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Tapping The Wave Power of Seas and Oceans using Piezoelectric Crystals on Salter Duck to Generate Electrical Power-:

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Abstract— This paper presents the system to tap or utilize the wave pressure of ocean and seas for the electrical power generation. The designed system depicts the real life system. As the phenomenon of piezoelectric is used thus the proposed work is done in relevance to the material science phenomenon of the piezoelectric power generation. The system uses the pressure from waves of water hitting an offshore structure creating strain on piezoelectric material thus generating power. The paper will provide an efficient alternative to tapping energy of sea waves by setting up an apt structure with an apt location away from the coastline, where the pressure impact produces the maximum energy generation opportunities. The generated power will be meted out to rural areas by using phase conversion and micro grids. The generation of power using normal wave's pressure has been given a holistic approach.

Keywords— Waves, Piezoelectricity, Off-Shore Structure, Power Electronics, Pressure impacts, Phase conversion, Micro-Grids, Wave Power.

I. INTRODUCTION

The world today faces an extreme energy crunch. As we consume more and more electricity to power our houses, industries etc. the conventional forms of energy are on the verge of depletion. Soon we will need an alternate viable energy source to foster our life. About three-fourths of earth's land mass is covered with water. This enormous amount is not potable. But it can be used to generate electricity. Along with the implementation process such as usage of ASVT along with phase conversion with respect to micro–grids will prove to be an efficient alternative. The oceans have proved to be a propitious source of energy. It is a renewable in nature. However, compared to the developments in other renewable energy technologies, ocean energy technologies like tidal and wave are still in rudimentary stages of development in India Use of rotating generators is not good enough as it depends on ricocheting cycle of tides. Also it requires construction along the coastline which is not always feasible. The use of ocean waves to generate piezoelectric power is an important technique which is easy to setup and cheap. The impact of pressure of sea waves can be tapped to create energy in huge amount. India with a 7000 km long coastline provides a conducive environment for electricity generation. As India forges ahead as an economic power, its power demand can be met using this technique. Wave energy is a clean and renewable source of energy. Since waves are ubiquitous, wave power is more consistent with electricity generation when compared with renewable energy sources like wind and solar. They can be capitalized as source of energy generation for off grid coastal areas and islands. Wave energy often used to run the desalination plants. Wave energy turbines when coupled with offshore breakwaters can serve as a bulwark for protection of sea shores.

II. EXISTING WORK

Wave Energy is an esoteric type of renewable energy which has been seeing sluggish development since many years now. The naive nature of the technology clearly states that most of the wave energy projects have been mostly been at pilot level. The same state of affairs exists in India as well with a few pilot projects being constructed. Though the government of Gujarat is constructing India's biggest tidal barrage off the coast of the Arabian sea, wave energy projects have been scarce and far between. Indian Wave Energy traces its history to 1984 when an Oscillating Water Column (OWC) type of device was put into tube at Vizinjham Harbour near Thiruvananthapuram in Kerala. In 1993 the National Institute of Ocean Technology was established. Wave Energy has not been feasible implemented on a commercial scale. This means it's hard to have a benchmark for the cost of wave energy unlike nuclear or biomass energy. Most of the wave power devices have to be custom made which calls for a higher cost. However it has been estimated that improving technology and economics of scale will allow wave generators to produce electricity at a cost of as in case of wind-driven turbines, which produce energy at about 4.5 cents/ kWh.For now, the best wave generator technology in active in the United Kingdom and producing energy at an average projected cost of 7.5 cents/ kWh. India is a country estimated to have a prospective of 40-60 gigawatts of Wave Energy around it cost with the current state of technology. The wave energy potential is estimated to be 5-15 MW per meter of all coastlines. Note there are no major wave energy plants in India except the pilot plant at Vizinjham Fisheries Harbor near Trivandrum in Kerala.

Maharashtra government has made a project that would generate about15 to 20 kilowatt of electricity located at Borya and Budhal villages in coastal Ratnagiri district. Similar pilot projects exploiting the tidal waves are being undertaken in 15 coastal villages.

Sagar Shakti is a 1 MW OTEC plant built off the Tuticorin coast which utilizes the temperature difference wave energy device.

The disadvantages of existing system are as follows-:

- Extremely conventional
- Time taking.
- Requires large financial investment.

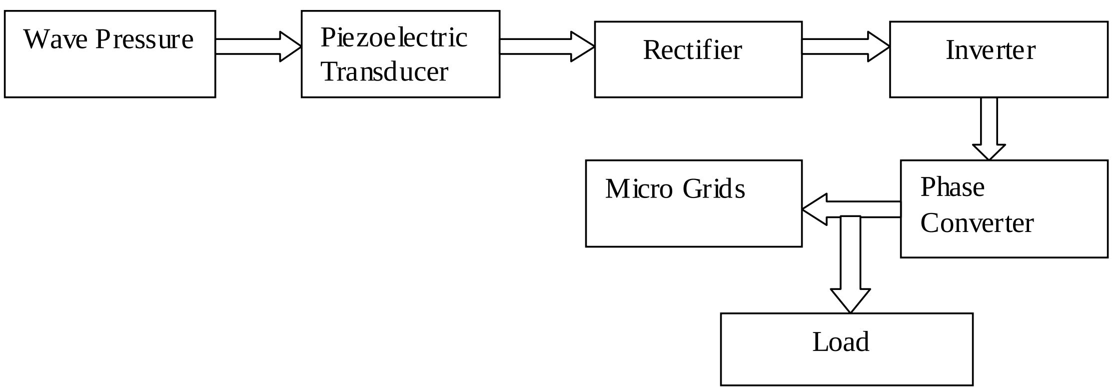
The Challenges in Wave power electricity generation are as follows-:

- Setting up of production and extraction infrastructure in sea or ocean .
- Weather Conditions
- Method to generate electricity through various means
- Providing cheap access to electricity to coastal areas .
- Supply of adequate power of desired quality.
- Supply of power at affordable price
- High initial capital cost for extending grid because of large coastal region of India.
- Low load density and slower load growth leading to unfavourable consumer mix.
- Higher cost of delivery and lower tariff leading to more financial distress to utilities\Low consumer density .
- Thefts & Pilferage leading to high AT & C Losses.
- Lack of policy and legal framework.
- Lack of institutional capacity.

III. PROPOSED WORK

3.1 Process Flow-:

The normal wave motion generally turbulent in nature contains a lot of power and the regularity of motion adds the power content over a long duration when utilised properly. The piezoelectric element coupled to a mechanical structure which is the Salter Duck structure (buoyant moored structure) and the wave motion will directly hit the piezoelectric crystal thus generating power by mechanical strain. With the help of power electronics devices the power is obtained as shown in the process flow above. The piezoelectric transducer produces the dc output which is pulsating in nature thus the rectifier reduces and decreases the pulsations and further the inverter converts the dc input to ac output for load supplying purposes. The phase conversion is then used with the help of Scott connected transformers to supply the coastal region as per demand as for heavy operation two phase is given which is cheap as compared to three phase supply and others are provided single phase. The power is supplied to load and the remaining power is stored with the help of micro grids which can work autonomously.



(Fig-3.1.1-Process flow diagram)

3.2 Wave Power -:

The wave parameters are as follows-:

- Wave Height
- Wave Period
- Wave Length

The wave power is described in the equation as follows-:

- P= (ρ*g^*a^2*T) / 8* π per metre of sea.
  Since a/2=H , thus new formula becomes P= (ρ*g^*H^2*T) / 32* π per metre of sea.

  Here, T (Time Period)= (2*pi*wavelength) ^1/2 ,

  ρ= Density of fluid, a= wave amplitude, g= acceleration due to gravity(9.8 m/s^2)

- Wave Velocity(V)= C= Wavelength/Time period
- Displacement= V / pi* F , F=frequency of wave (F=1/Time Period)
- P= (Force * Displacement / T) , getting Force from this equation

3.3 Piezoelectric Device

Piezoelectric materials are the ones which convert the mechanical stress to electric energy through the piezoelectric phenomenon.

For ocean engineering applications (Lead Zirconate Titanate (PZT) and Polyvinylidene Fluoride (PVDF) both are suitable but PZT is apt for electrical power generation as inferred from the table -:

Properties of PZT and PVDF (Roundy 2003) -:

Property	**PVDF**	**PZT**	**Units**
d31	20	320	10^ -12 m/V
k31	0.11	0.44	CV/Nm
d33	30	650	10^ -12 m/V
k33	0.16	0.75	CV/Nm
Elastic Modulus	0.3	5	10^ 10 N/m^ 2
Tensile Strength	5.2	2	10^ 7 N/m^ 2

The piezoelectric constants for the transverse (k31, d31 , and g31) and longitudinal (k33, d33, and g33) modes of operation were calculated by reckoning the resonance properties of the length and thickness of ceramics, respectively. From above we can perceive that the power generating ability of PZT is greater than PVDF, but the tensile strength plays an important role which is less, but in total the other qualities are better in PZT as compared to PVDF thus better efficiency will be seen in case of PZT which will provide stability to the structure with high elastic modulus.

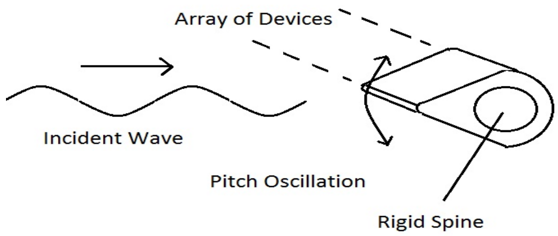
Here, d31= Transverse strain constant, k31= Transverse coupling coefficient, d33= Extensional strain constant, k33= Extensional coupling coefficient.

3.4 Salter Duck Structure

Salter's Duck is just a needle in a haystack of many concepts for wave energy conversion. It was developed by Prof. Salter at University of Edinburgh, having the potential to convert wave power to utilizable energy. It falls under a class of WECs known as terminators. These are projected perpendicular to the direction of the wave. The Duck itself is shaped like a water drop, and many of these are attached together to a long array to make the whole system. The tip faces incoming waves and dips as they pass. Essentially, this involves tapping, of the wave energy. The efficiency doesn't change much in moderate different amplitude wave. The piezoelectric crystal is riveted on the surface of the salter duck structure. With the help of power electronic devices and cables the power is tapped at the coasts. The suggested architecture consists of a sandwiched joist for which part of the core has been replaced by piezoelectric material. It consists a cantilever joist of dimensions prescribed for the Salter duck surface area in rigid foam core between two thick aluminium skins. The core is partially replaced by PZT piezo ceramics to form an actuator. Thus this is riveted to the salter duck surface through various mechanical processes on which the waves will impact directly producing mechanical strain and thus the piezoelectric phenomenon as shown in the diagram as the array of devices.

Design

The original archetype of Salter's duck was made of an array of floating buoys of basic duck cross-sections linked through a central axis. The string itself has 12 ducks attached to it that were 50 centimetres wide mounted on the axis 27 centimetre in diameter and 6 meter long. It was designed at University of Coventry, with materials from Ready to Make Concrete and In situ form. The final design works by allowing 20 to 30 ducks connected together by the jointed axis, with each duck moving with the waves that impact it and transferring the energy of the impact to six to ten pumps for each duck. The streamline shape of the ducks make them face the waves due to the pre-reckoned orientation of their axis so that they bob and turn over when a wave impacts. Here only the structure is required not Gyroscopes or other devices that are used for power generation through generator.



(Fig-3.4.1 Wave Action on Salter Duck Structure)

3.5 Power Electronic Devices

If the electrical energy is to be collected and stored, an electrical load or power storage system has to be connected to the circuit. However, some processing is often needed before feeding the current to the load. Electronic equipment and power storage systems such as batteries require a direct current (DC). Since the piezoelectric generator, if behaving as a resonator, would act as a sinusoidal voltage source when implemented in the ocean, the generated AC current has to be processed and rectified for proper usage.
The AC signal passes through the rectifier bridge first where it is converted to a DC signal. The filtering capacitor usually has a large capacitance and it only contributes in smoothing out the DC voltage by eliminating the ripple voltage.

Before storing the energy in a battery or supplying it directly to a load, the controller regulates the output voltage depending on the need of the specific application.

3.6 Phase Conversion-:

There are transformers utilized to reduce the number of phases. Again, these devices are considered to have a reference with respect to the converter mentioned at the end.). In order to achieve the phase conversion we took a system which was used in earlier times i.e. in 20th century i.e. “Scott Connection” for the “Phase conversion” and combined it with the existing method of using “Auxiliary Service Voltage Transformer” used at present as pilot projects in various parts of world for the rural electrification and intensification purpose in the perspective of India to achieve our aforementioned purpose. In many situations it becomes necessary to supply a balanced or unbalanced two phase or three single phase load on a balanced three phase supply. One way to do, let us say for a two phase load to connect the two phases between two lines, this is one possibility; however, even when these phases are balanced impedances are balanced, they will draw unbalanced current from the supply. Not only that many two phase loads will require a balanced two phase supply as well.

The power can range in megawatts. So, it has to be made sure that the loading of the three phase system is balanced to the extent possible. This can be done by what is called a Scott connected transformer.
This Scott connected transformer can convert a balanced three phase supply to a balanced two phase supply. If the load on the two phase is balanced, then the line current drawn from the three phase will also be balanced, For Scott connection, we take two single phase transformers; let us say here the turns is N. This turn is N 2, this is the dot polarity with 86.6%tapping; another transformer with a 50 per cent tapping, so that this number of turns is N 1 by 2 and this is N 1 by 2, and the corresponding secondary have the same number of turns N 2. Now let us connect this end of one of the transformers to the 50 per cent tapping point and keep balanced three phase supply to this side; that is V A, V B and V From the teaser transformer we get balanced 2 phase output.

For three-phase to single-phase conversion, short the negative polarity side of teaser transformer and positive polarity side of main transformer in the previous circuit. Note the load is kept across positive polarity side of teaser and negative polarity side of main transformer. (Note that the single-phase voltage is higher than the secondary voltage in two-phase conversion and connect the load accordingly. If necessary connect two loads in series to maintain the rated voltage of load greater than or equal to single-phase voltage.

3.7 Micro Grids

The problem arises in the above system due to phase conversion. Thus to eliminate we need to have a micro grid system to provide efficient supply to the rural areas..

Micro grid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously. These micro grids provide a range of services, from residential or home lighting alone to entertainment, refrigeration and productive commercial uses like milling. Depending on the number of customers served, the types of services provided, and the type of generation technology used, the installed capacity of a micro grid ranges from as little as 1 kW to as large as a few hundred kilowatts which is very much sufficient for rural areas.

A grid connects homes , offices and commercial buildings etc to central power facilities or sources through the help of which the different electrical and electronics appliances are used but as India is a land of topographical diversity there are places or village areas which are not connected to grid . So, providing a micro grid to those rural areas in combination to the rural electrification methods stated above can fasten the pace or electrification and improve the quality of rural electrification and most importantly the distribution. Thus a Micro grid setup has to be made for the completion and fastening of rural electrification process in order to make the supply reach to every household. Any traditional micro grid setup method can be used to make a micro grid.

3.7.1 Benefits of Micro grids in Rural Electrification

Coastal micro grids deliver benefits by replacing low-quality energy sources already being used with higher-quality energy fuels and technologies providing the same energy services that communities already have access too.
Problem of Phases Reduced.

IV Result analysis (Coastal Region of Tamil Nadu and Borders of Sri-Lanka from January 6 to February 6, 2018)

The meteorological data used in the following data has been obtained from ESSO -Indian national centre for ocean information services (An Autonomous Body under the Ministry of Earth Sciences, Govt. of India).

This is In-Situ data recorded specifically from moored buoy “BD 14” located off coast Tamil Nadu in the Bay of Bengal between the periods 6 January 2018 to 6 February 2018.

- wave period in seconds
- wave height in meters

Formulas of various wave variables which are required for power calculations are:-

Power (P) = $(\rho * g^2 * h^2 * T)/32 * \pi$ kW/m

Wave velocity (V) = λ / T metre/s

Displacement (D) = $V/f * \pi$ metre

Force (F) = $P*T/D$ Newton.

{Where $\rho = 1027$ kg/m^3, $g = 9.81$ m/s^2, $h = 1.36$ m, $T = 1/f = 5.9905$ s, $\lambda = (g*T^2/2\pi)$}

Power = 10,898.575 kW/m

Wave velocity = 9.3577 m/s

Displacement = 17.848 m

Calculated Force = 36, 57,996.052 N

The material chosen is Lead Zirconate Titanate(PZT) with two variants PZT-4 & PZT- 5A.We also incorporate a piezoelectric plate with proper length(L),width(W) and thickness(t). As per Industry standards the minimum length and width is 1 mm (as for a square plate) with minimum thickness ranging as low as 0.127 mm but the static voltage developed will not be extractable therefore we have proposed to develop 2-2.5KV static voltage per plate which can be varied as required by application. The voltage should not drop below 500 volts and should not exceed 10kv per plate as from various combinations of length, width and thickness for proper extraction and for the efficient working of extracting and processing circuitry.

The table with few combinations of length, breadth and thickness is shown as follows along with the static voltage developed-:

As shown follows, to generate in the desired range of voltage as stated above the minimum dimension sis take to be 72.4 mm for length and width and thickness of 0.4 mm and the maximum dimension for the same output is taken as 165 mm for length and width and thickness of 2mm as per the industry standards of piezoelectric ceramics currently. Static Voltage $V_{static} = (g_{33}F_3h)/ l*w$

For PZT-4 ($g_{33} = 8.5*10^{-3}$ Vm/N) -:

	Minimum dimensions Length= Width =72.4mm	**Maximum dimensions Length=Width= 165mm**
	For thickness(t) =0.127 mm V=753.3360V	t=0.127mm V=145.0434V
Static Voltage(V)	**t=0.4mm** V=2372.7119V	t=0.4mm V=456.8296V
	t= 2mm V=11,863.5597V	**t=2mm** V=2284.1481V
	t=3mm V=17,795.3396V	t =3mm V= 3426.2222V

For PZT-5A (g_{33} =16.6*10^{-3} Vm/N) -:

	Minimum dimensions L=W= 72.4mm	**Maximum dimensions L=W= 165mm**
	For thickness(t)= 0.127mm V= 1471.2210V	t =0.127mm V=283.2612V
Static Voltage	**t=0.4mm** V= 4633.7669V	t = 0.4mm V= 892.1614V
	t= 2mm V=23168.8343V	t =2mm V= 4460.8069V
	t =3mm V= 34,753.2515V	t =3mm V= 6691.2104V

V. Results

In our proposed system of wave power electricity generation, keeping ocean and coastal perspective in mind, we wish to fasten the pace of wave power electricity generation from the conventional sources in combination with the new technological advancement in an efficient, in an economical manner and in surplus. The purpose of the system is to generate electricity from ocean and sea water waves through piezoelectric ceramics and not with costly flexible piezoelectric devices , on a suitable structure which can withstand in the sea and ocean firmly and thus we have used the Salter Duck Structure. The system to tap or utilize the wave force of ocean and seas for the electrical power generation. The piezoelectric device when hit by such a force will produce voltage due to piezoelectric effect and thus the electrical power can be extracted as per the conventional methods. The structure incorporating this is the salter duck structure which is the most apt device to withstand the oceanic and sea rough conditions having a very high life cycle is available but no intensification to rural and coastal areas has been done to tap the transmission line directly. Since in . The auxiliary service voltage transformer (ASVT) can be used in developing country where the electrical infrastructure a rural area some families are into grazing animals and agriculture or fishing near the coastal region therefore some families require only single phase supply and some may require three phase power but three phase power is costlier and we need to be cost efficient so for families which require more power are provided with two phase power through phase conversion .The connection to national grids become difficult due to factors such as topographical diversity etc thus the concept of micro grids are used which can either be connected to national grids or it can wo rk autonomously in the coastal or rural areas near coastal region. As shown in the table above the different combination can yield several kilovolts of voltage and even a small change of dimension causes the voltage to increase rapidly therefore the suitable value of voltage has to be in the dimensional. The Salter Duck Structure with piezoelectric ceramic incorporated in it is found to be cheaper than other traditional implementation ways. The life cycle coasting of this structure is very less as compared to various traditional off shore structure. The maximum utilization of wave power will happen due to this tear shaped structure i.e the Salter duck. The ASVT will single headedly act as potential as well as distribution transformer for electrifying the coastal region. The Scott Connection will provide the flexibility to convert Phase and two phase will be cheaper than 3 phase thus we will also be able to provide cheap electricity to the people below poverty line in rural areas. As two phase is very difficult to Tap (Theft) therefore conversion to two phase will reduce theft. Those people who are in rural areas who do not do agricultural works on large scale can opt for single phase and those who require greater power can opt for two phase power , thus the supply can be done as per requirement.

VI. Conclusion And Future Scope

We have proposed the integration of piezoelectric ceramic plate on the Salter Duck Structure to tap the wave power for production of electricity in combination with the method of ASVT and phase conversion with the connection to Micro Grid system for fast and cost efficient coastal electrification. The method is simple and can be easily implemented with respect to India and elsewhere in world. The development of rural electrification will not only be of great benefit to rural people but also benefit the socio economic status of the country.

In the future, tides and waves will probably be the most important sources of energy from the seas, but not the only ones. Even though the major oceanic currents usually move far more slowly than tidal currents, they could provide energy. Researchers in Florida are studying whether the energy in the Gulf Stream, which flows along the East Coast, could be tapped. A method known as ocean thermal energy conversion (OTEC) takes advantage of the substantial temperature difference between cold deep-sea water and warm surface water, using both in a process that generates electricity.
Harnessing wave power and converting it to electricity at a cost competitive with fossil fuels, though, has remained elusive. A single Pelamis device, for example, generates enough electricity to provide supply to approximately 500-600 homes, compared to a medium-sized coal-fuelled power plant, which can power tens of thousands. Future wave farms, then, will most probably be relatively small-scale ventures pumping electricity to nearby grids supplying coastal towns and cities. To approach conventional utility-scale power generation, a wave farm would have to commandeer large swaths of ocean — a prospect that gives pause to fishermen and others working in ocean-dependent industries.

VII. References

[1] Emmanuel Bonifacio et al.,"Wave Energy", Submitted as coursework for Physics 240, Stanford University, Fall 2010 Page no.1.

[2]Z Liang et al. , " Research and development of wave power and converting technology" , IEEE Digital Library,2011.

[3] T.W. Thorpe et al. , "A Brief Review of Wave Energy," UK Department of Trade and Industry, ETSU-R120, 25 May 99 Page -71.

[4] Matthew W. Hooker et al. , "Properties of PZT-Based Piezoelectric Ceramics Between -150 and 250°C" , Lockheed Martin Engineering & Sciences Co., Hampton, Virginia, National Aeronautics and Space Administration(NASA),Langley Research Centre Hampton, Virginia 23681-2199 Prepared for Langley Research Centre under Contract NAS1-96014 September 1998.

[5] "IEEE Standard on Piezoelectricity – ANSI/IEEE Std 176-1987", IEEE Standard, 1988

[6] S.M. Calisal et al. , "A Note on the Derivation of Potential Energy for Two Dimensional Water Waves," Ocean Eng.10, 133 (1983).

[7] Jbaily, A. & Yeung, R.W. J. Ocean Eng. Mar. Energy 1: 101. https://doi.org/10.1007/s40722-014-0008-9 DOIhttps://doi.org/10.1007/s40722-014-0008-9 , Publisher Name: Springer International Publishing.

[8] CEC, "Wave Energy Converters - Generic Technical Evaluation Study", a report for the Commission of the European Communities, published by Danish Wave Power aps, August 1993.

[9] OST, "Energies from the Sea – Towards 2020. A Marine Foresight Panel Report", Office of Science and Technology, DTI, UK, 1999.

[10] Ravindran, M et al. , "Indian Wave Energy Programme: Progress and Future Plans", Proceedings of the Second European Wave Power Conference, Lisbon, Portugal, 8-10 November, 1995.

[11] Salter. S et al. , "Changes to the 1981 Design of Spine-based Ducks", Proceedings of the First European Wave Power Conference, Edinburgh, UK, 21-24 July, 1993.

[12] Vincent PIEFORT & Andr´ePREUMONT et al. , " FINITE ELEMENT MODELING OF PIEZOELECTRIC STRUCTURES", Structures Laboratory, ULB - CP 165/42 Av F.D. Roosevelt 50, B-1050 Brussels, Belgium.

[13] R. Bedard et al. , "Final Summary Report, Project Definition Study, Offshore Wave Power Feasibility Demonstration Project " Electric Power Research Institute, E2I EPRI Global WP 009 - US Rev 2, 22 Sep 05.

[14] R.Ramakumar et al. , "Renewable Energy Sources and Developing Countries", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 2, pp-502-510.- 1981. Page no.-242.

[15] National Digital Library Of India.

[16] National Programme on Technology Enhanced Learning, IIT Madras , Ocean Engineering Resources.