CHARGING STATION WITH LAND-INDEPENDENT SUBSEA TURBINES

KARADAN BAĞIMSIZ DENİZ ALTI TÜRBİNLERİ İLE ŞARJ İSTASYONU

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ÖZET

Dünyada fosil yakıt kullanımından dolayı çevre kirliliği oluşması ve canlıların soylarının tükenmesi gibi bir takım kaygı verici sorunlar ortaya çıkmıştır. Bunlara çözüm bulmak için yenilenebilir enerji kaynaklarına ilgi artmıştır. Ülkemizde de yenilenebilir enerji sistemleri üzerine çalışmalar yapılmakta ve kullanımı artmaktadır. Böylece ülkemizin dışa bağımlılığının da önüne geçilmiş olunmaktadır. Ülkemizde yenilenebilir enerji araştırılmalarına bakıldığında genellikle güneş enerjisi, rüzgâr enerjisi ve gelgit enerjisi ile ilgili uygulamalar yapıldığı görülmektedir. Güneş enerjisinden enerji alabilmek için güneşin olması beklenir. Rüzgâr enerjisinden enerji alabilmek için ise rüzgârın olması, gelgit enerjisi deniz seviyesinin yükselmesi gerekmektedir. Çalışma karadan bağımsız bir şekilde elektrikli deniz araçlarının elektrik ihtiyacını karşılanmasına yönelik bir araştırmadır. Denizaltı türbini, deniz altındaki akış enerjisinin dönme enerjisine dönüştürerek elektrik enerjisi elde eder. Deniz altından alınan enerji ise günün her saatinde kesintisiz elde edilir. Denizaltı türbinleri rüzgâr türbinlerine her ne kadar yapısal olarak benzese de birçok konuda farklılıklar göstermektedir. Bunlardan birisi denizaltındaki akıntı hızının 2 m/s ile 3 m/s arasında olan türbinden alınan enerjinin, eşdeğer bir rüzgâr türbininden alınan enerjiden yaklaşık olarak dört kat fazla yıllık güç elde edildiği tespit edilmiştir. Aynı zamanda su yoğunluğu hava yoğunluğundan 800 kat daha fazladır ve su akış hızı çok daha düşüktür.

Bu çalışma, karadan bağımsız bir elektrik santrali kurulmasını, 25-30 metre derinliğe bir denizaltı türbini yerleştirilmesini ve deniz yüzeyinde kurulu batarya sistemlerini denizaltı akıntılarından türbin vasıtasıyla en az kayıpla elektrik enerjisi elde ederek şarj etmeyi amaçlamaktadır. İnsansız deniz araçları da olmak üzere elektrikli deniz araçları bu istasyonlarda gerekli elektrik enerjisini temin edebileceklerdir. Denizaltı türbinler ile elektrik üretimi sadece karaya elektrik temin edilmesi için kurulan istasyonlar mevcuttur. Fakat karadan bağımsız istasyonları henüz literatürde ve uygulama da yoktur.

Anahtar Kelimeler: Şarj İstasyonu, Deniz altı Türbini, Yenilenebilir Enerji

ABSTRACT

Due to the use of fossil fuels, some worrisome problems such as environmental pollution and the extinction of living things have emerged in the world. To find solutions to these, interest in renewable energy sources has increased. In our country, studies are carried out on renewable energy systems and usage of this kind of energy is increasing. Thus, foreign dependencies of our country will be prevented. When we look at the renewable energy research in our country, it is seen that applications related to solar energy, wind energy, and tidal energy are mostly carried out. To obtain energy from

the sun, the sun is expected. To obtain energy from wind, there must be wind. To obtain energy from the tide, the sea level must rise. The study is research aimed at meeting the electricity needs of electric marine vehicles independently from land. The subsea turbine obtains electrical energy by converting the flow energy under the sea into rotational energy. The energy taken from under the sea is obtained uninterruptedly at all hours of the day. Although subsea turbines are structurally similar to wind turbines, they differ in many aspects. It has been determined that the energy taken from the turbine, one of which has a subsea current velocity between 2 m/s and 3 m/s, is approximately four times more annual power than the energy taken from an equivalent wind turbine. At the same time, the density of water is 800 times higher than the density of air, and the water flow rate is much lower.

This study aims to establish a land-independent power plant, to place a subsea turbine at a depth of 25-30 meters and to charge the battery systems installed on the sea surface by obtaining electrical energy with the least loss from undersea currents through the turbine. Electric marine vehicles, including unmanned sea vehicles, will be able to supply the necessary electrical energy at these stations. There are stations established for the generation of electricity with subsea turbines only for supplying electricity to the land. However, land-independent stations are not yet available in the literature and in practice.

Keywords: Charge Station, Subsea Turbine, Renewable Energy.

INTRODUCTION

Traditionally, marine vehicles are powered by fossil fuels. It is a well-known fact that over the last few years, the international shipping industry has produced a carbon footprint. According to the studies of the International Maritime Organization, the maritime industry produces 940 million tons of CO_2 per year. This corresponds to 2.5%-3% of the global greenhouse gas emitted in a year (Macola, 2020). In the maritime sector, instead of using environmentally harmful fossil fuels, increasing electric marine vehicles as an environmentally friendly alternative solution comes to the fore. The distance that electric marine vehicles that supply energy from the ports can travel on a single charge is limited. Such problems reduce the development of the electric marine vehicle industry.

Today, electricity can be produced from the seas with tidal energy, as well as from subsea water turbines. These turbines convert the kinetic energy generated by the water current under the sea into electrical energy, as in wind turbines. Considering the working conditions, the water density is 800 times higher than the air density and the water flow rate is much lower (Zupone et al., 2015). Since there is a continuous flow in underwater flow turbines, the energy output is uninterrupted compared to the wind.

In this study, it is aimed to popularize the use of electric marine vehicles and to reduce the harmful effects on the environment. Therefore, the establishment of a charging station with subsea turbines was studied and a prototype was created.

RESEARCH AND FINDINGS

The first step in installing a submarine turbine is to create a large mass of concrete or steel, known as the gravity structure, which is attached to the base of the structure to provide stability. Then the turbine is mounted on it. A charging station platform is created on the sea where battery groups are located, and ships can come and dock. Figure 1 shows the land-independent subsea turbines and the charging station.

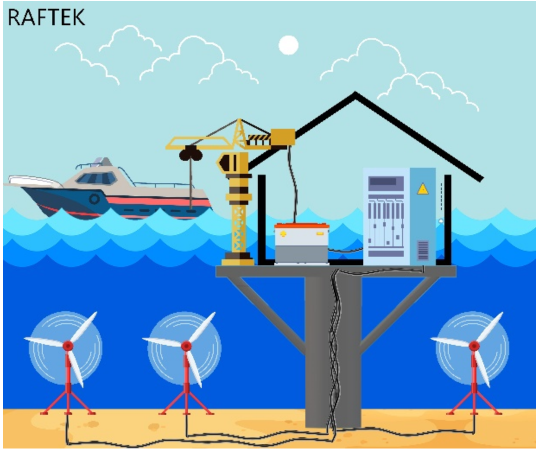

Figure 1. The land-independent subsea turbines and the charging station.

In general, subsea turbines consists of a hub (rotor), several blades mounted on the hub, a gearbox, and a generator. The hydrodynamic effect of the flowing water hits the blades and causes the rotor to rotate (Rourke et al, 2010). Thus, it turns the permanent magnet synchronous generator (PMSG) connected to the rotor.

The alternating current (AC) electrical energy obtained from the PMSG output is converted to direct current (DC) with a three-phase full-wave diode bridge rectifier (Mbabazi et al., 2012). It is then connected to the battery group on the surface platform for storage via subsea cables. This stored energy is transferred to electric marine vehicles and continues their transportation without being caught in the energy capacity limit that their batteries can store. All stages of the system are shown in Figure 2.

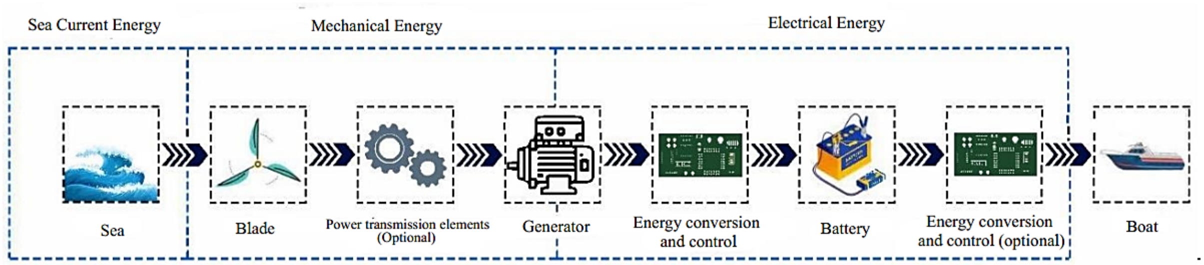

Figure 2. All Stages of the System

Conversion of sea currents energy into electrical energy in a subsea turbine depends on the blade profile. The geometric shapes of the lower and upper curves of the airfoil create different flow rates. Therefore, the pressure difference creates the buoyancy force. While selecting the blade profile, the standards created by the National Advisory Committee for Aviation (NACA) are used (Airfoil Tools, 2021). NACA 63-XXX series is widely used in horizontal axis subsea turbines. Cavitation is a type of wear that occurs when the blades rotate underwater. Considering the blade strength and cavitation effect, blade profiles with a thickness of 15% were preferred. The ratio of the lift force coefficient to the drag force coefficient (Cl/Cd) of NACA 63-X15 airfoils is compared with the Reynolds number of 105; NACA 63-615 was chosen as the airfoil (Zhu et al., 2020).

PMSGs play an important role in subsea energy generation to derive electrical power from mechanical power. PMSG was chosen because it has a low failure rate, high efficiency, high torque-current ratio (Dubois et al., 2000), and can be designed with a high pole number. PMSG will be used as a direct drive without using a gearbox, thus reducing its cost. The variable output AC electrical energy obtained from the PMSG was converted to DC voltage with a three-phase full-wave diode bridge rectifier. By using the output of the rectifier DA-DA buck-boost converter, the DC value is increased at the lower speed rotation of the rotor, or the DC value is decreased at the higher speed rotation of the rotor. The output voltage of this converter is kept at a constant value using a PI controller.

The electrical energy obtained from the subsea turbine should be transported to the surface platform with subsea cables. The subsea cables used are resistant to wear, tear, and low and high temperatures with their high insulation qualities. Lead-acid batteries are used as a battery group. They are widely used because they are not self-discharged and are less affected by cold. A prototype of a subsea turbine is shown in Figure 3.

Figure 3. A prototype of a subsea turbine

2.1. Power Calculation

The mechanical input power provided to a subsea turbine is defined as

$$P_t = \frac{1}{2}\rho A v^3 \quad (1)$$

Here, P_t is the power (Watt) to be produced by the turbine, ρ is the density of sea water (kg/m^3), A is the area swept by the turbine blades (m^2), v is the sea current velocity (m/s). The ratio of the turbine output power to the available input power is called the power coefficient C_p. A value of 0.5926, known as the Betz Limit (C_P Betz), indicates maximum efficiency. For a fixed pitch turbine, this coefficient depends on the ratio of turbine blade tip velocity Rω to flow velocity with the formula $\lambda = R\omega/V$. ω is the angular velocity of the turbine, and R is the radius of the blade.

The mechanical output power of the turbine is defined as

$$P_m = \frac{1}{2} C_p(\lambda)\rho A (\frac{R}{\lambda})^3 \omega^3 \quad (2)$$

It is assumed that the sea current velocity is 1.5 m/s on average, λ=4 and the blade length is chosen as 0.4 meters (Batten et al., 2008, Mbabazi et al, 2012). Considering the calculations, it was deemed appropriate to choose a 400-500 Watt PMSG.

2.2. Blade Design

The designed subsea turbine consists of three blades. While designing the blade, the ratios (r/R) between R and station points (r) were determined. The blade consists of 10 station points as in Table-1. The c/R ratio at different profile stations and the Veter length (c) at the station point are calculated. The angle formed by the airfoil with a flat plane is called the pitch angle. The pitch angle, which is 15° at the second station, decreases to 0°. NACA 63-615 blade profile was drawn as in Figure 4 by using the values in Table 1 of the blade.

Table 1. Design parameters of the modeled blade [8].

Profile Station	r/R	r(mm)	c/R	Pitch Angle (°)	t/c (%)
2	0.2	80	0.1250	15.0	24.0
3	0.3	120	0.1156	9.5	20.7
4	0.4	160	0.1063	6.1	18.7
5	0.5	200	0.0969	3.9	17.6
6	0.6	240	0.0875	2.4	16.6
7	0.7	280	0.0781	1.5	15.6
8	0.8	320	0.0688	0.9	14.6
9	0.9	360	0.0594	0.4	13.6
10	1.0	400	0.0500	0.0	12.6

Figure 4. Turbine blade design

2.3. Electronic Circuit Design

The electronic circuit to be connected to the PMSG output, the uncontrolled three-phase full bridge rectifier circuit, and the DC-DC buck-boost converter circuit are designed, and voltage control is provided with a PI controller. The electronic circuit of the whole system is shown in Figure 5.

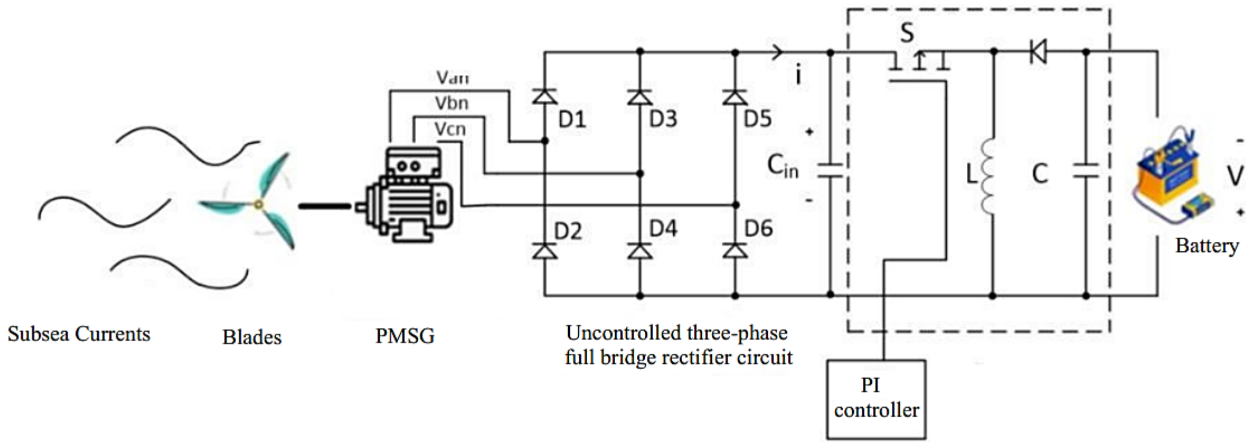

Figure 5. Electronic circuit used in the whole system

CONCLUSION

The study is the installation of a land-independent subsea turbine and a charging station system. Electricity is produced by subsea turbines. Land-independent charging stations are not yet available in practice and literature. These charging stations are intended to be used in the maritime industry to charge electric ships. Therefore, thanks to renewable energy, pollution in the seas will be prevented.

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