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Research paper

Design of genetic algorithm controller to fuel cell fed SEIG derived by DC motor

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Abstract

This paper presents new method for driving Self-Excited Induction Generator (SEIG); DC motor is used for drive the SEIG as a prime-mover which feed from Fuel Cell (FC) via DC-DC buck converter. FC is considering one of the promising renewable energy. The SEIG loaded by external load. Two control loops has been designed to enhance the performance of the proposed system to normalizing speed of DC motor, both controller are designed using hybrid Proportional Integral (PI) based on Genetic Algorithm (GA); the first control loop used to control the output voltage of the buck converter by controlling the gating signals of the convertor to adjust the speed. The second controller regulates the hydrogen gas flow rate (i.e. fuel composition ratio of the fuel cell) with regard to the error signal of speed. The speed response of DC motor and the output power of the generator are investigated under many load conditions. Based on simulation results it is observed that the controllers provide robust adjusting for speed, beside the output voltage of the generator is pure sine wave beside its very little content of harmonics and thus the amplitude of Total Harmonic Distortion (THD) is 0.42% which considered is very low.

Keywords: *Induction Generator; Fuel Cell; Genetic Algorithm; Proportional Integral Controller Direct Current Motor*.

1. Introduction

The primary advantages of a SEIG with capacitor bank (especially in squirrel-cage rotor) over a standard synchronous generator are: absence of brushes in construction, rugged rotor construction, minor size and low cost, no DC power supply for excitation, almost nil maintenance, and superior transient performance [1-2]. The idea of SEIG has been recognized then the 30s of the past century. Afterward the researchers and scientists from all completed the world have amplified their attention in the SEIG for enormous abilities for renewable energy resource. The SEIGs are progressively careful for remote renewable power sources micro-hydro turbine and wind - turbine system [3]. FC consider as one of the effectively renewable power source; compared with other renewable energy sources, such as micro-hydro turbine and wind-turbine system, FCs has the benefit that which can be set at any location in the electrical system, without any geographic restrictions as it doesn't be influenced by on the climate factors (water flow rate in hydro turbine, and wind speed which affected on wind turbine generator system)[4].Thus in this work, the FC is used for supply-ing DC motor and the last is operate as a driver for the SEIG instead of the micro-hydro turbine or wind turbine system. There are a lot of additional advantages of the FC as it generates energy with zero carbon emission, and low audible noise [5].

2. Scope of the work

In this work, the FC has been used as an electrical energy source, which fed to separately excited DC motor by the use of step down DC-DC buck converter; this motor directly used to rotation the three phase SEIG that connected to three phase resistive load as presented in the block diagram for the planned system in Fig. 1. Two control loops have been designed to enhance the performance of the system: the first one is to control the output voltage of the buck converter by controlling the gating signals of the convertor, and the second is to control the fuel composition ratio of the FC. These loops are designed based on a hybrid PI / GA controller.

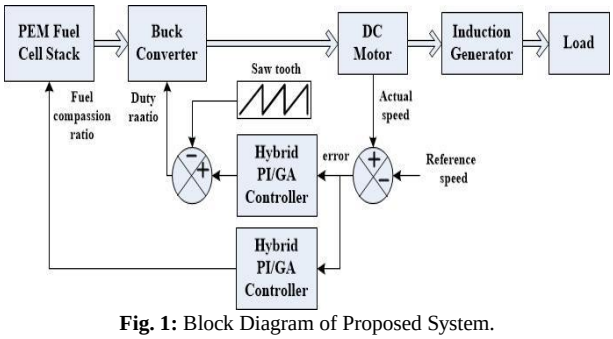


Fig. 1: Block Diagram of Proposed System.

2.1. Fuel cell

Among numerous types of FCs, PEMFC has comparatively great power compactness, lesser size, minor working temperature and informal start. A FC circuit converts the chemical energy to electrical energy. The core construction of FC is shown in Fig.2. The FC circuit varies than batteries in requiring a continuous source of the fuel and oxygen to survive the chemical answer [6-7]. The FC circuit can create electrical DC energy straight founded on the fuel and oxygen.

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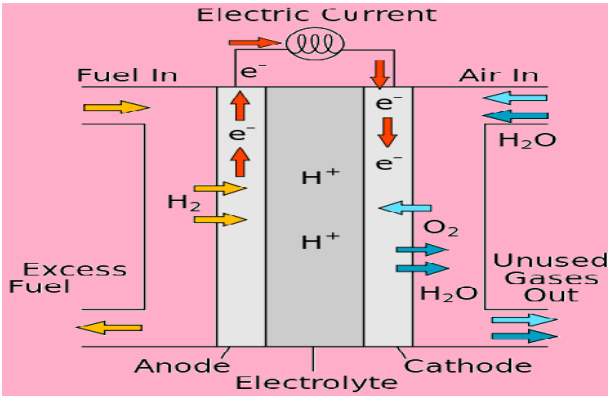


Fig. 2: Fuel Cell Internal Construction.

Table 1 lists the parameters of the fuel cell that's employed in this work.

Table 1: Fuel Cell Parameters

Parameters	Values
Rated power of stack	12 KW
Open circuit voltage	300 V
Nominal voltage	295 V
Nominal current	40 A
No. of cells	100
Nominal stack efficiency	55 %
Operating temperature	65C°
Nominal air flow rate	300 m

2.2. DC–DC converter

Several researchers studied DC drive systems to get mathematical and programmable method for the difference of load and speed with firing angle value differences [8, 9, and 10]. In present paper, DC-DC step down converter is used to control the output voltage of the FC in order to maintain the speed the separately excited DC motor constant below altered load settings to get finest system performance. The DC drive structure is controlled using hybrid controller that is PI based GA controller. A controlled system is used to obtain best value of firing angle of the converter (D) in order to improve the output system step response performance.

2.3. DC motor

In this paper, the separated excitation DC motor is used as a prime-mover for SEIG thus both mechanically coupled with them. The parameter values of the DC motor separately excited that operated in this work are scheduled in table 2.

Table 2: DC Motor Separately Excited Parameters

Parameter	Value
Terminal voltage of motor (Va)	Voltage of chopper (Vch)
Field resistor (R_f)	180 Ω
Armature resistor (R_a)	1.086 Ω
Armature inductor (L_a)	0.01216 H
Field inductor (L_f)	71.47 H
Mutual inductor (L_m)	0.6458 H
moment of inertia (J)	0.14251 Kg.m^2
Viscous friction coefficient (B)	0.003406 N.m.S/R
Field voltage (V_f)	190 V

2.4. Induction generator

In this work, a squirrel-cage SEIG has been used with 400 line to line voltage and 50 Hz frequency, the other parameters are scheduled in table 3.. It is mechanically coupled by a DC motor separately excited. In the output terminals of the generator, a 3-phased bank capacitor has been connected as self-excitation and a 3-phase 50 Kw resistive balanced load is connected via s-phase breaker which is activated after 2 second. The measurements of the generator are its output line and phase voltages, and the load three phase current. The generator output voltage, current and frequency is controlled by the DC motor derive speed, this speed is a function of the terminal peak voltage and frequency [11].

Table 3: Induction Generator Parameters

Parameter	Value
Line to line voltage	400V
Stator resistor and inductor	0.04587 Ω and 0.000424 H
Rotor resistor and inductor	0.02634 Ω and 0.000424 H
Mutual inductor	0.01599 H
P	4
initial conditions	[0 0 30 30 30 0 120 240]

2.5. PI controller

PI controller show a main role in various control methods where it used to improve the active behavior of the tested system. It is mainly used to decrease or to remove the system response steady-state error. The PI controller adds a pole at the origin, which add one to the system type and thus improve the step input response [12-13]. The general formula of the PI controller can be explained in equation (1).

$$PI = kp + \frac{ki}{s} \tag{1}$$

The control parameters are: the proportional factor (Kp) and the integral factor (Ki). Different methods had been used to suggest the controller factors like trial and error method, Ziegler-Nichols method and another modern algorithms methods [14]. In the present paper, the PI controller parameters (Kp and Ki) are computed by using the intelligent GA as hybrid algorithm [15].

2.6. Genetic algorithm

GA has a widely request in control process due to its skill to work as an optimization factors in its place of the conventional control type. GA technique is considered as an adaptive method for searching the solution of difficult problems where it can be used in combining with other intelligent methods. It consists of many steps like Initial population, Fitness function, Selection, Crossover, Mutation, and Stopping criteria [14-17].
Due to the drawback of conventional methods (long time to select the gain values of the PI controller), GA has effectively used to determine these values. Also GA has been used in current work to select the optimized value of the gain values of the GA controller as seen in table 4.

Table 4: GA Parameters

Parameters	Values
Number of Population	40
Number of Generations	20
Probability of Crossover	1.0
Probability of Mutation	0.01

2.7. Hybrid controller design

Try and error method is the one method that used to usual the limits of PI controller and necessary a long calculation time and cannot crop the best results. The GA that can be encoded and designed to grow a best controller of the system. The algorithm that used to thorough of the best PI controller parameter gains value, which can be produced the best act and remove the long computation time of calculating gains, whereas the PI controller based on GA that studied and designed to improve the system performance and reduce the long computation time of PI controller gains. The optimization algorithm was programed using MATLAB program. The hybrid PI-GA controller steps are clarified by the flowchart is shown in Fig. 3.

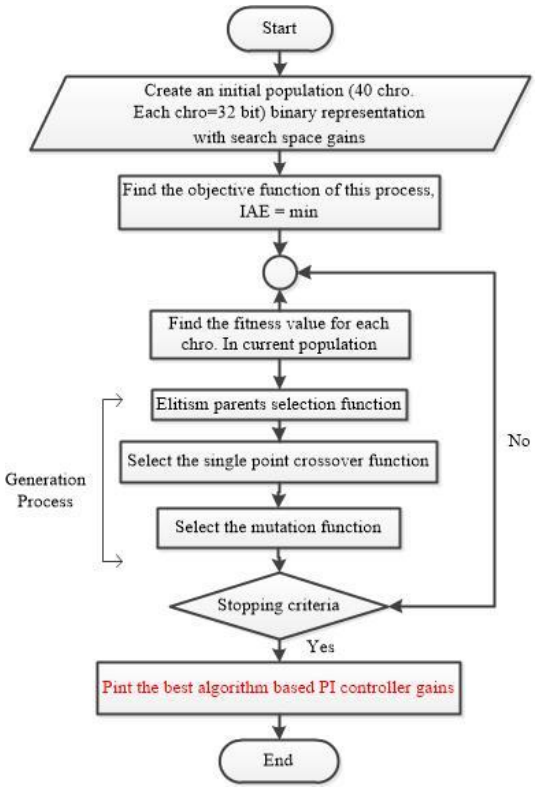


Fig. 3: The Flowchart of Hybrid PI Controller Based on GA

For the PI based GA flowchart, firstly set the initial population chromosomes with binary encoder representation with search space gains of each one. Each chromosome is expressed as the objective function of this process, which compared with the minimum selected objective function. After the GA programed to produce the optimal, the PI controller gains depending on the conditions of the stopping criteria, which was produced the best system performance.

3. Simulation work of proposed system

Fig. 4 illustrations the simulation block diagram of the proposed SEIG power system. As explained earlier, this system consist of FC, separately excited DC motor, this motor is mechanically coupled with a SEIG. This generator is loaded by three phase resistive load equal to 10 Kilowatt. Two controller loops based on hybrid PI - GA controllers were designed to adjust the speed of the coupled system. The input error signal of these controller loops is the difference between the reference and actual speed. This PI controller gains was calculated by using GA which programed using Matlab m-file program. The first controller loop (sub system 1) shown in Fig. 5 was designed to control firing angle of buck converter switch to regulate the DC output voltage, whereas the output signal of his controller feed to the PWM block to control the converter switch operation. The second controller (sub system 2) shown in Fig. 6 was designed to control and regulate the fuel (hydrogen) composition ratio for the FC, whereas the output of controller was feedback to the FC as the flow rate ratio which regulated as the required composition ratio.

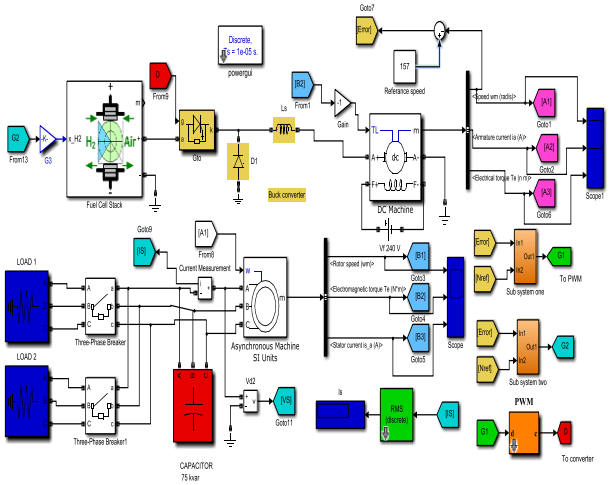


Fig. 4: Simulation Block Diagram of the Overall Proposed System.

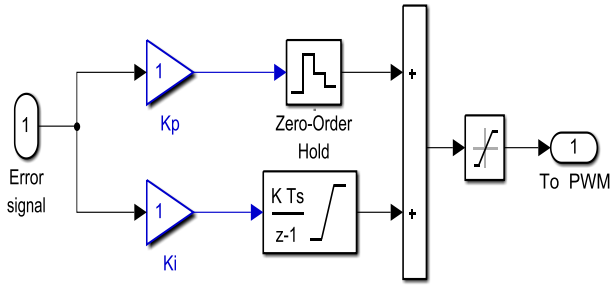


Fig. 5: First Controller Loop (Sub System One).

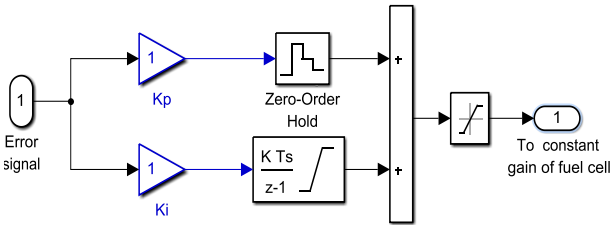


Fig. 6: Second Controller Loop (Sub System 2)

4. Results and calculations

The speed, armature current and electrical torque of the DC motor is measured at different load and it is illustrated in Fig. 7 below.

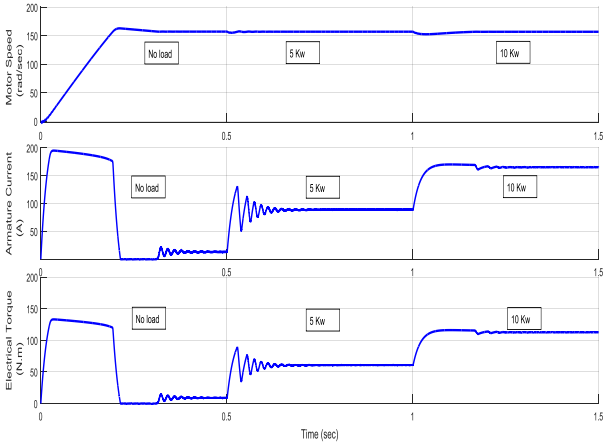


Fig. 7: Motor Output Responses.

For the induction generator, the electromagnetic torque, output phase current and voltage are measured as it is clear in Fig. 8.

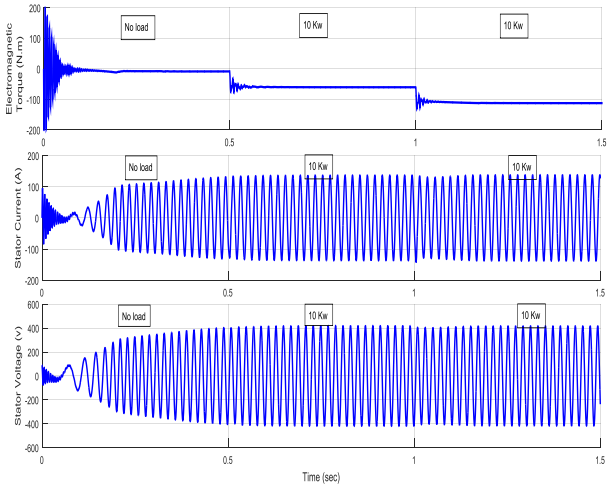


Fig. 8: Induction Generator Output Responses.

The Fast Fourier Transform (FFT) analysis of the output phase voltage of the SEIG and load current is performed; it shown in Fig. 9 and Fig. 10.

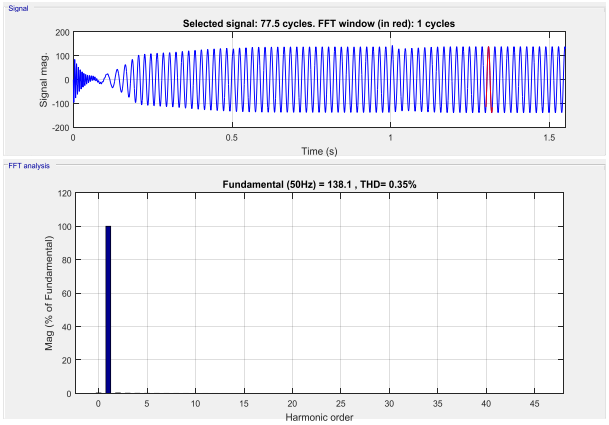


Fig. 9: FFT Analysis of the AC Load Current.

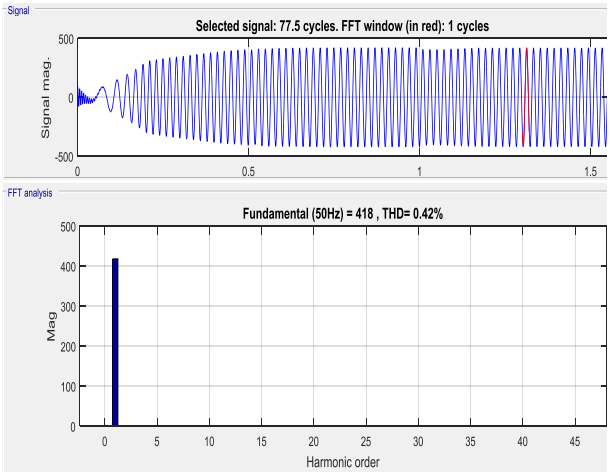


Fig. 10: FFT Analysis of the SEIG Output Voltage.

Finally, the step response parameters for the motor speed are calculated, and the results are shown in table 5 below.

Table 5: Step Response Parameters for the Proposed Controller

Step response parameter	Value
Delay time (td) [s]	0.072
Rising time (t_r) [s]	0.183
peak time (t_p) [s]	0.208
Setlling time (t_{ss}) [s]	0.285
Steady state error % (e_{ss}) when PL= 0 Kw	0.04
Steady state error % (e_{ss}) when PL = 5 Kw	0.15
Steady state error % (e_{ss}) when PL=10Kw	0.127

5. Conclusion

A FC energy system can be used, as a main energy source in the closer future for applications due to it is hard to discovery H2 in suitable method and expensive FC mechanisms. In this paper, a FC energy system with DC to DC buck converter, DC motor and induction generator outputs are studied and analyzed. The output power of FC is measured and supplied to the feedback control system of buck converter. The output power of converter is fed to the DC motor, that loaded by the synchronous generator, which loaded by external load torque. The studied system is simulated using MATLAB environment. By using two PI controllers based on GA to design the optimal controllers which improvement the output system performance as the steady state error, peak over shoot, peak under shoot, rising time of the speed response of dc motor and reduce the generated output current and voltage harmonics. The second controller was controlled of the fuel flow rate of the FC by controlling of the fuel composition ratio and this enhanced the performance and efficiency of the FC. This proposed system doesn't use any type of inverters and that increased the reliability of this system to generate the wanted power in the isolated areas without any complicated materials. In this work it is very clear that we don't use any type of inverter, this is a benefit of using seeing directly, and it can be generate an any amount of power because we don't have the limitations of using the inverters switches that have a limited power in their performance.

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