Wave Energy Performance Analysis: A Comparative Study on AWS Based Wave Energy Conversion System and Well's Turbine Based Wave Energy Conversion System

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Abstract –

The increase in installation of renewable energy power generation plants highlights the need for a research of various innovative technologies in order to achieve an improvement in current technology so that it can compete commercially. Already various renewable energies like solar energy and wind energy has reached the saturation level in terms of technological advancement. Wave energy, one of the most abundantly available energy is still in its developing stage and there is a need for incorporating novel technologies in this field. This opens the door for innovative research in this area. In this paper, two different wave energy technologies, one based on AWS (Archimedes wave swing) and the other based on Well's turbine is compared in various aspects of performance.

Index Terms – Wave energy conversion (WEC), AWS (Archimedes wave swing), Well's turbine.

I. INTRODUCTION

In the last decade, power plants started to focus more on modular and distributed systems. The usage of power electronic equipment by the power systems are also increasing which has numerous advantages in terms of reducing the cost, increased power density and flexibility. These advantages creates interest among governments and investors to take up alternate energy generation methods and renewable energy guidelines for better ecology [1]–[3].

The huge amount of energy available in Oceans and seas can be extracted in many forms, therefore they are very much capable to contribute a major part in supplying clean energy [4]. Among various ocean energy technologies, tidal and wave conversion systems are predicted to contribute a major share to the system [4], [5]. Wave energy is the type of ocean energy that has the highest utilization potential, which has 30 times more potential when compared with tidal energy.

Most of the power system components are modelled in dq0 reference frame for dynamic analysis of power system. So the AWS based WEC system also needs to be modelled in dq0 reference frame in order to make it compatible with rest of the components in power system. Such a kind of mathematical model is derived in [6]. In the derivation, the change of direction of motion of the translator has been considered in establishing dynamic model of the Linear Permanent Magnet Generator (LPMG) in dq0 reference frame. The dynamic responses obtained from simulation were compared with the results obtained from field test and found to be same which validates the model.

An oscillating water column system using Well's Turbine, which uses an innovative maximum power point tracking (MPPT) control scheme is proposed in [7]. An MPPT curve is established and the controller adjusts the energy conversion process of the doubly fed induction generator (DFIG) continuously to follow the established curve in order to optimize the generated power. The behavior of the proposed control scheme is tested and compared in two different case studies, one with air valve control and the other with proposed MPPT control scheme. Results shows that the proposed method successfully generates maximum active power.

The dynamic stability analysis of a grid connected induction generator driven by a Wells turbine is presented in [8]. Here the stator windings of the induction generator are directly connected to the power grid through a transformer and a transmission line. The dynamic equations of the studied system is established by d-q axis equivalent circuit model. The dynamic stability of the studied system under various operating conditions are determined by both frequency-domain and time-domain approach.

From the simulation results it is concluded that stable operation can be maintained by the studied system under different disturbance conditions.

II. SYSTEM CONFIGURATION AND MODELS

The Archimedes Wave Swing (AWS) drives the LPMG in a Wave Power Generation System (WPGS). The operating principle and elaborate configuration of the AWS-based WPGS can be referred in [6]–[10].

A. Model of AWS-Based WPGS

The Archimedes Wave Swing-based WPGS model describes the mechanical dynamics of the AWS and the electrical dynamics of the LPMG. In AWS, the floater is directly coupled with the translator of the LPMG and it can be combined into a single mass. The AWS dynamics is modelled by using the mass-spring-damper system. Thus, the equation of motion is used to describe the mechanical dynamics of the AWS as follows [11]:

$$p\,(z) = uz \qquad (1)$$

$$(mt\,)\; p\,(uz) = F_{\text{wave}} - K_S\, z - K_D\, uz - FLG \qquad (2)$$

where z and uz are the distance and speed of the floater, p is the differential operator with respect to time t (p = d/dt), mt is the total mass of the LPMG translator and the floater. F_{wave} is the driving force exerted by the waves on the floater, FLG is the force acting on the floater from the LPMG. K_S is the spring constant and K_D is the damping coefficient of the AWS.

B. Wells Turbine Model

The Wells turbine was invented in the mid-1970 by Dr. Allan Wells and it is a self-rectifying axial-flow turbine [12]. The interaction between the waves and the OWC system can be modelled in a Well's turbine by using the obtained airflow velocity. The equations describing the Wells turbine are given as:

The expression for pressure drop across the rotor (in Pa) is:

$$dp = C_a K\,(1/a)[\,v^2 + (r\omega_r)^2\,] \qquad (3)$$

where a is the area of cross section, Ca is the coefficient of power, r is the mean radius, ωr is the angular velocity of rotor and K is a constant (in kg/m) defined as:

$$K = \rho lbn/2 \qquad (4)$$

where *ρ, l, b and n* represents the air density, blade chord length, height of the blade and the number of blades respectively. The total torque of the turbine (in N·m) can be defined as:

$$T_t = rC_t\, K\, [v^2 + (r\omega_r\,)^2] \qquad (5)$$

where Ct is the torque coefficient.

The flow coefficient is defined as:

$$\varphi = vx\,(r\omega r\,)^{-1} \qquad (6)$$

The flow rate can be written as follow:

$$Q = av_x \qquad (7)$$

The performance of turbine is defined as:

$$\eta_t = T_t\, \omega_r\, (dpQ)^{-1} = C_t\, (C_a\, \varphi)^{-1} \qquad (8)$$

Based on the C_t and C_a coefficients, the power and torque values to be produced by the turbine can be calculated [13]. The curves of the power and torque coefficients against the flow coefficient are depicted in Figs. 1 and 2, respectively. These are the characteristic curves of the Wells turbine under investigation.

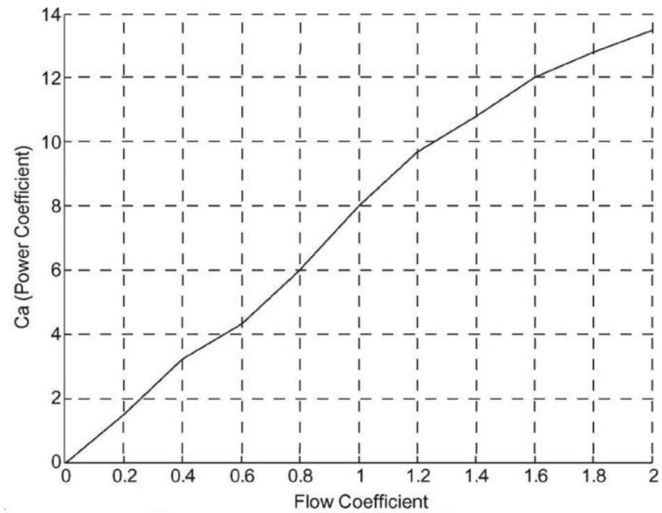

Fig. 1. Power coefficient Vs flow coefficient

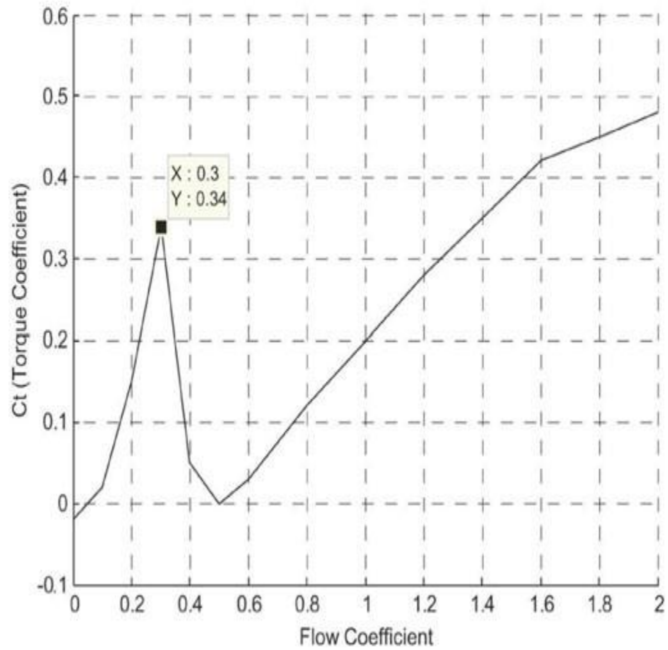

Fig. 2. Torque coefficient Vs flow coefficient

III. ANALYSIS OF RESULTS

The instantaneous output power of the LPMG and speed of the AWS, as shown in Fig. 3, is continuously varied with time as the wave force varies with respect to time. From the result it is found that, the frequency of the speed response and the frequency of the wave force is same while the output power frequency of the LPMG is twice the wave force frequency [11].

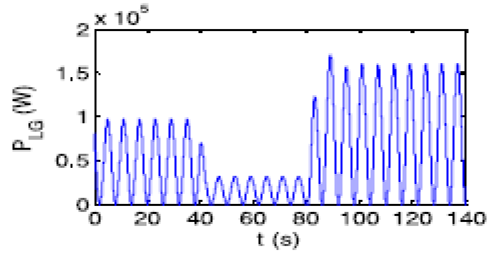

Fig. 3. Generated power versus time (using AWS)

Similarly the simulation has been carried out in Well's turbine based wave power generator and the instantaneous power versus time is shown in Fig. 4, in which the average value of power is also mentioned [12].

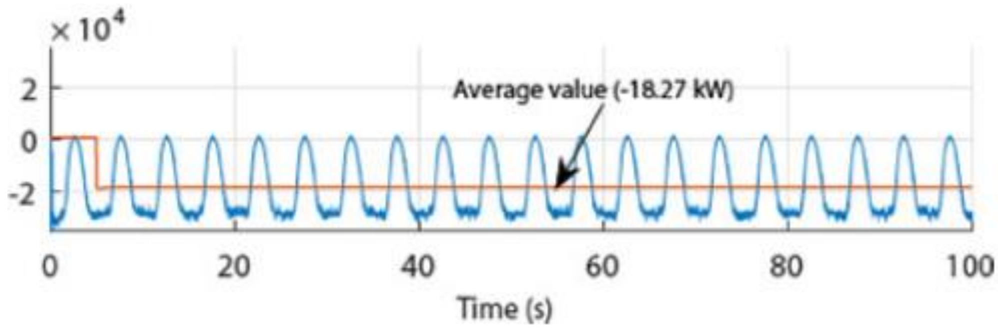

Fig. 4. Generated power versus time (using Well's turbine)

IV. CONCLUSION

In this paper, the two different types of wave energy conversion system, one using the AWS and the other using the Well's turbine were studied in detail. From the study, the performance of the WECS were identified. The linear motion of the wave is directly captured by AWS based system with linear permanent magnet generator whereas it is converted into rotatory motion by Well's turbine based system with synchronous generator. Based on the simulation results obtained in the literature, it is clear that, wave energy conversion system using AWS is more efficient and produces more output power for the same wave frequency when compared with wave energy conversion system using Well's turbine.

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