Determination of Optimal Droop Controller Parameters for an Islanded Microgrid System Using Artificial Fish Swarm Algorithm (AFSA)

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Abstract

This article presents the development of an optimized droop controller of microgrid during islanding using artificial fish swarm algorithm (AFSA). This is necessary in order to minimize the frequency deviation that occurs when microgrid switches to stand-alone mode or when there are changes or variation in loads. The optimized droop controller was developed using AFSA to optimally select the gainsk_p, k_{pv}, k_{iv}, k_{pi} and k_{ii} in order to achieve a better response in the frequency output of the micro-grid during islanding. All modeling and analysis are implemented in MATLAB 2015b. Simulation results show that the proposed optimized droop controller improves the power quality of the micro-grid by ensuring that the deviation in frequency whenever the micro-grid switches to island mode or when there is variation in load is minimal.

Keywords: Droop Controller, Microgrid, Islanding, Artificial Fish Swarm Algorithm, Stand-alone and Frequency Deviation.

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1 INTRODUCTION

Concerns over global climate change and environmental pollution cause increment of integration of renewable distributed energy resources [1]. Wide spread installation of distributed generations to the utility grid are now being used to deal with increase in electrical energy demand. However, when there is fault in the utility grid, the distributed generation must be disconnected [2].

Advancement in distributed generation (DG) systems and power electronic devices led to concept of microgrid. It can integrate renewable energy and other forms of DG and also increase reliability and efficiency [3]. The microgrid is a cluster of distributed generation units that interface with electrical distribution network using power electronic devices such as voltage source inverters (VSI) [4].A microgrid can be set to operate in grid connected mode or in standalone mode. When operating in grid connected mode, the micro-grid is used to improve the dynamic response of the utility [5].

It helps export power to the utility grid (when the price is advantageous) or absorbs power and store it in the energy storage system for later use. During power outage, the microgrid operates in stand-alone mode and provides power to the local loads (which are far away from central stations to eliminate the cost of the long transmission lines) or some critical loads[6]. When micro-grid switches to standalone mode or when the load is changed, the micro-grid voltage and frequency deviate from their nominal values [7]. These deviations affect the loads consuming power, supplied by the microgrid[1]. The inverters that constitute part of the micro-grid are controlled to feed the load with the predefined voltage and frequency values according to a specific control strategy [8].

The main task in the stand-alone mode is to maintain the voltage and frequency of the system and support the required active and reactive powers [9].The droop control is usually used for sharing powers between distributed generations connected together [9]. In the droop control, the inverter emulates the behavior of a synchronous machine. For P-w and Q-V droop control, the power angle (δ) depends mainly on real power, while the voltage depends mainly on reactive power [5].

The droop control makes it possible for the inverters to transfer seamlessly from the grid connected mode to the stand-alone mode [8].To achieve stability when micro-grid switches from grid connected mode to stand-alone mode, the control parameters are the main effecting parameters [5,8]. Selection of the power sharing controller parameters and the PI controller parameters carefully will promote the system performance against disturbances [3, 5].

Due to the problems of frequency and voltage deviation that occur when the micro-grid switches from grid connected to stand-alone mode or when the load changes, researchers have used a trial and error method for the selection of the control parameters[10, 11]. However the method required a lot of computational time and optimal results were not guaranteed. Computational intelligence techniques of genetic algorithm (GA) [3, 8] and particle swarm optimization (PSO) [5] techniques have also been used to optimize the droop control parameters. However results obtained showed that improvement still needed to be made. Artificial fish-swarm algorithm (AFSA) is inspired by the collective movement of fish and their various social behaviors [12]. The AFSA has found widespread application in complex optimization domains, and currently a major research topic, offering an alternative to the more established evolutionary computation techniques that may be applied in many of the same domains [13].

This paper proposes artificial fish swarm algorithm (AFSA) to optimize the droop controller due to its ability in solving non-linear complex problem and high convergence speed in attaining optimal solution [14]. This will ensure that the deviations in frequency that occur when the micro-grid switches or when there are changes in load are reduced to the barest minimum.

2 LITERATURE REVIEW

Selection of the droop parameters of micro-grid has been used by several authors to improve the power quality of the micro-grid. The paper presented in [15] proposed the modeling, analysis and testing of autonomous operation of an inverter-based micro-grid, but the inner loop of the droop controller was not considered which results in the system having high harmonics, thus making the inverters output power to be of low quality.

In 2013, [16] used particle swarm optimization to regulate the voltage and frequency in an autonomous micro-grid operation. However, the search space of the tuning algorithm was limited, which produce a high tendency of obtaining local best solution. [5] developed a real time implementation and optimal design of autonomous microgrids. However, stability analysis of the controllers used show that the voltage overshoot was high.

[17] proposed a droop control of a parallel dual mode inverters used in micro-grid. However, some critical parts of the load won't get supply immediately after islanding until the second inverter is connected to the network and this makes the system to be less reliable. [18] implemented control of transient power during unintentional islanding of microgrids. However, stability analysis of the controller used shows that it takes more than 20ms for the system to attain stability.

The research in [8] proposed an analysis and optimization of droop controller of microgrids based on small signal model. However, less emphasis was made in minimizing the deviations in frequency.

3 MICROGRID SYSTEM BASED ON DROOP CONTROL

A typical micro-grid consisting of DGs, voltage source inverters, output filter and loads as shown in Figure 1 was developed in MATLAB Simulink platform. The micro-grid consist of two DGs which are all assumed to be DC source based on the fact that most electric sources (wind, solar and hydro) can be considered as DC source after rectifications. Each DG is connected to the load through an inverter, LC filter and coupling inductor.

The appropriate values selected for these parameters are presented in Table 1.

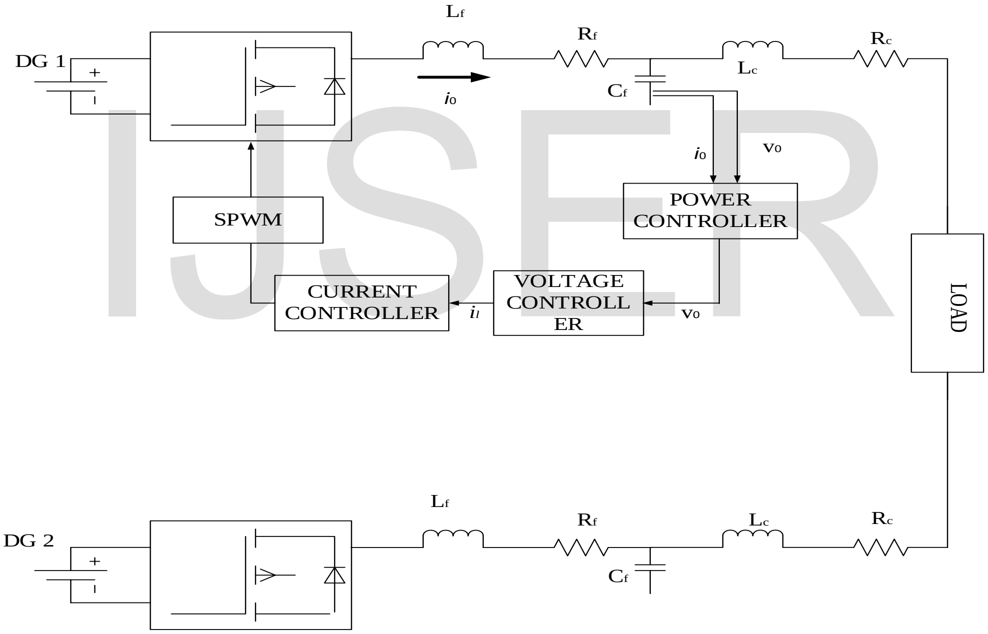

Figure 1: Block Diagram of DGs Connected in Parallel

Table 1: Microgrid Parameters

Parameters	Values
DC link voltage	580V
Inverter filter inductance	1.35mH
Inverter filter capacitance	50µF
Inverter switching frequency	8kHz
S_{rate}	10kVA
Parameters of line 1 and 2	0.03+j0.11Ω
Load	6kW
RMS line voltage	381.05

3.1 Controlling the Parallel Connected Inverters with a Droop Controller

The droop controller used consists of the power controller, the voltage controller and the current controller.

3.1.1 Power controller

The power controller which represents the (outer loop) is used to share the loads among the parallel connected inverters by decreasing the frequency when there is an increase in the load, while the voltage and current controller ensure minimized output harmonics. Figure 2 shows how the power controller is modeled in Simulink.

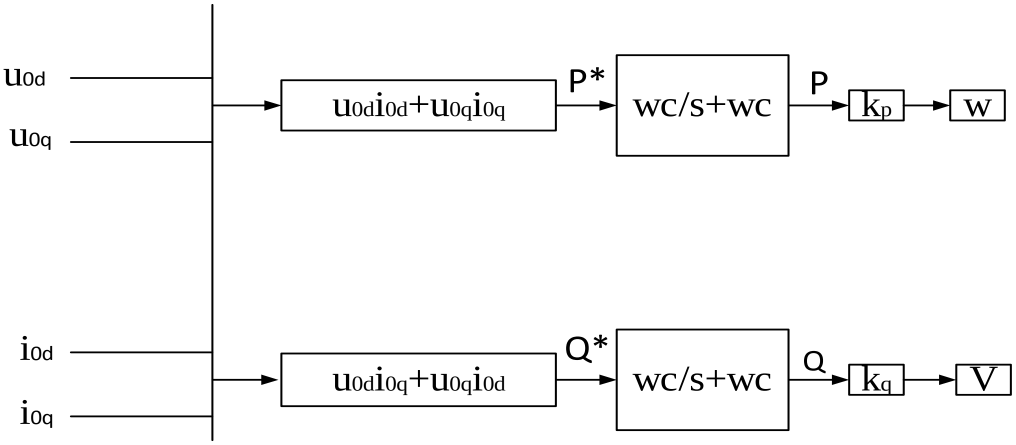

Figure 2: Power Controller Simulink Block Diagram

The instantaneous voltage and current are first converted to dq reference frame, after which a power calculation block was employed in calculating the active and reactive power from the measured instantaneous values of current and voltage using Equations (1) and (2). Then a low pass filter was adopted to filter through the measured powers in order to obtain real and reactive powers that are of high power quality using equations (3) and (4).

Finally, the frequency equivalent to the active power and the d-component of the output voltage reference corresponding to the reactive power were determined using Equations (5) and (6) respectively.

$$P = v_{0d} i_{0d} + v_{0q} i_{0q} \tag{1}$$

$$Q = v_{0d} i_{0q} - v_{0q} i_{0d} \tag{2}$$

$$P = \frac{w_c}{s + w_c}\left(v_{0d} i_{0d} + v_{0q} i0q\right) \tag{3}$$

$$Q = \frac{w_c}{s + w_c}\left(v_{0d} i_{0q} - v_{0q} i_{0d}\right) \tag{4}$$

$$w = w_n - k_p(\mathrm{P}) \tag{5}$$

$$V = V_n - k_q(\mathrm{Q}) \tag{6}$$

3.1.2 Voltage controller

The operation frequency and voltage calculated from the relationship of the droop characteristics (output of the power controller) was used to form the reference voltage command. The voltage controller controls the output voltage by employing a standard PI regulator which compares the sampled output voltage with the reference value given by the power controller after which the feed forward gain was obtained to compensate for the output voltage and generates the reference decoupling current vector as shown in Figure 3.

$$I_d = Fi_{0d} - w_c C_f V_{0q} + k_{pv}(\mathrm{V}_{0d} - V_d) + \mathrm{k}_{iv}(\mathrm{V}_{0d} - \mathrm{V}_d) \tag{7}$$

$$I_q = Fi_{0q} - w_n C_f V_{0d} + k_{pv}(\mathrm{V}_{0q} - V_q) + \mathrm{k}_{iv}(\mathrm{V}_{0q} - \mathrm{V}_q) \tag{8}$$

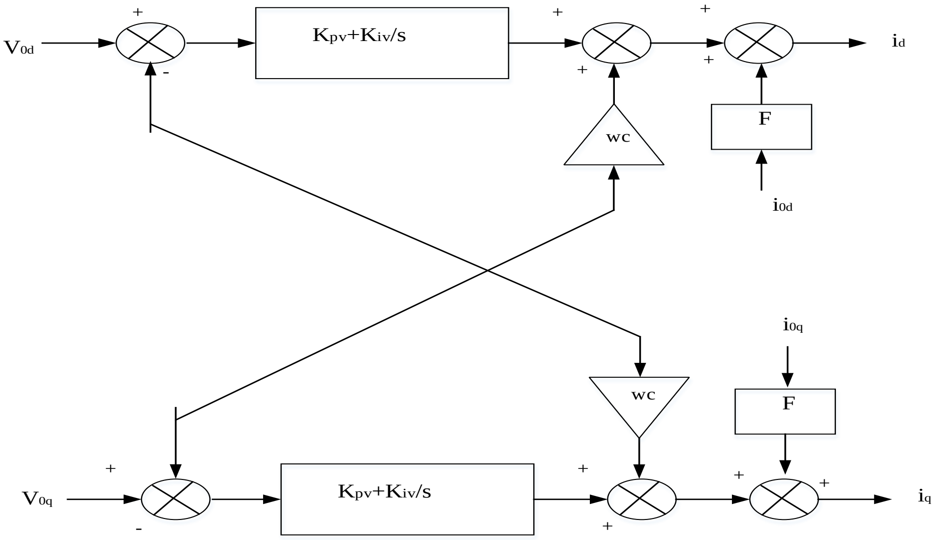

Figure 3: Block diagram of Voltage Controller

3.1.3 Current controller

Similar to the voltage controller, PI controller was used in the current controller to compare the current sampled filter current from the inductor and the reference value from the voltage controller output as shown in Figure 4 to minimize the current error. After which the PWM signal that serves as the input of the inverter is generated. Equations (9) and (10) represent the small signal state space form of the current controller.

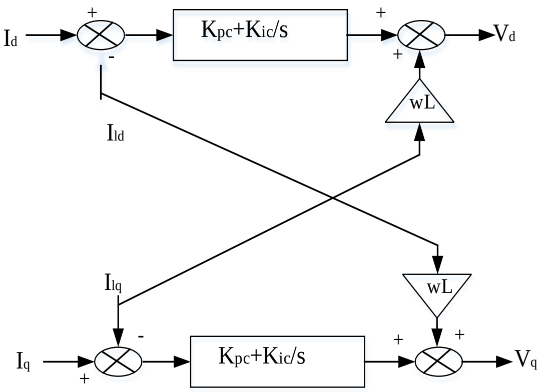

Figure 4: Block Diagram of Current Controller

$$V_d = -w_n L_f I_{lq} + k_{pc}(\mathrm{I}_d - I_{ld}) + \mathrm{k}_{ic}(\mathrm{I}_d - \mathrm{I}_{ld}) \qquad (9)$$

$$V_q = w_n L_f I_{ld} + k_{pc}(\mathrm{I}_q - I_{lq}) + \mathrm{k}_{ic}(\mathrm{I}_q - \mathrm{I}_{lq}) \qquad (10)$$

Where, L_f is the coupling inductor
K_p and k_q are the droop parameters
w is the cut-off frequency
s is the laplace transformation and
F is the feed forward gain

3.1.4 Current controller transfer function

Stability analyses of the controllers with the optimized gain are necessary in order to make sure that the controller reacts well to disturbance. For this purpose the transfer function of the current controller is determined. The block diagram used in determining the stability of the current controller for islanding operation is shown in Figure 5. V_0 serves as the disturbance input, while V is the voltage output from the inverter. The transient time associated with the inverter is modeled as an ideal gain since the transient time associated with it is not significant (Balaguer *et al.*, 2011). Equation (11) shows the transfer function for the current controller.

$$\text{Transfer function} = \frac{k_{pi}S + k_{ii}}{l_f S^2 + k_{pi}S + k_{ii}} \qquad (11)$$

Settling time and overshoot are obtained by carrying out step response on the controller.

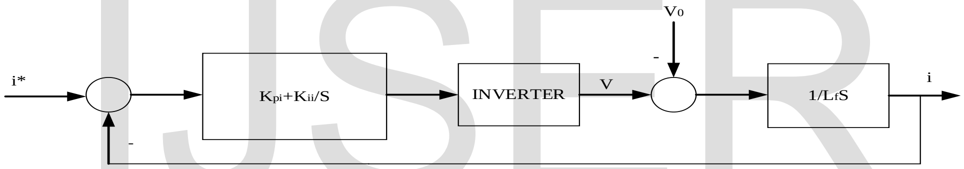

Figure 5: Block Diagram of Current Controller

3.2 AFSA-Based Model for the Optimal Determination of the Droop Controller Parameters (k_p and k_q)

In this paper, AFSA was employed to determine optimal droop control gains to ensure that the deviation in frequency that occurs when there is change in load is minimal.

Thus, the objective function can therefore be described as:

$$F = \min\{\Delta f\} \qquad (12)$$

Subject to the following constraints:

$$\left(0 \le k_p \le 6.25e^{-5}\right)$$
$$\left(0 \le k_{pv} \le 1\right)$$
$$(1 \le k_{iv} \le 1000)$$
$$\left(0 \le k_{pi} \le 1\right)$$
$$(1 \le k_{ii} \le 1000)$$

Where, k_p is the frequency droop coefficient,
k_{pv} is the voltage proportional controller,
$k_{iv}$is the voltage integral controller,
$k_{pi}$is the current proportional controller,
$k_{ii}$is the current integral controller and
Δf is the frequency deviation.

Therefore, (k_p, k_{pv}, k_{iv}, k_{pi} and k_{ii}) are the control parameters that must be optimized in order to achieve a minimized deviation in the frequencythat will ensure the power quality of the micro-grid is high and to also ensure that power are been shared equally between the inverters. To obtain the optimal values for the control parameters, which will ensure a minimized deviation in frequency an artificial fish swarm algorithm was developed in Matlab. This algorithm was linked with the developed simulink model in order to ensure that the optimized values obtained will minimize the deviations from the nominal frequency values of the micro-grid whenever there is disturbance. Steps taken to optimize the control parameters using AFSA are shown in the flowchart of Figure 6.

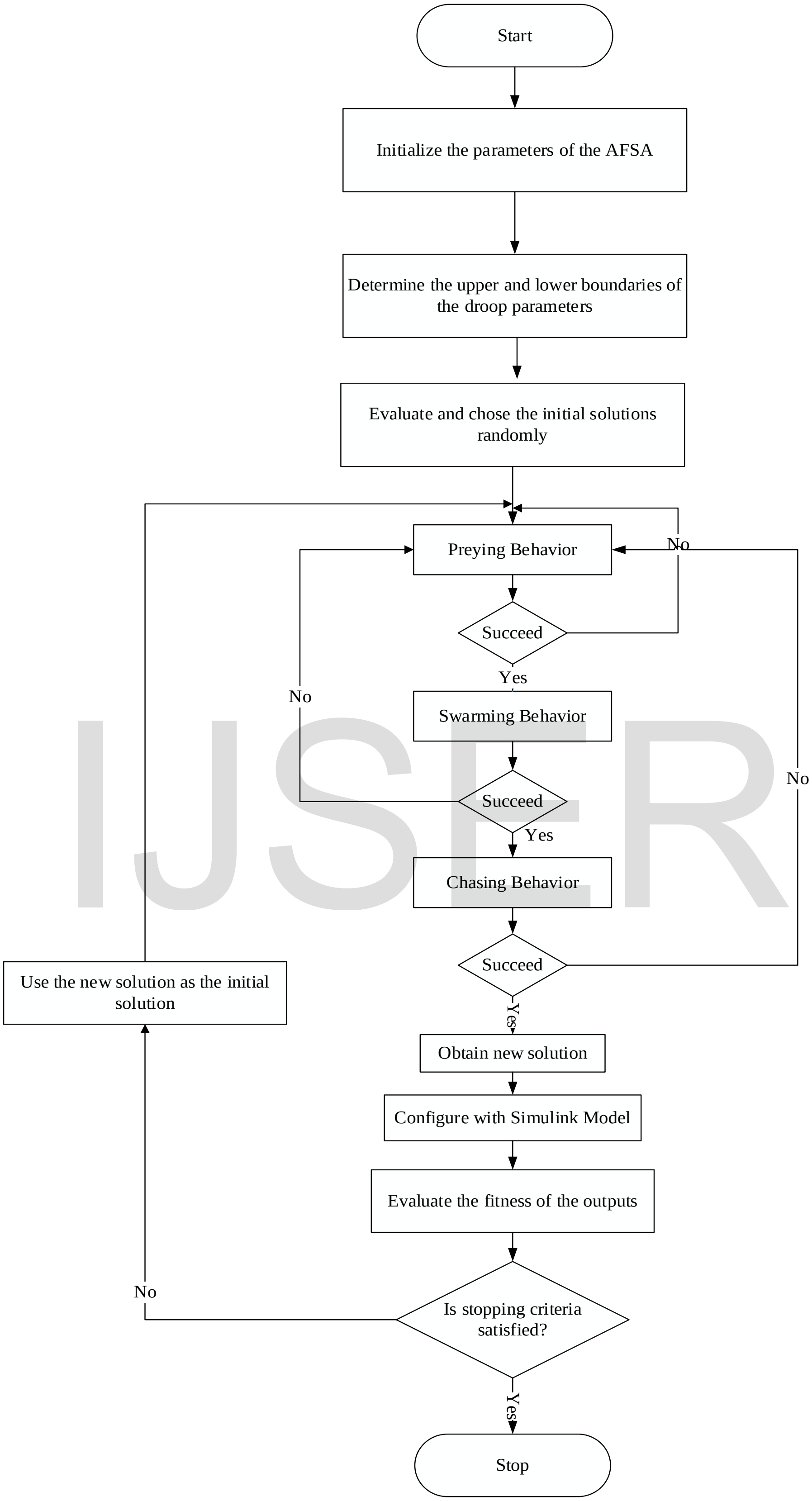

Figure 6: Flowchart of the AFSA Optimized Droop controller

V. RESULTS AND DISCUSSIONS

The islanded microgrid was modeled and simulated in MATLAB/Simulink as discussed in section IV using the parameters presented in Table 1. For verifying the level of deviations of the frequency from there nominal values, the micro-grid is started first in islanding mode with a load of 6kW from (0-0.3 seconds), the load was further increased to 10kW at time 0.3 seconds. The results obtained when AFSA was used to get the optimal values of the droop control parameters are presented.

4.1 Result of the Optimized Droop Controller using AFSA

Optimization of the droop control parameters was carried out with the developed AFSA model in this section. The values of the optimized parameters obtained after running the AFSA script are as shown in Table 2.

Table 2: Optimal Values of the Droop Parameters

S/N	Parameters	Values
1	k_p	0.00000000032
2	k_{pv}	0.05823899200
3	k_{iv}	831.96114292000
4	k_{pi}	0.99291179000
5	k_{ii}	409.00000000000

A Matlab script that links the AFSA with the simulink model was used to plot the output graphs of the micro-grid. Figure 7 shows a power plot of the DG against time using the optimized values of the control parameters.

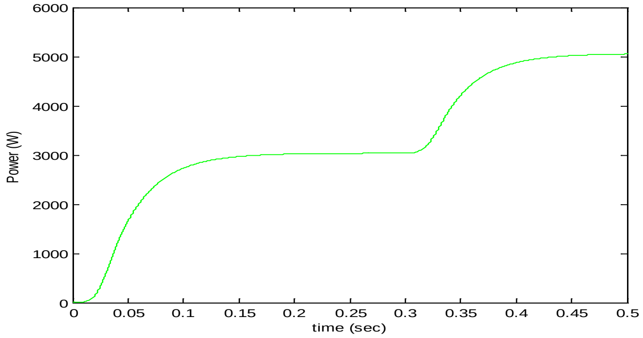

Figure 7: Power Output of DG1

It can be seen from the Figure that the load is shared equally, since the optimal values of the droop controller obtained are of the same value, the output values gotten are the same. The power generated by each inverter before the load changes at 0.3seconds is 3kW and after the load was changed from 6kW to 10kW each DG supplies 5kW to the load.

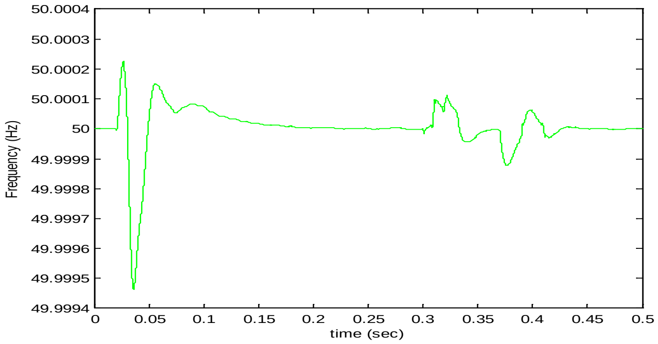

Figure 8: Frequency of the Inverter

Figure 8 shows how the frequency deviates from their nominal values (50Hz) immediately after islanding and when the load changes. Immediately after islanding, the frequency value deviates to 49.9995Hz. And when the load was increased to 10kW at time t=0.3s, the frequency deviates from 50Hz to 49.9999Hz. All these values obtained are well within the range of deviations that must not be exceeded (±0.2 Hz) when dealing with micro-grid.

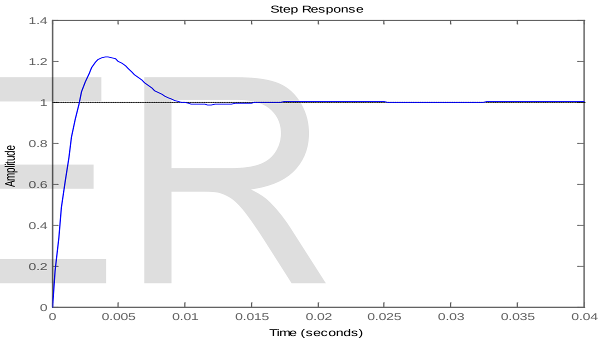

Figure 9: Step Response of the Current Controller

Figure 9 shows the step response of the current controller. The overshoot of the controller is 22.154% and the settling time is 0.00878 seconds. From this, conclusion can be made that the system has appropriate performance since the overshoot and settling time is less than 30% and 20ms respectively.

5 CONCLUSION

An optimized droop controller for transient power control of micro-grid during islanding and during change of load using Artificial Fish Swarm Algorithm (AFSA) has been developed in order to minmize the deviation in frequency. The optimized droop controller was implemented in MATLAB R2015b. From the analysis, it was observed that the frequency value obtained immediately after islanding was (49.995Hz) and that obtained when the load changes from 6kW to 10kW was 49.999Hz. as a result the proposed control optimization scheme ensures that the micro-grid do not loose its stability when the micro-grid switches to island mode or ewhen there are variations in the load.

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