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Optimal Control of Islanded Micro grid Using Particle Swarm Optimization Algorithm

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ABSTRACT

This paper presents an optimization method to optimize the parameters of the Microgrid controller in islanding mode. The controller optimal parameters have been obtained by using the particle swarm optimization (PSO). This is done based on minimization of the errors in the current and voltage controllers. Finally, simulation has been carried out to verify the effectiveness of the optimized controller. Stability analysis of the controller is verified using classical approach.

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I. INTRODUCTION

Microgrid is defined as a controllable unit which consists of Distributed Generations (DG), loads, energy storages and control devices[1,2]. Microgrid has two operation modes including grid connected mode and islanding mode. In grid connected mode, voltage and frequency of microgrid is controlled by main grid and DGs supply total or part of the loads. In the islanding mode, the microgrid is disconnected from main grid because of a fault or a preplanned switching in connecting line. In this mode, DGs should satisfy the power demand of sensitive loads in microgrid. Since the only generation units in an islanded microgrid are existing DG units which usually are from several types. Consequently besides feeding total loads, voltage and frequency of microgrid should be controlled by these DG units. Hence, the microgrid could supply high power quality and reliability to customers.

Controlling microgrid in both operation modes has been presented[3–8]. Controller of islanded microgrid has three parts. First part is power controller. It is based on the droop technique to share active and reactive powers with other DGs. The other parts include voltage and current controllers that use PI controller for their purpose.

Tuning of the controller parameters is very important to achieve the system stability and have a good performance against load variations. The main problems for controller parameter optimization are nonlinearity and complexity of the system. Small signal linearization is a usual method for designing of controller parameters[3–5]. But this method depends on the operation point[9].

Computational intelligence algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have been used to solve problems of the power system. However, some deficiencies in GA performance such as the premature convergence have been recorded. On the other hand, PSO has been widely implemented and stamped as one of the promising optimization technique due to its simplicity, computational efficiency, and robustness[10,11]. PSO is a population based search technique deriving from models of insect swarm or avian flock behavior during food search[12]. So parameters of the PI controllers are obtained using particle swarm optimization (PSO) in this paper.

In this paper, an optimization approach is used to optimize the parameters of the microgrid controller in islanding mode. First, this controller is introduced in detail. Then, a PSO based optimization is proposed to design PI coefficients of voltage and current controllers. The effectiveness of the proposed optimal controller under load variation has been tested through the simulations in MATLAB/Simulink. Finally, the stability of the controllers with optimized parameters is analyzed using classical control approach. The results show that the proposed optimization method is useful for performance of the microgrid.

II. CONTROL STRATEGY

This section presents inverter interfaced DG controller that connected to the loads through LC filter and coupling inductance. Fig. 1 shows power, current and voltage controllers for controlling DG in islanding mode.

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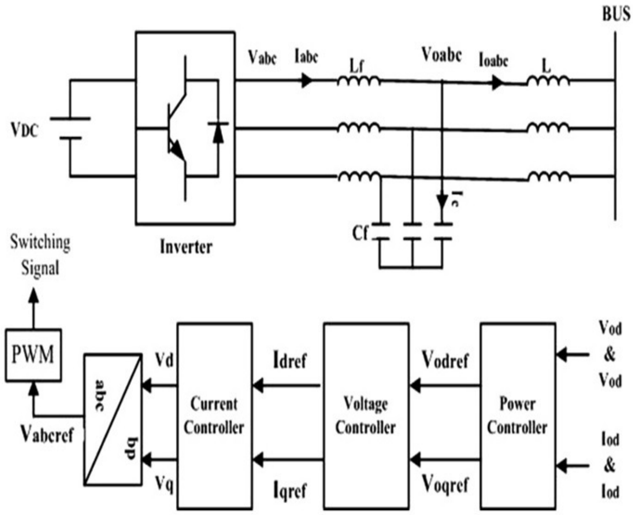

FIG. 1. DG controller in islanding mode.

Active and reactive powers of DG are calculated using the measured output voltage and current. Power controller determines DGs output voltage (magnitude and frequency) for active and reactive powers based on the droop characteristics. Then, the voltage and current controllers are designed to reject high-frequency disturbances and provide sufficient damping for the LC filter[13].

A. Power Controller

The basic idea behind the droop control is to mimic the governor of synchronous generator. In a conventional power system, synchronous generators will share any increase in the load by decreasing the frequency according to their governor droop characteristic. This principle is implemented in inverters by decreasing the reference frequency when there is an increase in the load. Similarly, reactive power is shared by introducing a droop characteristic in the voltage magnitude[13]. In islanding operation, droop method can be used to share loads and controlling voltage and frequency in special range.

Two coefficients control the change slope of frequency and voltage against active and reactive power.

$$W = W_n - mP \tag{1}$$

$$V = V_n - nQ \tag{2}$$

where W_n, V_n, m, n, P, Q are rated frequency, rated voltage, active power droop coefficient, reactive power droop coefficients, output active power and output reactive power and rated active power of DG, respectively.

Droop coefficients are defined below:

$$m = \frac{\Delta w}{P_{\max}} \tag{3}$$

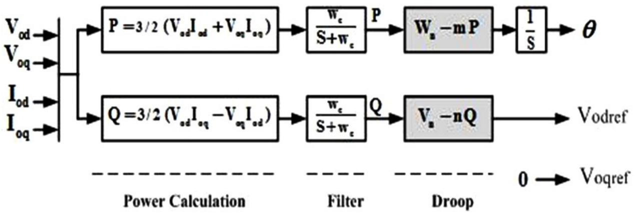

FIG. 2. Power controller.

$$n = \frac{\Delta V}{Q_{\max}} \tag{4}$$

where ΔW and ΔV are maximum allowable deviation of frequency and voltages. Also P_{max} and Q_{max} are maximum output active and reactive powers of DG. Fig. 2 shows the power control in details. First the instantaneous output active and reactive powers the DG are calculated using measuring output current and voltage. Following equations show this calculation.

$$P = \frac{3}{2}(V_{od}I_{od} + V_{oq}I_{oq}) \tag{5}$$

$$Q = \frac{3}{2}(V_{od}I_{oq} + V_{oq}I_{od}) \tag{6}$$

These calculated instantaneous powers are passed through a low pass filter to remove the fluctuations. Cut of frequency of this filter (w_c) is assumed to be 10% of nominal frequency.

The outputs of droop control are voltage magnitude and angular frequency which define the reference angle of the voltage using an integrator. The control strategy is chosen such that the output voltage magnitude reference is aligned to the d-axis of the inverter reference frame, and the q-axis reference is set to zero[14].

B. Voltage Controller

By using Kirchhoff law in Fig. 1, following equations are yields.

$$i_{abc} = i_C + i_{oabc} \tag{7}$$

$$i_C = C_f(\frac{dv_o}{dt}) \tag{8}$$

Applying parks transformation to above equation:

$$i_d = i_{Cd} + i_{od} \tag{9}$$

$$i_q = i_{Cq} + i_{oq} \tag{10}$$

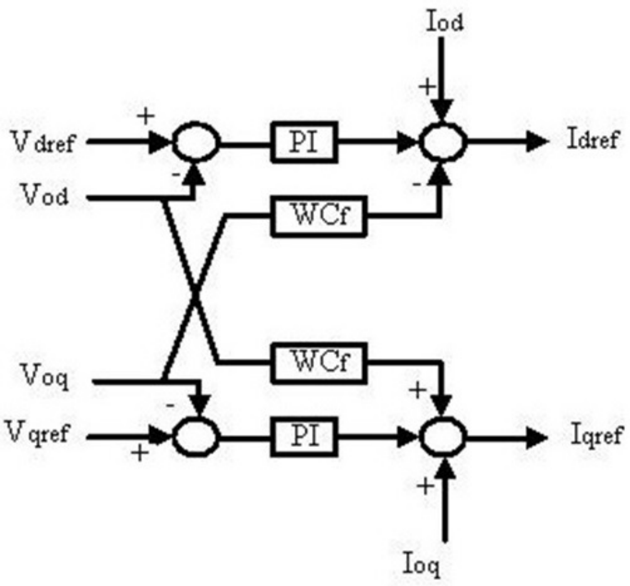

FIG. 3. Voltage controller.

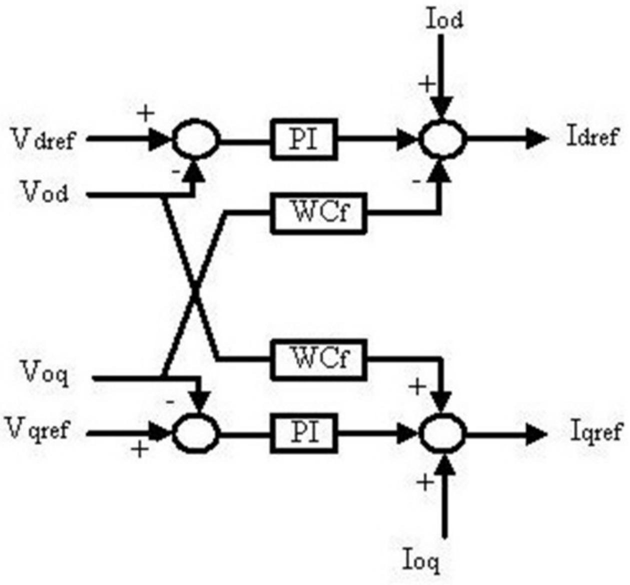

FIG. 4. Current controller.

$$i_{cd} = C_f(\frac{dv_{od}}{dt}) - wC_fV_{oq} \tag{11}$$

$$i_{cq} = C_f(\frac{dv_{oq}}{dt}) - wC_fV_{od} \tag{12}$$

To provide close voltage regulation, output voltage controller is adopted.

Fig. 3 shows the voltage controller. The controller employs PI regulator to generate the reference current. The dynamic of voltage controller can be given by

$$I_{dref} = (K_{PV}+\frac{K_{IV}}{S})(V_{odref}-V_{od})-wC_fV_{oq}+Iod \tag{13}$$

$$I_{qref} = (K_{PV}+\frac{K_{IV}}{S})(V_{oqref}-V_{oq})-wC_fV_{od}+Ioq \tag{14}$$

where K_{PV} and K_{IV} are the proportional and integral gains of PI controller, respectively. C_f is the filter capacitance.

C. Current Controller

By using Kirchhoff law in Fig. 1

$$V_{abc} = V_{oabc} + L_f(\frac{di_{abc}}{dt}) \tag{15}$$

Applying parks transformation

$$V_d = V_{od} + L_f(\frac{di_d}{dt}) - wL_fi_q \tag{16}$$

$$V_q = V_{oq} + L_f(\frac{di_q}{dt}) - wL_fi_d \tag{17}$$

After controlling voltage and defining the current reference, the current controller will follow its reference. The current controller employ PI regulator for current regulation.

Dynamic of the current controller can be given by

$$V_d = (K_{PI} + \frac{K_{II}}{S}(I_{dref} - I_d) - wL_fI_q + V_{od} \tag{18}$$

$$V_q = (K_{PI} + \frac{K_{II}}{S}(I_{qref} - I_q) - wL_fI_d + V_{oq} \tag{19}$$

where K_{PI}, K_{II} are the proportional and integral gains and L_f is filter inductance. Fig. 4 shows the current controller.

III. OPTIMIZATION ALGORITHM

A. Particle Swarm Optimization Theory

Particle swarm optimization (PSO) is a population-based stochastic optimization method[12]. It is a population-based search algorithm where each individual is referred to as a particle and represents a candidate solution. Each particle in the PSO flies through the search space with an adaptable velocity that is dynamically modified according to its own flying experience and that of the other particles. In PSO, each particle strives to improve itself by imitating the traits of its successful peers. Each particle has a memory and capability

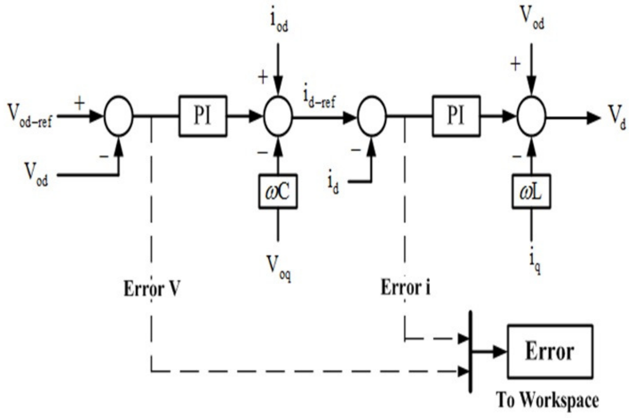

FIG. 5. Optimization of current and voltage controllers.

of remembering the best position in the search space it visited[15].

B. Control Objective

For enhancement of microgrid performance, coefficients of PI in voltage and current controllers must be optimized. The designing procedure is presented as follows.

Objective Function: *In islanding mode, the optimization parameters are* K_{PV}*,* K_{IV}*,* K_{PI} *and* K_{II}*. In this mode, the goal of optimization is to minimize the error of the voltage and current, as presented in* Fig. 5.

Limitation of Problem: *In islanding mode of operation, the problem limits are:*

$$K_{PV}^{min} < K_{PV} \tag{20}$$

$$K_{IV}^{min} < K_{IV} \tag{21}$$

$$K_{PV}^{min} < K_{PV} \tag{22}$$

$$K_{PI}^{min} < K_{PI} \tag{23}$$

K_{PV} and K_{IV} are the voltage controller proportional and integral gains, respectively. Also K_{PV} and K_{PI} are proportional coefficients of voltage and current controllers, respectively.

In this paper, minimum limits of all coefficients are set to zero. According to above, the optimization problem can be formulated as:

$$Min(Error) \tag{24}$$

Subject to limits as given in (20)-(23).

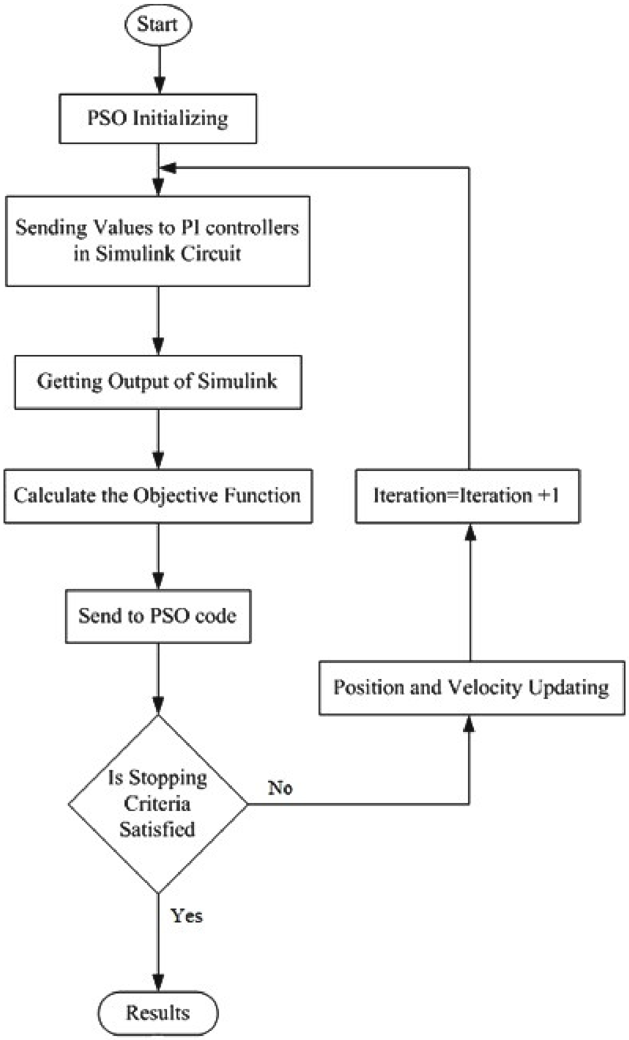

FIG. 6. Flowchart of the optimization scheme.

TABLE I. PSO parameters

Swarm Size	20
Number of Generation or Iteration	300
Acceleration Constant	$C_1 = C_2 = 2$
W_{start}	0.95
W_{end}	0.4

C. Implementation of PSO based Optimization

Fig. 6 shows the flow chart of the PSO-based optimization scheme that proposed in this paper. This was executed using codes in MATLAB software.

Parameters of PSO are presented in Table I. For best performance of optimization, these parameters should be selected carefully.

TABLE II. System parameters

Parameters		Values
DG_1 & DG_2	DC-link Voltage	580 V
	Inverter filter inductance	1 mH
	Inverter filter capacitance	50 μF
	Inverter switching frequency	8 KHz
	S_{rate}	10 KVA
Controller	M	$6.25e-5$
	N	$1.83e-3$
	W_n	50 Hz
	V_n	220 V
Z_1 & Z_2		$j0.4\ \Omega$
Load		6 KW
RMS line voltage		$220\sqrt{3}$

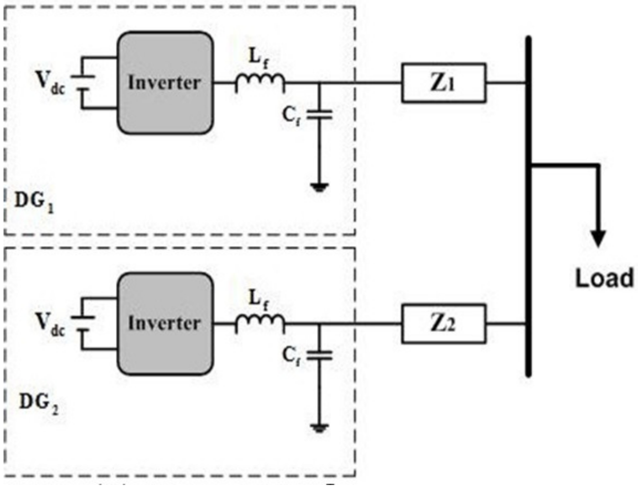

FIG. 7. System configuration.

IV. SIMULATION

A. System Configuration

A microgrid with two DG is shown in Fig. 7. System parameters are presented in Table II. For verifying the power sharing between DGs, load is changes from 6 kW to 10 kW at $t = 0.4$ s.

It should be noted that for determining droop coefficients in Table II, maximum frequency deviation (Δf) and maximum voltage deviation (ΔV) are considered to 0.5 Hz and 5%, respectively.

TABLE III. Result of optimization

	K_{PV}	K_{IV}	K_{PI}	K_{II}
PSO	0.32987	39.962	1.0926	656.58

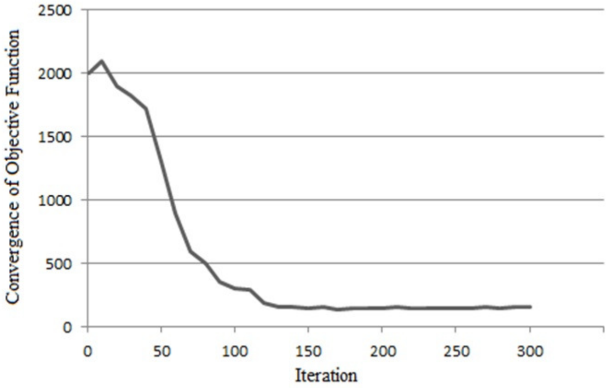

FIG. 8. Convergence of the objective function for the proposed PSO technique.

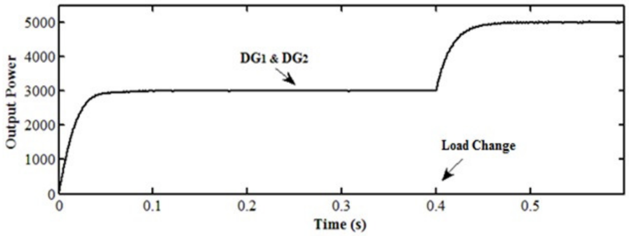

FIG. 9. Output powers of DGs.

B. Optimal Values

Table III shows the results of optimization.

Convergence of the objective function for the proposed PSO optimization technique is shown in Fig. 8. It can be seen that the PSO converge has a fast rate.

C. Simulation Results

Simulation outputs with the optimal values are presented below. According to figures 9 and 10, following results can be yields:

1. Power is shared between DG units correctly.
2. Frequency deviation is in the allowable range.
3. It can be seen that the DGs follow load change quickly and overshoot is minimized.

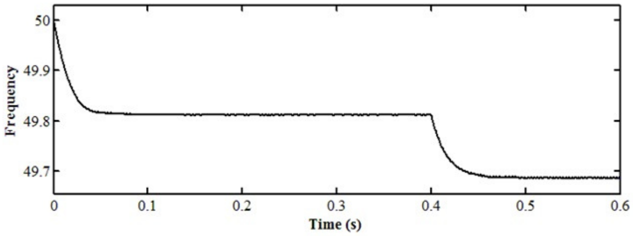

FIG. 10. Frequency of microgrid.

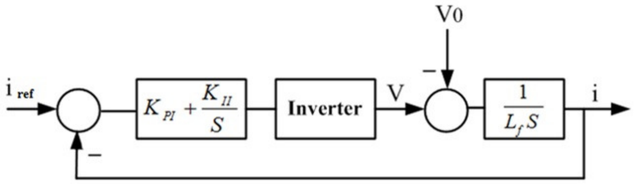

FIG. 11. Block diagram of current controller.

4. It is clear that the system has appropriate transient responses.

As a result, the microgrid has a good response and performance with the optimized controller.

V. STABILITY ANALYSIS

In this section, stability of voltage and current controllers with optimized PI gains are verified. For this purpose, their transfer functions should be determined.

A. Current Control Transfer Function

Fig. 11 shows the block diagram of the current controller for islanding operation. V_0 is the disturbance input. The inverter stage does not have any significant transient time associated with it[16], and hence, it modeled as an ideal gain. This ideal gain can be given by $G_{in}(s) = 1$. Block diagram of current controller is shown in Fig. 11.

The transfer function of the current controller is given by (25). It can be seen from (25) that the system is stable based on the conventional control theory.

$$T(S) = \frac{1.3123S + 309.08}{1.35 \times 10^{-3}S + 1.3123S + 309.08} \tag{25}$$

Fig. 12 Shows bode plot of the current controller. It can be seen that the system have positive phase margin and is stable. Fig. 13 shows step response of the controller. In Fig. 13, Rise time (t_r) is 0.00151, Overshoot is 13.3% and steady state error is zero. We can find out that the system has appropriate performance.

For analysis response of current controller to disturbance, the unit step is applied to disturbance input (V_0) in Fig. 14. It can be seen that the system have good response and disturbance is damped very soon. Settling time is less than 15 ms.

B. Voltage Control Transfer Function

Block diagram of voltage controller is shown in Fig. 15. The transfer function of this controller system is given by (26). According to (26), the system is stable based on the conventional control theory.

$$T(S) = \frac{4.511S^2 + 3438S + 491676}{6.75 \times 10^{-8}S^4 + 5.25 \times 10^{-4}S^3 + 4.811S^2 + 3438S + 491676} \tag{26}$$

Fig. 16 Shows bode plot of the voltage controller. It can be seen that the system have positive phase margin and is stable. Fig. 17 shows step response of the controller. In Fig. 17, settling time (t_s) is 0.00144, Overshoot is 24% and steady state error is zero. We can find out that the system has appropriate performance. For analysis the response of voltage controller to disturbance, the unit step is applied to disturbance input (i_o) in Fig. 18. It can be seen that the system have good response and disturbance is damped very soon. Settling time is less than 19 ms.

VI. CONCLUSION

This paper introduces a controller for controlling distributed generation resources of the microgrid in islanding operation mode. Optimization method was used to select the optimal parameters of this controller. Case study and PSO algorithm that has the task of finding the optimal solutions during the search were implemented in MATLAB software. Simulation results show that the power is shared between DG units correctly. Also, these results prove that parameters optimization are correct and system responses are good. Stability analysis was performed with optimized parameters. The results obtained in this study once again highlight the need for proper selection of control coefficients. Because incorrect selection may lead to oscillatory and undesirable system responses.

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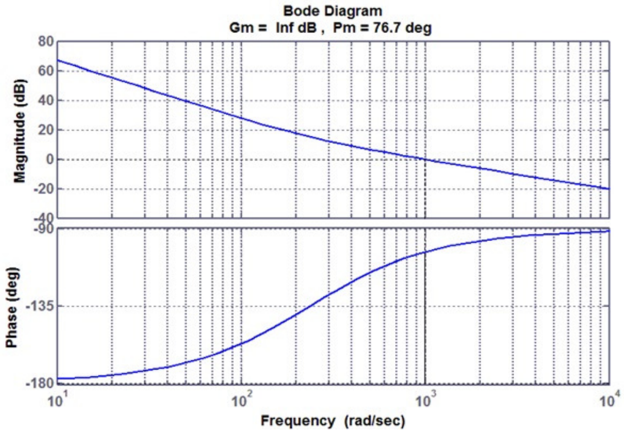

FIG. 12. Bode diagram of current controller.

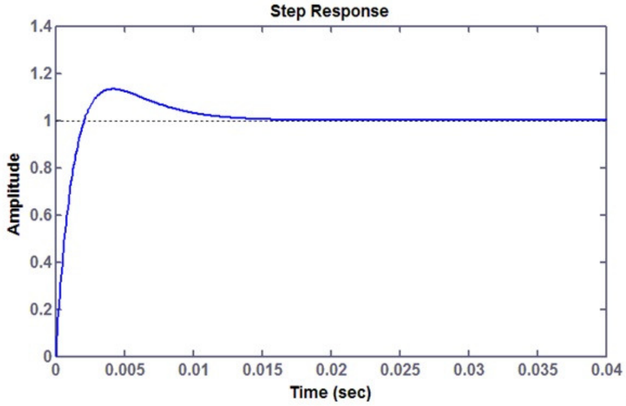

FIG. 13. Step response of current controller.

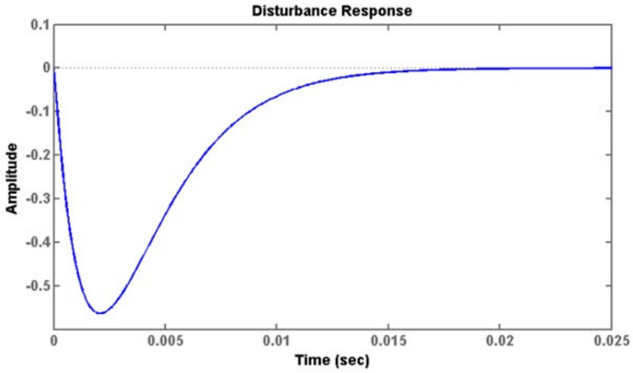

FIG. 14. Disturbance response of current controller.

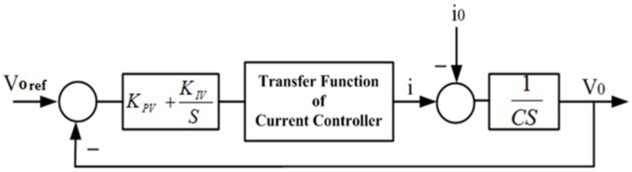

FIG. 15. Block diagram of voltage controller.

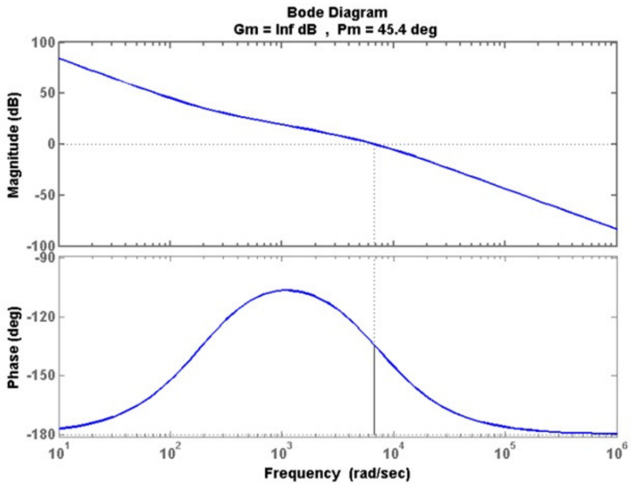

FIG. 16. Block diagram of voltage controller.

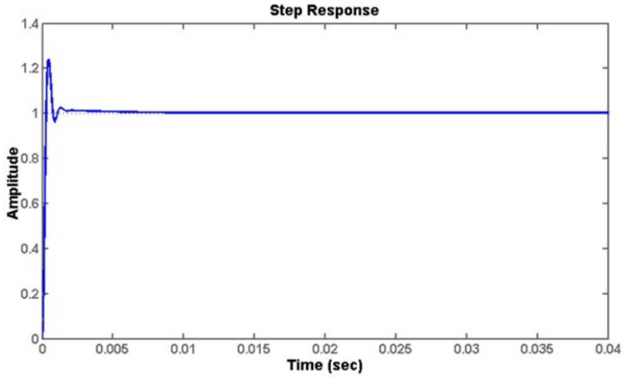

FIG. 17. Step response of voltage controller.

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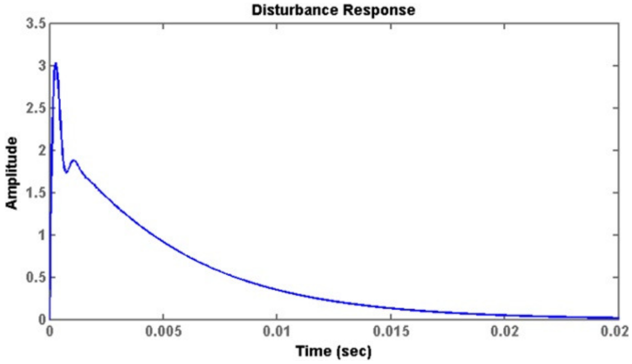

FIG. 18. Disturbance response of voltage controller.

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