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Full Length Research Paper

Designing controller in order to control micro-turbine in island mode using EP algorithm

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The ever increasing energy demand, along with the necessity of cost reduction and higher reliability requirements, are driving the modern power systems towards Distributed Generation (DG) as an alternative to the expansion of the current energy distribution systems. This paper is aimed to introduce the new controller in order to control of output power of one of the most important types of distributed generation namely micro-turbine, during system load variations. Micro-turbine output power should be controlled against the load variations in island mode condition and a controller should be designed for this purpose. Here, the PID controller is used which its coefficients are optimized based on 'evolutionary programming' algorithm. Simulation results are done for various loads in time domain, and the results show the efficiency of the proposed controller.

Key words: Micro-turbine, evolutionary programming, distributed generation, controller design, optimization.

INTRODUCTION

Power generation has seen an increased penetration of Distributed Generation (DG) in recent times. Distributed generation systems, powered by microsources, such as fuel cells, photovoltaic cells, and microturbines, have been gaining popularity due to their higher operating efficiencies, improved reliabilities and lower emissions. A part of the distribution system with its sources and loads can form an isolated electric power system-a microgrid (Daniel et al., 2009). During normal operating conditions, the microgrid is connected to the ac grid at the point of common coupling (PCC). Although full benefits of high depth of penetration of DG units are gained if a microgrid or a smart grid can be operated in both grid-connected and islanded (autonomous) modes. The current utility practice and the existing standards do not permit such islanded operations. The main reason is the safety concerns associated with that portion of the utility grid that remains energized as a part of the island. However, there are provisions to permit islanded operation of a DG unit and its dedicated load, if the island does not include any portion of the utility grid. In this context, the DG unit operates analogous to an uninterruptible power supply (UPS) for the load (Noradin, 2013). Until now, only few works were undertaken on the modeling, simulation and control of micro turbines in island mode. There is also a lack of adequate information on their performances. A dynamic model for combustion gas turbine has been discussed in Noradin (2011). In Daniel et al. (2009), in order to feed to vector controlled induction motor drive and other static loads, micro turbine based distributed generation system is implemented. The micro turbine provides input mechanical energy for the generator system. Aspects of dynamic modeling and simulation of fuel cell and micro-turbine units as a part of a multi-machine electrical network investigated in Ahmed and István, (2003).

Lecture (Guda et al., 2005) demonstrated the development of a micro turbine model and its operation

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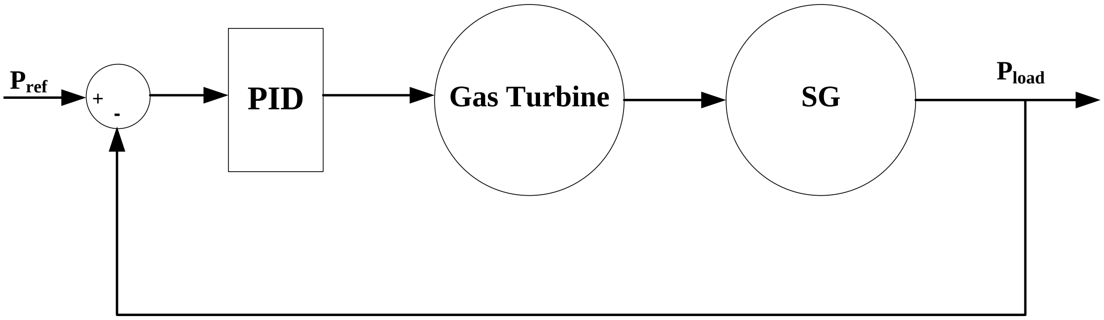

Figure 1. Study system containing gas turbine and synchronous generator.

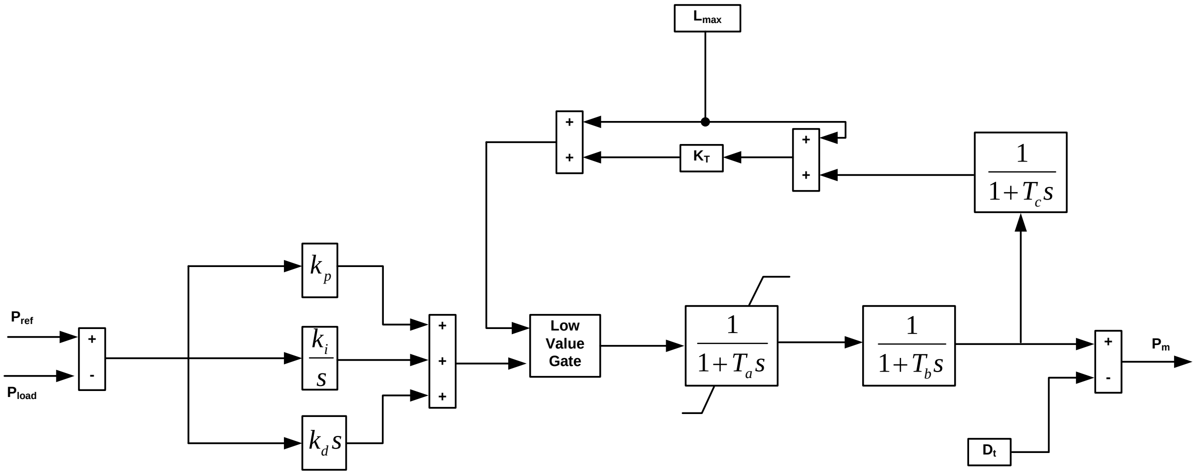

Figure 2. Single shaft gas turbine including all its control systems.

with a permanent magnet synchronous generator. A non-linear model of the micro-turbine is considered and implemented in NETOMAC software (Nikkhajoei and Iravani, 2002). Suter (2001) proposed an active filter for MT. Adaptive control of fuel cell and MT is well described in Jurado and Saenz, (2003). Authors demonstrated the development of a MT model from the dynamics of each part which is suitable for studying various operational aspects of the same (Noradin et al., 2012). In this paper, a simple PID controller for micro-turbine power control has been used except that the controller design has not been achieved through trial and error. But the problem has been proposed as an optimization problem and then solved by using ‘evolutionary programming’. About the advantages of the proposed control, we can point the followings: 1) controllers are simple; 2) being robustness against load changes; 3) fast transient response; 4) zero steady error.

Next, the test system used to verify the effectiveness of the proposed technique is described. It represents the EP algorithm in order to solve the optimization problem; then it explores the effectiveness of the proposed technique applied on simulation test system; lastly, the simulation test systems were simulated in MATLAB software and it concludes the paper.

SYSTEM DESCRIPTION

Originally, there are two kinds of small gas turbines, high speed single shaft turbines and split shaft turbines. In the single shaft turbines, the alternator generates a very high frequency three phase signal ranging from 1500 to 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage. In the split shaft design, a conventional induction or synchronous machine is mounted on the power turbine via gearbox and the power inverters are not required (Saha et al., 2008). The study system in this paper that the proposed algorithm applied to this system is shown in Figure 1. This system contain PID controller, split shaft gas turbine and synchronous generator. The simplified single shaft gas turbine including all its control systems is shown in Figure 2. All of parameters in this figure are given in Table 1. Figure 3 shows the synchronous generator, transformer and local load. A step-up transformer is located between

Table 1. Parameters of shaft gas turbine.

Parameters	Value
Rated power	100 KW
Real power reference	1.0
Damping of turbine (Dt)	0.03
Fuel system lag time constant (Ta)	10.0 s
Fuel system lag time constant (Tb)	0.1 s
Load limit time constant (Tc)	3.0 s
Load limit (Lmax)	1.2
Maximum value position (Vmax)	1.2
Minimum value position (Vmin)	-0.1
Temperature control loop gain (KT)	1.0

Table 2. synchronous generator and load parameters.

Parameter	Value
Rated power	100 KW
Rated voltage	440 V
Frequency	60 Hz
Number of poles	2
Damping factor (KD)	0.06 p.u.
Inertia constant	0.822 s
Internal resistance (R)	0.04 p.u.
Internal reactance (X)	0.3 p.u.
3-ph source base voltage	11 KV
Dist. trans. nominal power	150 KVA
Frequency	60 Hz
Dist. trans. primary voltage	11 KV
Dist. trans. secondary voltage	440 V

synchronous generator and local load in order to change the voltage level. V_{ref} and P_m are the input of synchronous generator that V_{ref} is set to 1 p.u and Pm provides bye gas turbine. All parameters of synchronous generator, transformer and local load is present in Table 2.

CONTROLLER DESIGN

EP algorithm

In this optimization method like the other methods, the initial points are selected in the stochastic manner as shown in the flowchart of Figure 4. As it can be seen from the figure, after selecting these points, for each of them the power flow will accomplished and the objective function will be calculated. Therefore, this point are checked in the constraints and any of them which are not within this viable solution zone should be eliminated and for the points within this area, the value of the objective function should be determined, and in the next state, particles are moved within this area and if the omitted particles are more, new particles will be regenerated and this process is continued until the selection of the optimum point (So and Li, 2000). Particles' changes are done according to the Gauss normal distribution. These changes are expressed in Equation 1. Which, xi is the ith particle position in the current state, $x_i^{'}$ is the position of the particle in the next stage. $N_i(0,1)$ is the Gauss normal distribution, and σi is a weighted function obtained from Equation 2. β_i is the movement coefficient; here it is equal to 1, γ_i is the offset value adjusted in zero, and Φ(x) is the value of objective function for the particle in the previous stage which affects the next movements (So and Li, 2000):

$$x_i^{'} = x_i + \sigma_i . N_i(0,1) \tag{1}$$

$$\sigma_i = \sqrt{\beta_i . \Phi(x) + \gamma_i} \tag{2}$$

Using EP to tune controller parameters

With so much development in controlling systems and making applicable of these controllers, in power system, simple controllers are still considered desirable controllers. In most cases in the power systems, compensators are PID controllers. And these controllers can be implemented easily in analog and digital systems. In this paper, PID controller is used to control voltage of load voltage of micro-turbine in island condition. The overall controller schematic is shown in Figure 5. Controller general form is expressed in Equation 3. The controller parameters that must be optimized include: k_p, k_i, k_d. It is clear that the transient mode of the system in the load variations depends on the controller coefficients. Controller design methods are not viable to be implemented because this system is an absolute nonlinear system. So these methods would have not efficient performance in the system:

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s \tag{3}$$

In order to design controller using 'evolutionary programming' for the micro-turbine from the load power curve, we consider the worst condition for load design controllers for these conditions. Figure 6 displays the worst condition for load power in the system. Now, problem should be written as an optimization problem and then be solved. Selecting objective function is the most important part of this optimization problem. Because, choosing different objective functions may completely change the particles variation state. In optimization problem here, we use error signal:

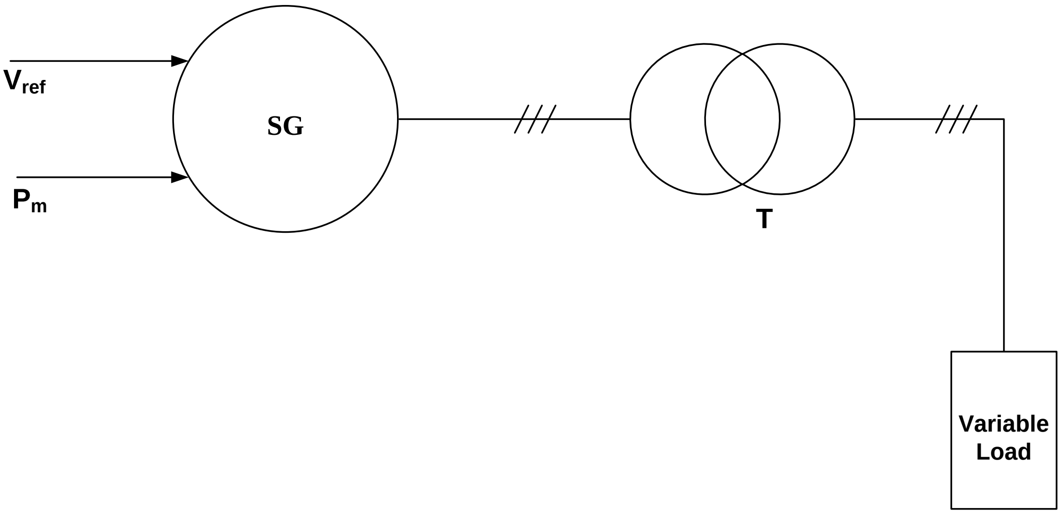

Figure 3. Synchronous generator, transformer and local load.

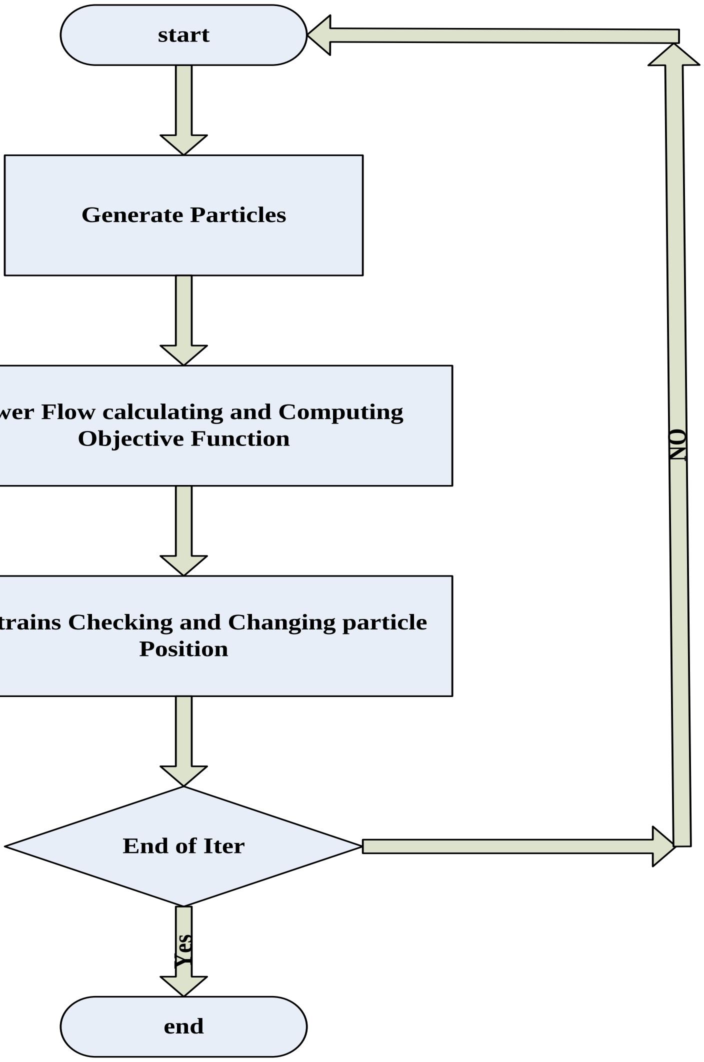

Figure 4. Optimization flowchart in EP.

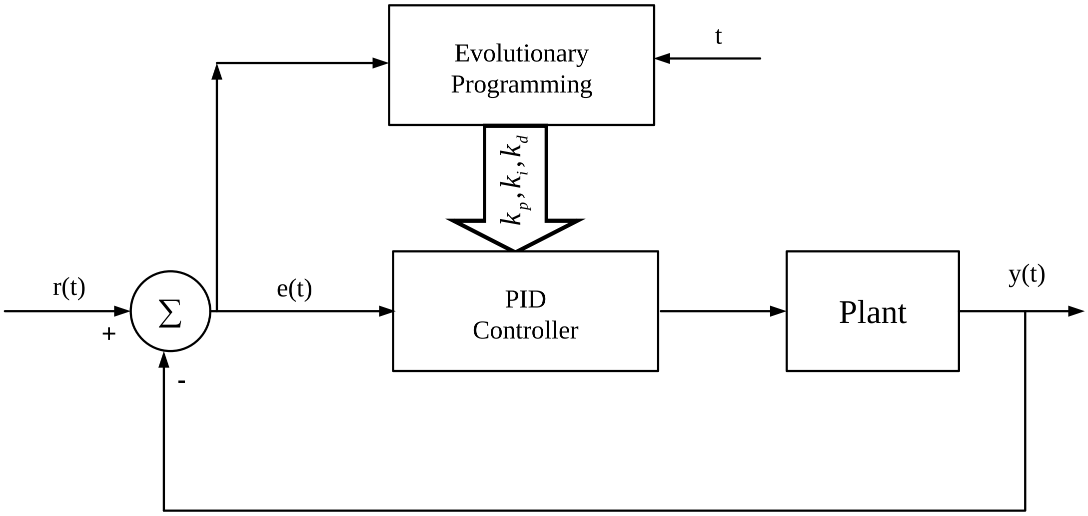

Figure 5. Scheme of design proposed controller.

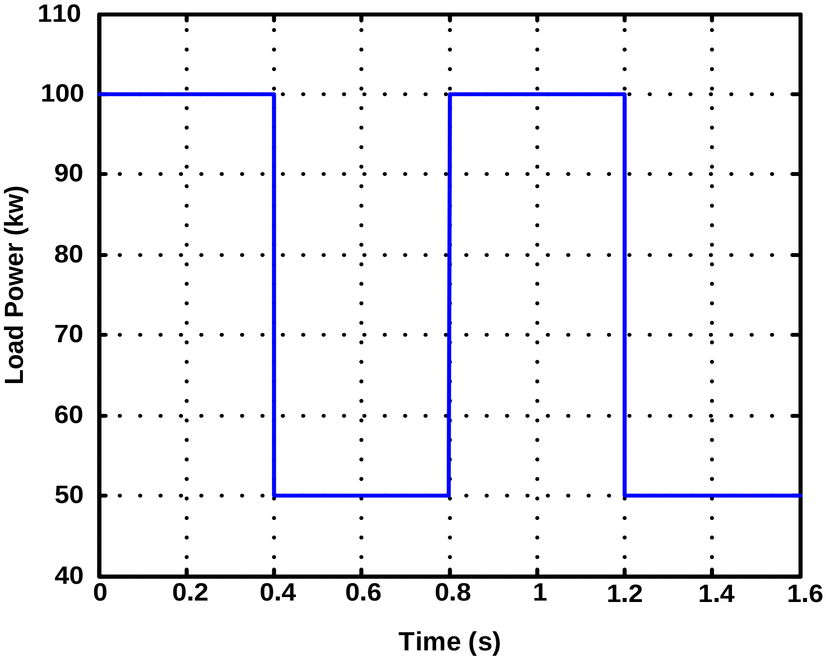

Figure 6. Worst condition for load power.

$$J = \int_0^{t=tsim} \left| P_{ref} - P_{load} \right| dt \tag{4}$$

Where *tsim* is the simulation time in which objective function is calculated.

We are reminded that whatever the objective function is a small amount in this case the answer will be more optimized. Each optimizing problem is optimized under a number of constraints. At this problem constraints should be expressed as:

$$\begin{gathered} \text{Minimize } J \text{ Subject to} \\ k_p^{\min} < k_p < k_p^{\max} \\ k_i^{\min} < k_i < k_i^{\max} \\ k_d^{\min} < k_d < k_d^{\max} \end{gathered} \tag{5}$$

Where k_p, k_i are in the interval (0.01 300) and k_d in the

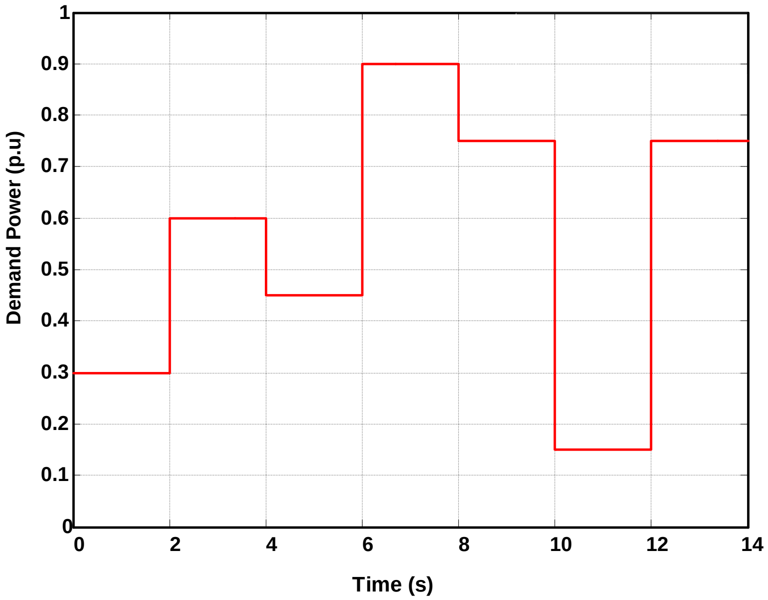

Figure 7. Power demand for micro-turbine in island mode.

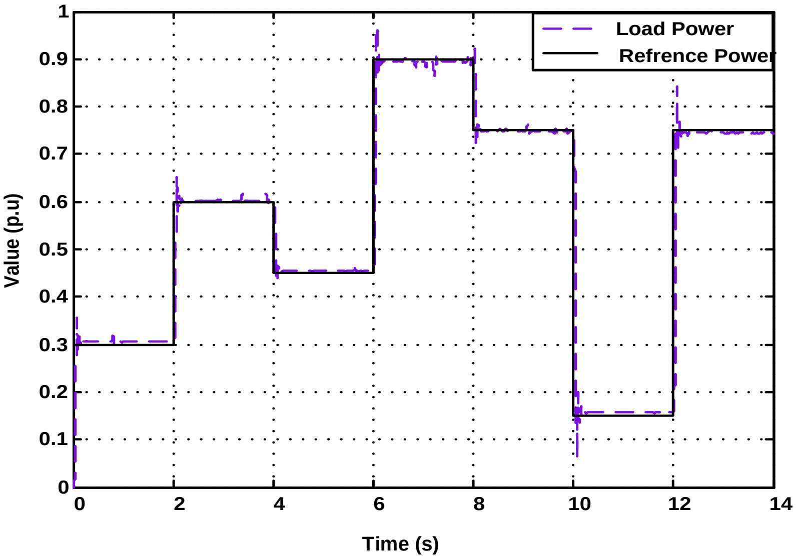

Figure 8. Reference and output power related to the proposed controller.

interval (0.001, 20).

In this problem, the number of particles, dimension of the particles, and the number of repetitions are selected 20, 3 and 40, respectively. After optimization, results are determined as follows:

$$k_p = 151.4319 \ \ k_i = 115.6443, k_d = 0.018957 \quad (6)$$

SIMULATION RESULTS

To show good performance of the proposed algorithm, we consider variable load in order to supply by micro-turbine in island mode. Desired load power is shown in Figure 7. As can be seen, desired load is changing between the range of 0.15 to 0.9 per unit which change within 14 s, and the numbers of its changes are considered more to show the performance of the proposed controller. Simulation output results obtained from the proposed algorithm which is expressed in Equation 6 are shown in Figures 8, 9 and 10. Figure 8 depicted the output power of micro-turbine that provides the demand loads in island mode and reference power. From this figure, it can be seen that by changing load

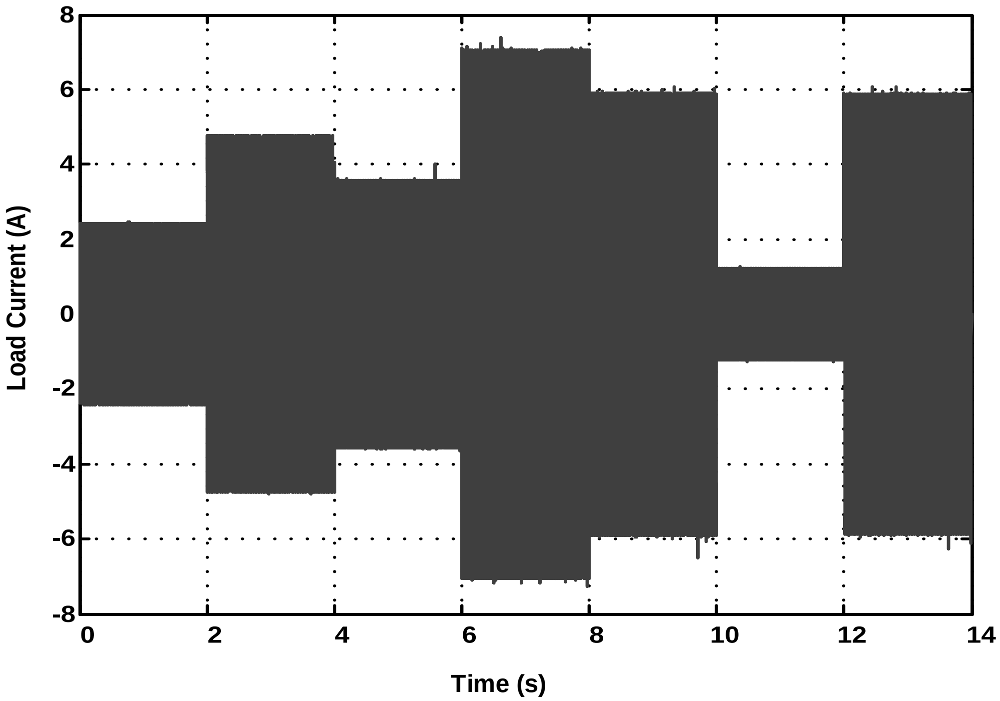

Figure 9. Load instantaneous current related to the proposed controller.

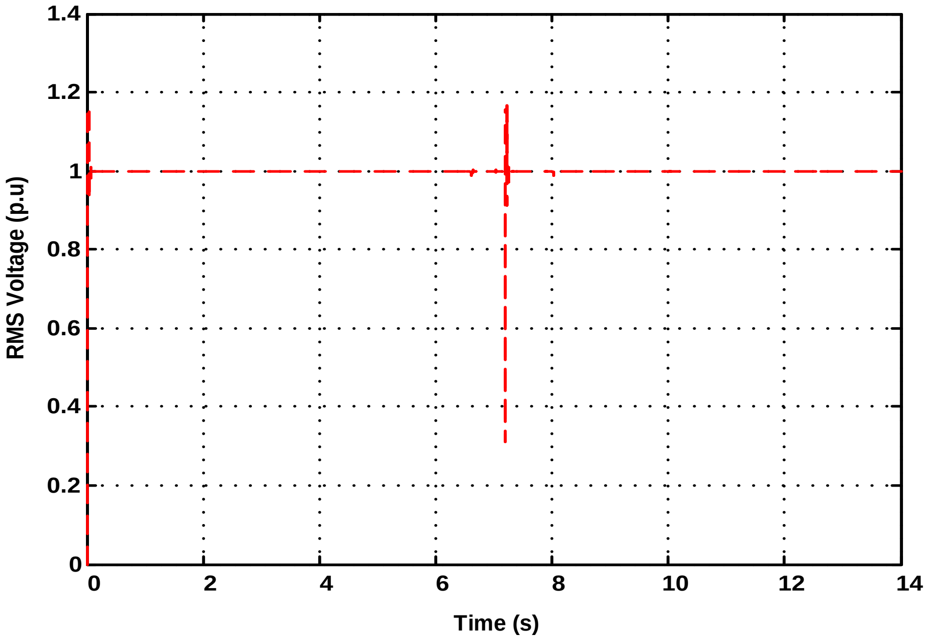

Figure 10. Micro-turbine output voltage related to the proposed controller.

power; supplied power change quickly to keep stable the output frequency of the micro-turbine under the desired voltage and this show good performance of the proposed controller albeit simplicity. In Figure 9, instantaneous of output current of load for phase (a) is shown, according to the figure, it is obvious that controller response is appropriate and it could control the output current of mention system properly. In Figure 10, the load voltage is plotted which the high efficiency of the proposed algorithm shown clearly.

Conclusion

In this study, a new controller based on 'evolutionary programming' and PID controller to control the micro-turbine output power in island mode was proposed. This controller is chosen because of its simplicity and because the implementation of this controller is simple and it could obviate the problem of the previous controller and its efficiency is higher than previous controllers. EP algorithm was utilized to design the PID controller to have the most optimized state. In solving this problem, at first problem was written in the form of the optimization problem which its objective function was defined and written in time domain and then the problem has been solved using EP. And the most optimal mode for gain coefficient of controller was determined using the algorithm.

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