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Full Length Research Paper

Designing the intelligent controller for photovoltaic system in islanding mode operation

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In this paper, an optimal controller is proposed to control the voltage of photovoltaic system as distributed generation (DG) using intelligent algorithm in islanding mode operation. The control algorithm used in the studied control plant during load variations is based on the reinforcement learning (RL) algorithm. To control the examined plant, this algorithm has tried to prevent controller output voltage changes due to the load variations by changing the constant and integral coefficients of load variations, and to keep the output voltage of photovoltaic system in certain constant value in the islanding mode. The proposed controller performance to achieve this goal is verified by the simulation results.

Key words: Renewable energy, controller design, reinforcement learning (rl) algorithms, photovoltaic systems.

INTRODUCTION

Considering the high consumption of fossil fuels in recent years and given that these fuels are perishable, and since fossil fuels consumption increases emissions of carbon dioxide and results in global warming it is essential that new and unlimited energy sources, such as water power, wind and photovoltaic generations should be used .To use these kinds of energies, it is necessary for these energy sources to be converted into electrical energy. Water and wind usually produce the electrical energy by rotating the prime driver. (Ogawa et al., 2006; Manesis, 2009).

Some of these distributed generation sources are connected to the network directly and/or others through the power electronic interfaces which the latter is used mostly to connect the distributed generations to the network (Nikkhajoei and Reza, 2007). The main challenge of a distributed generation (DG) performance with connected and separated local load is that the DG should be equipped with a voltage source converter (VSC) having the controls that meet the following conditions:

1) The inverter should be able to keep constant the voltage and frequency of the DG's.

2) Regardless of the plant parameters, the inverters should be able to feed the predetermined load.
3) VSC control should be on the feedback from the local load (Sao and Peter 2008).

In (Sinha et al., 2008a), a controller is proposed to maintain constant voltage and frequency for wind turbine which is connected to the power grid through the power electronics devices. In (Sinha et al., 2008 b), an adaptive controller has been proposed to reduce losses and increase reliability of DC Micro grids. Small signal dynamic model and transient mode of Micro grid including distributed generations with electronic interfaces is discussed in (Katiraei and Iravani, 2006, Katiraei et al., 2007). Current control strategies for the DG units in islanding mode of Micro grid based on active/frequency and reactive power/voltage drops is the method which the reference (Nikkhajoei and Robert, 2009) has been founded base on it. In (Salomonsson et al., 2008), the design of an adaptive control system for a upper case micro grid for data centers has been suggested which coordinates the control of the two converters, the energy storage device, and the two switches used in the proposed dc micro grid. In (Yun et al., 2007), a detailed study of a micro grid system

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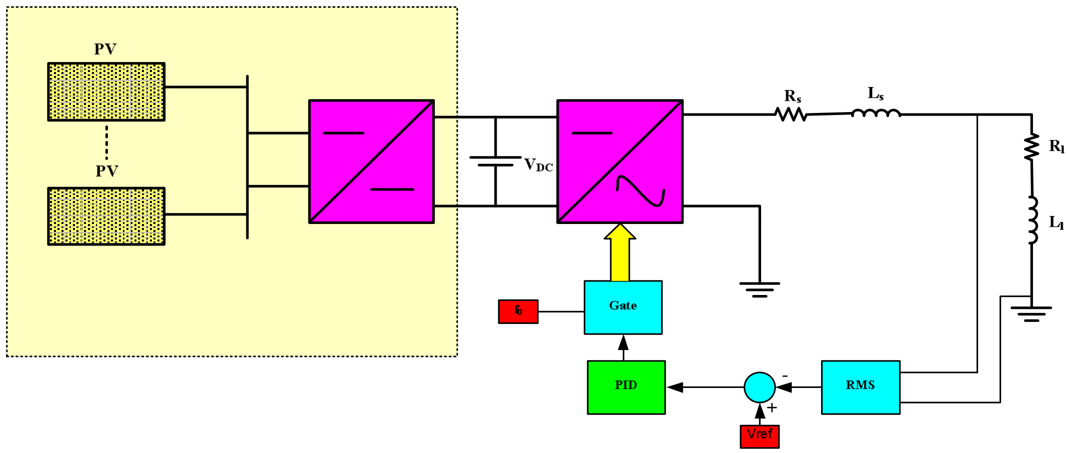

Figure 1. Photovoltaic system with battery, inverter and load.

Table 1. The value of the study system parameters.

Value	Parameter
350 v	V_{DC}
1 Ω	R_s
7 mH	L_s
50 Ω	R_l
35 mH	L_l
220 v	V_{ref}
50 Hz	f_0
1 kW	Nominal power
50 Hz	Nominal frequency

with a PFC capacitor-bank connected has presented.

In this paper, a simple controller was proposed to control the output power of photovoltaic system in the islanding mode, which the coefficients are variable in an online and intelligent mode using reinforcement learning (RL) algorithm. This system is simulated in the MATLAB/Simulink environment.

STUDY SYSTEM

The diagram of the study system is shown in Figure 1, in which the (DG) has been depicted equally as a DC source and a VSC connected through low pass filter to the local load. Total impedance of the low pass filter is displayed as R_s and L_s. The system parameters are given in Table 1.

The system should be able to operate in off grid mode. In grid-connected mode, the intermediate VSC will be a current-controlled voltage source controller, that is the typical strategy operates for VSC unit. In this paper, the goal is to achieve a desirable controller which is able to keep constant the load voltage in islanding mode in terms of load variations. As regards, generated energy by photovoltaic system is stored in a battery, therefore the photovoltaic system can be considered as a constant voltage source.

REINFORCEMENT LEARNING (RL) ALGORITHM AND THE PROPOSED CONTROLLER BASED ON IT

Reinforcement learning (RL) algorithm is based on trial and error method used to apply appropriate control action indirectly to systems. In this method, for each mode a different control action is applied, for example if xt and ut represent the mode and control of system at instant t, respectively, at instant t+1 the system mode will be shown which is depend on the mode and control of system at instant t, which can be written as [10]:

$$x_{t+1} = f(x_t, u_t) \qquad u_t \in U, \forall t > 0 \qquad (1)$$

At any time, a reward or penalty is attributed for each control action. If the control action improves the system error, in this case a reward is considered for the action; otherwise a penalty will be dedicated. As it can be seen from Figure (2), the choice of rewards or penalties is distinguished from the comparison between measured errors at instants t and t+1. The reward choice for each action is calculated as follows:

$$R(x_0, u\{t\}) = \sum_{t=0} \gamma^t r(x_t, u_t) \qquad (2)$$

Where γ is the discount factor between 0 and 1 and $r(x,u(t)) < B$ is the reward function. Then from the obtained values, the value function will be defined from which the control signal is selected for the next instant:

$$V(x) = \max_{u(t)} R(x, u(t)) \qquad (3)$$

Using Bellman equation [11], the value function can be defined as follows:

$$V(x) = \max_{u \in U}[r(x,u) + \gamma V(f(x,u))] \qquad (4)$$

The optimal control action is obtained as follows:

$$u^*(x) = \arg\max_{u \in U}[r(x,u) + \gamma V(f(x,u))] \qquad (5)$$

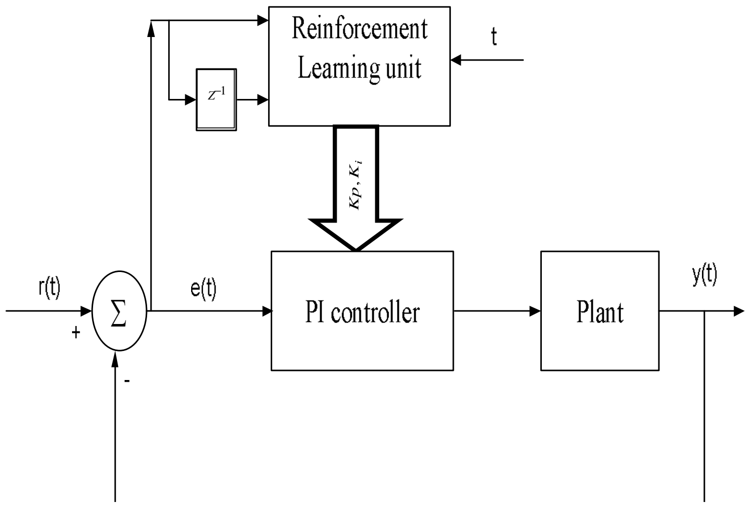

Figure 2. Structure of the proposed controller.

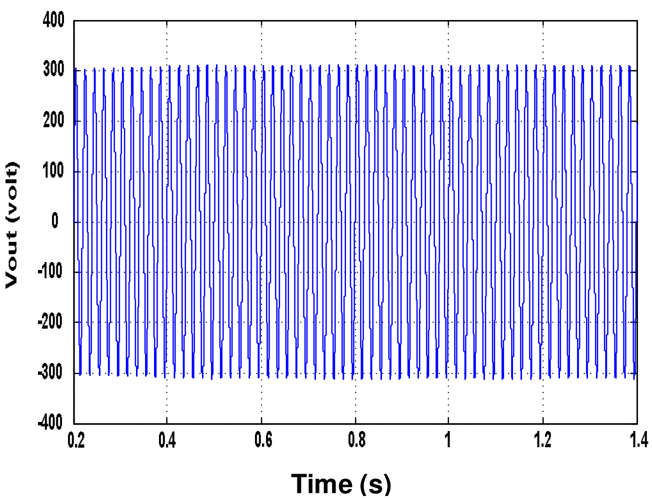

Figure 3. The instantaneous load voltage in terms of load variations with proposed controller.

Based on aforementioned equations, in each steps, a penalty or reward function Q for each action is expressed as Equation (6) and to select operation for the next step the value of this function will be indispensable.

$$Q(x,u) = r(x,u) + \gamma V(f(x,u)) \quad (6)$$

V (x) in equation (6) is described as (7):

$$V(x) = \max_{u \in U} Q(x,u) \quad (7)$$

Thus, optimal control behavior is as follows:

$$u^*(x) = \arg\max_{u \in U} Q(x,u) \quad (8)$$

In PI controller which its transfer function is shown in (9), five different actions are considered for each of the controller gain and integrator coefficient. In each step, the adaptive unit should select one of the actions among 25 action modes. In this process, some actions are removed through penalty turns and a random process is carried out to select another action between the remaining actions. This random selection will be decreased by the time until a specific action to be selected according to its desirable performance. Degree of freedom in this method is the number of adaptive parameters and the number of actions. The proposed controller structure based on the reinforcement learning method is shown in Figure (2).

$$G_c(s) = k_p + \frac{k_i}{s} \quad (9)$$

SIMULATION RESULTS

Here, simulation results are performed for different loads, and output power results show the proposed controller robustness. First the load of system is 550 W and 120 Var, and the DG could supply the mentioned load. At instant t = 0.4 s, a load with active and reactive powers P = 130 W, and Q = 30 Var respectively is added to the system, and also the same amount of load in at t = 0.8 s and t = 1.2 s is added to the system and finally the active and reactive power of systems reach P = 940W, and is Q= 210 Var, respectively. Simulation results are shown in terms of these values in Figures 3, 4 and 5. According to the Figure 3, it is clear that during load variations the load voltage has constant value. Figure (4) depicts the load current in terms of load variations. According to the Figure 4 it is obvious that the system response is fast and current increases rapidly with load variations. In Figure 5, active and reactive power of load is shown which according to the figure, the good performance of system can be realized. Proportional coefficients and integral variations of the proposed controller based on

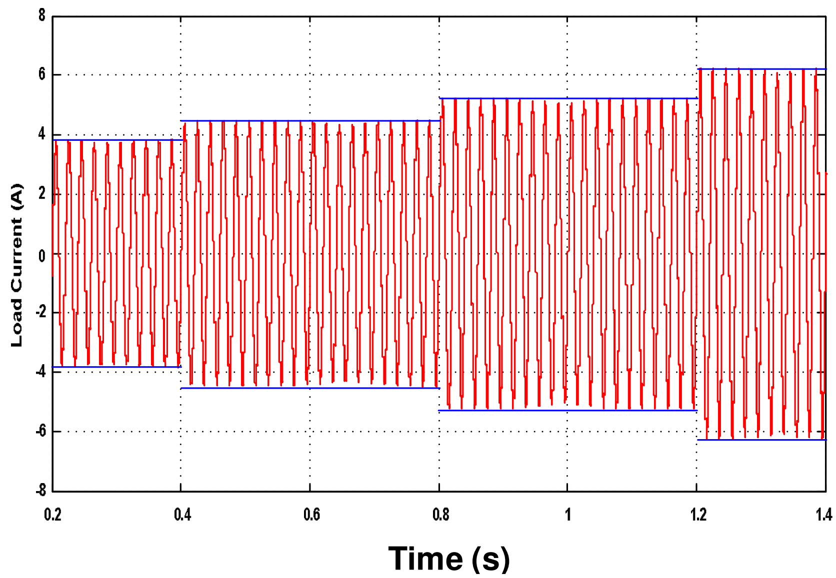

Figure 4. The instantaneous output current of DG in terms of the output load variations with the proposed controller.

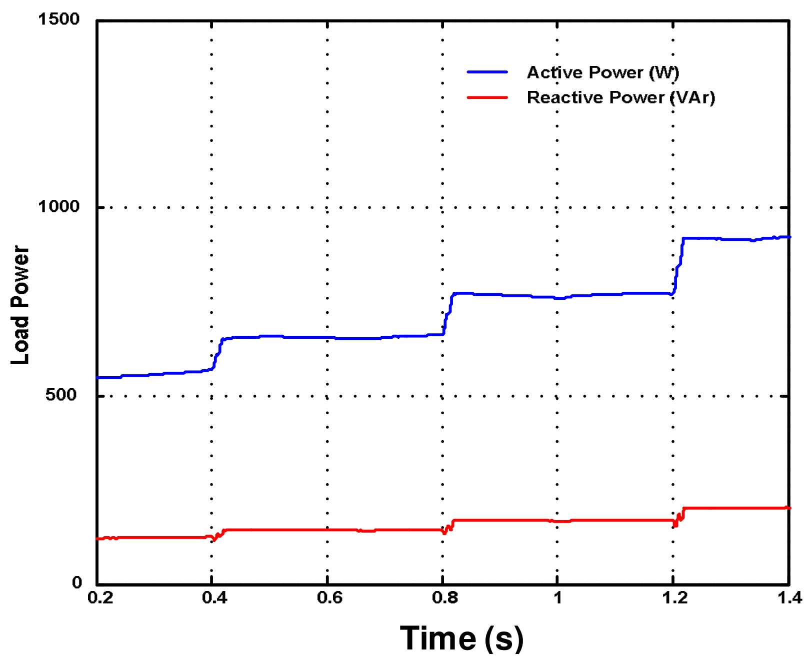

Figure 5. Distributed generation output power in terms of output load variations with the proposed controller.

reinforcement learning method to control the load variation of system can be seen in Figures 6 and 7.

Conclusion

This paper introduces a specific PI control method. In this method, the proportional and integrator coefficients of controller have been changed according to the load variations and based on reinforcement learning these coefficients reach the values in each steps such that the PI controller by having it has the best values in its response to load variations and causes optimal control of output voltage. Having fast response, less errors and lack

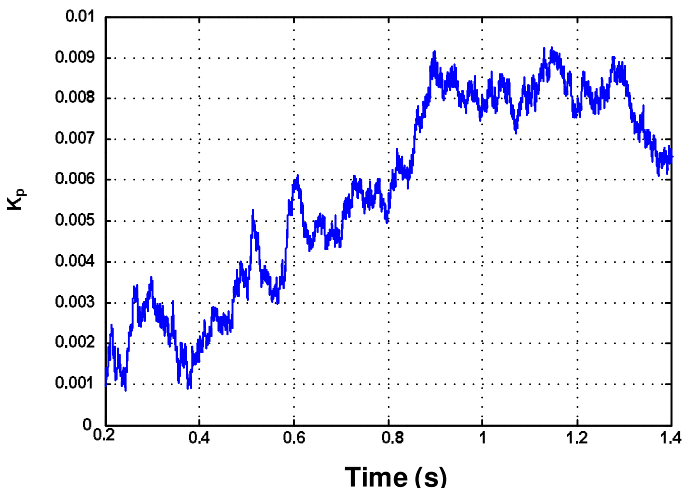

Figure 6. Gain coefficient in the proposed control method.

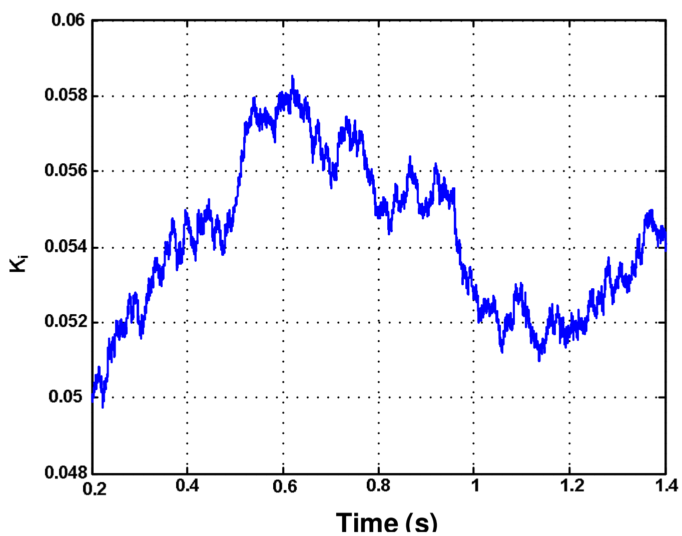

Figure 7. Integrator coefficient changes in the proposed control method.

of the major distortions of the proposed method usually exist in adaptive control methods are the main reasons for using this control method. The proposed controller could control the system output voltage changes in terms of the load variations. The effectiveness of the proposed controller has been confirmed using Simulations in MATLAB/Simulink environment.

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