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A NOVEL METHOD USING IMPERIALIST COMPETITIVE ALGORITHM (ICA) FOR CONTROLLING PITCH ANGLE IN HYBRID WIND AND PV ARRAY ENERGY PRODUCTION SYSTEM

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Abstract- With growing concerns on energy issues, the development of renewable energy sources is going to more attractive. But the amount of power attainable from these natural resources will vary continuously from place to place depending on its geographical locations, altitude and climatic conditions. Therefore the energy supplied from these sources are not sustainable, thus this hybrid system must be connect to support system. This paper first reviews both of wind power and photovoltaic (PV) power generation techniques and maximum-power-point-tracking (MPPT) method of PV. Then a novel method by using imperialist competitive algorithm (ICA) is proposed to stabilize the wind generator in high and low speed of wind. This article focuses on modeling a photovoltaic connected to variable speed wind turbine based on Synchronous Generator (SG) and support with distribution system. Finally, the results obtained from imperialist competitive algorithm (ICA) are compared with PID controller optimized by Particle Swarm Optimization (PSO) algorithm.

Keywords: Wind Turbine, Photovoltaic (PV), Imperialist Competitive Algorithm (ICA), Particle Swarm Optimization (PSO) Algorithm, MPPT, 12-Pulse Inverter, Optimal Control.

I. INTRODUCTION

With enhancement concerns about environmental pollution and possible energy lack, great works have been taken by the governments surrounding the world to do renewable energy programs, established on Hydropower, Biomass/Bioenergy, Geothermal Energy, Wind Energy, Photovoltaic (PV) Cells, etc [1]. Wind power is one of the most encouraging clean energy sources since it can be captured easily by wind generators with high power capacity. Photovoltaic (PV) power is another encouraging clean energy source since it is global and can be harnessed without using rotational generators [2].

The modern development of wind turbine systems began in the 1980's with sites of a few tens of kilowatts to multi-megawatt range wind turbines today. e.g., Denmark has a high penetration (20%) of wind energy in major areas of the country and in 2004 16% of the whole electrical energy consuming was covered by wind energy [3]. Wind energy has appeared again as one of the most important maintainable energy resources, partly because of the increasing price of the fossil fuels such as oil and safety worries of nuclear power and its environmental issues. Moreover, as wind energy is opulent and it has an infinite potential, it is one of the best and modern technologies to provide a maintainable electrical energy supply to the world development [4].

There are two types of utility-scale wind turbines: fixed- and variable-speed [5]. This article focuses on variable-speed. In the wind turbine systems for production energy both synchronous and induction generators can be used. In this article a synchronous generator has been utilized to produce wind power. In the 21st century solar energy has become one of the important types of renewable energy resources. A photovoltaic (PV) system converts sunlight to electricity straightly when the photons of the sunlight hit on the PV array. The performance of a solar PV array is powerfully relying on operational requirements, like the sun's geometric location, the ambient temperature and its irradiation levels of the sun [6].

Photovoltaic for power generation is considered the ideal resource in distributed generation systems, which are located at or nearby the load point. A single PV cell, being too small for accessible power applications, it is usually connected as series or parallel combinations to give a required voltage and current so called PV module. PV modules can be joined in series or parallel to make a PV array. The DC output voltage is converted into AC at standard frequency. The PV system application can be used as stand-alone, grid connected or hybrid [7].

In this paper, a new approach using imperialist competitive algorithm (ICA) is presented for optimizing the generator produced power by tuning pitch angle during changes in wind speed (which is made by approximating mechanical and electrical power). This work will increase the efficiency of wind generators.

The paper is organized as follows. In section 2, modeling of photovoltaic generation is explained briefly. Modelling of wind turbine is described in section 3. In Section 4, intelligent parameter estimation based on imperialist competitive algorithm (ICA) is demonstrated. In Sections 5 the results are discussed.

II. MODELING OF PHOTOVOLTAIC GENERATION

In this paper a PV solar cell has been modeled which is connected to set up boost DC-DC converter. The Maximum Power Point Tracker (MPPT) is used to ensure that the PV system always operates at the MPP. Also in this article for feeding 3-phace AC load, a 12-pulse inverter has been used to reduce the voltage THD. Photovoltaic cell is a non-linear device and can be depicted as a current source in parallel with a diode [8], [9]. The model of practical PV cell (Figure 1) contains the complex connection of series and parallel interior resistance, namely R_s and R_p, which is extracted as the following equations [10, 11]. For a real apply, BP340 PV data sheet has been used, the electrical characteristic of this data sheet is presented in Tables 1 and 2.

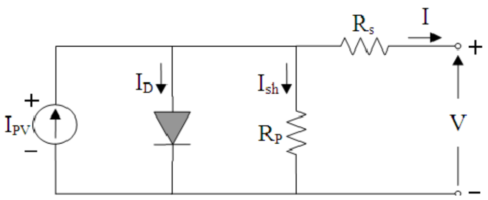

Figure 1. Circuit model of PV solar cell

$$I = I_{PV,cell} - I_0 \left(e^{\left(\frac{V + R_s I}{a V_t} \right)} - 1 \right) \tag{1}$$

$$I_{PV,cell} = (I_{PV,n} + K_i \Delta t) \frac{G}{G_n} \tag{2}$$

$$I_0 = \frac{I_{sc,n} + K_i \Delta t}{e^{\left(\frac{I_{sc,n} + K_i \Delta t}{a V_t} \right)} - 1} \tag{3}$$

Table 1. Electrical characteristic of BP340 PV module

Parameter	Variable	Value
Maximum power	P_{mpp}	40 W
Voltage at P_{max}	V_{mpp}	17.3 V
Current at P_{max}	I_{mpp}	2.31 A
Short-circuit current	I_{sc}	2.54 A
Open-circuit voltage	V_{oc}	21.8 V
Temperature coefficient of open-circuit voltage	K_v	–(80±10) mV/°C
Temperature coefficient of short-circuit current	K_i	(0.065±0.015) %/°C

Table 2. Parameters of PV model

R_s	0.46
R_p	239.41
$I_{sc,n}$	2.54
$I_{pv,n}$	2.5448
$V_{oc,n}$	21.8
T	25 ºC

A. Model of Boost Converter

Figure 2 shows the schematic diagram of a Boost converter; the output voltage of PV model is connected to the boost converter to raise the PV voltage for supplying three phase 12-pulse inverter. The output voltage of converter is determined by Equation (4). The output of boost converter with the parameters in Table 3 is connected to MPPT for maintaining PV in maximum power.

$$V_{out} = \frac{1}{1-D} V_{in} \tag{4}$$

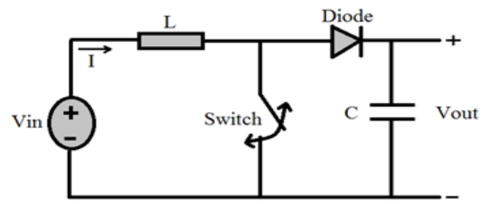

Figure 2. The schematic diagram of a boost converter

Table 3. Parameters of boost converter

Switching frequency	20 KHz
Inductor	20 mH
Capacitor	6 mF

B. Maximum Power Point Tracker

The PV module produces the current-voltage characteristic by a singular point which is known as the Maximum Power Point (MPP). MPPT is essential to ensure that the PV system always operates at the maximum power [8]. In this article, P and O technique of MPP algorithm has been used; Figure 3 shows the flowchart of this system. This algorithm compares the measured power in the prior cycle with the power of the current cycle to determine the next direction. If the operating point passes the peak of power and diverges to the right side of the P-V characteristic curve, at the next moment the power will decrease thus, the direction of the disturbance reverses.

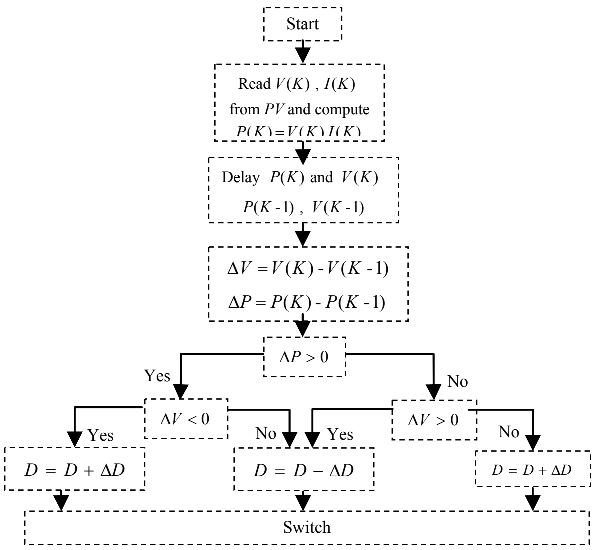

Figure 3. The flowchart of P and O technique of MPPT algorithm

C. Pulse Width Modulated Inverter Model

For converting a dc input into a 3-phase ac output, various circuit topologies and control methods can be used. An ordinary circuit-topology is a voltage-source inverter which is shown in Figure 4. In practice, the 12 pulses inverter and 6 pulses inverter have more application between multi-level inverter. Hence, in this paper a 12-pulse inverter has been used. The advantage of 12-pulse inverter toward the other types of inverters (such as 6 pulse inverter) is lower THD. This advantage is derivated of the number of waveform level. The waveform level in 12 pulses inverter is more than 6 pulses inverter and this causes the output waveform to be close to sinusoidal [12, 13]. The amplitude of the inverter output voltages is controlled by tuning the amplitude of the DC control voltages [12]. The output of photovoltaic system connected to the wind turbine in parallel. In the next part the method of wind turbine modeling is described.

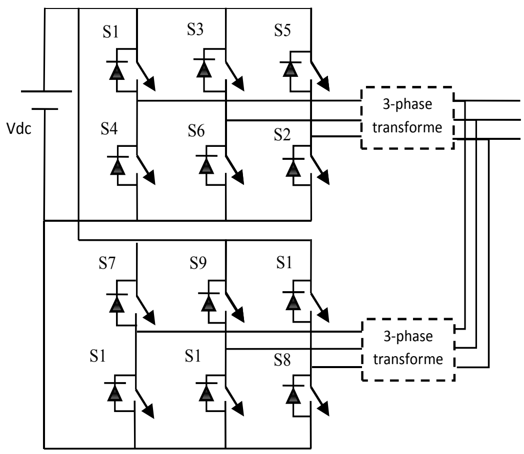

Figure 4. Simulating circuit for 12-pulse inverter using two 6-pulse inverter

III. MODELING OF WIND TURBINE

A variable wind speed turbine system established on a synchronous generator (SG) has been analyzed in this work; the present work considers a variable wind speed from 13.5 m/s to 9 m/s; the base speed is 11 m/s. The power extracted from the wind is determined by the following equations.

$$P_w = \frac{1}{2} C_p \rho A V \omega^3 \tag{5}$$

$$C_p = \frac{1}{2}\left[\frac{116}{\lambda_i} - 0.4\theta_P - 5\right] e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \tag{6}$$

$$\lambda = \frac{\omega_w}{v_\omega} R \tag{7}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\theta_P} - \frac{0.035}{\theta_P^3 + 1} \tag{8}$$

θ_P is the angle between the plane of rotation and the blade cross-section chord [14, 15] which is shown in Figure 5. The Figure 6 shows the model of the wind turbine implemented. The production power of wind generator is directly related to the wind speed. Since most wind power production is produced at high speed, a half of the energy produced by wind turbines is produced in only 15% of working time. As a result, wind power plants are not sustainable like fuel energy production. The information is shown in Table 4. The wind power generators installations must use a system to support the power generator for the time that wind turbine produces energy is low. In case of adjusting pitch angle in order to control wind turbine produced power in high and low wind's speed, a novel method using Imperialist Competitive Algorithm (ICA) is presented. In the next part ICA is explained.

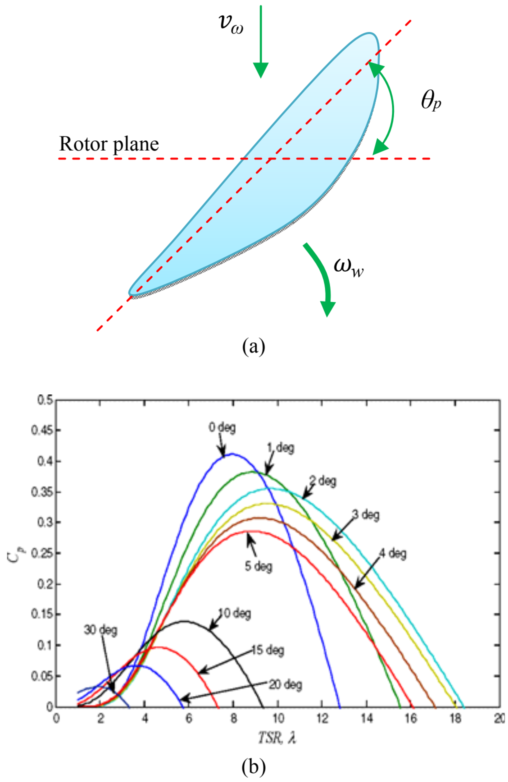

Figure 5. (a) Blade pitch angle θ_P - (b) Power coefficient versus blade pitch angle

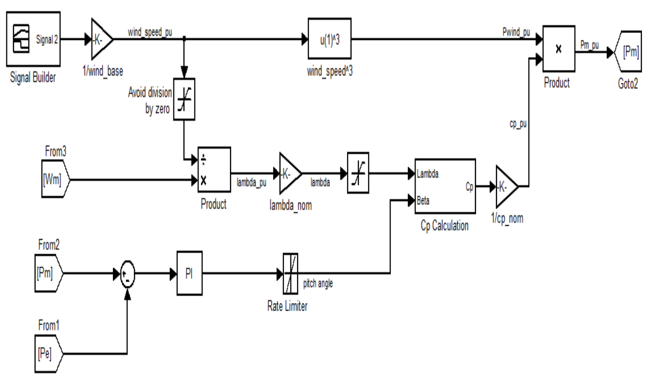

Figure 6. Wind turbine modeled with Simulink

Table 4. Parameters of wind turbine model

Wind Base	11
Lambda Nom	8.11
C_p Nom	0.48

IV. INTELLIGENT PARAMETER ESTIMATION BASED ON IMPERIALIST COMPETITIVE ALGORITHM (ICA)

Imperialist Competitive Algorithm (ICA) is a novel global search investigative that uses imperialism and imperialistic competition process as a source of inspiration like other evolutionary ones, this algorithm starts with an initial population.

In this algorithm each individual of the population is called a country. Some of the best countries in the population are selected to be the imperialist states and all the other countries form the colonies of these imperialists. All the colonies of initial population are divided among the mentioned imperialists based on their power which are inversely proportional to their cost. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist country. This movement is a simple model of assimilation policy that was perused by some imperialist states [16, 17]. Figure 7 shows the flowchart of the proposed algorithm.

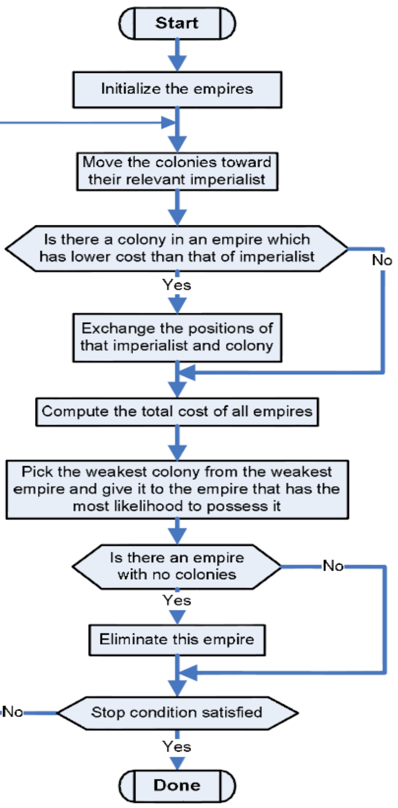

Figure 7. Flowchart of the ICA algorithm

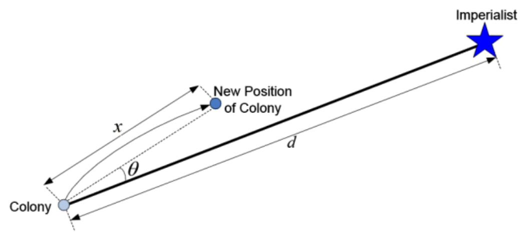

Figure 8. Colonies movement into their relevant imperialist

Figure 8 shows the motion of a colony into its relevant imperialist. In this motion, θ and x are random numbers with uniform distribution as demonstrated in Equations (9) and (10).

$$X \sim U(0, \beta d) \quad (9)$$

$$\theta \sim U(-\gamma, \gamma) \quad (10)$$

where β is a positive number less than 2, d is the space between the imperialist and its colony and order the derivation from original direction [17, 18]. In this paper β and γ are considered as 1.5 and 0.3, respectively. The objective function for optimization by ICA algorithm is presented as below:

$$\int_0^{t_{sim}} t\left|\Delta p(t)\right| dt \quad (11)$$

V. SIMULATION RESULTS

This hybrid system model is fed into a three phase of 3.5 MW load. Nominal wind speed of wind turbine is 11m/s and wind speed between 9 m/s and 13.5 m/s is considered. The production of photovoltaic system is 800 KW and wind generator is produced 1.5 MW. Power transmitted from transmission line is 1.5 MW. The parameters used in this paper are given as below.

Figure 10 shows the hybrid energy production system which simulated in this paper. In this paper 2 control methods (PI-ICA and PI-PSO) are compared for damping power oscillation with together. Table 5 shows the necessary information for PSO algorithm [19, 20].

Table 5. PSO's parameter setting

Population size	40
C_1	2
C_2	2
W	0.9
Iteration	10

Figure 11 shows schematic of pitch angle control system. In this paper, a novel method using ICA is presented for optimizing the generator produced power by tuning pitch angle during changes in wind speed (which is made by mechanical and electrical power are approximately). This work will increase the efficiency of wind generators.

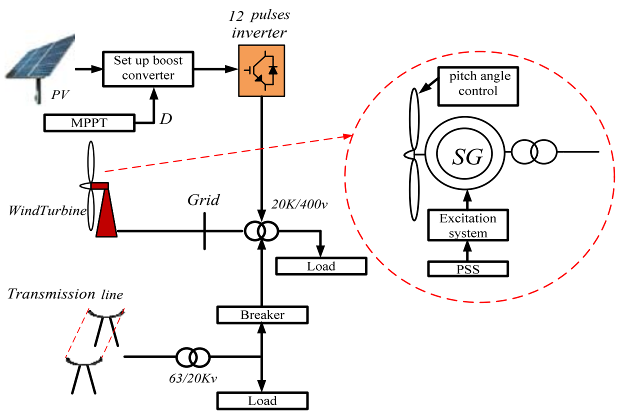

Figure 10. Wind generator and photovoltaic hybrid systems with transmission line

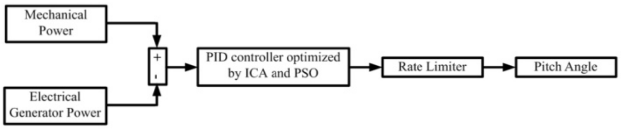

Figure 11. Pitch angle control with PID-ICA and PID-PSO

Figure 12 shows the intensity of solar irradiance in a day. To perform the simulation easily this radiation is in the period of 10 seconds. Figure 13 shows duty cycle curve changes by MPPT for maintaining the maximum power output of solar cells. When the solar irradiance is low, duty cycle has been increased to compensated solar cells production power shortage and vice versa.

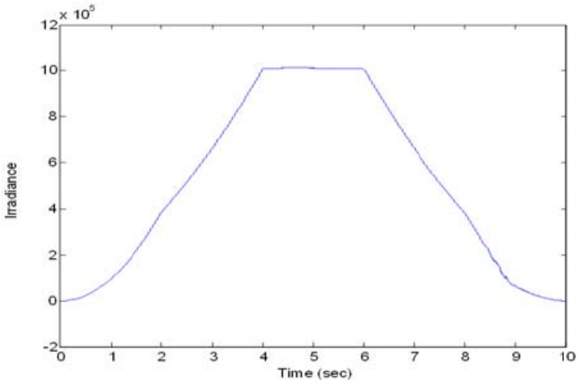

Figure 12. Intensity of solar irradiance

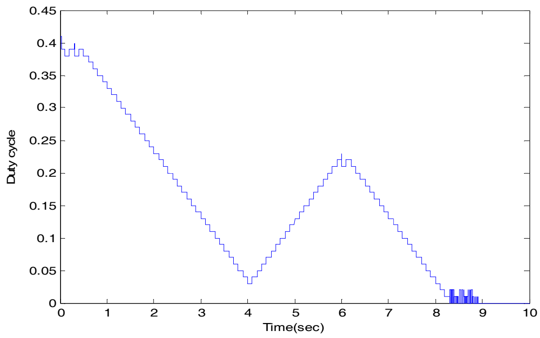

Figure 13. Boost converter duty cycle

The output voltage of the inverter and the frequency of the production system are shown in Figures 14, 15 respectively; the output of this voltage has 380 V in magnitude and the frequency of the produced system is 60 Hz in value (with a little swing). Figure 16 shows current output inverter that produced by photovoltaic cells. Figure 17 shows Total harmonic distortion (THD) of 12-pulse inverter output voltage. Cycloid changes of the rotor speed in generator are shown in Figure 18.

According to Figures 18, 19 and 21 at 4s sudden drop in wind speed, rotor speed is reduced and with pitch angle control rotor speed returned to 1 pu. At 7s wind speed returned to previous value, rotor speed is increased and with pitch angle control rotor speed returned to 1 pu; as it can be seen in diagram, after an optimize control of the pitch angle, and approximating the mechanical power produced with wind and electrical power of generator, motor speed swings is damped and the rotor speed is maintained in 1 pu.

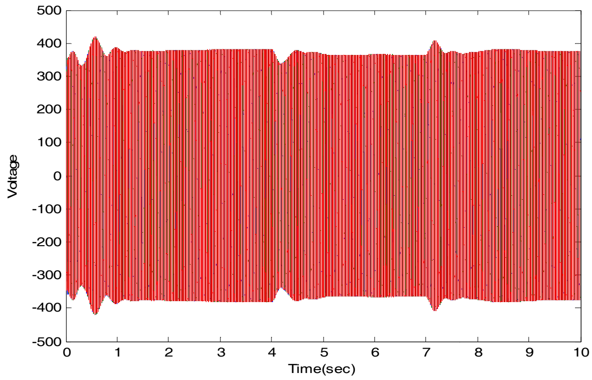

Figure 14. Voltage output inverter

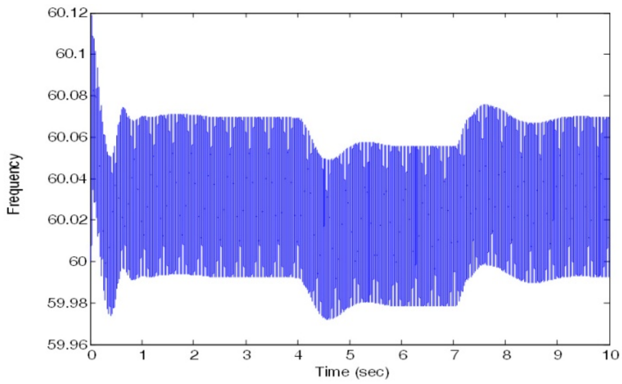

Figure 15. System frequency

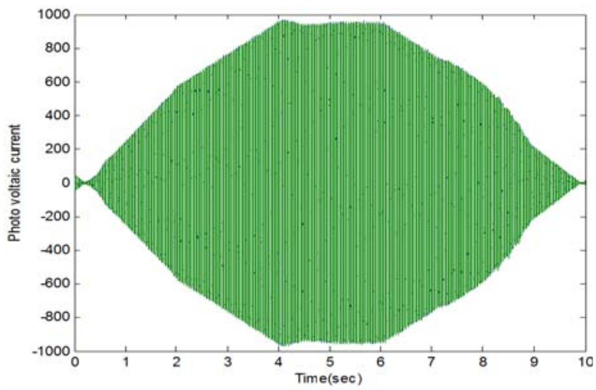

Figure 16. Current output inverter

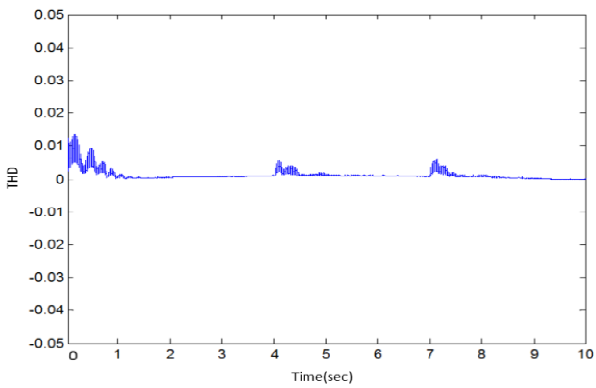

Figure 17. Load voltage THD

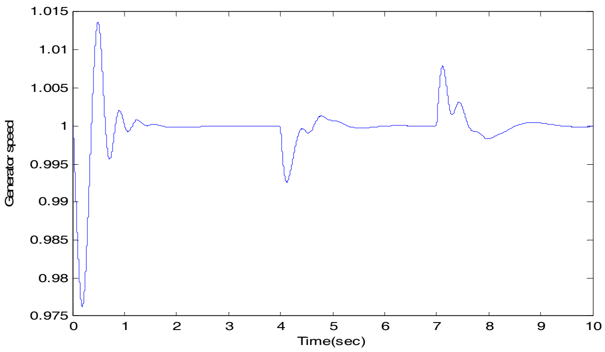

Figure 18. Generator rotor speed (pu)

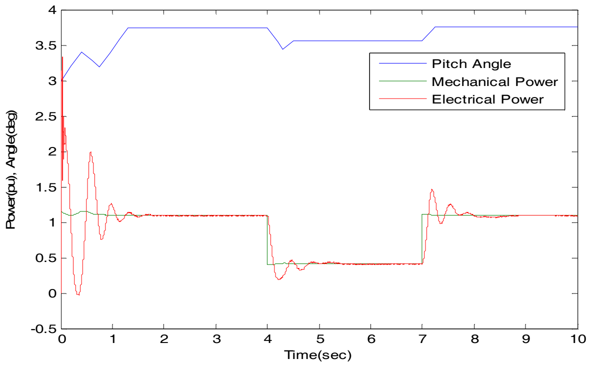

Figure 19. Mechanic and electric power (pu) by ICA for controlling pitch angle (deg)

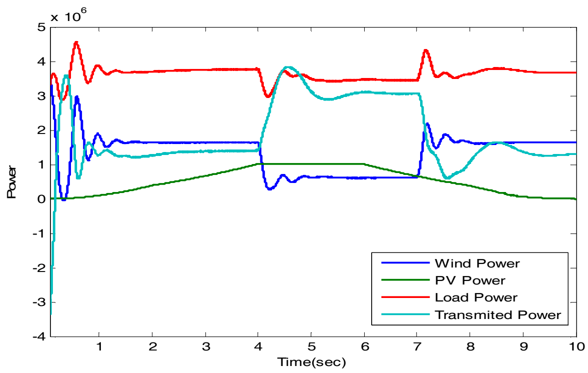

Figure 20. Power produced from PV, wind generator, and transmission line

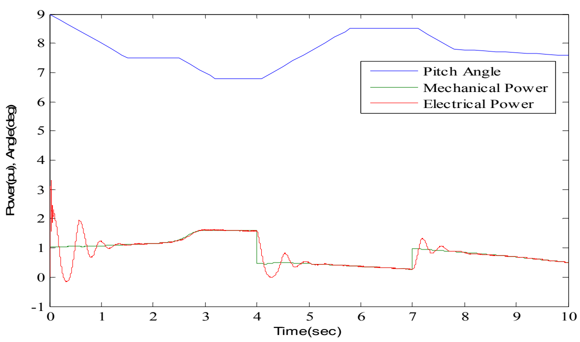

Figure 21. Mechanic and electric power (pu) by PSO for controlling pitch angle (deg)

Produced power from PV, wind generator, transmission line and the load consumption power are shown in Figure 20. In second 4, when the wind speed is reduced from 13.5 m/s to 9 m/s wind turbine power production is decreased and for supplying the load, the rest of power is transmitted by support system. In Figures 19 and 21 it can be seen that the performance of the ICA is better than PSO in order to close the mechanical and electrical power. The ICA could control the production Power with Minimum fluctuation in pitch angle; this makes increasing the marginal stability of the generator in high wind speeds. According to Figure 21 the PID controller optimized by PSO is able to control the production power with the gradual increase or decrease of pitch angle. At the end of simulation time, pitch angle value in PID-ICA is 3.7 deg and in PID-PSO is 7.7 deg that shows the marginal stability of the generator in ICA method is more than the PSO in different wind speed.

VI. CONCLUSIONS

In this paper a hybrid energy production system presented with PV array and wind turbine with pitch angle optimal control by Particle Swarms Optimization (PSO) and Imperialist Competitive Algorithm (ICA). MPPT was used to operate PV in maximum power.

With pitch angle control by using ICA in high and low wind speed, mechanical power and electrical power were closed to together. This caused to operate wind generator in higher efficiency. Results showed that ICA could control the production power with minimum fluctuation in pitch angle; this makes to increase the marginal stability of the generator in high wind speeds. This paper found that the marginal stability of the generator in ICA method is more than PSO in different wind speed. Nowadays because of expensive fossil fuels, using of renewable energy sources makes the cost of consumed electricity to decline. It also diminishes the detrimental effects of fossil fuels delivered to the environment significantly.

NOMENCLATURE

I : Photovoltaic output current

I_{pv} : Current which produced by the incident light

V_t : Thermal voltage of array with Ns cells connected in series

I_o : Diode saturation current

a : Diode ideality constant

K : The Boltzmann constant (1.3806503 e−23 J/K)

q : Electron charge (1.60217646 e−19 C)

T : Temperature of the p-n junction in the unit of Kelvin

G_n : Integral of the spectral irradiance extended to all wavelengths of interest (1000 W/m^2)

T_n : Nominal temperature (25 °C)

R_s : Series interior resistance

R_p : Parallel interior resistance

D : Duty cycle

ρ : Air density, which is equal to 1.225 Kg/m^2 at sea level at temperature T = 25 °C

C_p : Power coefficient

A : Area swept by the rotor $A=\pi\times R^2$, R the radius of the blade (m)
v_w : Wind speed
ω_W : Angular velocity of rotor (rad/s)
v_ω : Wind speed upstream of the rotor (m/s)
R : Rotor radius (m)
θ_P : Pitch angle (°)

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BIOGRAPHIES

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