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Comparative Study of Two Topologies Of Linear Electrical Generator Suitable for Wave Energy Conversion

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Abstract

The perspective of fossil-based fuels exhaustion in the next decades created the need of new types of energy resources; amongst them the renewable energies (wind, solar, wave, etc.) are of great perspective. The most popular is the wind energy, with a total installed power of 47.000 Mw [1]. The exclusive use of wind farms is not practical, due to the high number of units necessary to cover the total energy need [2], so the development of the other types of renewable energies is a priority. Wave energy conversion devices have become a domain of high interest in the last years, due to the enormous energy potential of the oceans, which are covering more than 2/3 of the Earth's surface.

The usable energy of the oceans is of two types: tidal and wave energy. Conventional devices for wave energy conversion usually include mechanical interfaces such as hydraulic systems, used to convert the slow reciprocating motion of the waves into high speed rotational motion (usually 1500 rpm), suitable for conventional electric generators such as the induction machine. A new solution, which implies the use of linear electric generators, has been proposed in the latest years, with specific advantages and problems.

Introduction

An energy production system using a linear generator has the structure presented in (fig. 1). The system is quite simple, consisting in a buoy floating at the surface of the ocean connected trough a flexible rope to the device placed at the bottom of the ocean. The stator of the linear generator is fixed on the ocean floor, while the translator is moved up and down along with the buoy.

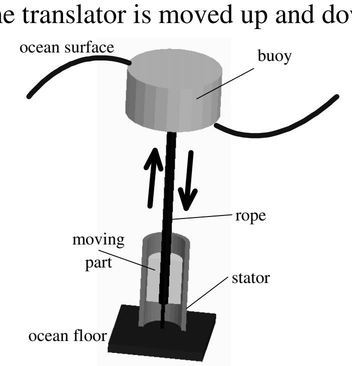

Fig. 1. Wave energy conversion system using a buoy.

The use of direct drive electrical power take off systems has the potential to simplify the power conversion system by the elimination of mechanical linkages, which imply losses due to mechanical friction and add reliability problems.

Linear generator topologies

Different topologies of linear electrical generators have been proposed. The linear generators suitable for this type of application would be very large and heavy, considering the low oscillating frequencies of the waves. One option would be the transverse flux linear generator, with high shear stress, but with very low power factor and high structural complexity. Two different topologies will be presented in this paper, one with the permanent magnets placed on the oscillating part and one with the permanent magnets in the stator: the air cored permanent magnet tubular machine and the linear vernier hybrid permanent magnet machine.

Air cored tubular machine with permanent magnets

A major drawback of linear generators using permanent magnets is the high attraction / repulsion forces that occur between the stationary and the moving part, which can interfere in the normal operation of the machine. A proposed solution for this problem is the use of a generator with no magnetic material in the stator, as presented in (fig. 2).

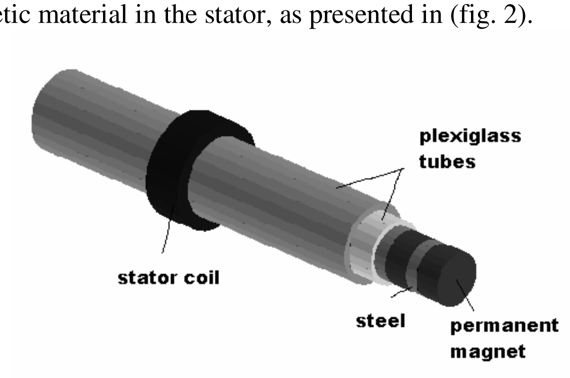

Fig. 2. Main parts of an air cored pm tubular electrical generator.

The entire structure is created around two tubes made of plexi-glass that have two purposes: holder for the stator coil and bearing system for the linear oscillatory motion. The moving translator consists in disc-shaped permanent magnets mounted between iron pieces in a sandwich type topology so that alternating N-S poles are created. The permanent magnets are polarized in the direction of the motion. The iron pieces make the mounting of the magnets easier and concentrate the flux in the desired direction.

The major drawback in using this topology is the poor magnetic circuit, requiring the need for much more magnetic material to obtain the necessary flux through the airgap. This represented a problem a few years ago because of the high price of rare-earth permanent magnets, but nowadays the market price of high performance magnetic materials such as Neodymium-Boron-Iron has drastically decreased.

The tubular structure of this machine eliminates the presence of attraction and repulsion forces between the stator and the translator that can affect the bearing design and support structure. Because of the symmetrical structure of the tubular linear machine the resulting attraction force is zero.

The working principle of this generator is quite simple: when the magnetic core is moved by an external force back and forth inside the stator, the magnetic flux surrounding the winding changes rapidly and induces a current in the cables. The wave form of the obtained current is non-sinusoidal, but can be transformed into useful DC current with an electronic part.

Linear vernier permanent magnet generator

The linear vernier pm generator has salient structure both in the stator and in the translator, thus belonging to the variable reluctance machine family. The working concept is similar to that of the transverse flux machine [3]. While the structure presented above had the permanent magnets placed on the translator this generator has a passive moving part, made of steel, with salient structure. The generator has a modular structure for each phase; one phase is presented in (fig. 3).

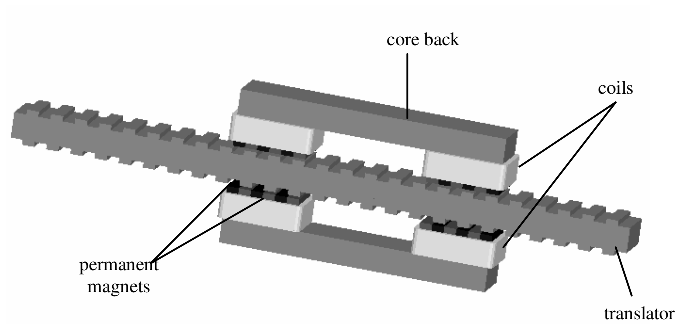

Fig. 3. One phase module of a linear vernier pm generator

Different topologies of linear vernier machines were proposed, with stator on one, two, or more sides of the moving part. The topology presented above is two-sided, with the permanent magnets placed near the airgap. The permanent magnets have the same width as the tooth and slots of the translator. For a three-phase balanced voltage system to be produced each phase must be placed in such way that the relative position of the magnets and translator teeth are 120 degrees out of phase. If the translator teeth of the first phase are fully aligned with the permanent magnets placed on the stator core back, the other two must be unaligned. The coils of the electrical generator are mounted around the stator core back.

Considering one module of a three-phase vernier permanent magnet generator presented in (fig. 4), 3 translator poles are fully aligned with 3 magnets of one polarity on one limb and 3 of opposing polarity on the facing limb. The reluctance offered is a minimum, and so flux flows through the steel core, across the airgap, through the translator poles across the opposite airgap ant into the opposing magnets in the translator core back. When the translator moves one tooth pole pitch the polarity of the flux changes sign producing a rapid flux reversal. The low velocity of the translator is geared up to a high electrical frequency. During the flux reversal an energy change takes place over a small distance, resulting in high thrust forces at the airgap.

Our staff is currently studying different VHM structures using FEM based simulation programs, to obtain an optimized topology. In the same time, Matlab based simulations will be performed and the research will be finalized with the construction of a prototype.

Considering the sinusoidal velocity variation of the translator [4] the wave form of the induced emf in the electrical generator is of pulsating nature. The emf varies in amplitude and frequency during a wave cycle (fig. 5), typically 10 seconds.

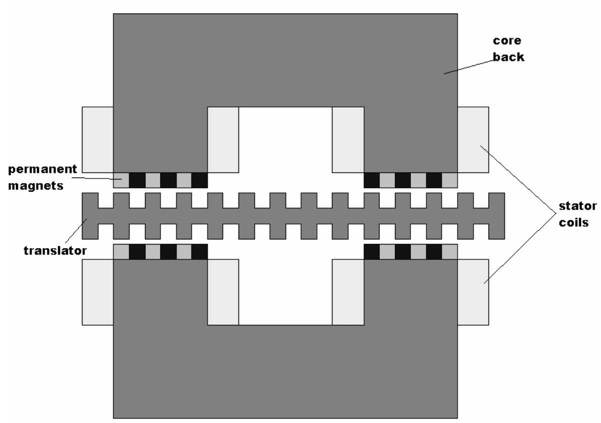

Fig. 4. Cross section of one module of a 3-phase VHM.

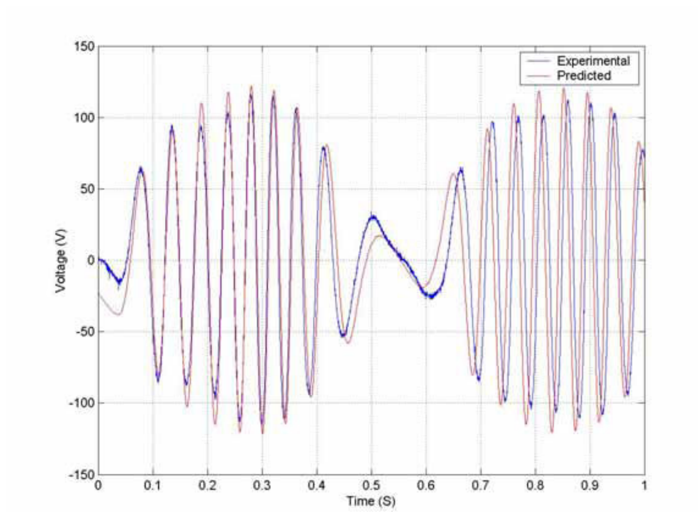

Fig. 5. Experimental and predicted emf when the VHM is excited by a sine wave displacement.

The frequency depends upon the velocity and pole pitch of the magnets. For grid connection an electronic rectifier is necessary.

The translator moves parallel to permanent magnets placed on both sides creating a variable flux in the core back. The resulting voltage in the coils is of high pulsating nature with frequency depending on the translator speed.

Dimensions comparison between the two topologies

Two structures of 100 kW rated at 1 m/s were analyzed [5]. The estimated mass of the raw materials to be used is presented.
The estimated dimensions of the two linear generators are presented in (tab.1).

As expected, the magnet mass is way greater at the air cored tubular generator, while the steel mass of the vernier hybrid generator is three times greater. The total mass of both topologies is very high.

Considering the above presented information the use of a large number of smaller installed power units would be better suited for wave energy conversion instead of one large power unit. This way, off-shore power farms would be created to obtain higher electrical power.

Table 1. Main dimensions of the generators

Dimension	Air cored tubular generator	Vernier hybrid generator
Magnet [kg]	1700	67
Cooper [kg]	1100	780
Steel [kg]	1730	5600
Total mass [kg]	4770	6447
Stator length [m]	1.4	1.72
Stator diameter/width [m]	0.58	1.2
Airgap [mm]	1	1

In (fig. 6) a side view of the two topologies is presented.

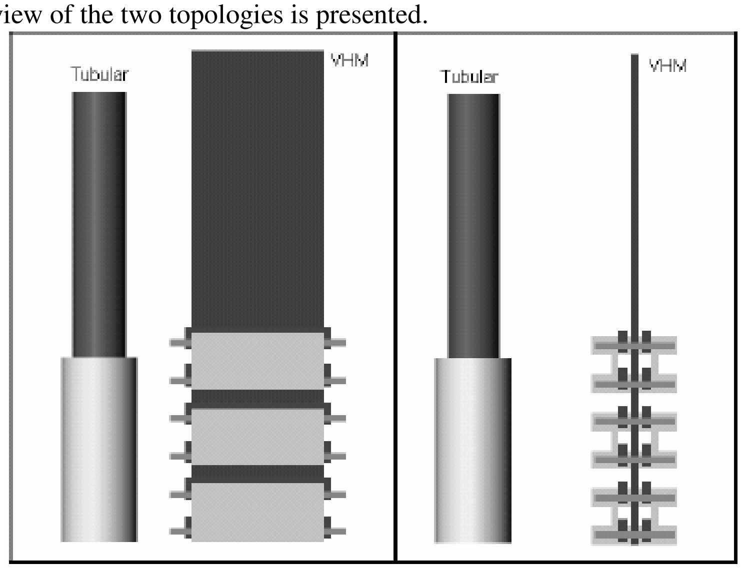

Fig. 6. Side view comparison of the air cored tubular generator and the vernier hybrid generator.

Conclusion

Both topologies presented above are suitable for direct drive energy conversion for wave energy converters. The VHM has a translator made of iron, with the permanent magnets placed on the stator. The usage of permanent magnets is minimized. The wave form of the obtained voltage is highly unregulated; a power converter is necessary to couple the electrical generator to the grid. The large amount of iron used both on the translator and the stator produces important magnetic attraction forces between them. Any small imperfection in the airgap can produce an unbalanced attraction pull forcing the two to come into contact. Important constrains appear in designing the bearings.

The tubular air-cored electrical generator has some important advantages compared to the VHM: the total attraction force is zero thanks to the cylindrical symmetry and a good sealing is easier to obtain when operating in marine environment. The total mass of the generator is significantly reduced because of the air-cored stator, but much more magnetic material is necessary due to the poor magnetic circuit created. This implies higher manufacturing costs than in the case of the linear vernier hybrid electrical generator.

Both topologies can be connected to the power grid only through an electronic converter.

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Studiu comparativ a două structuri de generatoare electrice liniare utilizabile în sisteme de conversie a energiei oceanelor

Rezumat

În perspectiva epuizării rezervelor naturale de combustibili fosili în următoarele decenii, nevoia de noi tipuri de surse de energie devine tot mai stringentă. Dintre acestea, sursele de energie regenerabile (eoliană, solară, energia oceanelor) par a fi de perspectivă. Cea mai populară formă de energie regenerabilă este energia eoliană, cu o putere instalată la nivel mondial de peste 47.000 MW. Utilizarea exclusivă a centralelor eoliene nu este o soluţie viabilă datorită numărului mare de unităţi necesare pentru a acoperi necesarul de energie, astfel că dezvoltarea altor tipuri de energie regenerabilă este o prioritate la nivel mondial. Sistemele de conversie a energiei valurilor în energie electrică au devenit un domeniu de mare interes în ultimii ani, datorită potenţialului energetic imens al oceanelor, care acoperă mai mult de două treimi din suprafaţa Pământului.

Energia utilizabilă a oceanelor apare sub două forme: energia curenţilor de apă şi energia valurilor. Sistemele convenţionale de conversie a energiei valurilor în energie electrică conţin de obicei sisteme de conversie a mişcării oscilatorii a valurilor în mişcare rotativă, compatibilă cu generatoarele electrice clasice cum ar fi generatorul de inducţie (în general 1500 rpm). O nouă soluţie, care introduce utilizarea generatoarelor electrice liniare, a fost propusă în ultimii ani, care prezintă avantaje şi probleme specifice.