EM-FL-PSO Design Optimization of WAD

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***Abstract*- The feasibility of developing a design optimization environment utilizing an Electromagnetic-Fuzzy Logic, EM-FL, robust identifier for use with Particle Swarm Optimization, PSO, technique is investigated. The developed environment is applied in a case study to increase the electric energy output of a Water Activated Device, WAD, This optimization problem requires accurate mathematical representation of the wave motion and accurate characterization of the key electromechanical components of the WAD, which include a linear actuator constrained by a dual degree of freedom mechanism. The basic objective of maximizing the output of electricity is met through the implementation of a PSO algorithm.**

***Index Terms*--Optimization and Design, Devices and Applications.**

I. Introduction

Much research centered on finding renewable energy alternative sources is being conducted in order to respond to the energy needs and to secure an environmentally friendly and green economy [1]. Ocean energy is one branch of alternative energy that is developing very fast to become a strategic energy resource. However, challenges remain in developing an optimum convertor that can be used to more effectively harness usable electric energy out of the wave oscillating energy. These systems are classified in three types. The first is an Oscillating Water Column, OWC, device which consists of a chamber immersed partially in the water. The oscillating water inside the chamber creates a pressure zone higher than the atmospheric pressure; when discharged it will turn a turbine that generates electricity. The second type is an Overtopping Device, OD, which consists of a reservoir that traps water in. The collected water is then directed to hydro turbine to generate electricity. The third type is known as oscillating body, or Wave Activated Device, WAD, which is a linear electromagnetic actuator where the relative motion between the permanent magnets of the field and the coils of the armature, created by the oscillating ocean wave, will generate the electrical energy [2].

This work proposes an AI fuzzy logic based algorithm to obtain the optimum design of the WAD shown in Fig. 1. The optimization problem is to maximize the terminal voltage V by finding the optimum length of the translator arm and the optimum ratio of the Permanent Magnet, PM, length to the armature winding length, subject to the constraint of minimum PM material. This optimization problem involves conflicting factors as the length of the translator arm has reverse effects on the airgap flux and the field–armature relative motion, respectively. The implementation of the proposed optimization algorithm necessitates the developing of accurate representation of the wave motion, the translator arm motion and accurate modeling of the WAD linear electromagnetic actuator.

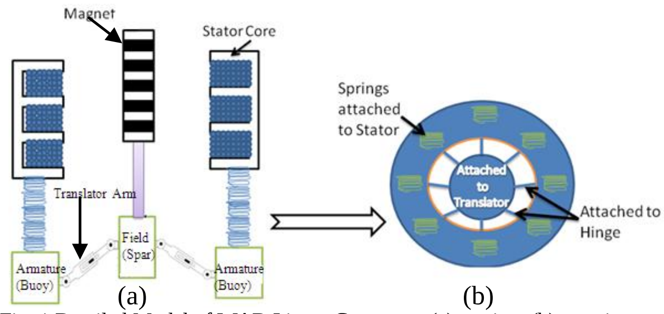

Fig. 1 Detailed Model of WAD Linear Generator: (a) section, (b) top view

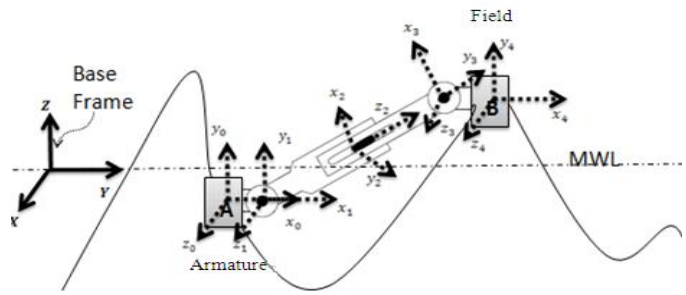

Fig. 2 Armature-Field Translator Arm Relative Motion

II. The WAD System Representation

In the following we present a brief description of a prototype mechanism and the WAD model.

A. System Description

The WAD system, shown in Fig. 1, is basically a linear generator that has a field (spar) and an armature (Buoy). The armature is made up of nonlinear magnetic material and containing slots that hold the winding coils. The field is also made up of nonlinear magnetic material that holds permanent magnets. The WAD translates kinetic motion into linear motion from the wave excitation force. This force moves both the armature and the field. However, these components are connected by mechanical translator arms that constrain the relative motion between them. The relative motion between the permanent magnets and the coils will generate the electrical energy.

B. Wave Motion Representation

Ocean waves are created by the wind which is due to solar and moon activities. The wind exerts pressure (shear stress) randomly on the surface of the ocean leading the ocean water particles to move up and down. Accordingly, it creates a gravity wave. The sun and the moon gravitational forces have also a contribution in creating a tidal wave [2].

For simplicity considers the motion in the x-z plane for which the wave potential is given by:

$$\Phi_{w(x,z,t)} = P(z) * \sin\,(kx - wt) \quad (1)$$

where P(z) is an unknown function of z in the x-z plane given as follows:

$$\frac{d^2P(z)}{dz^2} - k^2P(z) = 0 \quad (2)$$

The corresponding kinematic equations of the wave are as follows:

$$\vec{V} = u\vec{i} + w\vec{k}$$

$$u = \frac{akg}{\sigma}\frac{\cosh[k(z+h)]}{\cosh kh}\cos\theta + \frac{3}{4}\frac{a^2k^2g}{\sigma}\frac{\cosh[2k(z+h)]}{\sinh^3 kh\cosh kh}\cos 2\theta$$

$$w = \frac{akg}{\sigma}\frac{\sinh[k(z+h)]}{\cosh kh}\sin\theta + \frac{3}{4}\frac{a^2k^2g}{\sigma}\frac{\sinh[2k(z+h)]}{\sinh^3 kh\cosh kh}\sin 2\theta \quad (3)$$

And the acceleration is given by

$$\vec{a} = a_x\vec{i} + a_z\vec{k}$$

$$a_x = \frac{\partial u}{\partial t} + \vec{V}^{(1)}\nabla u^{(1)} = akg\frac{\cosh[k(z+h)]}{\cosh kh}\sin\theta + a^2k^2g\left[\frac{3}{2}\frac{\cosh[2k(z+h)]}{\sinh^3 kh\cosh kh} - \frac{1}{\sinh 2kh}\right]\sin 2\theta$$

$$a_z = \frac{\partial w}{\partial t} + \vec{V}^{(1)}\nabla w^{(1)} = -akg\frac{\sinh[k(z+h)]}{\cosh kh}\cos\theta - a^2k^2g\left[\frac{3}{2}\frac{\sinh[2k(z+h)]}{\sinh^3 kh\cosh kh}\cos 2\theta - \frac{\sinh[2k(z+h)]}{\sinh 2kh}\right] \quad (4)$$

where $k=\frac{2\pi}{\lambda}$, h is the height from seabed, θ is the angle on the wave, a is the acceleration.

C. *Translator Arm Model*

The wave exciting force and the hydro mechanical force acting upon the floating structure will lead to a relative movement between the armature and the field. This relative motion is constrained by the translator arm holding the armature and the field together as shown in Fig. 2.

The kinematic equations of the floating structure shown in Fig. 2 are as follows:

$$\vec{V}_B = \vec{V}_A + \vec{W}_{AB} * \vec{r}_{AB} + \vec{V}_{AB} \quad (5)$$

$$\vec{a}_B = \vec{a}_A - W_{AB}^2\,\vec{r}_{AB} + 2\vec{W}_{AB} * \vec{V}_{AB} + \vec{a}_{AB} \quad (6)$$

It is to be noted that both the velocity, V_A and V_B, and the acceleration, a_A and a_B, are derived from the wave equation (1) and (2). Hence the only unknowns are the relative velocity V_{AB} and the relative acceleration a_{AB}.

D. *Linear Electromagnetic Actuator Model*

The governing state space equation of the Linear Electromagnetic Actuator is as follows:

$$V = L\frac{dI}{dt} + (R + \frac{dL}{dt})I \quad (7)$$

where, the output voltages are represented by vector V, the armature winding currents are represented by vector I, the winding resistance are represented by matrix R and the armature windings self and mutual inductance are represented by matrix L. The main parameters of this equation are the armature windings self and mutual inductances. These inductances are computed from a series of nonlinear finite element magnetic field solutions [3].

III. EM-FL-PSO Algorithm and Results

The objective of the proposed algorithm is to maximize the terminal voltage by varying the length of the translator arm and finding the optimum ratio of the permanent magnet length to the armature winding length, subject to the constraint of minimum PM material. This optimization problem involves conflicting factors as an increase of the translator arm length will increase the relative motion between the field and the armature but will reduce the air gap flux. The above objectives are modeled as fuzzy membership functions. The parameters of these functions are obtained from a rule base knowledge derived from the ocean wave data. The above objectives are achieved by utilizing an integrated FL-PSO algorithm shown in Fig. 3 which utilizes the robust EM-FL identifier described above. In the proposed algorithm, the fuzzy inference system, ANFIS, is applied to determine the search space of the PSO and the control parameters of the proposed cross-mutated operation by using rule base system. The EM based state space, equation (7), is utilized to train the FL-ANFIS. Next, the PSO coupled with a cross-mutated operation method is used for the search of the optimum design vector. The results of applying the proposed algorithm to the WAD system of Fig. 1 are shown in Fig. 4. Full details and more results will be presented in the paper.

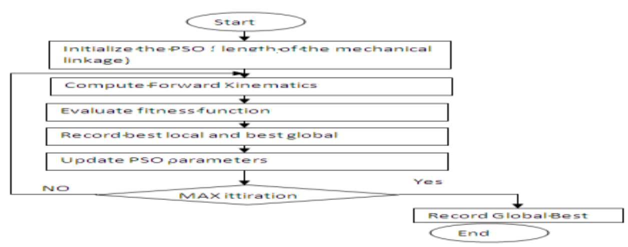

Fig. 3 EM-FL –PSO flow chart

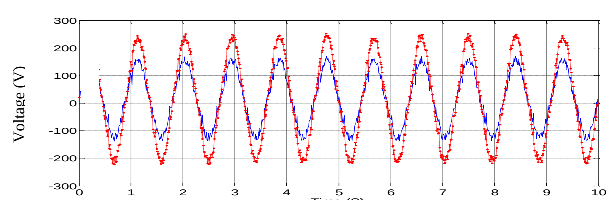

Fig. 4 Phase Terminal Voltage: Initial design (-), Optimized Design (-●-)

REFERENCES

[1] M.H. Nehri, "*A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications,*" IEEE Trans. on Sustainable Energy, Vol. 2, Issue 4, PP 392-403, Oct 2011.

[2] J.A. Revilla, "*Application to Fluid Mechanics: Water Wave Propagation*", EOLSS, section Physical Sciences, Engineering and Technology Resources, Chapter 5, 2002.

[3] N. Al-Aawar, T.M. Hijazi and A. A. Arkadan, *"Particle Swarm Optimization of Coupled Electromechanical Systems,"* IEEE Trans. on Magnetics, Vol. 47, No.5, PP. 1314-1317, 2011.

[4] M.W. Song, S. Hutchinson, M. Vidyasaqar, *Robot Modeling and control*, Wiley, edition 1, ISBN 0471649902, 2005.