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ANFIS based hybrid solar and wave generator for distribution generation to grid connection

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ABSTRACT

With a long coastal border of about 7500 Kms, India would need an efficient option of hybrid power generation in the coastal region. Abundant availability of wave power and sunlight due to its closeness to equator makes it clear base for power generation from wave generator and the solar power. This paper develops the implementation, which combines both the wave generator and the PV array for a hybrid power delivery controlled using Adaptive Neuro Fuzzy Inference Engine (ANFIS) controller. The super capacitor is used for higher efficiency compared to batteries. It absorbs power and delivers power fast, where it is more important in wave generation as the power and voltage is not stable. The power delivery improvement in this hybrid system while different controllers like the PI and the ANFIS controller is analysed. There is a higher power delivery improvement when ANFIS controller is chosen.

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1. INTRODUCTION

On an average about 23% of the energy produced in India has lost in the transmission and distribution losses [1]. Thus, to prevent such highly pronounced losses a distributed generation of power has to be considered. The higher potential of tidal power improve the chances of usage of wave generators in the coastal regions throughout coastal India. The Sea Wave Energy Conversion system (SWECS) would become an important source remote power generation alternative along with the Photovoltaic Array (PV array) based implementation. The research on the SWECS is in full throttle in a couple of decades [2]. Different types of the SWECS techniques are discussed in detail [3]. Turbine type, Bouy type and the Archimedes Wave Swing (AWS) types of SWECS techniques are discussed [3]. Among all the SWECS techniques AWS is more advantageous which is totally submerged inside the sea and the linear motion of the conversion system would be useful in generating the power by means of Maxwell theory [4]. Few literatures [5-10] are few major contributors in the development of the linear generators using AWS technique. Many problems regarding the linear generators has been solved in [6] which is noticed in the previous literatures. The permanent magnet linear generators are classified as Tubular and Flat [11]. The generators are termed as Linear Permanent Magnet Generators (LPMG).

This paper attempts to carry out a performance analysis of the different control methods like the PI controller and ANFIS controller on the Hybridisation of the LPMG with the PV array. The parameters like the power delivery are optimized by the use of the ANFIS implementation. Hybrid solar and LPMG wave generator are made as hybrid with control of maximum power transfer, super capacitors and ANFIS controller are used.

This paper which is the improvement of the previous works [1]-[3] is organized as follows, the Section –II has the description about the Mathematical Modeling of the solar and the LPMG, Section –III discusses about the ANFIS controller and hybridisation of both PV array and LPMG, Section-IV examines the results and discussion with inference of the different methods, and it is followed by the conclusion and references.

2. MATHEMATICAL MODELING OF PV ARRAY AND LPMG MODEL

In order to develop the simulation of the hybridised model of both the PV array and the LPMG the mathematical equivalent of both the model is developed. In this paper, single diode model of the PV array is used and that are connected with series and parallel to get the required voltage and power. The single diode model is as shown in the Figure 1.

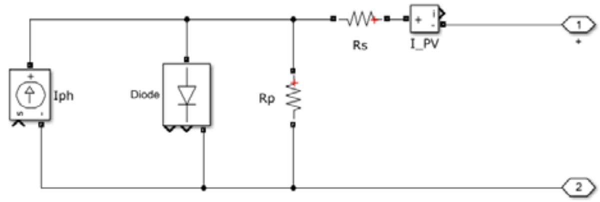

Figure 1. Single diode model -PV cell

The single diode model would generate the voltage and the current at the output by considering the current source in the input with the diode in parallel to the current source for generating the equivalent voltage and current if a variable irradiation is supplied to the PV cell, which would generate the current that is proportional to current supply. The important portion that needs to be calculated in the PV model is the current through the diode since other parameters can be calculated by applying KVL and KCL.

The diode current is derived as

$$I_d = I_{sat} * e^{\frac{V_d}{V_T}-1} \quad (1)$$

$where\ , I_d - Diode\ current\ (A)$
$V_d - Diode\ voltage$
$I_{sat} - diode\ saturation\ current\ (A)$
$V_T - temperature\ voltage\ (V)$
$R_s - Series\ resistance\ in\ ohms$
$R_p - Paralell\ resistance\ in\ ohms$

The circuit output gives voltage and current of a single cell photovoltaic. The analysis of generator performance under constant speed operation is done using generator equivalent circuit shown in Figure 2. If the speed is constant, power generated depends on the load impedance. It is assumed the load impedance to be a pure resistive RL [11]. In this case output power is shown below,

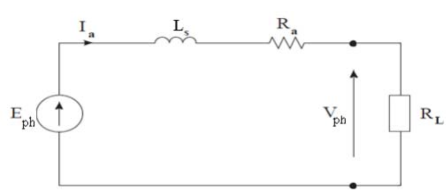

Figure 2. Steady state equivalent electrical LPMG model

$$P_{out} = 3 * R_l \ | (I_a)^2 | \quad (2)$$

The armature currents I_a can be determined from voltage equation:

$$E_{ph} = V_s + I_a R_a + j2\pi f L_s I_a \tag{3}$$

$where:$
$E_{ph} - phase\ induced\ votlage$
$X_s - Synchronous\ reactance$

$$X_s = 2\pi f L_S \tag{4}$$

$f - frequency\ calculated$ average speed
L_s – is the field inductance
R_a – armature resistance
R_l – load resistance (R_L)
The current is

$$I_a = \frac{E_{ph}}{(R_L+R_a)+j2\pi f L_a} \tag{5}$$

Here L_a is armature inductance
The emf E_{ph}, which is induced in the armature winding is given by:

$$E_{ph} = \frac{E_{ph\,m}}{\sqrt{2}} \tag{6}$$

Where the amplitude of the voltage is

$$E_{ph\,m} = M_s . W_s . N_{ph} B_m U_{av} \tag{7}$$

$M_s - number\ of\ armature$
$W_s - Number\ of\ turns\ per\ phase$
$B_m - Flux\ density\ in\ the\ airgap\ under\ the$
$permenant\ magnet\ obtained\ from\ FEM\ simulation$
$U_{av} - Average\ Speed, which\ changes\ sinusoidally\ in\ time. thus\ it\ is$

$$U_{av} = \frac{2}{\pi} u_m \tag{8}$$

where u_m is the speed amplitude.

The above equations are take as Simulink model and used with a voltage source and buck converter for testing in simulations.

3. IMPLEMENTATION PROCEDURE AND CONTROLLER DETAILS

The block diagram in Figure 3 represents the complete test bed of the grid-connected system. The solar and wave generator are the inputs given to the two boost converters and a buck converter respectively. The solargives lesser output voltage and higher output current. So, boost converter is used to achieve required voltage at DC-link. Wave generator produces higher output voltage and lower current so buck converter is chosen with voltage and current control. From DC link to converter produces the DC to AC conversion, which is connected to the grid via transformer. The rating of the diagram is given in Table 1.

Table 1. ANFIS rules

Error \ change in error	High	Medium	Low
High	Medium	Low	High
Medium	Medium	Low	High
Low	Medium	Low	High

3.1. ANFIS Controller

The logic controller is used for making the decision of duty cycle to optimize the power. The output of conventional Incremental (IC) controller is calculative as it is equation-based output. The fuzzy logic can be programmed to achieve better results compared to IC controller. In Figure 3 IC controller, which is replaced with ANFIS controllers.

Here de-fuzzification method used is weighted average method and sugeno type fuzzy inference system. It is used to fix the output problems in IC controller. The rules table is shown below. A 3X3 rule table is used here. But here the sugeno output is a constant fixed constant variable to adjust the duty cycle.

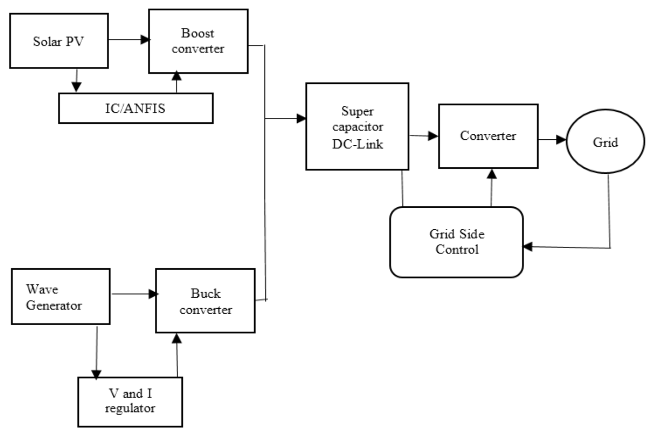

Figure 3. The complete block diagram of the test bed

The fuzzy inference system used for ANFIS also where the rules are adjusted according to the backpropagation method of neural network. This neuron trains the fuzzy inference system to improve the power.

4. RESULTS AND ANALYSIS

4.1. IC Controller Results

The solar power generation and wave generator are connected as cascaded and hybrid then it is connected to grid. The power generated by river and solar is connected to grid for supplying power. The super capacitors are used for stabilizing the DC supply.

Figure 1 shows the solar PV cell model. Figure 2 shows the LPMG model. Figure 3 shows the complete proposed block diagram. Using IC controller, Figure 4 shows the solar irradiance, Figure 5 shows the input solar power in watt. Figure 6 depicts Voltage in Grid in V. Figure 7 shows the Current in Grid in A. Figure 8 shows the Power at grid. Figure 9 Voltage of wave generator (rectified). Figure 10 shows Current of wave generator (rectified). Figure 11 shows the Terminal Voltage in V, Induced Current in A & Phase current in A of wave generator. Figure 12 shows the Wave Generator Power in wattage. Figure 13 shows the super capacitor current, voltage and state of charge (SOC). It can be seen that fast-dynamic charging and discharging is happening due to the ripples in wave generation. Figure 8 shows the power delivered to the grid, which can be increased by using ANFIS controllers.

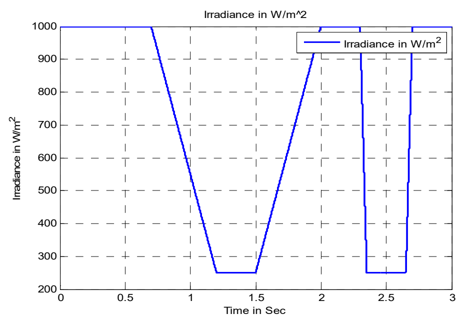

Figure 4. Solar irradiance

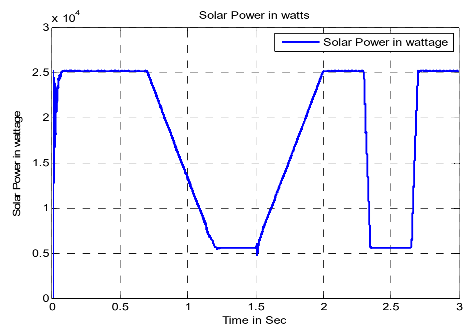

Figure 5. Solar power in watt

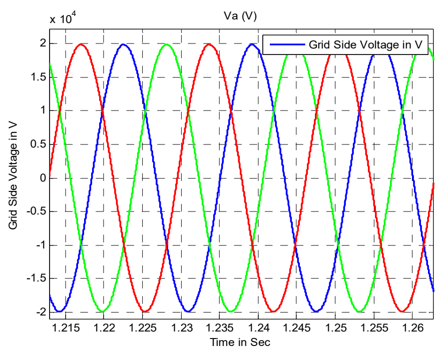

Figure 6. Voltage in grid in V

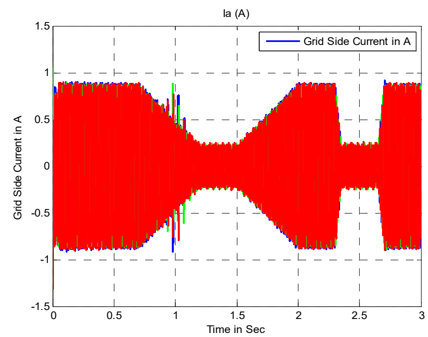

Figure 7. Current in grid in S

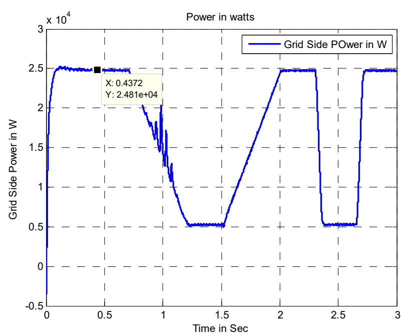

Figure 8. Power at grid

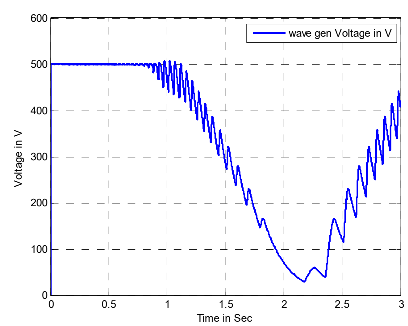

Figure 9. Voltage of wave generator (rectified)

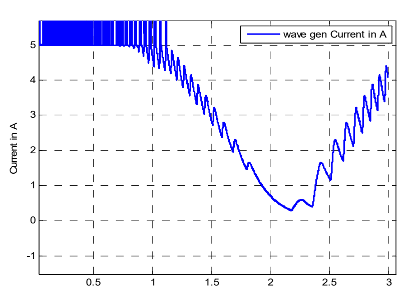

Figure 10. Current of wave generator (rectified)

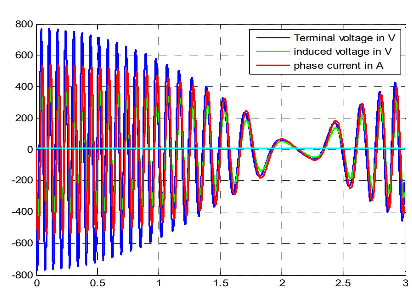

Figure 11. Terminal voltage in v, induced current in a, phase current in a of wave generator (PI)

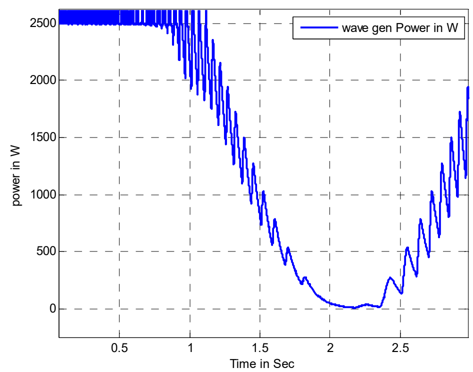

Figure 12. Wave generator power in wattage

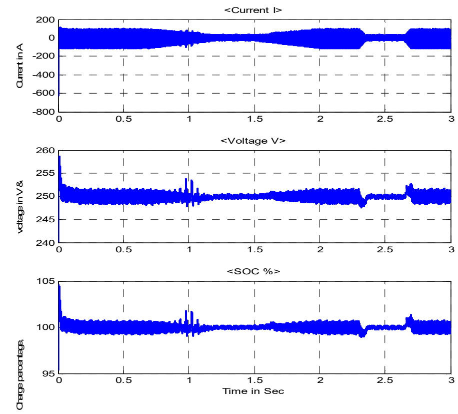

Figure 13. Super capacitor (I, V and % of SOC)

4.2. ANFIS Controller

After adding the ANFIS controller the Figures of 4-6 and 9-13 remains same as IC controller but the power sent to the grid Comparing Figure 8 and Figure 15, which is increased using ANFIS controllers. The power generation **24.81 Kw** is sent to grid with IC controller. That is increased to **25.28Kw** in ANFIS controller.

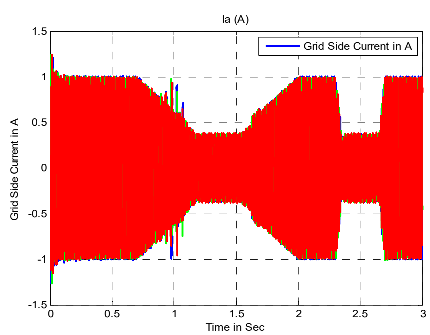

Figure 14. Voltage in grid in v

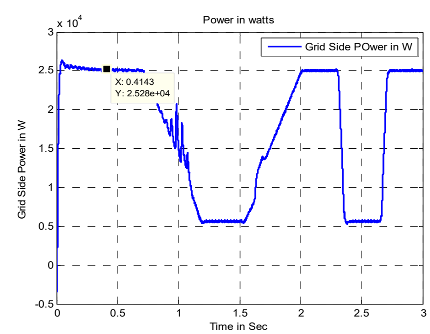

Figure 15. Current in grid in

The **0.41 Kw** is extracted more from the solar due to ANFIS MPPT controller. By seeing Figure 14. and compared with Figure 7 it can be seeing that current passed towards the grid is increased. Due to the change in waves and solar irradiance the power change is created.

Table 2. Specifications

Solar details	Parameters
Module type	SunPower-SPR-305-WHT
Number of cells/module	96
Series connected module/string	5
number of parallel strings	17
Voc (V)	64.2
Isc (A)	5.96
Vmp (V)	54.7
Imp (A)	5.58
wave generator details	
Voltage in V	500
Current in A	8
Power in Watts	2000

5. CONCLUSION

The usage of intelligent technique in hybrid operation of solar andwave generator connected to the grid is done with super capacitors for good power tracking of solar and dynamic performance of wave generator. Which combines to provide improvement in the overall power absorption. The simulation results prove the same that 0.41KW power is improved by using ANFIS controller and dynamic performance also good comparatively. So, ANFIS gives good performance in hybrid power generations.

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