

Ocean Wave Energy Power Generation and Fault Removal using UPFC in Hybrid Grid System

Devanshu Kanojiya

M.Tech Scholar

Department of EX

Lakshmi Narain College of Technology

Bhopal, M. P, India

Dr. Manish Khemariya

Professor

Department of EX

Lakshmi Narain College of Technology

Bhopal, M.P, India

Abstract- Ocean wave energy, ocean tidal energy as well as ocean thermal energy is an immense source of renewable energy. Oceans water cover approximately 71 % of volume of earth. Waves carry enormous quantity of energy among them. Tides generated as a result of gravitation between earth and moon and partially between earth and sun facilitate in generating high heads of water to generate pollution free energy. As a result of high value or cost of generation and lack of enough research, this sustainable supply of energy has not been totally exploited yet. Though the technology employed in harnessing marine energy is taken into account as a threat to aquatic life, however appropriate ways and focused research in this field that will result in benefit of this ample supply of renewable energy. Wave energy is obvious source for renewable energy harvesting in oceans.

In this paper a concept of a new OWEC is proposed and developed numerical model to describe the proposed OWEC. The performance of the proposed system was determined by several parameters: wave conditions, floating body geometry and power storage system including generator and electrical load. In this study, we found optimal design of HACPSS from quantitative simulation by using the numerical model. In addition, we constructed a conceptual prototype of for proposed work based on mathematical model. However, the output fluctuation was shown in every case. The proposed wave-to-wire model is very useful to address several design and analysis issues without modifying the actual system, for instance, to implement a fault detection strategy. The acceptable limits of power oscillation depend on whether the converter is connected to an islanded system, or a weak or strong power grid. In this research work, proposed Ocean Wave Energy Converter (OWEC) based power grid system, performance of grid system is analyzed under no fault condition, fault condition and fault removal condition using UPFC device.

Keywords- Wave energy converter; Energy harvesting system; Wave turbine; HACPSS; Fault Removal; UPFC;

I. INTRODUCTION

Sun provides more than 99.99% of energy and earth contributes about 0.01% [1]. Fossil fuels are a form of antediluvian eon solar energy. All sources of energies, except geothermal and nuclear, are ultimately powered by the sun [2]. Earth radiates heat and its thermal energy come from radioactive decay (80%) and planetary accretion (20%) [3]. Oceans encompass over 70% of the earth's mass. Ocean tides are caused by earth's gravitational interaction with the

moon (68%) and sun (32%). Ocean waves are caused by friction of winds with the water surface. Oceans are a great form of renewable energy which is stored in the form of thermal energy (heat), kinetic energy (tides and waves), chemical energy (chemicals) and biological energies (biomass). Tidal current or wave generators harvest kinetic energies, and osmotic power plants and thermo-electric generators reap salinity and thermal gradients [5].

Wave energy comes from the winds as they blow across the oceans, and this energy transfer provides a convenient and natural concentration of wind energy within the waves. Once created, waves will travel thousands of kilometres with very little energy loss. the power in a very wave is proportional to the square of the amplitude and to the period of the motion. Therefore, long period (~7-10 s), large amplitude (~2m) waves have energy fluxes usually averaging between 40 and 70 kilowatt per meter breadth of oncoming wave [3]. Nearer the coastline the common energy intensity of a wave decreases because of interaction with the ocean bed. Energy dissipation in near shore areas are often compensated for by natural phenomena like refraction or reflection, resulting in energy concentration. As wave energy is distributed inconsistently around the world like most kinds of the renewable energy sources.

There are 3 predominant varieties of WECs: attenuator, point absorbent and terminator shown in figure 1-3. The Attenuator wave energy converters are situated parallel to the wave direction and 'ride' the waves. An example of an attenuator WEC is the Pelamis, developed by Ocean Power Delivery Ltd [7].



Figure 1: Attenuator device

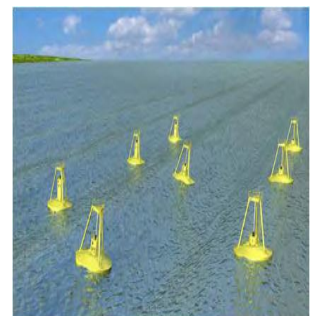


Figure 2: Point absorber device



Figure 3: Terminator device

The Pelamis device is a semi-submerged, articulated structure composed of cylindrical device connected by hinged joints. From the hinged joints motion is induced due to ocean waves which consequently generates the hydraulic power that can be transferred as electricity to the grid system [6]. The Point absorbent wave energy converter is a device that has small dimensions relative to the incident wavelength that is floating in nature which oscillates up and down on the surface of the ocean water or submerged below the ocean surface oscillating on differential pressure differential. The Terminator devices have their principal axis perpendicular to the predominant wave direction. In such type of device relative rotation of device is converted into energy.

II. RELATED WORK

Liliana Rusu et al. [9] reviewed the global wave energy resources according to the most recent datasets available, to identify the locations with the worldwide highest wave energy potential and to assess in those locations the performance of some state-of-the-art wave energy converters. For this purpose, 15 years of wave data provided by the European Centre for Medium-Range Weather Forecasts, covering the time interval 2000–2014, were considered, processed and analysed. Nikolaos et al. [10] presents the design procedure and modeling of performance for a special coupled electromechanical system, for use in ocean wave energy extraction applications. In order to efficiently use the wave energy using a point absorber like a floating buoy, it is important to tune the movement of the coupled mechanism, with the main frequency of the incident wave by using appropriate control. The system analysis requires particularly developed electromagnetic mechanical hydraulic simulation models for the time variation representation of the system's operational parameters. Douglas et al. [11] presented the methodology for numerical simulations and field experiments using point absorption ocean wave energy harvesting buoy systems, using the heave motion of the buoys to produce useful electrical power. Results showed that RMS values for armature displacement and armature velocity and mean harvested electrical power were generally within 10% between model simulations and experimental data. Paula et al. [12]

addressed the dynamic modeling and the energy storage analysis of a wave energy hyperbaric converter, which consists of a set of oscillating bodies (named as pumping modules) linked to hydropneumatic accumulators and an electric generating unit. A mathematical model of the accumulator is presented and a model for the generating unit is proposed, including a nonlinear model of a Pelton turbine. N. Khan et al [13] reviewed the present progressive of tidal, wave, OTEC and OTEG ocean energy technologies as ocean tidal currents, water waves and thermal gradients are an excellent supply of renewable energy. Hangil Joe et al. [14] proposed a new WEC named wave turbine. The proposed system consists of a floating body and a submerged body. To describe the proposed system, researchers developed numerical model. The performance of the proposed system was determined by several parameters: wave conditions, floating body geometry, blade shape, rotor hub design, and power storage system including generator and electrical load. Quantitative simulation was conducted to find optimal parameters including design of blade and rotor hub size. N.Y. Sergiienkoa et al. [15] investigates the differences between floating and fully submerged point absorber converters from the number of perspectives including energy extraction, bandwidth, and optimal size for a particular wave climate. The results show that when compared with floating converters, fully submerged buoys: (i) generally absorb less power at longer wavelengths, (ii) have narrower bandwidth, (iii) cannot be replaced by smaller units of the same total volume without a significant loss of power, and (iv) have a significant advantage as they can effectively utilize several modes of motion (e.g. surge and heave) in order to increase power generation. Thanh Long et al. [16] presented a robust stability certificate that can rigorously guarantee the grids stability with respect to the variation in power injections. Interestingly, quadratic Lyapunov function approach is presented to transient stability assessment, offering real-time construction of stability certificates. The effectiveness of the proposed techniques is numerically illustrated on a number of IEEE test cases. Siming Wei et al. [17] illustrated that synchronous generator is a key element in maintaining stability in traditional power system and performs well. However, the high penetration of renewable energy will challenge the stable operation of future power system because the characteristics of converter-based resources differ from those of a synchronous generator. As a result, weak grid caused by a lack of short circuit capacity and inertia, damping and fault ride-through abilities become important issues for grid stability. To solve these problems, the synchronous motor-generator pair (MGP) was proposed as a possible approach.

III. MATHEMATICAL MODEL OF OWEC

Most of the invented WECs convert the energy from ocean wave to usable energy directly without energy storage. Those systems totally depends on real time ocean wave conversion result, if the wave is strong enough then the energy converted will be high. On the other hand, if the ocean wave is weak then the converted energy will be weak or no energy will be converted at all. The most promising and reached commercialized stage and widely used WEC is the oscillating wave column (OWC) [18]. OWC becomes a part of Hydraulic-to-Air-Constant Pressure Storage System (HACPSS) in extracting the ocean wave energy. HACPSS acts as storage cylinder that stores air pressure and supply constant pressure to the turbine for its rotation and electricity generation. Figure 4 illustrates the block diagram of HACPSS for electricity generation.

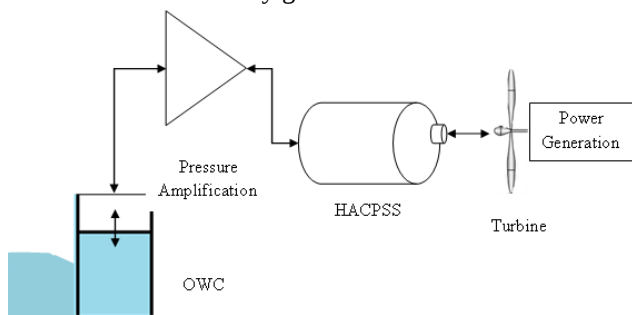


Figure 4: Conceptual Model of HACPSS

The complete system consists of ocean wave energy extraction and air pressure development using OWC, air pressure amplification, air pressure storage; air pressure distribution, turbine system and electricity generation. The ocean incident waves forced the ocean water into the column of OWC through the submerged opening. This will cause the water free surface inside the column to lift upward. When the incident wave force is zero, the free water surface will stop raising and starts to fall down due to gravity. This creates an oscillation inside the column. The trapped air will be occupied on the upper part of the free water surface inside the column. The oscillation of free water surface inside the column due to the incident wave action displaces a volume flow rate of air and produces an oscillating air pressure. This oscillating air pressure will be directed to the Air Pressure Booster which is an amplification device. The amplified pressure or pressure ratio from the Pressure Booster is then stored in HACPSS and shown by the following equation:

$$Pressure_{ratio} = \frac{Output_{pressure}}{Input_{pressure}}$$

A. Determining Ocean Wave Energy

The energy from a single incident wave entering the OWC is taken as the beginning point. The ocean wave consists of potential energy (PE) and kinetic energy (KE). Assume a particle on one point of the wave

line. This particle will follow the wave motion up and down results in vibration. The vibrating particles produce a Simple Harmonic Motion (SHM) and the equation of an SHM is given by equation (i):

$$y = A \sin \frac{2\pi}{\lambda} (vt - x) \quad (i)$$

Where:

A= Sea Wave Amplitude (in m)

v: Wave propagation velocity (in m/s)

λ : Wave length (in m)

t: Wave cycle time (in s)

The particle velocity v_p , can be determined by differentiating equation (ii) with respect to time:

$$v_p = \frac{dy}{dt} = \frac{2\pi A v}{\lambda} \cos \frac{2\pi}{\lambda} (vt - x) \quad (ii)$$

Potential Energy PE, per unit volume can be determined as in equation (iii):

$$PE = \frac{2\pi^2 \rho v^2}{\lambda^2} A^2 \sin^2 \left(\frac{2\pi}{\lambda} (vt - x) \right) \quad (iii)$$

The kinetic energy KE, per unit volume can be derived as in equation (iv):

$$KE = \frac{1}{2} \rho v_p^2 = \frac{2\pi^2 \rho v^2}{\lambda^2} A^2 \cos^2 \left(\frac{2\pi}{\lambda} (vt - x) \right) \quad (iv)$$

The total energy, generated per unit volume as resulted in equation (v),

$$E_t = PE + KE = \frac{2\pi^2 \rho v^2}{\lambda^2} A^2 \quad (iv)$$

B. Developed Energy in OWC

The energy developed in the OWC can be represented from the water flow in Figure 5 When a volume of ocean water enters the OWC through the submerged opened end, the upward force generated and caused free water surface to rise in the opposite direction of the gravity:

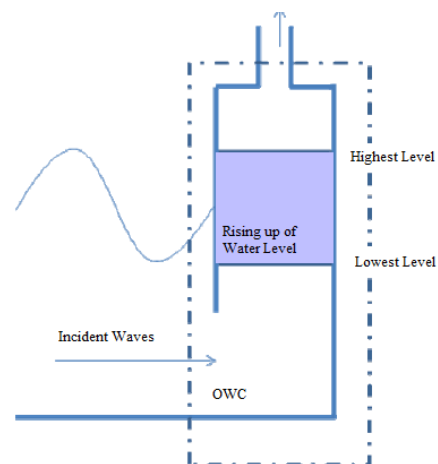


Figure 5: Developed energy in OWC

The rising up of the free water surface developed an energy termed as E_{owc-ow} , resulted from the product of the propagating wave and the volume of the ocean water

inside the OWC. The volume of free water surface is the volume being displaced. The energy developed inside the OWC due to the rising up of free surface ocean water can be determined as follows in equation (v):

$$E_{owc-ow} = E_t V \quad (v)$$

Where, $V = \pi r^2 h$

V: volume of displaced sea water (in m³)

r: internal radius of OWC (in m)

h: distance of water free water surface travels from lowest level to highest level (in m)

Assuming that the lowest level of free water surface and the highest level is equal to ocean wave peak to peak, (that is twice the amplitude), therefore, $h=2A$.

C. Energy Conversion

The law of energy conservation states that energy can be neither created nor be destroyed. If we assume that the air inside the OWC is incompressible and by ignoring the energy loss, the energy due the rising water free surface E_{owc-ow} , is equal to the energy due to the air motion. That means the volume displaced by the water free surface is equal to the volume displaced by the air, $E_{owc-air}$, as stated in equation (vi):

$$E_{owc-ow} = E_{owc-air} = \frac{4\pi^3 \rho v^2 A^3 r^2}{\lambda^2} \quad (vi)$$

Where,

ρ : density of sea water (in kg/m³)

r: internal radius of OWC (in m)

D. Amplified Constant Pressure generation using HACPSS

The power generator requires high pressure and rotary torque in ensuring that the mechanisms to function accordingly. The characteristics of the ocean wave and the developed air pressure from the trapped air on the upper side of the water free surface inside the column will be considered [6]. It is known that the upward force, also called as the lifting force of the free water surface is greater as compared to the downward force. By differentiating equation (vii), the force generated due to the rising up of the free water surface can be given by:

$$Force = \frac{dE_{owc-air}}{dr} = \frac{8\pi^3 \rho v^2 A^3 r}{\lambda^2} \quad (vii)$$

The generated force at OWC which is then transferred to HACPSS primary section. The pressure developed at the primary section, P_{air} can be written as in equation (viii):

$$P_{air-primary} = \frac{Force}{Area_{primary}} = \frac{8\pi^3 \rho v^2 A^3 r}{\lambda^2 Area_{primary}} \quad (viii)$$

Force acting on primary section; $F_{primary}$ is equal to the force acting on secondary section $F_{secondary}$ but pressure at secondary section of HACPSS is as in equation (ix):

$$P_{air-secondary} = \frac{Force}{Area_{secondary}} = \frac{8\pi^3 \rho v^2 A^3 r}{\lambda^2 Area_{secondary}} \quad (ix)$$

This amplified pressure is used to give high torque to rotate the turbine system for power generation in grid system.

IV. FAULT REMOVAL IN HYBRID POWER GRID

To increase the system efficiency, high efficiency devices based on power electronics equipments have been increasingly used in many applications. This causes increasing harmonic levels on power systems and concerns about the future impact on system capabilities. So, if there is any fault in the subsystems there will be disturbances, disruptions and the other effects, which decrease the power quality in the system. In the proposed Simulink model of hybrid grid system using Unified Power Flow Controller (UPFC) is introduced [19,20]. Such renewable source hybrid generator are required to remain grid connected during grid faults so that they can contribute to the stability of the power transmission system. This raises problems in power quality of system during fault. To improve the power quality of system during fault condition UPFC has been introduced and shown in figure 6. Unified Power Flow Controller (UPFC) is “A combination of Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC) which are coupled via a common D.C link to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM; and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source.”

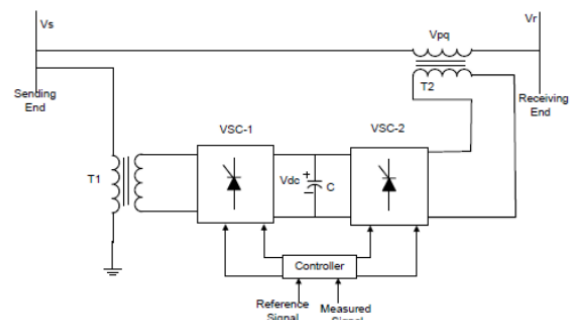


Figure 6: Schematic diagram of UPFC

V. RESULT ANALYSIS

The power generation of the proposed Ocean Wave Energy Converter (OWEC) is determined by wave environmental conditions and operational conditions such as:

The dominant wave period, significant wave height, floating body geometry and generator and power storage system.

The Wave turbine converts wave energy to electrical power. In this process, there are two energy conversions: vertical wave energy to rotational mechanical energy, and rotational mechanical energy to electrical energy. The generated amount of electrical energy depends on the amount of mechanical power generated to rotate the turbine of the power generators. So, to rotate a turbine mechanical power provides torque which provide initial acceleration to the turbine of the generator. Different test cases are demonstrated for ocean energy generation using simulink model.

Case I: Different Torque Condition

First of all we demonstrate the different torque generated by mechanical power generated by ocean wave energy. For generation of variable mechanical power following parameters are used as illustrated below:

Wavelength of the ocean wave = 2 m

Amplitude of the ocean wave = 2 m

Velocity of the wave = 2 m/s

In this research work focus is on the design of HACPSS. The variable radius directly affect the mechanical power as well as generated torque. And after experiments it is concluded that as much the radius is kept small it will create more air pressure that will results in high mechanical power. In this case different sub cases are generated by varying the outlet radius of HACPSS which causes variable torque for rotation of turbine of the synchronous generators. The simulation results as shown in figure 7 illustrates angle difference between three machine system power grid system for 0.36 torque.

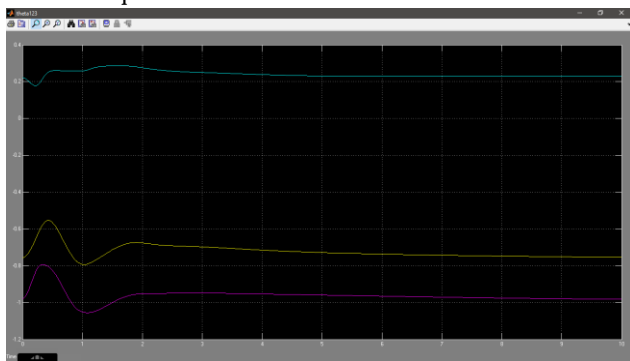


Figure 7: Angle Difference between 3 Machine System for 0.36 Torque Generated by Ocean Energy

Case II: No Load No Fault Condition

Figure 8 shows the simulink model for no load no fault condition in hybrid grid system. The simulation results as shown in figure 9 illustrates angle difference between three machine system power grid system and figure 10 shows the machine swing under no load no fault condition.

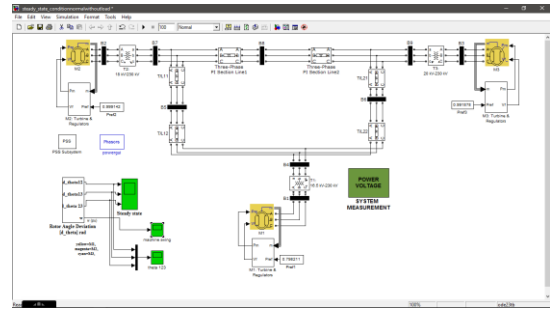


Figure 8: Simulink Model Hybrid Power Grid System for No Load No Fault Condition

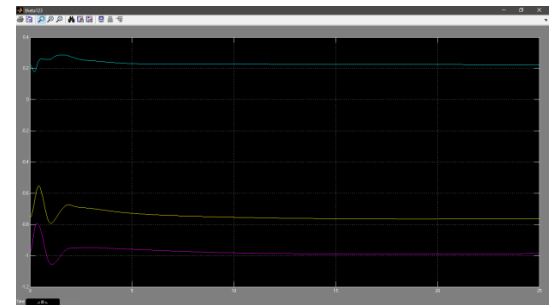


Figure 9: Angle Difference under No Load No Fault Condition

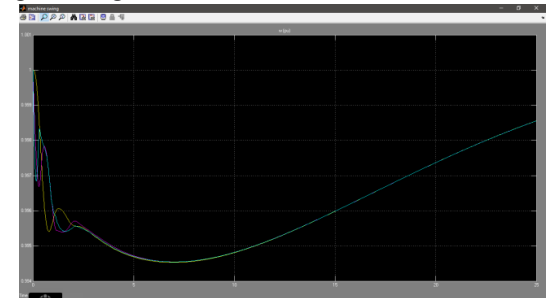


Figure 10: Machine Swing under No Load No Fault Condition

Case III: Load with No Fault Condition

Figure 11 shows the simulink model for load with no fault condition in hybrid grid system. The simulation results as shown in figure 12 illustrates angle difference between three machine system power grid system and figure 13 shows the machine swing under load with no fault condition.

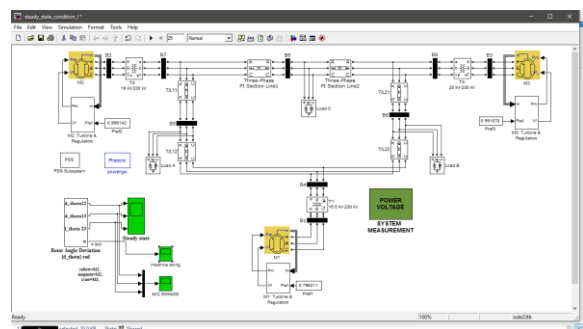


Figure 11: Simulink Model Hybrid Power Grid System for Load with No Fault Condition

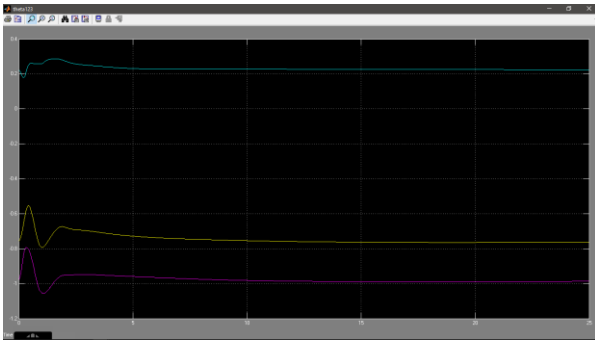


Figure 12: Angle Difference under Load with No Fault Condition

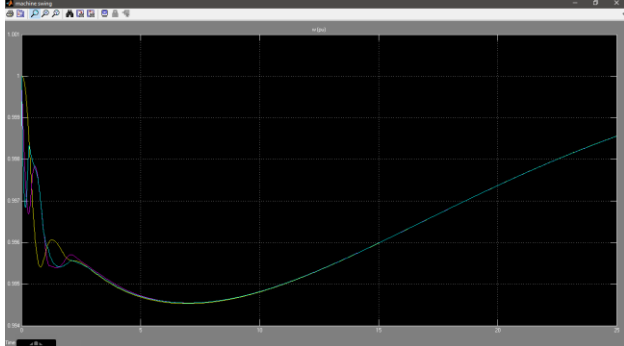


Figure 13: Machine Swing under Load with No Fault Condition

Case IV: Load with LG, LLG and LLLG Fault Condition

Figure 14, 15, 16 shows the simulink model for load with LG,LLG and LLLG fault condition in hybrid grid system respectively.

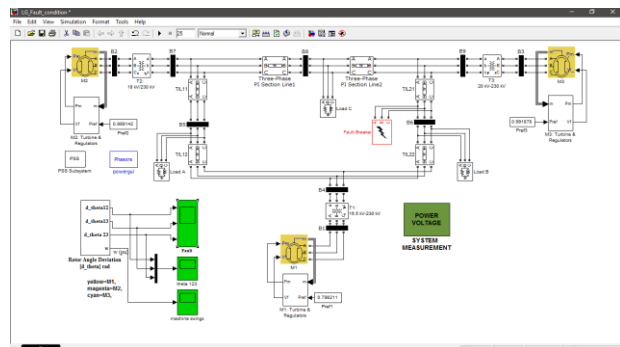


Figure 14: Simulink Model Hybrid Power Grid System for Load with LG Fault Condition

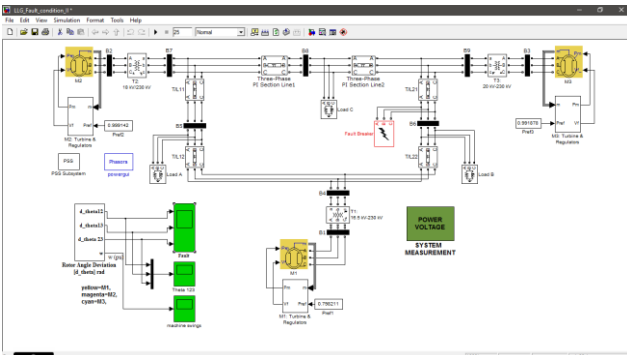


Figure 15: Simulink Model Hybrid Power Grid System for Load with LLG Fault Condition

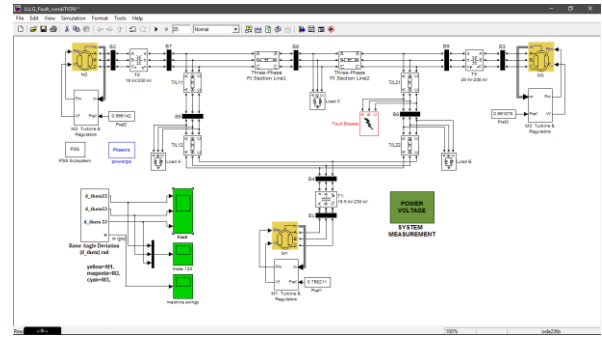


Figure 16: Simulink Model Hybrid Power Grid System for Load with LLLG Fault Condition

The simulation results as shown in figure 17, 18, 19 illustrates angle difference between three machine system power grid system for load with LG,LLG and LLLG fault respectively and figure 20, 2, 22 shows the machine swing under load with LG, LLG and LLLG fault condition respectively.

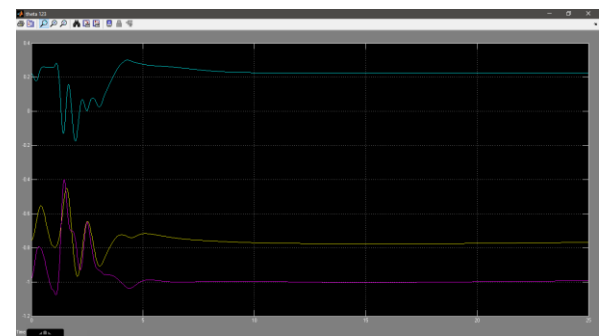


Figure 17: Angle Difference under LG Fault Condition

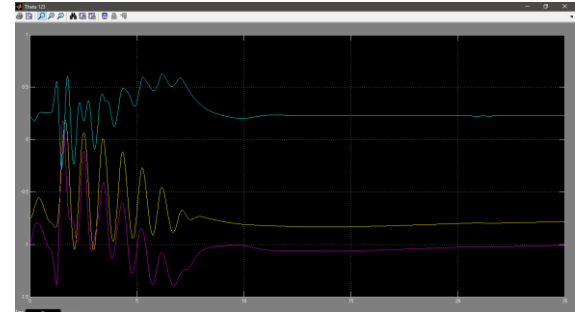


Figure 18: Angle Difference under LLG Fault Condition

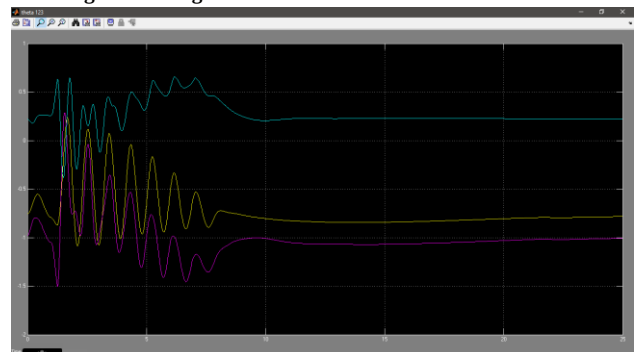


Figure 19: Angle Difference under LLLG Fault Condition

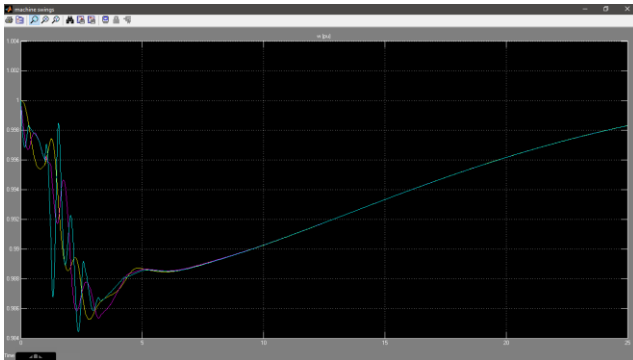


Figure 20: Machine Swing under LG Fault Condition

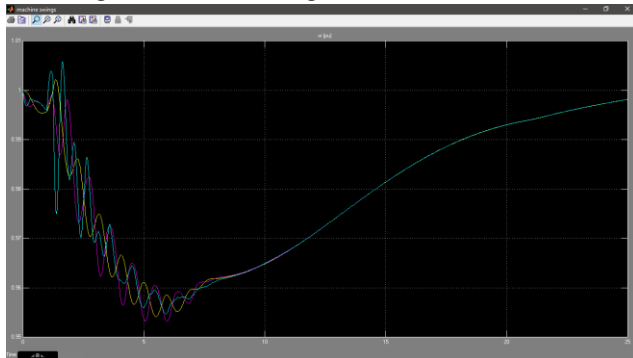


Figure 21: Machine Swing under LLG Fault Condition

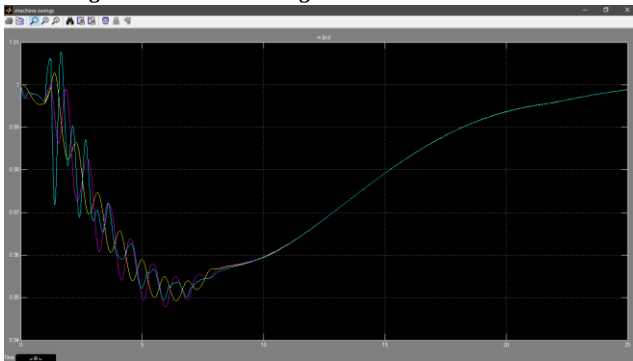


Figure 22: Machine Swing under LLLG Fault Condition

Case V: Fault Removal using UPFC Device

Figure 23, 24, 25 shows the simulink model for load with LG,LLG and LLLG fault removal using UPFC device in hybrid grid system respectively.

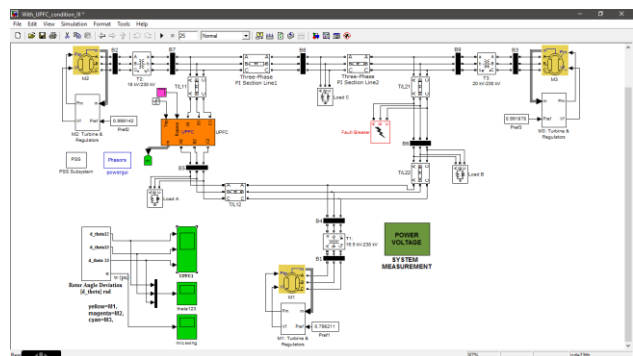


Figure 23: Simulink Model Hybrid Power Grid System for LG Fault Removal using UPFC device

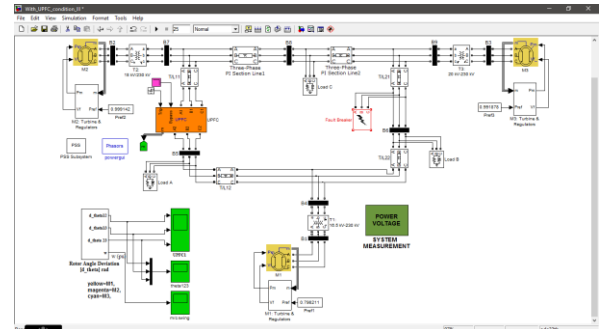


Figure 24: Simulink Model Hybrid Power Grid System for LLG Fault Removal using UPFC device

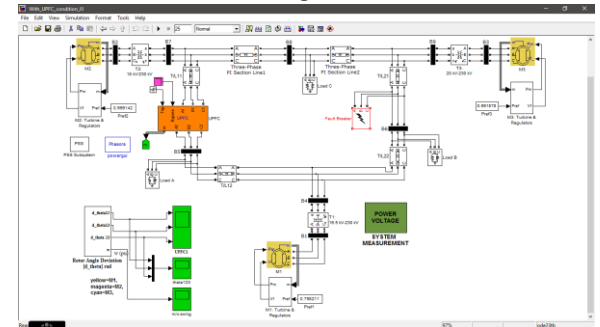


Figure 25: Simulink Model Hybrid Power Grid System for LLLG Fault Removal using UPFC device

The simulation results as shown in figure 26, 27, 28 illustrates angle difference between three machine system power grid system for LG,LLG and LLLG fault removal using UPFC device respectively and figure 29, 30, 31 shows the machine swing under LG, LLG and LLLG fault removal condition using UPFC device respectively.

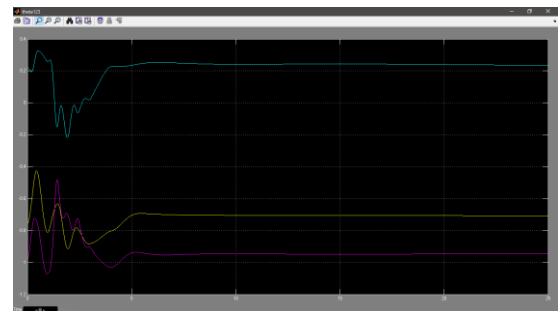


Figure 26: Angle Difference for LG Fault Removal using UPFC device

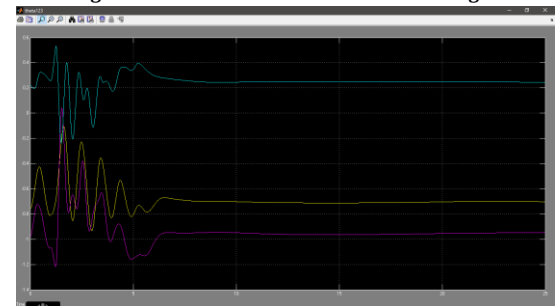


Figure 27: Angle Difference for LLG Fault Removal using UPFC device

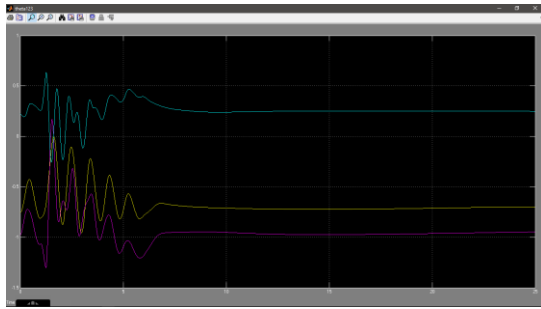


Figure 28: Angle Difference for LLLG Fault Removal using UPFC device

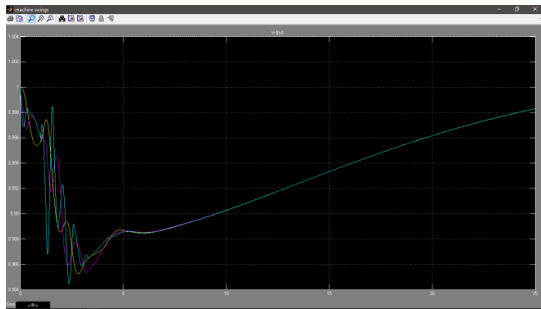


Figure 29: Machine Swing for LG Fault Removal using UPFC device

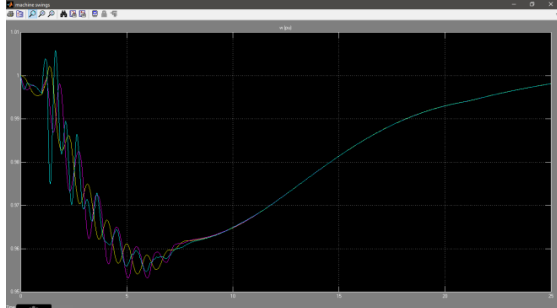


Figure 30: Machine Swing for LLG Fault Removal using UPFC device

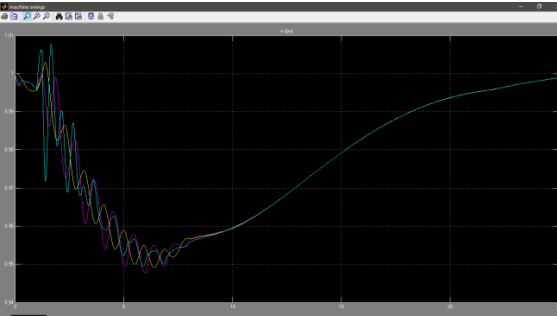


Figure 31: Machine Swing for LLLG Fault Removal using UPFC device

VI. CONCLUSION

In this paper, a complete mathematical wave-to-wire model of the ocean wave energy converter is presented. The main subsystems of the converter were described, and the dynamic models were integrated to evaluate the energy storage of the system. Then, the hydrodynamic, mechanical, and electrical characteristics of the main subsystems were discussed and the dynamics of the entire process is evaluated. Simulation results considering the proposed dynamic model under the action of regular and irregular incident waves illustrate the performance of the system. The

largest value of the HACPSS chamber volume reduces the amplitude oscillations in the variables pressure which in result reduces the power oscillations. In this research work, a new Ocean Wave Energy Converter (OWEC) based power grid system is proposed and conducted power generation under no fault condition, fault condition and fault removal condition using UPFC device. The performance of the proposed system was determined by several parameters: wave conditions, floating body geometry and power storage system including generator and electrical load. In this study, we found optimal design of HACPSS from quantitative simulation by using the numerical model. In addition, we constructed a conceptual prototype of for proposed work based on mathematical model. However, the output fluctuation was shown in every case. Furthermore, this model can be used in the development and simulation of control strategies to improve the global performance and reliability of the OWEC, e.g., frequency/voltage controllers and strategies to improve power absorption and power generation. In future work, it is recommended to investigate the superior controllability of the UPFC device via optimization techniques.

REFERENCES

- [1] Khan N, Abas N, "Powering the people beyond 2050", *SCI Echnology Dev* 2012;31:131–51.
- [2] Abas N, Kalair A, Khan N, "Review of fossil fuels and future energy technologies" *Futures* 2015;69:31–49.
- [3] Turcotte DL, Schubert G. *Geodynamics*, 2nd ed. England: Cambridge University Press; 2002.
- [4] Williams GE, "Geological constraints on the Precambrian history of Earth's rotation and the Moon's orbit", *Rev Geophys* 2000;38:37–59.
- [5] Ben Elghali SE, Benbouzid MEH, Charpentier JF. Marine, "Tidal Current Electric Power Generation Technology: State of the Art and Current Status", In: *Proceedings of the 2007 IEEE International Electr. Mach. Drives Conference*, IEEE, p. 1407–1412.
- [6] B. Czech, P. Bauer "Wave Energy Converter Concepts, Design Challenges and Classification" *IEEE Industrial Electronics Magazine*, June 2012.
- [7] B. Drew, A. R. Plummer, M. N. Sahinkaya "A review of wave energy converter technology", Department of Mechanical Engineering, University of Bath (UK), 2009.
- [8] EU-OEA. European Ocean Energy Association. (<http://www.oceanenergy-europe.eu/index.php/association/about-the-association/articles-of-association>) [accessed 05.05.16]; 2016.
- [9] Liliana Rusu, Florin Onea, "The performance of some state-of-the-art wave energy converters in locations with the worldwide highest wave power", *Renewable and Sustainable Energy Reviews*, Elsevier, 2016.
- [10] Nikolaos M. Kimoulakis, Panagiotis E. Kakosimos, Antonios G. Kladas, "Power Generation by using point absorber wave energy converter coupled with Linear Permanent Magnet Generator", *Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion*, 2010.
- [11] Douglas A. Gemme, Steven P. Bastien, Raymond B. Sepe, Jr., John Montgomery, Stephan T. Grilli, Annette Grilli, "Experimental Testing and Model Validation for Ocean Wave Energy Harvesting Buoys", *IEEE*, pp.337-343, 2013.
- [12] Paula B. Garcia-Rosa, José Paulo Vilela Soares Cunha, Fernando Lizarralde, Segen F. Estefen, Isaac R. Machado, and Edson H. Watanabe, "Wave-to-Wire Model and Energy Storage Analysis of an Ocean Wave Energy Hyperbaric Converter", *IEEE Journal of Oceanic Engineering*, VOL. 39, NO. 2, pp. 386-397, 2014.
- [13] N. Khana, A. Kalaira, N. Abasb and A. Haiderc, "Review of ocean tidal, wave and thermal energy technologies", *Renewable and Sustainable Energy Reviews*, Elsevier, vol. 72, pp.590-604, 2017.

- [14] Hangil Joe, Hyunwoo Roh and Son-Cheol Yu, "A New Wave Energy Converter using Flap-type Blade and its Power Generation Test", Underwater Technology (UT), IEEE, 2017.
- [15] N.Y. Sergienkoa, B.S. Cazzoltoa, B. Dinga, P. Hardya, M. Arjomandia, "Performance comparison of the floating and fully submerged quasi-point absorber wave energy converters", Renewable Energy, Elsevier, 2017.
- [16] Thanh Long Vu, and Konstantin Turitsyn, "Robust transient stability assessment of renewable power grids", IEEE International Conference on Sustainable Energy Technologies, 2016.
- [17] Siming Wei, Yingkun Zhou, Yongzhang Huang, "Synchronous Motor-generator Pair to Enhance Small Signal and Transient Stability of Power System with High Penetration of Renewable Energy", IEEE, vol 5, 2017.
- [18] Li Wang, Quang-Son Vo, Min-Han Hsieh, "Transient stability analysis of Taiwan Power System's power grid connected with a high-capacity offshore wind farm", International Conference Future Energy Electronics Conference, IEEE, 2017.
- [19] Mitra Mirhosseini, Vassilios G. Agelidis, "Performance of Large-Scale Grid-Connected Photovoltaic System under Various Fault Conditions", IEEE, pp. 1775-1780, 2013.
- [20] Ahmed Nasr Zeinoh, "Optimal sizing and allocation of Unified Power Flow Controller (UPFC) for enhancement of Saudi Arabian interconnected grid using Genetic Algorithm (GA)", Smart Grid (SASG), IEEE, 2017.