A MODIFIED DROOP CONTROLLER FOR MICRO-GRID POWER QUALITY IMPROVEMENT USING ARTIFICIAL FISH SWARM ALGORITHM (AFSA)

I. Abdulwahab, J. Yusuf, and A. A. Olaniyan

ABSTRACT

This paper presents a modified droop controller for improving the power quality of micro-grid using Artificial Fish Swarm Algorithm (AFSA). This is necessary in order to reduce the frequency and voltage deviations that occur when the micro-grid changes from grid-connected to an autonomous mode or when the load changes. AFSA was used to optimally select and tune the droop controller gain parameters in order to achieve an improved response in the frequency and voltage outputs of the micro-grid in the course of islanding. The performance of the AFSA-based droop controller was compared with that of the genetic algorithm (GA) based droop controller using the values of frequency and voltage deviations as performance metrics. And from the results obtained, it was observed that the result obtained from the micro-grid when AFSA was used to optimize the droop controller outperforms that obtained when GA was used in terms of frequency and voltage by 0.213% and 1.0453% respectively. All modeling and analysis were implemented in MATLAB 2015b.

1.0 INTRODUCTION

Continuous increase in electric energy demand, worries over global climate change, and environmental pollution cause increment of integration of renewable distributed energy resources (Rahmani and Fakharian, 2016). Wide spread installation of distributed power generations to the utility grid are now being used to deal with increase in electrical energy demand (Sanjari and Gharehpetian, 2014).

Advancement in distributed generations (DGs) and power electronic devices led to concept of micro-grid. Typically, a micro-grid can integrate renewable energy and other forms of DG and also increase reliability (Vandoorn et al., 2013). Micro-grid can either operate in grid connected mode or autonomous mode. In the grid connected mode, the micro-grid is used to improve the dynamic response of the utility (Hassan and Abido, 2014). When there is loss of power from the grid, the micro-grid operates in autonomous mode and provides electrical energy to the local loads. When micro-grid switches to autonomous mode or when there is change in load, the micro-grid voltage and frequency deviate from their nominal values thereby reducing the quality of power supplied to the load (Yu et al., 2016). These deviations from their nominal value scan cause equipment malfunction (). In order to ensure that the frequency and voltage values of the system do not deviate beyond their nominal values, the inverters that form a portion of the micro-grid are controlled according to a specific control strategy (Yu et al., 2016). The main challenge in the stand-alone mode is to ensure that the voltage and frequency of the system do not
deviate beyond the allowable limit and also to support the required active and reactive powers (Hassan and Abido, 2013).

The droop control is a control technique used when generators are connected in parallel. In the droop control, the inverter imitates the operational principle of a synchronous machine (Pogaku et al., 2007) where the frequency depends on the active power and the voltage depends on the reactive power (Hassan and Abido, 2014). Selection of the droop controller parameters carefully will promote the system performance against disturbances and load changes (Razavi et al., 2012).

Selection of the droop parameters of micro-grid has been used by several authors to ensure that the power quality of the micro-grid is improved. Pogaku et al., (2007) developed a modeling and analysis scheme for stand-alone 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 to be of low power quality. Razavi et al., (2012) major aim was on how to optimize the control parameters of the frequency droop controller and the proportional integral controller for minimizing frequency deviation. However, the minimization of the deviation of the voltage from the nominal value was not considered. Wen et al., (2015) presented a micro-grid consisting of inverters in parallel dual mode using droop control. Nevertheless, critical parts of the load does not get supply immediately after islanding until the second inverter is linked to the network and this makes the system to be less reliable. Yu et al., (2016) proposed an improved droop control for micro-grids based on small signal model. However, less emphasis was made in minimizing the deviations in frequency. Rahmani and Fakharian (2016) developed an optimized controller that will reduce the deviations in frequency due to the micro-grid experiencing load change. However, results obtained showed that the deviations in frequency still needed to be improved on.

It is evident from the reviewed literature that frequency and voltage deviations still remains an issue that need to be addressed. Careful selection of the droop control parameters will ensure these deviations are minimized. In line with these, this work introduce an Artificial Fish Swarm Algorithm (AFSA) to optimize the control parameters of the droop controller, due to its ability in solving non-linear complex problem and high convergence speed in attaining optimal solution.

2.0 DROOP CONTROL BASED MICRO-GRID SYSTEM

A micro-grid comprising of two distribution generators, two voltage source inverters, output filter and loads shown in Figure 1 was developed in MATLAB Simulink environment. The DGs in the micro-grid are assumed to be direct current (DC). An inverter, a coupling inductor and LC filter help serve as the medium through which Each DG is connected to the load. Table 1 shows the appropriate values selected the parameters of the micro-grid. The parameter values are adopted from the work of Razavi et al., (2012) for the basis of comparison.

Figure 1: Block Diagram of DGs Connected in Parallel

Table 1: Micro-grid Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC link voltage</td>
<td>580 V</td>
</tr>
<tr>
<td>Inverter filter inductance</td>
<td>1.35 mH</td>
</tr>
<tr>
<td>Inverter filter capacitance</td>
<td>50 µF</td>
</tr>
<tr>
<td>Inverter switching frequency</td>
<td>8 kHz</td>
</tr>
<tr>
<td>S admitting</td>
<td>10 kVA</td>
</tr>
<tr>
<td>Line 1 ad 2 Parameters</td>
<td>0.03+j0.11 Ω</td>
</tr>
<tr>
<td>Load</td>
<td>6 kW</td>
</tr>
<tr>
<td>RMS line voltage</td>
<td>381.05 V</td>
</tr>
</tbody>
</table>

3.0 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 Power controller

This controller which represents the (outer loop) ensures that the load is shared equally among the parallel connected inverters by reducing the frequency
whenever there is a rise in the load connected to the system, while output harmonics is reduced using the voltage and current controller.

In the power controller, conversion of the instantaneous current and voltage to dq reference frame is first priority, secondly, the power calculation block is employed in calculating the active and reactive power from the measured instantaneous values of current and voltage

\[ P + v_{od}i_{od} = v_{oq}i_{oq} \]  \hspace{0.5cm} (1)

\[ Q - v_{od}i_{od} = v_{oq}i_{oq} \]  \hspace{0.5cm} (2)

\[ w = v_n - k_p (P - P^*) \]  \hspace{0.5cm} (3)

\[ V_n = v_n - k_q (Q - Q^*) \]  \hspace{0.5cm} (4)

Where, \( w_n \) and \( V_n \) are the nominal values of DG frequency and voltage magnitude, \( P \) and \( Q \) are the measured active and reactive power after filtering, \( k_p \) and \( k_q \) are the droop control gains of the active and reactive power droop slopes. \( P^* \) and \( Q^* \) are the active and reactive power set points, \( k_f \) is the feed forward gain, \( W_c \) represents the cut of frequency, \( L_f \) is the coupling inductor, \( v_{oq}, v_{oq}, i_{oq} \) and \( i_{oq} \) are the voltage and current outputs using equations (1) and (2). A low pass filter for ensuring that the active and reactive power are of high quality was then adopted to filter through the measured powers. Finally, equations (3) and (4), were used to determine the frequency equivalent to the active power and the d-component of the output voltage reference corresponding to the reactive power respectively.

### 3.2 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

\[ I_q = F_i_{od} - w_n C_f V_n + k_p (V_{oq} - V_q) + k_i (V_{oq} - V_q) \]  \hspace{0.5cm} (5)

\[ I_q = F_i_{oq} - w_n C_f V_n + k_p (V_{oq} - V_q) + k_i (V_{oq} - V_q) \]  \hspace{0.5cm} (6)

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 helps control the voltage output by using the conventional PI regulator that relates the reference value obtained from the power controller with the sampled output voltage. Then, the feed forward gain was obtained to compensate for the output voltage and creates the reference decoupling current vector as shown in (5) and (6).

Where, \( w_n \) and \( V_n \) are the nominal values of DG frequency and voltage magnitude. \( F \) is the feed forward gain, \( W_c \) represents the cut of frequency, \( k_{pi} \) is the voltage proportional controller, \( k_i \) is the voltage integral controller, \( L_f \) is the coupling inductor, \( v_{oq}, v_{oq}, i_{oq} \) and \( i_{oq} \) are the voltage and current outputs.

### 3.3 Current controller

The current controller uses PI controller to compare the current sampled filter current from the inductor and the reference value from the voltage controller output so as to reduce the current error. Then the PWM signal which serves as inverter input is generated.

Equations (7) and (8) represent the small signal state space form of the current controller.

\[ V_{q} = -w_n L_f I_q + k_p (I_{q} - I_{q}) + k_i (I_{q} - I_{q}) \]  \hspace{0.5cm} (7)

\[ V_{q} = w_n L_f I_q + k_p (I_{q} - I_{q}) + k_i (I_{q} - I_{q}) \]  \hspace{0.5cm} (8)

Where, \( w_n \) and \( V_n \) are the nominal values of DG frequency and voltage magnitude, \( P \) and \( Q \) are the measured active and reactive power after filtering, \( k_{pi} \) and \( k_i \) are the current proportional and current integral controller respectively, \( k_p \) and \( k_q \) are the droop control gains of the active and reactive power droop slopes. \( P^* \) and \( Q^* \) are the active and reactive power set points, \( F \) is the feed forward gain, \( W_c \) represents the cut of frequency, \( L_f \) is the coupling inductor, \( v_{oq}, v_{oq}, i_{oq} \) and \( i_{oq} \) are the voltage and current outputs.

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

In this work, AFSA was employed to determine optimal droop control gains to ensure that the deviation in frequency and voltage that occur when there is change in load is minimal (minimize equations (3) and (4)).
Thus, the objective function can therefore be described as:

\[
\min J = \frac{1}{\Delta V(t)} + \frac{1}{\Delta f(t)}
\]  
(9)

Subject to the following constraints:

\[
(0 \leq k_p \leq 6.25e^{-5}), (0 \leq k_q \leq 6.25e^{-5}), (0 \leq k_{pv} \leq 1),
\]

\[
(1 \leq k_{pi} \leq 1000), (0 \leq k_{pi} \leq 1), (1 \leq k_{ii} \leq 1000)
\]

Where, \( k_p \) is the frequency droop coefficient, \( k_q \) is the voltage droop coefficient, \( k_{pv} \) is the voltage proportional controller, \( k_{vi} \) is the voltage integral controller, \( k_{pi} \) is the current proportional controller, \( k_{ii} \) is the current integral controller, \( \Delta V \) is the voltage deviation and \( \Delta f \) is the frequency deviation.

To obtain the optimal values for the control parameters, which will ensure a minimized deviation in frequency and voltage, an AFSA was developed in Matlab.

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

6.0 Results and Discussion

In this section the performance of the optimized droop controller whose optimal gains were obtained using AFSA for minimizing the deviations in frequency and voltage of a micro-grid are discussed and relevant results reported.

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

\[
k_p = 0.32 \times 10^{-9}, k_q = 3.85 \times 10^{-5}, k_{pv} = 0.0582,
\]

\[
 k_{pi} = 831.9612, k_{pi} = 0.9929 \quad \text{and} \quad k_{ii} = 409
\]

Figure 2 shows the power plot of the DGs against time using the optimized values of the control parameters.

Figure 2: Power Output of (a) DG1 and (b) DG2.

It is seen from Figure 2 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 0.3 seconds is 3 kW and after the load was changed from 6 kW to 10 kW each DG supplies 5 kW to the load.

Figure 3: Frequency Output of the Inverter

\[
\begin{align*}
\text{Figure 3: Frequency Output of the Inverter} \\
\end{align*}
\]
Figure 3 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 which gives a maximum deviation of 0.0005Hz from the nominal frequency. And when the load was increased to 10 kW at time $t = 0.3s$, the frequency deviates from 50Hz to 49.9999Hz and this shows that each DG gives a deviation of 0.0001 Hz. All these values obtained are well within the range of deviations that must not be exceeded ($0.2$ Hz). Figures 4(a) and (b) show the voltage outputs of the micro-grid, as seen from the plot that the peak voltage obtained from the micro-grid model immediately after islanding and when the load changes from 6 kW to 10 kW at time 0.3 seconds is 1.0045 p.u. This shows that the deviation in voltage experience by the micro-grid is very minimal.

Figures 4(a) and (b) show the voltage outputs of the micro-grid. As seen from the plot that the peak voltage obtained from the micro-grid model immediately after islanding and when the load changes from 6 kW to 10 kW at time 0.3 seconds is 1.0045 p.u. This shows that the deviation in voltage experience by the micro-grid is very minimal.

**Result of the Optimized Droop Controller using Genetic Algorithm (GA)**

Genetic algorithm was used in selecting the droop parameters in this case. The values obtained for the parameters are as shown below:

$$k_p = 0.0206 \times 10^{-5}, \quad k_q = 1.83 \times 10^{-5},$$

$$k_{pv} = 0.4296, \quad k_{in} = 81.946,$$

$$k_{pi} = 1.3123 \text{ and } k_{ii} = 309.08$$

It is seen from the figure that immediately when the micro-grid is started in island mode the power output supplied to the load by each DG was 3 kW and after the load was increased to 10 kW, the power supplied by each DG was 5.1 kW.
Immediately after islanding, the frequency deviates to 49.8930 Hz which shows a deviation of 0.1070 Hz from the nominal frequency, and when the load was increased to 10 kW at time $t = 0.3s$, the frequency value was 49.9950 Hz which shows a deviation of 0.0050 Hz.

Figures 7(a) and (b) show the plots of output voltage of the first DG against time during switching to islanding mode and during change in load.

From the plots, it is seen that the peak output voltage of the micro-grid after islanding was 1.015 p.u. This shows that the voltage output of the micro-grid experiences a maximum deviation of 0.015 p.u. after islanding.

<table>
<thead>
<tr>
<th>Table 2: Comparison Between GA and AFSA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
</tr>
<tr>
<td>GA</td>
</tr>
<tr>
<td>AFS A</td>
</tr>
</tbody>
</table>
It is seen from Table 2 that the deviation in frequency when the droop controller was optimized using AFSA immediately when the micro-grid starts operating in island mode is minimal (0.0010%) when compared with that obtained from the GA optimized droop controller (0.2140%). Furthermore the deviation in frequency when the load of the micro-grid was increased to 10 kW is also very minimal (0.002%) when compared with that obtained from the GA droop controller (0.01%).

6.0 CONCLUSION

A modified droop controller for improving micro-grid power quality of using Artificial Fish Swarm Algorithm (AFSA) has been developed so as to reduce the deviation in frequency and voltage that occur during islanding and when there is change in load. From the analysis, it was observed that the frequency value obtained immediately after islanding was (49.9995Hz) and that obtained when the load changes from 6 kW to 10 kW was 49.9999 Hz. These results when compared with the GA optimized droop controller showed that the AFSA droop controller outperformed GA by 0.213% and 0.01% for recorded frequencies after Islanding and during load change (i.e. from 6 kW to 10 kW) respectively. Furthermore, the AFSA droop controller obtained a peak voltage value of 1.0045 p.u. as compared to 1.015 p.u. obtained when using the GA droop controller. This shows that the optimized droop controller using AFSA produces a 1.0453% improvement over the GA optimized droop controller. The results showed that the deviations in frequency and voltage due to islanding and load changes do not exceed the allowable limits given by UCTE (for 0.2 Hz ± and 0.1 p.u. ±).

REFERENCES


