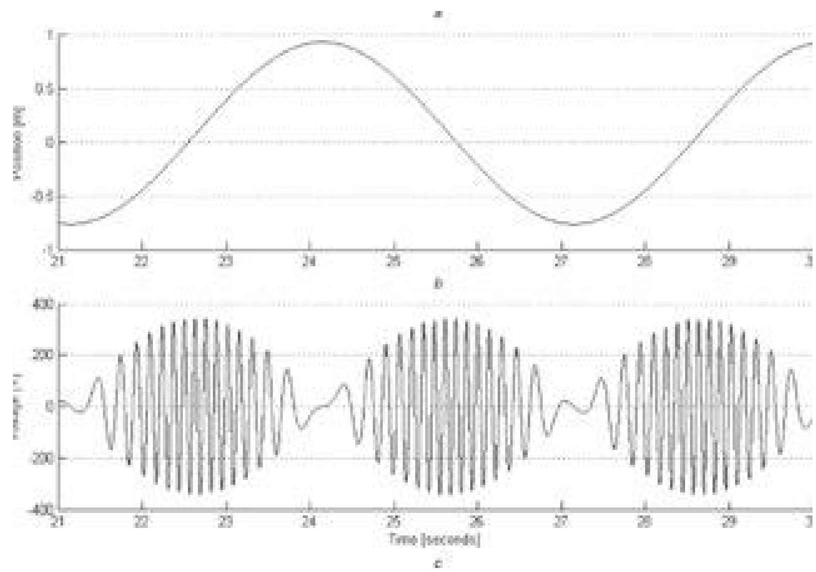

Figure 6.7 : Simulation Result of Linear generator (Generated Voltage)[10]

Currently, the power gathered by rotatory generators is more reliable than that which is collected by linear generators, and the efficiency of rotatory generators has also greatly grown in recent years. Fig. 6.6 and 6.7 show us that the voltage output of a linear generator is disrupted at some point, but the voltage output of a rotatory generator is unaffected by disruptions and creates voltage in a continuous way. This dichotomy can be seen by comparing the two sets of figures. In light of this, I feel that it is better to use an extraction system that is situated on land as opposed to one that is located offshore. This is because land-based extraction systems are more easily accessible.

6.3 Conclusion :

The model was evaluated, and the results that were obtained are presented here. These results demonstrate that the proposed model is suitable for producing adequate energy even at wave heights of 0.5 to 0.8 meters; the fact that this model is suitable for doing so even at these wave heights is the defining characteristic of the model. However, the model that was provided in this study illustrates that continuous supply is possible owing to the fact that it can work at very low wave height as well as larger wave heights. This ability to perform over a wide range of wave heights demonstrates the versatility of the model. Despite the fact that there are points along the path of the translator movement at which SPLGEs do not provide any power, this is still the case. The efficiency under full load is maintained between 84 and 90 percent of its former level while the process is being performed. The newly developed model is straightforward, has a quick reaction, is reliable, and is solidly constructed.

Currently, the power gathered by rotatory generators is more reliable than that which is collected by linear generators, and the efficiency of rotatory generators has also greatly grown in recent years. Fig. 6.6 and 6.7 show us that the voltage output of a linear generator is disrupted at some point, but the voltage output of a rotatory generator is unaffected by disruptions and creates voltage in a continuous way. This dichotomy can be seen by comparing the two sets of figures. In light of this, I feel that it is better to use an extraction system that is situated on land as opposed to one that is located offshore. This is because land-based extraction systems are more easily accessible.

Under the same conditions of operation, the proposed OWE system's translator is able to achieve a higher power output and is more reliable as a result of being lighter in weight than the conventional one. Furthermore, because it is installed on shores, the system requires less maintenance because it is easier to access. Because of this, the system is capable of producing a higher amount of energy and maintaining a constant level of power production. The efficiency of the proposed system is nearly 20-30 percent higher than that of the conventional SPLEGs under the same wave conditions because the piston accumulator can maintain the flow and pressure of fluid throughout the operation. This is because the new floaters have a lower mass than the conventional one.

6.4 Onshore energy Extraction over Offshore :

Several companies that work on developing wave energy have moved their systems offshore in order to take advantage of the enormous energy potential offered by offshore waves. On the other hand, commercialization of these systems was difficult due to the following:

- High prices: The CAPEXs that are connected with offshore systems are high because there are high expenses implied in the installation, maintenance, and connection to the electrical grid of such systems. These high costs may be attributed to the fact that offshore systems need more space. Given that their installation in an offshore location necessitates the utilization of ships, divers, underwater electrical transmission lines, and underwater anchoring, it follows that their deployment will demand a significant investment.
- Low Reliability: The climates of offshore oceans are often quite severe, and the wave heights that may be experienced there can reach up to twenty meters. Machines that are stationary and were developed by humans have a difficult time surviving in settings like this for lengthy periods of time.
- Lack of availability of insurance for risks associated with offshore systems: Because of the high costs and limited dependability associated with offshore wave energy systems, obtaining insurance for offshore wave energy power plants proved difficult.
- Impacts on the environment, both positive and negative, caused by offshore systems: Environmental groups have a significant amount of input on the process of implementing new technology. However, many people have voiced their opposition to the deployment of offshore wave energy systems due to the fact that many of these systems need anchoring to the ocean bottom. This disrupts the local marine ecosystems and may also restrict the migratory of marine life.

In this study, a new method is examined following the obstacles experienced by its offshore rivals in the wave energy business. As a result of these challenges, it is good to install the OWE systems in the onshore and nearshore environments and to attach them to marine structures, such as breakwaters.

6.5 Future Scope :

Many models have been studied; however, this does not imply that any of these models are ideal; as there is no such thing as a perfect model, all models have room for improvement. The primary focus of this thesis is to investigate ways in which the power quality and dependability of the power distribution system might be improved. Wave condition plays essential roles in the processes that produce wave energy from the piston, hydraulic fluid, accumulators, hydraulic motor, and generators. These operations are derived from the wave. As technology advances, there is a possibility that power quality may also increase, and that large-scale power production could become feasible.
Demand for energy has risen throughout the years as a result of changes in consumer preferences about their way of life. A more efficient management of energy may be a useful tool in the fight against this rising demand. The discovery of new energy sources is very necessary in order to satisfy the ever-increasing need for energy. Wave power in India offers a significant amount of untapped potential. In light of this potential, the Government of India needs to undertake concerted efforts to encourage the use of wave energy. Wave energy would have a beneficial impact on the economy of the nation by delivering three different kinds of returns, which are economic, social, and environmental respectively. The expensive cost of installation to generate energy from waves is a matter for worry; however, the operating cost of this technology is nothing. As a result, it is essential to place a strong emphasis on the research and development of innovative, technically sophisticated wave energy trappers that are also economical and help to lower the cost of wind power per unit. It is essential for the government of India to boost the amount of money invested in research and development of wave energy generation. Due to the fact that India is a peninsula, it has an abundance of access to waves with a high energy level. This article makes a few feeble attempts to explore the viability of a wave energy extraction system at coasts and provides a foundation for future work in this area of study.

APPENDIX 1

Introduction to SCADA :

Supervisory Control And Data Acquisition is what "SCADA" stands for in its abbreviated form. SCADA stands for supervisory control and data acquisition, and it is a common type of process automation system. Its purpose is to collect data from sensors and instruments situated at remote sites, transmit that data to a central location, and display it there for the purposes of control or monitoring. The data that has been gathered may typically be accessed on one or more SCADA Host computers that are situated at the central or master site.

A SCADA system that is used in the real world may monitor and control anywhere from tens of thousands to hundreds of thousands of I/O points. In a typical Water SCADA application, the water level would be monitored at various water sources such as reservoirs and tanks, and when the water level reaches a predetermined threshold, the system of pumps would be activated to move water from reservoirs with high water levels to tanks with low water levels.

SCADA systems monitor and regulate a wide variety of analogue signals, the most common of which are levels, temperatures, pressures, flow rate, and motor speed. Level switches, pressure switches, generator status, relays, and motors are all examples of typical digital signals that may be monitored and controlled.

In most cases, a further layer of apparatus is located between the distant sensors and instruments and the primary computer in the facility. On the distant side is where you'll find this intermediary piece of equipment, which links to the many sensors and field devices. In most cases, sensors will have either digital or analogue I/O, neither of which are formats that lend themselves well to being readily sent over extended distances. In order for the sensor signals to be able to be digitally communicated across long distances to the central location, the intermediate equipment must first digitize them and then packetize them. Only then can they be sent via an industrial communications protocol.

Introduction to MATLAB :

The software package known as MATLAB is an environment that supports high-performance mathematical computing, visualization, and programming. It offers a user-friendly environment that is equipped with hundreds of pre-programmed capabilities for technical computing, graphics, and animations.

Matrix Laboratory is what MATLAB is abbreviated as. The LINPACK (Linear system package) and EISPACK (Eigen system package) programmes were responsible for developing MATLAB's straightforward approach to matrix software. MATLAB was first built to use this simple technique.

MATLAB is a contemporary programming language environment that has improved data structures, built-in editing and debugging tools, and support for object-oriented programming. Additionally, MATLAB has enhanced data structures.

MATLAB is Multi-paradigm. Therefore, it is compatible with a wide variety of programming methodologies, including Visual, Object-Oriented, and Functional techniques.

Introduction to PYTHON :

Python is a high-level programming language that may be used for a variety of purposes and is quite popular. It was first developed in 1991 by Guido van Rossum, and since then, the Python Software Foundation has continued to improve upon it. Readability of the code was a primary design goal, and the structure of the language makes it possible for programmers to communicate their ideas with fewer lines of code.

You'll be able to work more quickly and integrate systems more effectively when you choose Python as your programming language of choice.

APPENDIX 2

V-Curves of Synchronous Generator :

When the armature current Ia is plotted against the excitation or field current under a variety of load circumstances, a collection of curves that are known as "V-Curves" is obtained. These curves get their name from the fact that their form is similar to the letter V in the English alphabet.

The V-curve of a synchronous generator is seen here, and it demonstrates how the armature current Ia varies with excitation for the same input while the generator is operating with no load, half full-load, and full-load.

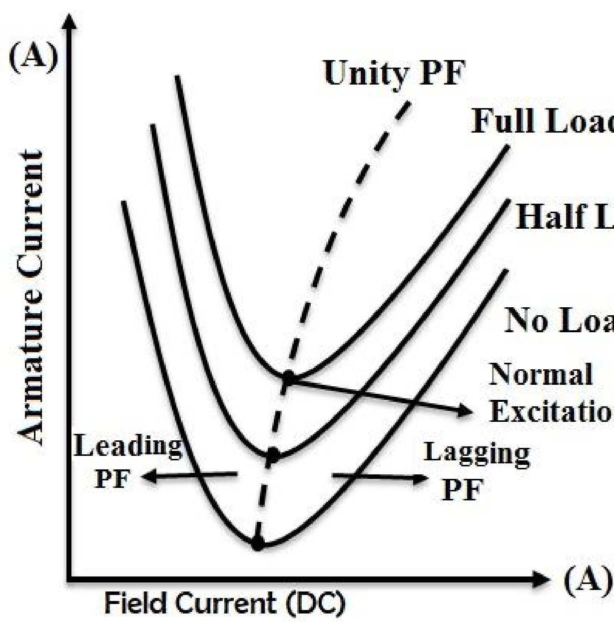

Figure A.2.1: V-Curve of the Synchronous Generator

It can be seen from the V-curves that the armature current has considerable values for both low and high levels of excitation (though it is lagging for higher excitation and leading for lower excitation). In the middle, it has a value that is at its lowest point, which corresponds to the power factor of unity (normal excitation).

Inverted V-Curves of Synchronous Generator :

When the power factor is plotted against the excitation under a variety of different load situations, we get a collection of curves that are collectively referred to as "Inverted V-Curves."

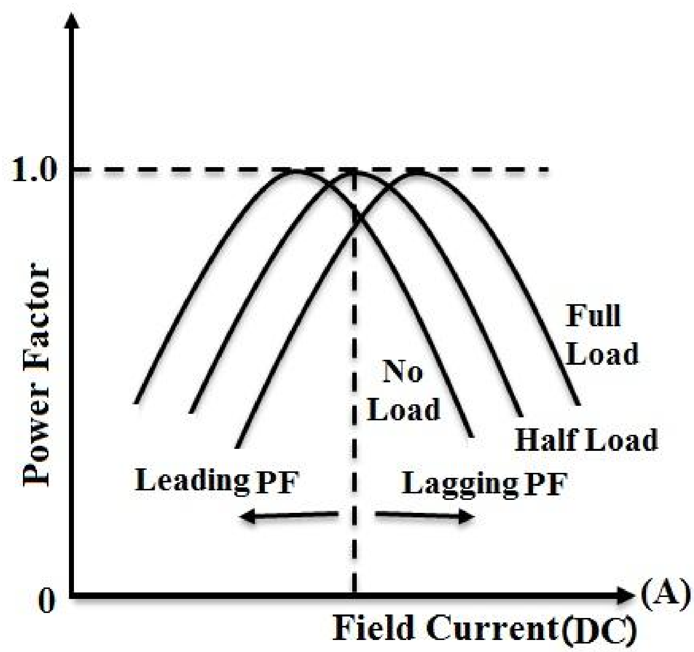

Figure A.2.2: Inverted V-Curve of the Synchronous Generator

The inverted V-curves of a synchronous generator illustrate how the power factor shifts in response to changes in the excitation. It can be seen from inverted V-curves that the power factor is in the lead when the motor is under excited and in the lead when it is over excited. When the motor is over excited, the power factor is in the lead. The element of power that lies in between is unity.

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LIST OF RESEARCH PUBLICATION

1. Ankita Pandey and J.N.Rai, 'Extraction Of Wave Energy By Synchronous Generator: Design And Performance Analysis' in 7th Students' Conference on Engineering and Systems (IEEE Allahabad section SCES-2022). Paper is accepted and will be present on 1-3 july.
2. Ankita Pandey and J.N.Rai, 'Extraction Of Wave Energy By Induction Generator: Design And Performance Analysis' in 3rd International Conference of Emerging Technology (IEEE Banglore section INCET 2022). Presented Paper on 28th May 2022. Paper will be published in the SCOPUS Indexed journal.

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