Hull Capacitance: The Unconventional Green Fuelling Technology Harnessing Plug Power Navigate Concept for Inland Waterways Navigation

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ABSTRACT

With the huge increase in global liquid fuels usage, an alarming situation has risen to develop and adopt alternative green technology to mitigate global warming attributable to high pollutant emission. Transportation sector, being one of the major fuel and energy consumers, effective substitution is required for Inland waterways over land and rail transport. This paper focuses on the development of a 'Plug Power Navigate' concept to bring out an infrastructure to utilize the offshore wind and solar platform generated electricity for Inland Vessels navigation. Solar energy, available wind etc. can massively save fuel and keep environment pollution free. Technology like Wind and Solar resource assessment, wind energy installations, have been studied in this paper based on the climatic and technological sophistications. One of the major technological sophistications include, storage of this energy on board as Hull Capacitance. To harness the concept of Plug Power Navigate with the above mentioned technological sophistications, the vessel has been modified to accomodate the power storage facility on the principles of Hull Capacitance. It is based on the acquisition of power by means of an external source and its storage within the hull frame work, which can then be utilised later, for the purpose of navigation. The structural frame work is modified in compliance with the safety norms. Care has been taken to make minimal modifications to the hull structure from both safety and operation point of view, keeping the operation perspective unhindered. The inception of greener technologies in the shipping strata can be boosted by the tapping of renewable sources of energy along with the inclusion of power storage sophistications, and this debut in the maritime sphere can act as Pole Star for future research and exploration of various technologies in this direction bringing out an innovative set up for the Inland Water Transport worldwide.

INTRODUCTION

Maritime sector is the largest stake holder of the world's cargo transport facilities and is an indispensable part of the world's freight trade. The upcoming world is not merely focusing on the economic feasibility of trade but also towards the biological and environmental aspects. The competition is intensifying both with the growth of maritime giants and also due to the level of advancement and investments in the technology and R&D. The theme buzzing round the maritime strata is – A penny saved is a penny earned.

The inception of cleaner and safer seas brings our concept of Plug Power Navigate into the aperture of maritime efficiency. The concept of Plug Power Navigate is about - to acquire energy from an external / internal source of power in the form of electrostatic charge which shall be stored in the hull structure of the vessel itself. The structure is transformed to form a capacitor which shall receive charge from an external source. This charge via an electrical circuit at 11kv supply shall be fed to the inbuilt hull capacitors connected in series combination which shall store the charge in it. As we know, once the potential applied across the capacitor is removed it stars to discharge its stored energy, which shall be utilized as power source for due course of navigation. The greatest advantage of this system is that the external or internal source of energy required for charging of capacitor can be obtained by a sub-station at the jetty or by harnessing the unconventional source of energy also.

METHODOLOGY

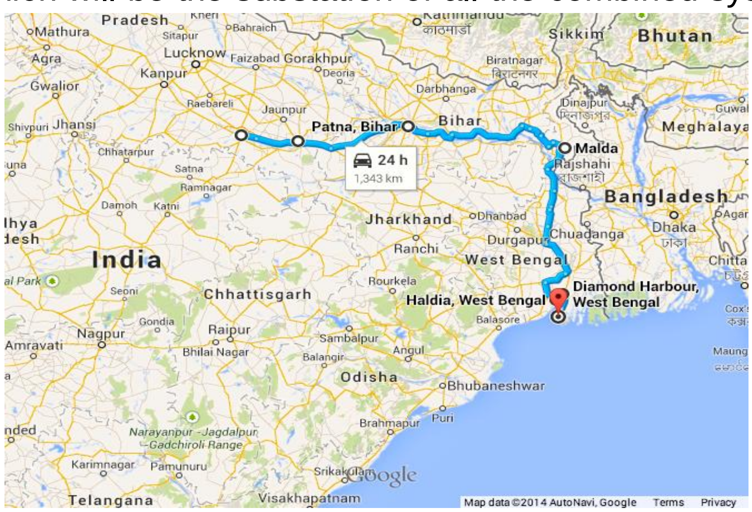
Designing of Hull Capacitor and insulation provision is done. Construction and fabrication of dielectric material with calculation of capacitance is done.

Plug Power and Navigate Concept

The necessity of hull capacitance arose with the development of a PLUG, POWER and NAVIGATE CONCEPT which focused towards the development of a fully reliable and green fuelling technology based navigation for the Inland Waterways. The region shown below was used for the study of this concept. To fulfill the purpose of green fuelling for the Inland Vessels wind and solar assessments of the region shown below, also called the National Waterway 1 of India were carried out. The following conclusions were drawn:

1) **Wind Assessment Report**: 6 cities with their Wind Rose Data gave us their total power generation capacities with 10 wind turbines installed for each station to a total power of 162.2. MW (Sagar Island:6.8MW,Haldia:3.5MW, Diamond Harbour:2.8MW, Malda :1.6 MW Allahabad:5.5MW and Varanasi:6.8MW)

The single cities with their offshore wind power capacities will act as substation for the vessel travelling in this route. The vessel depending on its engine capacity shall travel for a particular distance, after which it may charge itself during the time of loading/unloading at the berth via a power barge/dock which will be the substation of all the combined systems in that place for its further voyage.



2) **Solar Assessment Report**: The solar assessment report studied the aspects required in order to maximize solar resource for the region. These mainly include sustained clear skies, absence of Haze (atmospheric turbidity), dry atmosphere, minimal air mass (minimum latitude) and high site elevation (minimum pressure).

The temperature table in this regard suggested favorable sunlight throughout the year indicating a favorable solar availability. The Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) were also studied which suggested a favorable sunbelt, however the presence of aerosol causing haziness results in 5% less solar power, a drop of 0.86 watt per square inch due to this effect.

The above data after keeping in view the other factors to hinder solar power harness, the map of Global Horizontal Irradiance was used to get the estimate of a 20 square metre solar cell which generates a capacity of 3KW.However the total number of such panels for a single place can be expected to be 300 which gives power output of single berthing station to be 0.9 MW and number of places for such offshore solar installations if taken are 8 (Sagar Island, Haldia, Diamond Harbour, Malda, Bhagalpur, Patna, Varanasi and Allahabad) then it comes to a total of 7.2 MW.

This added power capacity of each berthing station will pool the power to the power docks/barges to harness the renewable energy for the fuelling of ships.

Table 1: Plug Power Navigate Concept Feasibility Report

THE CONCEPT — **1 WAY TRIP NW-1 PLUG POWER NAVIGATE CONCEPT FEASIBILITY REPORT**

ASSUMPTION	ENGINE	POWER(KW)	QUANTITY(twin screw)	SPEED(km/hr)	TOTAL POWER(KW)
		248	2	9	496

Route						AVERAGE ENERGY CONCEPT(55029.32MJ)	TIME EFFICIENT CONCEPT
Origin	Destination	DISTANCE(KM)	POWER BARGE/DOCK CAPACITY(MW)	ENERGY REQUIRED(MJ)	MINIMUM TIME FOR CHARGING(min)*	ALLOWABLE TIME(min)	ALLOWABLE TIME(min)
Sagar Island	Haldia	89	7.7	17639.8	38.18	120	164.84
Haldia	Diamond Harbor	64	4.4	12684.8	48.04	208.2	208.2
Diamond Harbor	Malda	414	3.7	82054.8	369.6	247.8	240
Malda	Varanasi	700	2.5	138740	924.6	366.6	240
Varanasi	Allahabad	121	7.7	23982.2	51.9	120	120

The above table explains the energy management for fuelling the vessel (L:75m B:15m Dispalcement: 3000 tonnes Draft:2.5m) on the route studied in the paper. An average of 55029.32 MJ is required between different stations for traversing these stations. The power barge/dock capacity is the combined capacity of offshore solar and wind farms. However adding more number of berthing stations and power barges substation can bring down the average energy requirement. The time efficient concept involves a total of 16.21 hrs for charging the battery for travelling through the voyage but if more stations are added this power charging time can be reduced to a value of loading/unloading time. However the average time for charging at one station is near to 2 hrs 44 min. Also the capacitor required to store this energy is a restriction but this can be overcome by adding more intermediate power barges or developing the **concept of HULL CAPACITANCE.**

This study will make the whole infrastructure of IWT to be self reliant by not depending on other fuels thereby adding a share to protection of non renewable source. This will subsequently add to the eco-green factor to this sector of Inland Waterway Transport. In all the concept studied has a very promising future and can be applied in different parts of the world along with the futuristic development of HULL CAPACITANCE which has been explained in the further section.

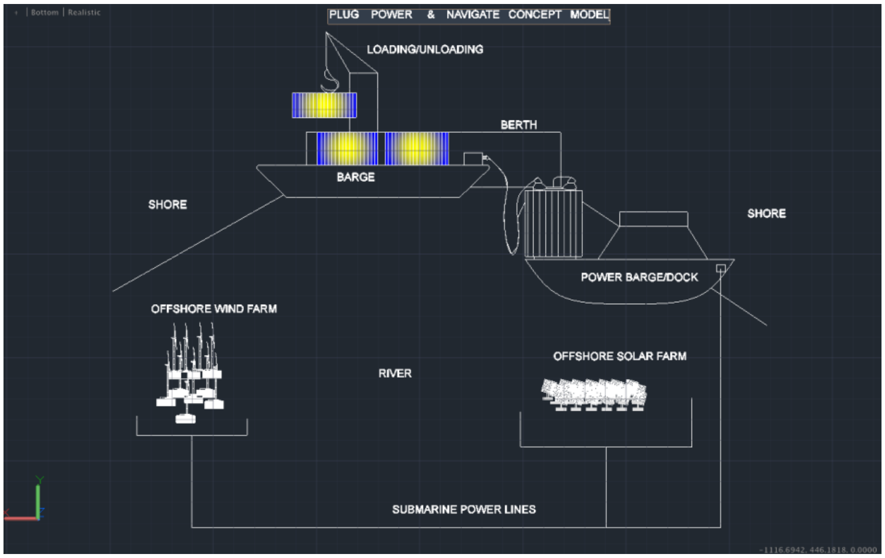


Fig.1 An AutoCAD view of the Plug Power Navigate Concept Model

DESIGN

Any portion formed of parallel plates can be transformed to a parallel plate capacitor to obtain hull capacitance. In our study we have considered only the free-board deck and the various transverse bulkheads which shall serve our purpose of hull capacitance, as they render least safety considerations and structural modifications.

HULL CAPACITOR

The parallel plates of a transverse bulkhead shall be separated by a distance of 5cm. This intermediate space shall be fit in by dielectric material called Barium titanate. Together this set-up of parallel plates and the dielectric material shall form a capacitor. Similar structural modifications are required to transform a freeboard deck into a capacitor. Minimum structural modifications have been introduced for the creation of hull capacitor so that the fundamental principles of stresses and bending moments are applicable to the system and hence the analogy of basic structural design can be followed while creation of the load bearing members. This reduces the production complexities and also fetches a scope of further development of the concept.

INSULATION OF CAPACITORS

The two parallel plates of the capacitors act as charge storage cells. These cells should not come in contact with each other as they may conduct their charges to neutralize each other. This shall cause a short circuit in the connections and the entire set-up shall fail. Secondly, if these plates shall come in contact with any other structural plate then it shall distribute its charge over that plate as well bringing the lives of people in jeopardy. This induces a strong need for proper insulation of these plates. These bulkheads are to be insulated on its outer surfaces (surfaces not forming the inner walls of the capacitor) to disengage its contact with cargo /machinery /personnel. Also the system of hull capacitance is to be pocketed in the form of a photo-frame casing of insulation material to disengage its contact with the adjoining structural plates in order to cut its conductivity to the adjacent plates forming its boundary.

There are several options for insulation material available in the market which is to be short-listed on the basis of its resistance to thermal conductivity, high tensile strength and good wear resistance properties.

$$H = (\Delta Q / \Delta T) = KA (\Delta T / X)$$

The above formulation shall serve the need full requirement for the selection of the insulation material. The current study has been done taking neoprene- silicone-rubber as the insulating material to form the casing around the bulkheads and a film of it is coated on the outer surfaces of the bulkheads forming the capacitor.

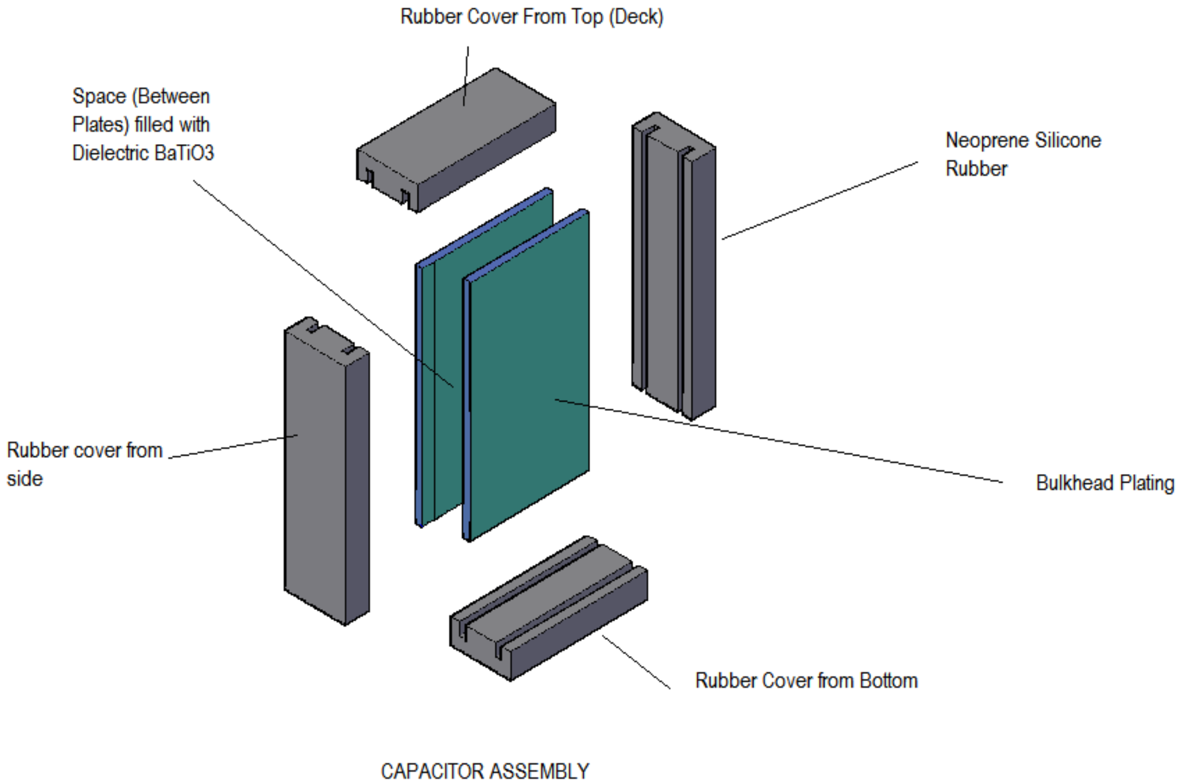


Fig 2: Capacitor Assembly

DIELECTRIC MATERIAL

The process of charging and discharging of a capacitor involves vast variation in temperatures. The selection of dielectric material was the toughest and most cumbersome task of our study which involved the short-listing of dielectric material on the basis of high dielectric strength, minimal variation in temperature, lower operating temperature range. Dielectric strength of the materials was studied along with the force induced on the capacitor plates due to charging of the capacitor to maximum value. This study proposed several materials as alternatives to the selection of the dielectric material, few of which are Barium Titanate, Lead Zirconium Titanate , Calcium Copper Titanate, Conjugated Polymers etc.

Of these materials Barium Titanate was taken as the standard material for our study. Barium Titanate is a quite suitable Pervoskite material in respect that it has a high dielectric strength ranging from 4000 – 15000 F/m for an operating temperature range of 20 – 120 °C. It has an ignition temperature of 1100 ºC, which implies no botheration for explosion or burning of the material making it completely safe for usage. It exists in solid state in the entire working range of temperature making its handling easy and reducing the complexities involved in the manufacturing of capacitor.

CONSTRUCTION & FABRICATION

The bulkheads are constructed as a part of two plates separated by a distribution of 5cm to embed the dielectric material into it. These plates can be separately formed as ordinary bulkhead plating by joining the horizontal strips of plates using welding process, which are sequentially arranged from bottom to top. These bulkheads can then be fixed in a photo-frame sort casing formed of insulating material. This casing can be riveted to the bulkhead plates and then be bolted to the adjoining plates or riveted to them as well. These bulkhead plates are to be enclosed in the insulating material casing from all sides providing perfect isolation from the surrounding environment. Also the surfaces of the plate exposed to the holds / decks are to be covered with a layer of insulating material forming a film on it.

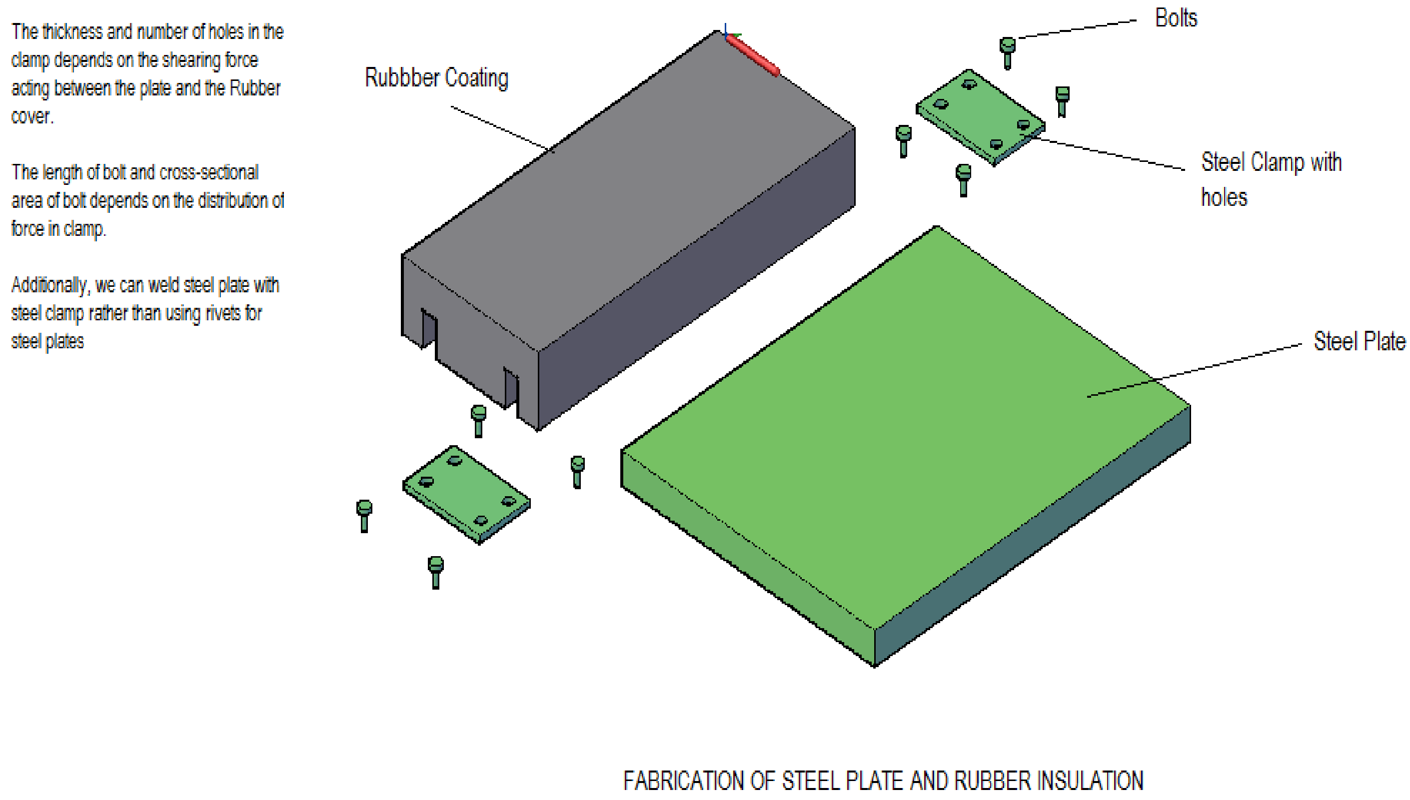


Fig 3: CAPACITOR ASSEMBLY FABRICATION

ELECTRICAL THEORY

The '**Hull Capacitor'** once fully charged is a power packed module of electrical energy which starts dissipating its energy or starts discharging its electrostatic potential energy as soon as the feeding power is removed. This system discharges with an exponential decay in the potential of the capacitor leading to an all time decaying voltage in the circuit, which has been formulated as follows

$$V = E\,(1 - e^{-t/RC})$$ where V = p.d of capacitor, E = Maximum Emf
R= resistance, C = Capacitance, t= time

To acquire a constant voltage source to be fed to various on- board machinery we connect an inductor in series with the hull capacitor which has exponentially increasing charging characteristics resulting to neutralize the exponential decay of the capacitor potential.

$$V = E * e^{-R*t/L}$$ where V = p.d about inductor L = Inductance, t= time
R = Resistance E= Maximum Emf across the inductor

On addition of these two potential differences, we get

$$2 * V = E$$

$$V = E/2 \quad \text{(constant)}$$

This constant voltage source can be fed to the distinct systems on board according to their ratings and requirements by modulating the discharging the voltage to the necessary ratings. The losses accompanied with this system are mostly heat losses which will dominate in deciding the time factor for which this system is to be used. Since Capacitor discharges completely in infinite time and inductor gets charged in infinite time as well. So, the system is a proofed combination provided,

$$L/C = R^2$$ where L = inductance, C = Capacitance, R= Resistance

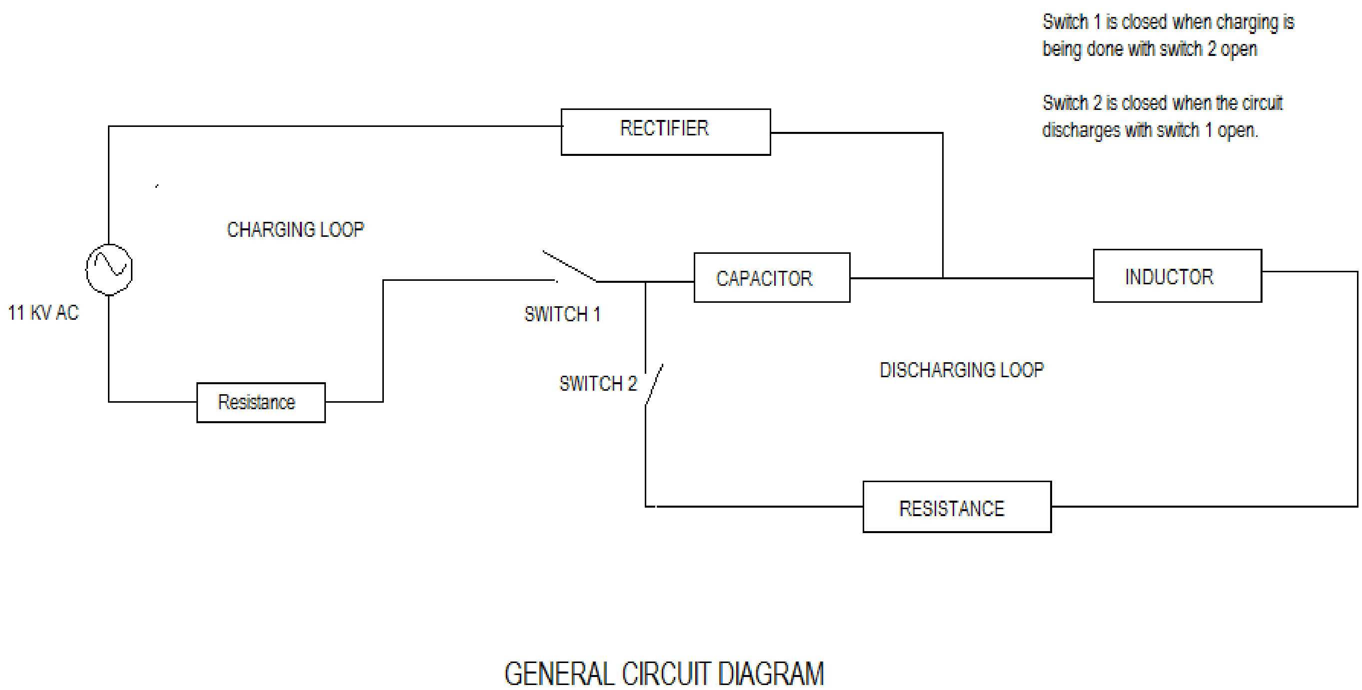


Fig 4: Capacitor Charging/Discharging Circuit

CALCULATIONS

Capacitance Calculation:

The hull capacitor evolved in the current study has been theoretically verified for its performance basing on the followed calculations. This assembly has been oriented to store sufficient energy as required by the standard barge whose geometrical particulars have been mentioned to navigate its due course of voyage without bunkering at intermediate jetties for recharging.

Basic Geometrical Particulars of the Barge

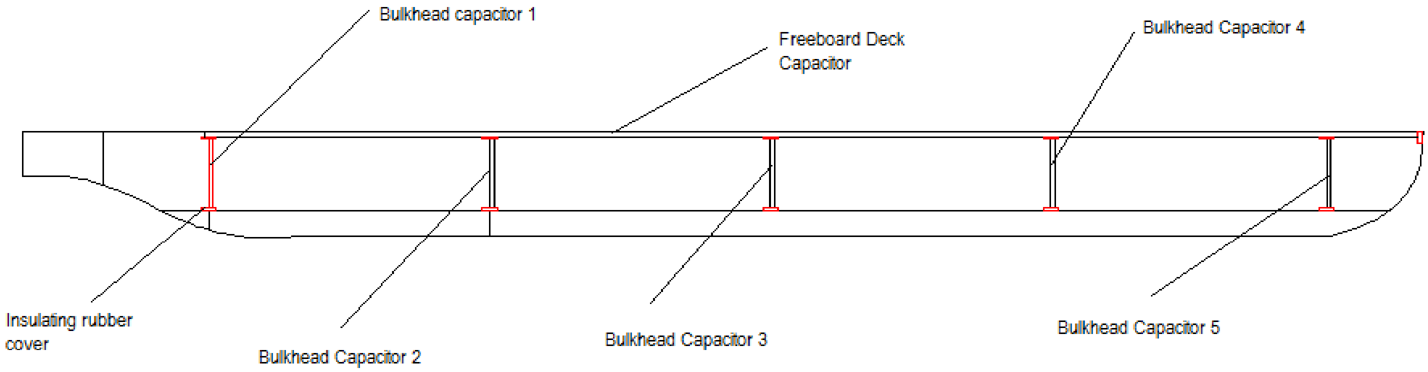
L = 75m, B= 15.25m, D= 3.2 m, d.b = 0.7 m   (Considering d.b at 0.7 m from base)

Bulkhead Dimensions

B = 15 m (approx), H = 2.5 m

Freeboard Deck Dimensions

L = 60 m , B = 15 m



NOTE :-
This profile Plan is not to be taken as any G.A plan for the Barge used for the HULL Capacitance , Plug and Power conept.

This plan is intended to represent Concept Design of the vessel (Barge) modified for this technology.

** If any one copies the plan for any other purpose the AUTHORS of the paper are not to be held responsible for the loss

GENERAL PROFILE PLAN FOR HULL CAPACITANCE (BARGE)

TABLE 2: VOYAGE PARTICULAR VS ENERGY SUMP

Station	Distance (km)	Energy required (J)
Sagar - Haldia	89	17639.8
Haldia- Diamond Harbor	64	12684.8
Diamond Harbor- Malda	414	82054.8
Malda-Varanasi	700	138740
Vaanasi-Allahabad	121	23982.2

CAPACITANCE CALCULATION

Maximum available energy = 1,38,740 J

Operating voltage = 11 kv = 11,000 volts

Energy stored in a capacitor = $C*V^2/2$

As we know Capacitance for a parallel plate capacitor is given by $k\varepsilon_0 A/d$, where:

k= Dielectric constant, ε_0 = Electrical permeability of vacuum = 8.85×10^{-12} F/m,

A=Area of the Plate (m^2), d = distance maintained between the plates (m)

As we are considering 5 bulkheads connected parallel with the freeboard deck, so net capacitance is

= 5 × Area of Each bulkhead + Area of freeboard deck

= 5 (15 m × 2.5 m) + 60 m × 15 m

= 1087.5 m^2

We maintain the distance (d) between plates as 5 cm = 0.05 m

$$\text{Hence } k = 2.28\times10^{-3} / (\varepsilon_o \times 21750)$$

Therefore, for such system of parallel plate capacitors connected in parallel we get the required dielectric constant of the material to be used in the plate is = 11,913

As this dielectric constant is very high and we have maintained very small distance of 5cm, the material suitable for it, comes from the Pervoskite Family (Barium Titanate). These have been used for making high voltage capacitors in small applications these days.

The results show that the capacitor has sufficient capacitance to satisfy the maximum energy required in the current study performed. The added advantages of using this material as our dielectric material are a) It is a solid material. Hence there is no leakage problem during heavy motions of ship. b) It has a high specific heat capacity (0.527 J / kg-K). So, the temperature gradient would not be high.

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NOTE: -The calculations have been done to satisfy the minimum requirements and accommodates good scope of optimization.

FORCE CALCULATION

The forces induced between the plates due to the action of electrostatic charge present on the plate of capacitor is given by

$$\tfrac{1}{2} \times \varepsilon_o \times A \times (V/d)^2$$
$$= 232.80 \text{ N}$$

This force accounts for determining the thickness of the rubber cover and dimension of the bolts used in fabrication of the capacitor along with the Wave loads and Cargo loads.

DIELECTRIC AMOUNT CALCULATION

The amount of dielectric required to form the capacitor assembly in a general bulkhead has been calculated as under

Specific gravity of Barium Titanate = 5.85 gm/cc = 585 kg/m^3

Volume of dielectric in the capacitor = 15 m × 2.5 × 0.05 m

= 1.875 m^3

Hence total mass = 1.875 m^3 × 585 kg/m^3 = 1096.875 kg = 1.1 tons/ bulkhead

TEMPERATURE CALCULATION

The capacitor charging action causes a rise in temperature which shall be assessed as follows Specific heat Capacity

= 0.527 j/g-K = 0.527 kj/g-K

$= m\times C_p (\partial T) = 1{,}38{,}740$ J

∂T comes to be 0.3 K.

The temperature rise in the capacitor is negligible posing no threat to the cargo and other operations. Also, this small rise in temperature is helpful for innovators to increase the storage capacity as well as substituting the dielectric with some other provided dielectric constant is maintained.

FUTURE DEVELOPMENTS

The idea of plug power Navigation is inspired by the ideas of M.K Gandhi who said

" We have not inherited this world from our ancestors but borrowed it from our children "

To plug, to power and then to navigate will revolutionalize the methods of navigation in the trading economies with its huge potentials to further developments. This study is merely an initiation to a method of energy storage system in the form of "**Hull Capacitors**" by utilizing the parallel plate capacitor model in the hull structure of the vessel. The parallel plate model can be further utilized in spaces as main decks or double bottoms, solid floors tween decks etc. with consideration to safety requirements.

Development of portable charging vessels may enhance the capabilities of these vessels by serving as portable power houses to the vessel and hence reducing the dependency of these vessels on the jetty based power stations. This will eliminate the need of jetties at regular short span lengths during the voyage for re-powering of the hull capacitors. The development of portable powering stations can lead to the introduction of this '**Hull Capacitors**' by utilizing the parallel plate capacitor model. This technique can be expanded further by introduction of '**Cylindrical Capacitor'** models in the hull structure of the vessel. Development of portable charging vessel may enhance the capabilities of these vessels by serving as portable power houses to the Sea-going vessel also where the existing technologies can be used in both Inland water channels and the coastal vessels.

In the present study the concept of the power and navigate has been assessed upon a BARGE with dry cargo only. The permutation and combination possible from the various types of vessels and the wide variety of cargo types that can be carried shall broaden the expanses of application of this technique by manifolds. All of these aspects of development of this technology indicate enriching R&D prospects in future.

CONCLUSION

The objective of present study was to prepare a model to store electrical energy within the hull structure of a vessel to harness the plug power navigation concept. The proposed design has been verified using energy storage calculations which were done to meet the energy requirements of an Inland navigation Barge. This design has also been verified for its response to the charging and discharging actions of the capacitor accounting for the change in temperature and the forces induced due to this action. This study also caters to the need for further development of energy storing techniques and has fair future prospects.

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