FEM BASED ANALYSIS OF ADVANCED LINEAR GENERATORS FOR WAVE POWER PLANTS

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ABSTRACT

Ocean energy technologies have been around for decades. But for a variety of reasons, including rising oil prices, technological advancements and the sheer grit of a handful of pioneer developers, ocean energy has made a huge splash only in the last years. The specialists working in this field concluded that generation of electricity from wave energy may be economically feasible in the near future and as such, warrants continued investigation. Hence any new contribution in this field should be of real interest.

In this paper a new variant of the tubular permanent magnet linear generator to be used in wave power take-off converters will be presented. Its performances will be analysed by means of advanced finite elements method based field computations.

INTRODUCTION

Energy sources are of great importance in today’s world. Due to the pending exhaustion of fossil fuels and to their environmental impact it is crucial to develop clean renewable energy sources.

Ocean energy resources, as a derivatives form of solar energy are promising candidates to the non-renewable energy resources, being a huge, yet unexploited clean, renewable energy source on the Earth. Preliminary surveys show that marine power has a potential for making a significant contribution to the alternative usable energy supply.

In the past several decades, various designs have been developed to utilize the oceans to generate electricity [1]:

i.) *wave energy converters* can extract the power of ocean waves and convert it into electricity. Typically, these systems use either a water column or some type of surface or just-below-surface buoy to capture the wave power.

ii.) *tidal/current* systems capture the energy of ocean currents and tides below the wave surface and convert them into electricity. Typically, these systems rely on underwater turbines, either horizontal or vertical, which rotate in either the ocean current or changing almost like an underwater windmill.

iii.) *ocean thermal energy* technology based systems generate electricity through the temperature differential in warmer surface water and colder deep water.

iv.) *offshore wind turbines* are mounted in offshore environments. As offshore technology gains more experience, developers are now looking towards moving offshore wind further offshore into deeper waters.

v.) *marine biomass*: harvesting marine algae for use in energy generation by producing gaseous or liquid fuel.

vi.) *marine solar* power is exploited in photovoltaic cells (solar cells). With oceans making up 70% the earth's surface, offshore solar installations are viewed as a non-land alternative to the solar installations on land.

Most of these are by now moving toward commercial prototype testing. It seems that from these possibilities the wave energy conversation has the greatest general application potential.

The ocean waves are generated by the influence of the wind on the ocean surface first causing ripples. As the wind continues to blow, the ripples become chop, fully developed seas and finally swells. In deep water, the energy in waves can travel for thousands of miles until that energy is finally dissipated on distant shores.

Specialists estimate that the worldwide economically recoverable wave energy resource is huge, being in the range of 140÷750 TWh/year considering the existing wave-capturing technologies that have become fully mature [2]. It should be mentioned that the total electrical demand of the USA is nowadays about 11,200 TWh/year of primary energy. From other estimations this enormous energy resource could power as much as 10% of the entire world's electrical demand.

A characteristic of wave energy that suggests that it may be one of the lowest cost renewable energy sources is its high power density. Processes in the ocean concentrate solar and wind energy into ocean waves, making it easier and cheaper to harvest. Solar and wind energy sources are much more diffuse, by comparison.

Regarding the environmental impact of the wave power plants several studies stated out that, given proper care in site planning and early dialogue with local stakeholders, the offshore wave power promises to be one of the most environmentally benign electrical generation technologies [3].

The researches in this field are catalysed also by a strong political motivation to reduce drastic the emissions of greenhouse gasses in the near future (see the Kyoto Protocol or the Marrakech Agreement). As a result of these political commitments the renewable energy industry is developing around the world being one of the highest priorities of mankind.

LINEAR GENERATORS FOR WAVE ENERGY CONVERTERS

The potential wave power can be converted to electricity via mechanical means. Harnessing the energy provided by oceanic waves has been developed for over the past thirty years via numerous technologies.

Several wave power take off systems, called *Marine Energy Converters* (MECs), were already proposed [2]. The most complicated constructions are with direct mechanical linkage, with pneumatic (for example the Oscillating Water Column system [4]) or with hydraulic systems (as Pelamis [2]).

The direct drive power take off system, which is proposed also by our research team, is very uncomplicated.

The simplest such variant uses a floating buoy joined together with no intermediate mechanical systems to a linear generator. The generator is fixed on a concrete foundation, which stands on the bottom of the ocean (see Fig. 1). The power take-off system works upon the difference in height between wave top and wave bottom. Its main advantage is, that it is mechanically simple, having only a few moving parts.

Between the off-shore generator and the on-shore gird AC/DC, respectively DC/AC converters must be coupled. Various topologies are cited in the literature, as concerning both the way as the independent generators are coupled together and the types of power converters to be used [5].

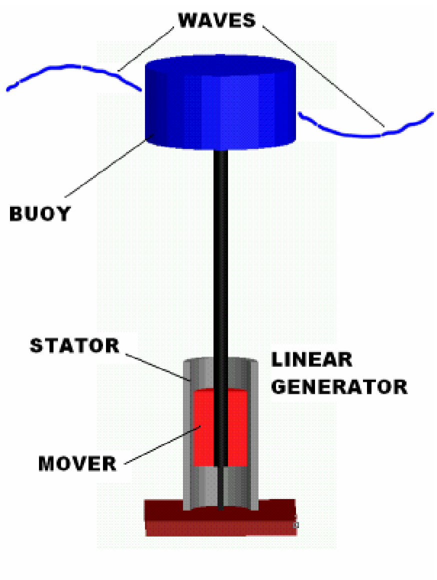


Fig. 1. The direct driven power take off system

The wave power take-off system in study by the researchers from the Technical University of Cluj, Romania, is intended to be placed in the Black Sea near the Romanian coast. Taking into account the particularities of the Black Sea it was concluded that it should be more efficient to install wave power plants consisting of large arrays of small wave energy converters (of about tens of kW) having specifically designed linear generators driven by a point absorbing buoy [6].

The crucial part of such a marine renewable energy devices is the efficient conversion of kinetic energy into electrical energy. Hence the optimal design of the linear generator used, the main topic of our research, is a very important issue in the development of the entire power plant [7].

In the literature mainly the following linear generators are proposed for wave energy converting power plants [6]:

i.) Linear permanent magnet synchronous machines, both with surface and buried permanent magnets.

ii.) Vernier hybrid linear machines.

iii.) Air cored permanent magnet tubular machine.

The descriptions and the performances of the above mentioned machines had been studied also by us from the point of view of their applicability in the power plants intended to be placed in the Black Sea. Their power should be relatively low (of order of kW), they have to work at low speeds (up to 1 m/s) and to have short strokes (under 1 m). Of course as they are placed under the water in hard to mount and to access places they have to be maintenance free and to have great force density in order to have as low mass and volume as possible.

Previously the research team studied two variants of the Vernier hybrid linear generator, respectively the air cored permanent magnet tubular generator, both designed for the above specified application [6, 8]. Neither one of the designs did not fulfilled the preset requirements for the given purpose. In the case of the Vernier hybrid linear machines only a small part of the magnetic flux generated by the permanent magnets were closed through the coils. In the air cored permanent magnet tubular machine the magnetic flux was not properly concentrated inside the linear generator's windings.

Therefore a new tubular permanent magnet linear generator was designed and analysed by means of 2D finite elements method (FEM) based field analysis.

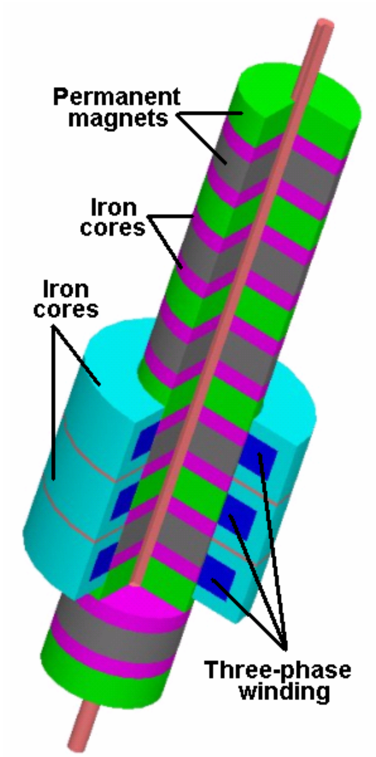


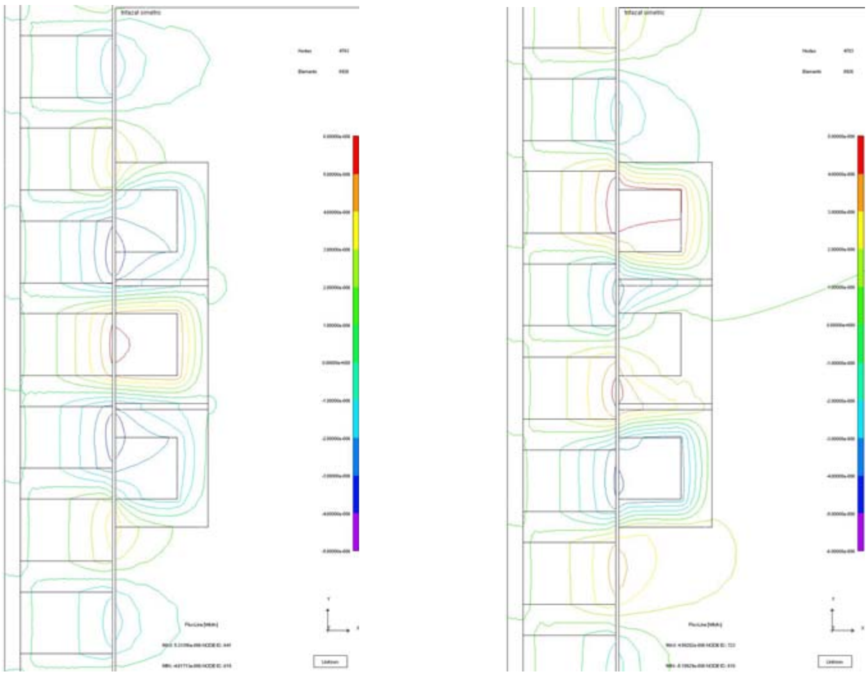
Fig. 2. The proposed linear generator

FEM ANALYSIS OF THE NOVEL TUBULAR PERMANENT MAGNET LINEAR GENERATOR

An armature of the proposed linear generator given in Fig. 2 has alternately polarised radial magnetised permanent magnets separated by ring shaped iron cores used for flux concentration. The other armature has three properly shifted U-shaped cross section iron cores and a three phase winding. When one of the armatures is moved relatively to the other emf is induced in the three coils of the linear generator.

The magnetic field analysis was performed using JMAG Version 8.4 software of JRI Solutions Ltd. (Japan) [9]. Due to the symmetrical tubular design of the machine, the simulation task could be formulated as an axially symmetric problem. Both static and dynamic transient analysis was performed during our study. The more interesting results were obtained when the relative position of the two armature was modified. In this stage of the researches a constant speed movement (of 1 m/s) was imposed for the armature carrying the three coils of the linear generator.

Next some of the most significant results of the field analysis will be given.

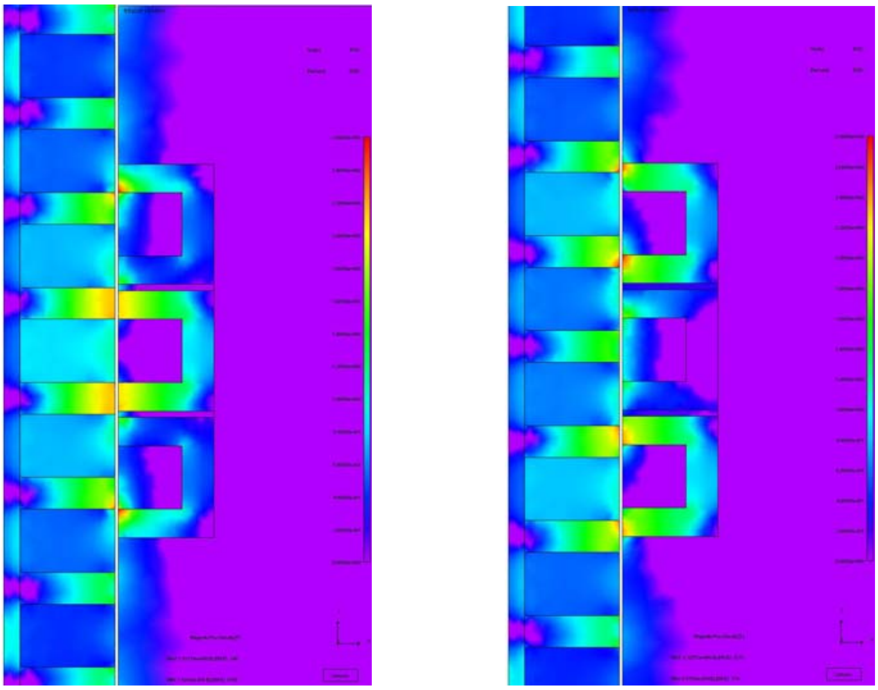


a) b)

Fig. 3. The plots of the field lines in two positions of the moving armature

The plots of the field lines in two positions of the moving armature are given in Fig. 3. In the first position (Fig. 3a) the middle poles of the mover are aligned with two permanent magnets of the other armature. The second position in study is when the above mentioned poles are aligned with the middle of the flux concentration iron core rings. It can be clearly observed the significant change of the magnetic flux through the middle U-shaped cross section iron core.

Next, in Fig. 4 the colour map of the flux density in the linear generator are given. Also in this case the same two positions from Fig. 3 are considered.



a) b)

Fig. 4. The colour map of the flux density in two positions of the moving armature

Also in this figures the significant variation of the magnetic flux through the mover cores of the machine can be clearly seen.

The waveforms of the induced emf in the three coils of the linear generator are given in Fig. 5. It can be observed that the amplitude of the voltages is constant due to the constant imposed speed of the mover.

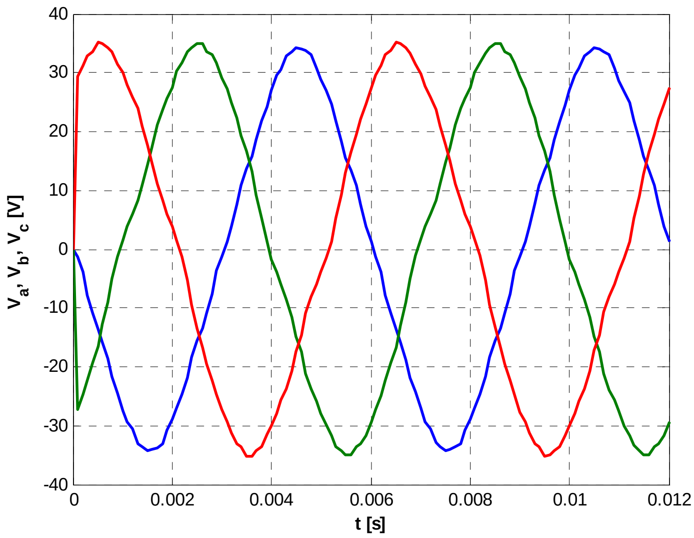


Fig. 5. The induced voltage in the three coils

CONCLUSIONS

All the obtained results emphasize the correct concept of the proposed linear generator.

By minor changing in the design both the frequency and the amplitude of generated voltages can be changed in a manner as to fit also the requirements of the power electronic devices connected with. In the future the analysis has to be performed also for sinusoidal variation of the speed, in order to simulate the movement of the buoy driven mover taken by the ocean waves. Also the control and the power system of the proposed marine power converter have to be designed.

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