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Energy Management of Grid Connected Hybrid Solar/Wind/Battery System using Golden Eagle Optimization with Incremental Conductance

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Abstract. Renewable Energy Sources (RES) are currently being used on a much larger scale to support and satisfy the higher energy demands caused by industrialization and population growth. Due to this rise in the number of consumers of power systems and the unpredictable nature of the electric load, the vast power demand proves to be a tough challenge for electric utilities and system operators. So, power demands have occurred over many periods and become a threat to the system's functionality. Therefore, an effective Energy Management System (EMS) name called Golden Eagle Optimization with Incremental Conductance (GEO-INC) is proposed to meet the load demand. Three different systems, namely: RES Photovoltaic (PV) module, wind turbine, and battery create an effective EMS. The proposed method extracts more power from the PV panel and effectively controls the switching between the wind turbine and the battery storage system. The proposed method achieves 1.98 % distortion from the results, which is less than the existing methods.

Keywords: Battery, Energy Management System, Golden Eagle Optimization, Incremental Conductance, Photo-Voltaic and Wind Turbine.

1. Introduction

Nowadays, Renewable Energy Sources (RES) are used widely to fulfill the higher power demand of the modern world. The usage of non-renewable energy sources is gradually decreased due to the impacts of global warming and the usage of RES [1]. The different types of RES are tidal power, the solar, wind, hydroelectric, and geothermal energy [2]. Also, the PV systems have various benefits like lack of noise, deficiency of fuel cost, high dependability, and simplicity in allocation [3]. The major drawback of the RES is mainly dependent on the topological condition of certain sites and its outputs are sporadic [4]. The major challenges faced in the RES-based EMS are: wind and solar are omnipresent and environmentally friendly in nature. The EMS process is quite difficult due to the formation of continuous variation in RES and variable loads [5].

The organization of this research paper is presented as follows: The literature survey of existing research related to the PV/wind/battery system is presented in Section 2. The PV/wind/battery system issues are discussed in Section 3. Section 4 offers the objectives of this research. The proposed EMS system using the combination of GEO-INC is discussed in Section 5. The comparative results of the GEO-INC are presented in Section 6. Finally, the conclusion is drawn in Section 7.

2. Literature Review

A thorough literature study about PV, Wind, and Battery EMS was carried out.

Mandal [6] presented a Meta dynamic Flower Pollination Algorithm (MFPA). Kumar [7] introduced a control algorithm for EMS between PV/Wind/Battery systems. Mostafa Bouzi [8] has introduced Perterb and Observe (P&O). Nitai Pal [9] has demonstrated Incremental Conductance (INC). BOUCHIBA et al. [10] presented

MPPT methods. Satish Kumar et al. [11] has been shown an efficient energy management system for a small-scale hybrid source-based micro-grid to test the functionality of the distribution system. Sharma et al. [12] demonstrated 3IMPL (Three Phase Improved Magnitude Phase Locked Loop). In contrast, Satish Kumar et al. [13] showed an effective EMS for a small-scale hybrid source-based micro-grid to verify the distribution system's functionality.

3. Problem Statement

Current issues of the EMS are stated in this section, and it describes how the proposed methodology gives the solution to this problem. The problem of the EMS is:

- The use of a single renewable energy source such as wind or solar energy is inadequate to meet the demand for long periods due to the high cost of the system as well as the storage subsystem
- Inappropriate selection of parameters in RES material and design, constraints of load, generator, battery, converter, and cost function, so the system performance has been decreased.
- Under varying every hour and everyday weather conditions, the optimum number of facilities to use the average hourly data may not be able to be supplied without outages over a year.

4. Objectives

- To analyze and evaluate the renewable energy potential mainly for those two resources, solar and wind, at different load conditions;
- To assess the technical feasibility of a hybrid solar-wind-battery power system to meet the load requirements.
- To analyze the effect of load size or load variation by extending the combination of the hybrid energy systems.

5. Proposed Methodology

The block diagram of the grid-connected RES with the proposed GEO-INC controller is presented in Figure 1.

This diagram clearly shows that the proposed controller receives the input power from the three and the load demand of the grid. While processing the input values, it provides the required randomness to the control variables, suitable for the study of MPPT. After calculating those control variables, the proposed controller produces the proper duty cycle, which triggers the multi-level inverter and extracts the maximum power.

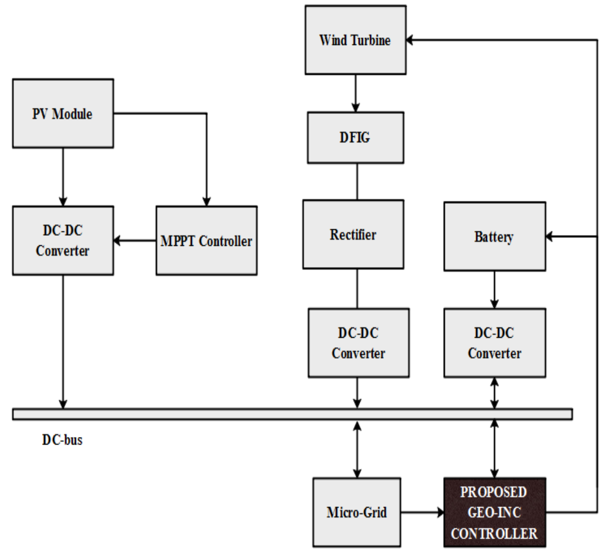

Fig. 1. Block Diagram for the proposed method

A. Golden Eagle Optimization (GEO)

The proposed mathematical approach for simulating the motions of golden eagles hunting for prey is described in this subsection. The golden eagle attack vector may be estimated using i Equation (1).

$$\overrightarrow{A_i} = \overrightarrow{X_f} - \overrightarrow{X_i}\,, \tag{1}$$

where eagle i attack vector is stated as $\overrightarrow{A_i}$; best position is signified as $\overrightarrow{X_f}$; present situation is indicated as $\overrightarrow{X_i}$. In j-dimensional space, equation (2) shows the scalar form of the hyperplane equation.

$$h_1x_1 + h_2x_2 + \cdots .. h_nx_n = d \rightarrow \sum_{j=1}^{n} h_jx_j = d \tag{2}$$

$$\sum_{j=1}^{n} a_jx_j = \sum_{j=1}^{n} a_j^t x_j^* \tag{3}$$

Using Equation (4), discover the fixed, variable value.

$$c_k = \frac{d - \sum_{jj\neq k} a_j}{a_k}\,, \tag{4}$$

where c_k is the destination point $c\ of\ k$-th element, a_j is the j-th element of the attack vector $\overrightarrow{A_i}$, d is the right-hand side of the Equation (2). The general representation of the destination point on the cruise hyperplane is shown in Equation (5).

$$\overrightarrow{C_i} = \left(c_1 = random, c_2 = random, \ldots c_k = \frac{d - \sum_{jj\neq k} a_j}{a_k}, \ldots, c_n = random\right) \tag{5}$$

In Equation (6), the step vector for golden eagle i in the iteration is mentioned as,

$$\Delta x_i = \vec{r_1} P_a \frac{\vec{A_i}}{\|\vec{A_i}\|} + \vec{r_2} P_c \frac{\vec{C_i}}{\|\vec{C_i}\|}, \tag{6}$$

where golden eagles are affected by attack and cruise in iteration t, where p_a^t is the attack coefficient in iteration t, and p_c^t is the cruise coefficient in iteration t. The Euclidean norms of the attack and cruise vectors ($\|\vec{A_i}\|$and$\|\vec{C_i}\|$) are determined using Equation (7).

$$\|\vec{A_i}\| = \sqrt{\sum_{j=1}^{n} a_j^2}, \|\vec{C_i}\| = \sqrt{\sum_{j=1}^{n} c_j^2} \tag{7}$$

The position of the golden eagles in iteration $t + 1$ is calculated simply by adding the step vector in iteration t to the places in iteration.

$$x^{t+1} = x^t + \Delta x_i^t \tag{8}$$

The linear transition shown in Equation (9) can be used to calculate intermediate values.

$$\begin{cases} P_a = P_a^0 + \frac{t}{T} |P_a^t - P_a^0| \\ P_c = P_c^0 + \frac{t}{T} |P_c^t - P_c^0| \end{cases}, \tag{9}$$

where t denotes the current iteration, T represents the maximum iterations, P_c^0 and $indicate$ote the starting and final values for propensity to attack (p_a), respectively. It's worth noticing that Equation (9) modifies the parameters linearly.

B. Incremental Conductance (INC)

According to the literature, the P&O approach is the most effective and widely used MPPT procedure for achieving maximum power. The proposed IC is designed to overcome the drawbacks of the traditional P&O approach. Here, MPP is attained using the association between $\frac{\partial I}{\partial V}$ and $-\frac{I}{V}$, as stated in Eq. (10).

$$P = V\ I \tag{10}$$

After taking the derivative on Eq. (10) at both sides at MPP, the Eq. (11) is written as:

$$\frac{\partial P}{\partial V} = 0 \tag{11}$$

Therefore, the Eq. (12) will be expressed as:

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \tag{12}$$

So this Eq. (12) is used for controlling the duty cycle of a boost converter. Then, MPPT controls the PWM signal of the inverter until the maximum power is reached.

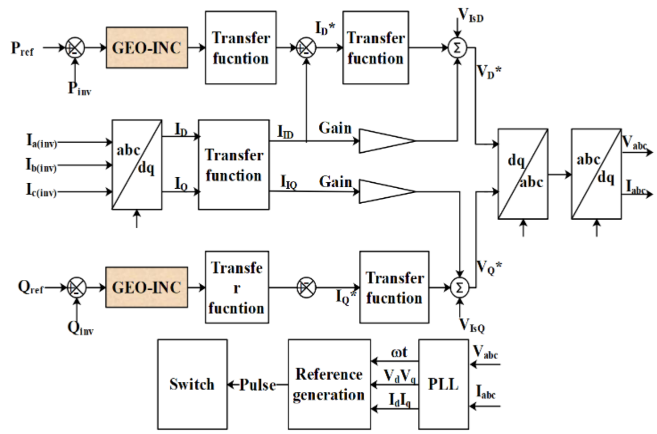

Fig. 2. The control circuit of the proposed controller

Figure 2 depicts the control circuit proposed for this PV/wind/battery system. When there is a change in power due to a disturbance of the reference voltage or variation in the sunshine, the suggested GEO-INC efficiently controls the PV module.

6. Result and Discussion

The outcomes of this investigation were validated using MATLAB software. MATLAB R2018a is used to implement and simulate the GEO-INC controller in the grid-connected RES, which runs on a Windows 8 operating system with an Intel Core i3 processor and 4GB RAM. The suggested GEO-INC is tested in simulations to ensure that the proposed control technique has a compensatory impact under varied irradiation situations. This research designs different schemes of a hybrid system (solar energy, wind energy, and battery).

In the simulation, GEO parameters such as population size are considered 200, an iteration count is taken as 200, attack propensity is deliberated as 2.5, and archive size is accepted as 100. Figure 3 displays the proposed model. The duty cycle value is altered due to the correct scaling factor, allowing the PV to reach the peak point and extract maximum power.

A. Performance analysis

The performance of the GEO-INC controller in grid-connected RES is carried out using three integrated controllers: P&O, INC, and GEO-P&O.

1) MPPT Current and Voltage

Figures 4 and 5 depict the results of the MPPT voltage and current measurements. The suggested GEO-INC controller has greater MPPT current/voltage values and increased system performance in both stable and dynamic states, as shown in Figures 4 and 5.

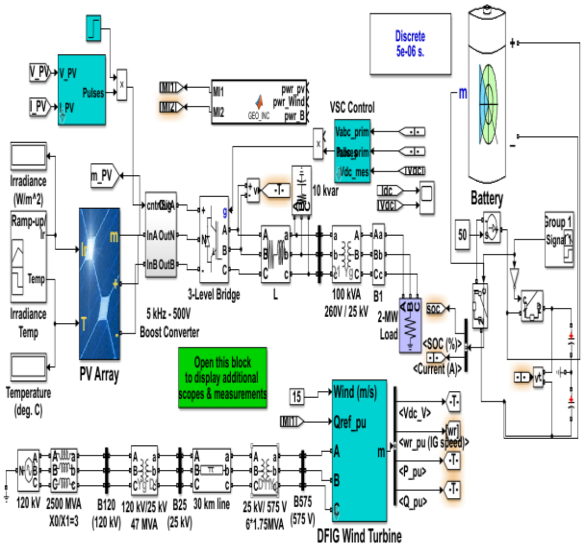

Fig. 3. Simulink view of the proposed model

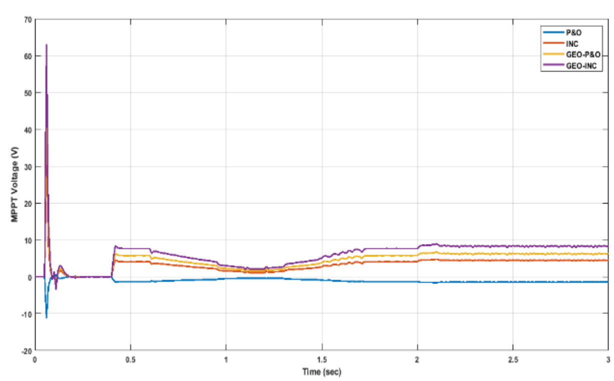

Fig. 4. Voltage on MPPT

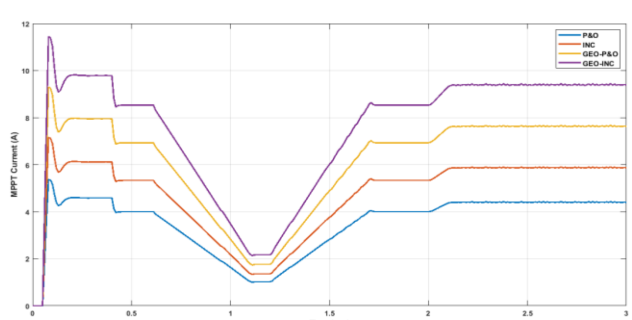

Fig. 5. Current on MPPT

2) Grid voltage

Figure 6 represents the grid voltage in graphical form, whereas Figure 7 depicts the grid voltage between 0.92 *s* and 1.04 *s*.

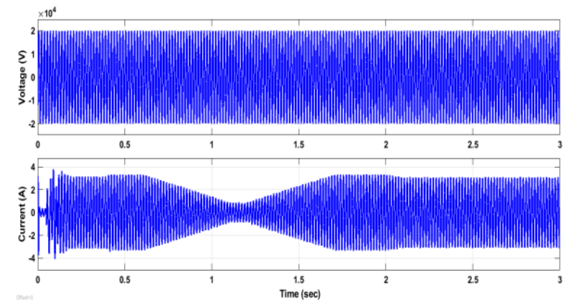

Fig. 6. Grid voltage

Figure 7 indicates that the proposed GEO-INC produces more voltage when compared to traditional demand compensation systems.

3) Real and Reactive power

Figures 8 and 9 show the real and reactive power established through the utility grid.

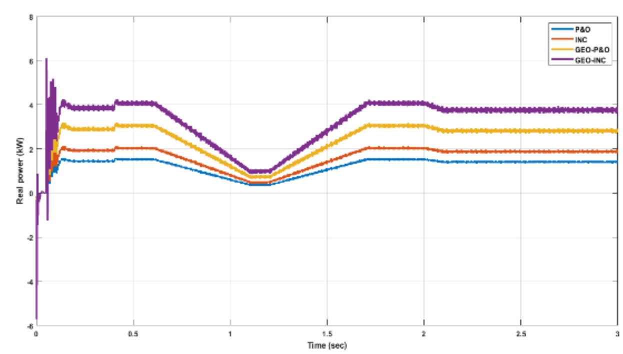

Fig. 7. Real power

Figures 7 and 8 indicate that the GEO-INC controller outperforms conventional techniques.

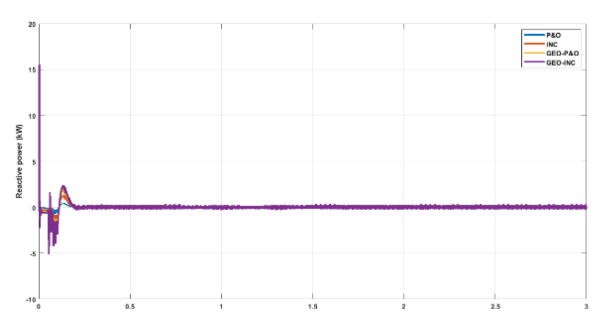

Fig. 8. Reactive power

As a result, the suggested GEO-INC controller can meet the increased energy demand of the grid.

B. *Comparative analysis*

The effectiveness of the GEO-INC is carried out to validate the system with the GEO-INC to earlier RES designs. The proposed GEO-INC control is compared to the current 3IMPL [12] and 3MPLL [12] control algorithms to illustrate the uniqueness of control techniques.

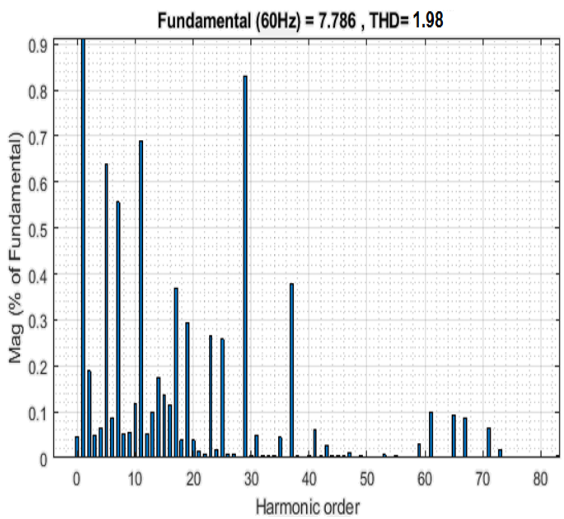

Fig. 9. FFT Analysis

Table 2 shows the results of the THD comparison. Harmonics are present in the magnitude component of 3IMPL [12], measured as 4.8 % and 3 %.

Table 2. Comparative Analysis of THD

Techniques	THD (%)
3MPLL [12]	4.8
3IMPL [12]	3
P&O [8]	5.1
INC [9]	4.9
GEO-P&O	3.1
Proposed GEO-INC	1.98

The suggested GEO-INC control estimates fewer harmonics, as shown in Figure 9. Figure 10 depicts a visual representation of the THD comparison

Table 3 shows the comparative analysis of PV power, Wind power, and Battery power. Table 3 indicates that the proposed GEO-INC achieves higher power generation than the existing controller [13], which attains less power generation only.

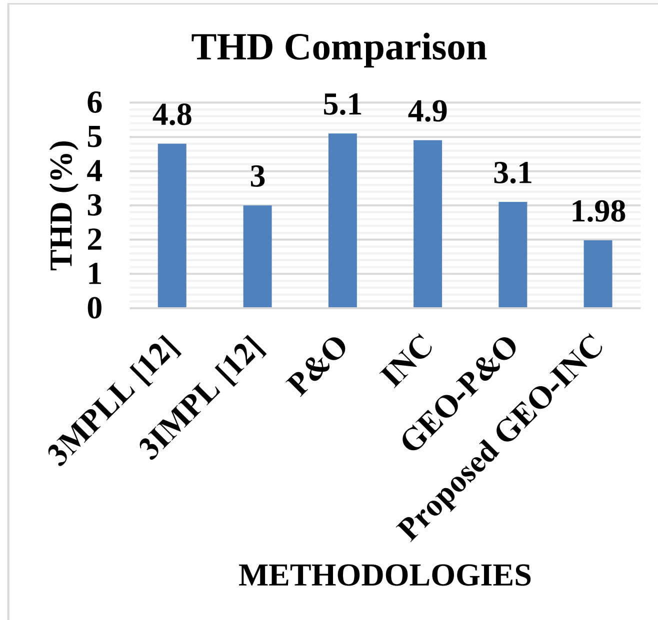

Fig. 10. Graphical illustration of THD comparison

Table 3. Comparison of Power Generation

Time (Min)	PV Power (W)		Wind Power (W)		Battery Power (W)	
	MPPT Controller [13]	Proposed GEO-INC	MPPT Controller [13]	Proposed GEO-INC	MPPT Controller [13]	Proposed GEO-INC
0	50.00	67.78	35.00	50.62	2.0	19.12
10	54.26	69.28	42.18	52.35	-22.2	2.72
20	54.26	70.08	42.18	54.71	-43.1	1.37
30	54.26	70.27	42.18	55.10	-43.1	3.48
40	54.26	76.25	42.18	57.19	-22.1	2.51
50	54.26	76.25	42.18	57.19	2.9	8.70
60	54.26	76.25	42.18	57.19	16.13	19.68
70	54.26	76.25	42.18	57.19	22.24	26.81

7. Conclusion

Renewable Energy Sources have gained popularity due to their quantity, availability, and ease of harnessing for electrical power generation. The GEO-INC approach will construct an effective EMS using a PV/wind/battery system in this research. The modulation index from the suggested GEO-INC approach was used to govern an effective switching between battery and wind. The simulation results demonstrate that the proposed GEO-INC generates more electricity and has a THD of 1.98 % than the existing 3IMPL approaches.

This research work can be extended in the future to test the EMS under various climatic circumstances using multiple hybrid methods.

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