Optimization of harnessed Energy of an Onshore Wave Energy Converter

***Abstract* – In this work, a new Wave Energy Converter (WEC) system with storage is discussed. The system uses pressurized water to store the energy. KKT optimization technique is applied to find the optimal volume to store maximum energy.**

I. Introduction (&Problem Definition)

Recently, sustainable energy applications for off-grid and rural areas have gained momentum. Wave energy converters have shown effectiveness in terms of electrifying coastal off-grid applications. Easy installation, resiliency against surges, energy storage for delayed use, and mechanical redundancy are considered vital for wave energy converters [1]. This work focuses on economical wave energy converters that can store energy and generate power as needed. Very limited literature is available to address energy storage-based onshore wave energy converters. An integrated approach for wave energy converter utilizing pressurized water-based energy storage is developed in this work. This system has advantages such as high torque, more controllability, and reduced losses.

Proposed device converts sea wave energy into compressed air and then into electricity. Where the proposed device contains three major parts those are single acting pneumatic pump, Air storage tank and a turbine coupled with DC generator. Sea Wave is used to drive the single acting cylinder which will pump the air into the storage tank. Then the air is used to rotate the turbine. Finally, the DC generator will produce electricity. Presented work in [2] has a problem that the efficiency of the system is low due to losses. In order to minimize losses, the storage tank is partially filled with water.

The schematic of the proposed WEC is shown in Figure 1, it consists of a front plate, pneumatic pump, storage tank, and a Pelton turbine. When an incident wave hits on the front plate, it moves the force rod of the pneumatic pump and pumps the air into the storage tank. The storage tank is partially filled with water. As the sea waves continue to pump the air into the storage tank, the tank pressure will increase. When power generation is required, the outlet valve will be opened which will cause the water to flow at high speed into a Pelton turbine thus electricity is produced.

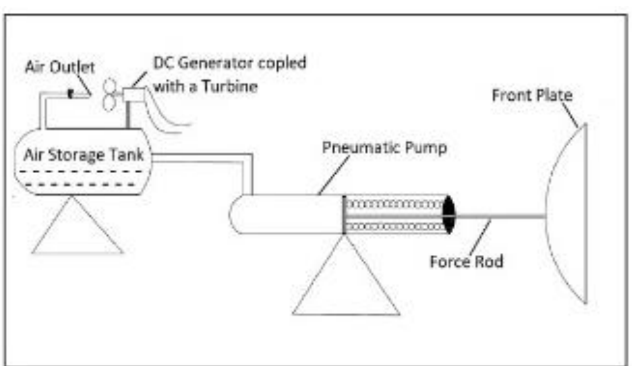


Figure 1

II. Methodology and Analysis

A. Problem formulation

As discussed, in this work energy is stored in storage tank using pressurized water technology. As shown in below figure 2 water is partially filled in the storage tank. Rest of the tank is filled with compressed air. Instantaneous kinetic energy of the outflow water can be written as

$$E = \frac{1}{2}\rho_w A v^3$$

Where ρ is density of the water. A the cross sectional area of the outlet pipe and v is the speed of the out flow water. Objective of this work is to maximize the stored energy in the tank.

The storage tank system in Figure 2 can be considered as iso thermal thermodynamic system since heat capacity of water is much higher than air.

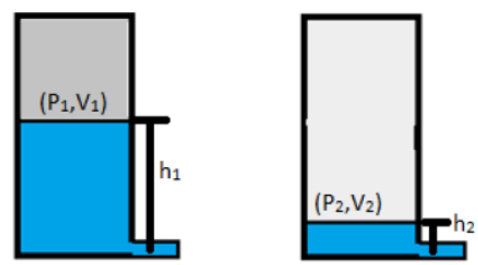


Figure 2

Therefore, the thermodynamic equations can be written as:

$$P_{1t}V_1 = P_{2t}V_2$$

$$W = \int_{V_1}^{V_2} P.dV = \int_{V_1}^{V_2} \frac{nrT}{V}.dV = \int_{V_1}^{V_2} \frac{P_{1t}V_1}{V}.dV$$

$$W = P_{1t}V_1 \ln\left(\frac{V_2}{V_1}\right) \text{ Or } W = P_{1t}V_1 \ln\left(\frac{P_{1t}}{P_{2t}}\right)$$

Where P_1-initial pressure of the stored air, V_1-volume of the air. is density of the water. Work done by the gas is the energy stored in the storage system. objective of a storage system will be to always maximize the stored energy.

$$\max_{P_t,V_w}\{Energy\} = P_t V_w ln\left(\frac{K}{V_w}\right)$$

$$P_t \leq 5$$

$$V_w \leq 10$$

The volume of the water filled cannot exceed the volume of the storage tank and the highest pressure of the storage tank also

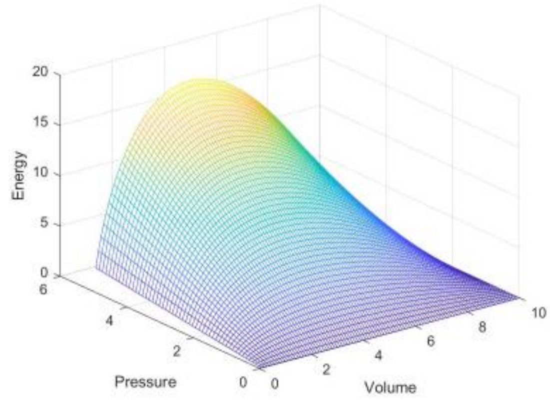


Figure 2

cannot exceed the safety threshold. In this analysis the constraints are taken as maximum pressure 5 Nm^{-2}, and volume 10 m^3. This problem can be considered as nonlinear in equality constrained problem.

Below figure shows the 3d plot of the constrained objective function. It can be seen that that increase in pressure (P_t) will always increase the output energy therefore the objective function can be simplified as

$$\max_{P_t, V_1} V_1 ln\left(\frac{10}{V_1}\right)$$

Simplified objective function plot is shown in below figure.

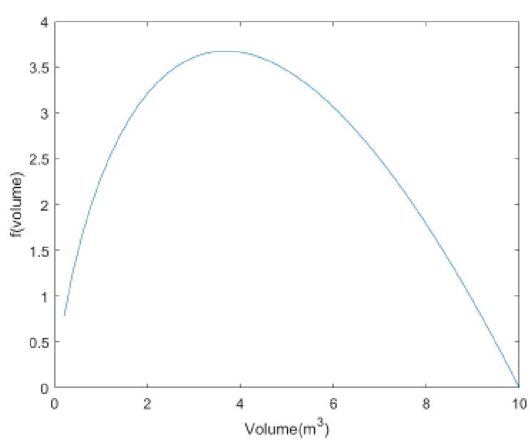
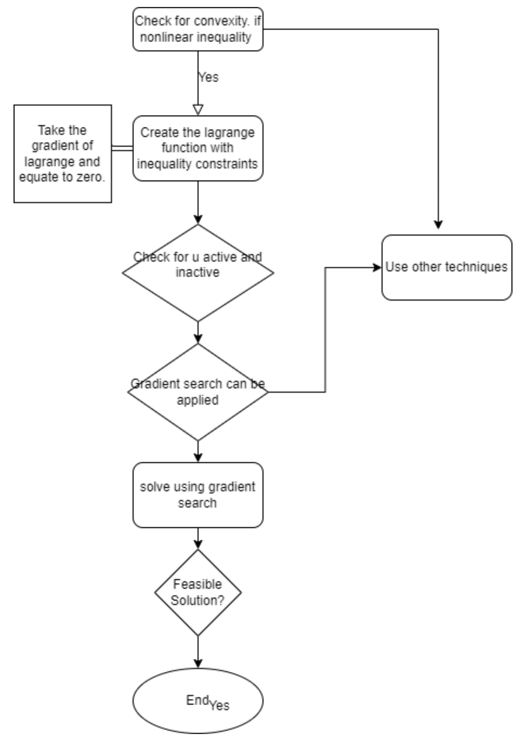


Figure 3

Solution for this function is obtained using KKT method.

$$f(V_1) = V_1 ln\left(\frac{10}{V_1}\right), g(V_1) = 10 - V_1$$
$$\mathcal{L}(V_1, \mu) = V_1 ln\left(\frac{10}{V_1}\right) + \mu(10 - V_1)$$

Solution exists only for μ inactive case and optimum values are obtained when V_1=3.678 m^3 and P_t=5 Nm^{-2}. Maximum energy for this storage value is 1.839 MW. Following steps in the flow chart were followed in obtaining the optimal solution.



Therefore, KKT method provides solution for this optimization problem. Since the simplified function has only one extremum point any gradient search method can be used find the solution. Here the important point to consider is this operating curve will vary for different maximum pressures. Therefore, when the operating range of the pressure changes the objective function also should be changed accordingly.

III. Conclusion

In this work, new type of wave energy converter device with storage system is discussed. Mathematical model for the device is developed and optimization technique is applied to find the optimal operating parameters for storing maximum energy. Combination of KKT method and gradient search method is used to find the optimal solution.

References

[1] Q. Gao, N. Ertugrul and B. Ding, "Analysis of Wave Energy Converters and Impacts of Mechanical Energy Storage on Power Characteristic and System Efficiency," 2021 31st Australasian Universities Power Engineering Conference (AUPEC), 2021, pp. 1-6, doi: 10.1109/AUPEC52110.2021.95978.

[2] S. Sangar, T.Thiruvaran, V.Aravinthan, B.Thanatheeban, "Design of an Onshore Wave Energy Converter Device for Electricity Generation" IESL Annual Conference.203, 2021.