Abstract—This paper focuses on an optimization method for a droop controlled microgrid in islanding operation. The ultimate goal is to optimize droop coefficient to minimize frequency variation. Also, gains of PI controllers are optimized to ensure good behavior of the controller. Optimizations are implemented in MATLAB software using Genetic Algorithm (GA). Stability of optimized PI gains of voltage and current controllers are analyzed.

Keywords—Microgrid; Distributed Generation (DG); Droop Control; Islanding operation; V/f control; power sharing; Voltage Source Inverter (VSI); Genetic Algorithm (GA).

I. INTRODUCTION

Advancement in Distributed Generations (DGs) 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 [1]. Many forms of DG such as fuel cell and photovoltaic are interfaced to the network through power electronic devices. These interfaced devices make the system more flexible in their operation and their control compared to the conventional electrical machine [2- 4]. Consequently, control strategy of parallel connected inverters is important for microgrid operating.

The basic objective in microgrid control is to achieve an accurate power sharing and regulation of the microgrid voltage and frequency. Centralized control of microgrid is proposed in [5]. However, this method is impractical and costly in microgrid with long distance between DG units. To overcome this limitation, decentralized controllers based on the droop control method are proposed [6-9]. This method does not need any communication.

In normal condition, Microgrid operates in grid-connected mode and the main grid can support the system frequency and voltages by supplying the power mismatch immediately. When a fault occurs in the main grid, Microgrid needs to disconnect from the main grid to provide uninterrupted power to the loads. In islanding operation mode, DGs operate in V/f control for supplying microgrid load and controlling voltage and frequency [10]. To this purpose, droop control that assigns the amount of power sharing for changes of load without communication is used [11].

After transition from grid-connected to islanding, the frequency of microgrid is determined by the droop coefficients of DGs. Since the droop control changes the system frequency to supply the power mismatch, the frequency variation occurs. To maintain frequency close to the nominal value, droop coefficients should be determined properly. The droop coefficient and sharing ratio may be dictated by economic interested of the system operators [12]. The choice of droop coefficients in such case is analyzed in [13].

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. But this method depends on the operation point [14]. Hence, in this paper simulation model in MATLAB/Simulink is employed as a replacement for small signal method for optimization.

This paper concentrates on optimization of microgrid controller. Genetic algorithm is used to optimize the droop coefficients. The proportional and integral gains of voltage and current controller are optimized to achieve the system stability.

II. MICROGRID CONFIGURATION

A microgrid configuration with two DG is shown in Fig.1. Each DG consists of DC source, voltage source inverter (VSI) and LC filter for rejecting high frequency harmonics. Load 1 is sensitive load. Load 2 is non sensitive load.

Under normal operation, the microgrid is a part of main grid. In this mode, DGs injected predefined active and reactive powers and main grid regulate voltage and frequency of microgrid. When disturbance such as fault occurs in the main grid, the switch k opens and microgrid operate in islanding mode. Hence, increase the reliability of the microgrid. In islanding operation mode, due to absence of main grid, DGs should be able to share the power mismatch to supply loads and to maintain power quality. In this situation, DGs operate in V/f control for controlling the voltage and frequency of microgrid and feeding the loads.
III. CONTROL STRATEGY

This section presents the control strategy for islanding operation mode of microgrid. Fig. 2 shows the V/f controller and Fig. 3 shows the power controller that consists of power calculation and droop controller. The droop control is used for sharing power between DGs in islanding operation.

![Fig. 2. V/f Control](image1)

Power calculation block calculates active and reactive powers from measured instantaneous values of d axis and q axis voltage and current. Equations 1 and 2 show the calculation procedure of powers:

\[
P = \frac{W_r}{S + W_q} \left( V_{qo} I_{ad} + V_{do} I_{qo} \right)
\]

\[
Q = \frac{W_q}{S + W_q} \left( V_{qo} I_{qo} - V_{do} I_{ad} \right)
\]

where \( W_r \) and \( W_q \) are rated active and reactive powers of VSI, respectively. Droop coefficients are defined below:

\[
m = \frac{\Delta w}{P_{\max}}
\]

\[
n = \frac{\Delta V}{Q_{\max}}
\]

where \( \Delta w \) and \( \Delta V \) are maximum allowable deviations of frequency and voltages. Also \( P_{\max} \) and \( Q_{\max} \) are maximum output active and reactive powers of DG.

The reference frequency and amplitude of the output voltage can be obtained by the droop control. Then \( V_{\text{ref}} \) and \( V_{q\text{ref}} \) are obtained by dq transformation.

![Fig. 3. Droop Control](image2)

IV. OPTIMIZATION ALGORITHM (GA)

A. Genetic Algorithm

In this paper, Genetic Algorithm is used to optimize the objective function. To optimize a problem, using the GA, a population is required to be defined at the first step. This population is formed by binary accidental quantization of chromosomes. In the next step, produced population is applied to the objective function and the fitness of chromosomes is obtained, using equation 7. Some of the best answers are chosen and new generation is produced by the genetic operators of crossover and mutation. In the first type, two genes, that should be combined, are placed beside each other and are divided from a specified point. Then, the sides that are placed in front of each other are combined together. In the second type, a percent of chromosomes are substituted by another value of their allowable confine, in order to make the optimization, global and not local. To have a global and the fastest answers, both of these genetic operators are used in this paper [16].
The main problems in control optimization are nonlinearity and complexity of the system. A method for this purpose is small signal linearization. But linearization of microgrid for optimization of droop controller may result in difference with the actual microgrid [14, 17]. Hence in this paper, simulation model in MATLAB/Simulink is used for optimization.

After transition from grid-connected to islanding, the frequency of microgrid is determined by the droop coefficients of DGs. Since the droop control changes the system frequency to supply the power mismatch, the frequency variation occurs. To maintain frequency close to the nominal value, droop coefficients should be determined properly.

The control problems are formulated as optimization problem. The criteria of droop control optimization are:

1) Frequency of microgrid should be maintained near nominal value. It means that, frequency variation of microgrid after transition to islanding and load changes should be minimal.

2) DGs output power should be equal to load power and power sharing between DGs should be based on the droop control.

The proportional and integral constants of PI controllers for voltage and current controller are determined by GA to obtain good response and stability of system.

C. Technical Constraints

1. Frequency Deviation

Selection of appropriate droop coefficient results lower deviation of microgrid frequency. Frequency deviation after change of load is determined by following equation, as explained in Appendix.

\[
\Delta f = \frac{m_1m_2}{m_1 + m_2} \Delta P_{\text{Load}}
\]  \hspace{1cm} (8)

According to equation (8), droop coefficient should be optimized for minimizing the frequency deviation. The constraint for droop coefficient is presented below.

\[
0 < m_{\text{optimized}} < m
\]  \hspace{1cm} (9)

where m value is determined according to equation (5).

I. Power Sharing

In optimization process, load should be supplied and shared between DGs correctly. Following equations shows the power sharing mechanism between DGs after any change of the load, as explained in Appendix.

\[
\Delta f = \frac{m_1m_2}{m_1 + m_2} \Delta P_{\text{Load}}
\]  \hspace{1cm} (10)

\[
\Delta f = \frac{m_1m_2}{m_1 + m_2} \Delta P_{\text{Load}}
\]  \hspace{1cm} (11)

According to equations (10) and (11), change of the load between DGs should satisfy the following equation.

\[
\Delta f = \frac{m_1m_2}{m_1 + m_2} \Delta P_{\text{Load}}
\]  \hspace{1cm} (12)

D. Objective Function

The proposed objective function of this paper consists of droop coefficient and power sharing. The first part of objective function represents frequency deviation, as in equation (13).

\[
F_1 = \min(\Delta f)
\]  \hspace{1cm} (13)

If the constraints of \( F_1 \) are violated, the output would be infinite value.

The second part of objective function represents the power sharing accuracy between DGs.

\[
F_2 = \min(P_1 - \frac{m_1}{m_2} P_2)
\]  \hspace{1cm} (14)

It should be note that, in this paper it’s assumed that DGs have the same droop coefficients. So, the purpose of second part is to equally share load between DGs.

V. SIMULATION RESULTS

The control method for islanded microgrid of Fig.1 have been modeled and simulated in MATLAB/Simulink. System parameters are presented in TABLE I. For verifying the power sharing between DGs, load is changes from 6 KW to 10 KW at t=0.3 s. Results are presented in two cases. In these cases, the droop coefficients of DGs are chosen equally, so that the power is shared between them equally.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG1 &amp; DG2 DC-link Voltage</td>
<td>580V</td>
</tr>
<tr>
<td>Inverter filter inductance</td>
<td>1.35mH</td>
</tr>
<tr>
<td>Inverter filter capacitance</td>
<td>20uF</td>
</tr>
<tr>
<td>Inverter switching frequency</td>
<td>8kHz</td>
</tr>
<tr>
<td>Nenv</td>
<td>10kVA</td>
</tr>
<tr>
<td>Controller m</td>
<td>6.25e-5</td>
</tr>
<tr>
<td>Controller n</td>
<td>1.83e-5</td>
</tr>
<tr>
<td>Wn</td>
<td>50Hz</td>
</tr>
<tr>
<td>Vn</td>
<td>220V</td>
</tr>
<tr>
<td>Parameters of Lines1 &amp; 2</td>
<td>0.03 + j0.12Ω</td>
</tr>
<tr>
<td>Load</td>
<td>6KW</td>
</tr>
<tr>
<td>RMS line voltage</td>
<td>220v3</td>
</tr>
</tbody>
</table>
Case 1:
In this case, selection of droop coefficients are based on the equations 5 and 6. Allowable frequency deviation is considered to 0.5 Hz for determination of droop coefficient. Parameters of PI controller for Voltage and current controller are obtained using try and error. These parameters are presented below.

\[ K_{PV} = 0.19, \quad K_{PV} = 398, \quad K_{PI} = 0.5, \quad K_{P} = 800 \]

Fig. 5 depicts the output active powers of DGs. Since DGs have a same droop coefficient, change of the load is shared between them equally.

Fig. 6 shows the frequency of islanded microgrid. After transition to islanding and change of load in this mode, frequency of microgrid is determined by droop coefficients of DGs in microgrid. It can be seen from Figs. 5-6 that the system does not have a good behavior. Although the deviation of frequency in islanding mode is in allowable limit, but it can be minimize using Genetic algorithm.

Fig. 7 shows the output active powers of DGs with optimized parameters. Since DGs have a same droop coefficient, change of the load is shared between them equally.

Case 2:
Selection of droop coefficient in this case is based on the Genetic Algorithm. Constraints on the droop coefficient for optimization are 0 and 6.25×10⁻⁵. Value of 6.25×10⁻⁵ is obtained based on equation (5) for 0.5Hz allowable deviation. Optimized parameters are:

\[ m = 0.0206 \times 10^{-5}, \quad K_{PV} = 0.4296, \quad K_{PV} = 81.946, \]
\[ K_{PI} = 1.3123, \quad K_{P} = 309.08 \]

Fig. 7 shows the output active powers of DGs with optimized parameters. Since DGs have a same droop coefficient, change of the load is shared between them equally.

Fig. 8 shows the frequency of islanded microgrid. It can be seen from Fig. 8 that the frequency variations of microgrid in this case become very smaller than the case 1. Also it can be seen from Figs. 7-8 that the system behavior with optimized PI gains is better than case 1. As a result, with optimization of droop coefficient and PI gains, frequency deviation become smaller and the system behavior is improved.

VI. 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.

1) Current Controller Transfer Function:
Fig. 9 shows the block diagram of the current controller for Islanding operation. \( V_{dc} \) is the disturbance input. The inverter stage does not have any significant transient time associated with it [18], and hence, it modeled as an ideal gain. This ideal gain can be given by \( G_{ss}(s) = 1 \). Block diagram of current controller is shown in fig. 9.

The transfer function of the current controller is given by equation (15). It can be seen from equation (15) that the system is stable based on the conventional control theory.

\[ T(S) = \frac{1.3123S + 309.08}{1.35 \times 10^{-3}S^2 + 1.3123S + 309.08} \]  

(15)

Fig. 10 shows bode plot of the current controller. It can be seen that the system have positive phase margin and is stable.
Fig. 11 shows step response of the controller. In Fig. 11, Rise time (tr) 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 ($V_d$) in Fig. 12. It can be seen that the system have good response and disturbance is damped very soon. Settling time is less than 15ms.

2) **Voltage Controller Transfer Function:**
Block diagram of voltage controller is shown in Fig. 13.

The transfer function of this controller system is given by equation (16). According to equation (16), the system is stable based on the conventional control theory.

$$T(S) = \frac{4.511S^2 + 3438S + 491676}{6.75 \times 10^4 S^4 + 5.25 \times 10^5 S^3 + 4.811S^2 + 3438S + 491676} \quad (16)$$

Fig. 14 Shows bode plot of the voltage controller. It can be seen that the system have positive phase margin and is stable. Fig. 15 shows step response of the controller. In Fig. 15, settling time (ts) is 0.00144, Overshoot is 24% and steady state error is zero. We can find out that the system has appropriate performance.
This paper described an optimization method for a droop controlled islanded microgrid based on the Genetic Algorithm, which successfully implements optimal frequency deviation by selecting droop coefficients from a region where the frequency deviation is in an allowable range. The proportional and integral gains of PI controller are optimized to achieve good response and stability of the system.

Particular emphasis has been paid to the impact of droop coefficient on frequency deviation, because this coefficient plays a significant role in the microgrid frequency deviation after transient to island and change of load in this situation.

Simulation results are presented that support validity of this optimization. A comparison has been done between optimized and common method for coefficient selection. Finally, stability analyses for optimized PI gains are presented.

APPENDIX

If the load of microgrid is changed in islanding mode, the frequency of microgrid and share of DGs are determined according to following equation.

$$\Delta P_{\text{DG}_1} + \Delta P_{\text{DG}_2} = \Delta P_{\text{load}}$$ (1A)

According to droop equation:

$$\frac{-\Delta f}{m_1} - \frac{-\Delta f}{m_2} = \Delta P_{\text{load}}$$ (2A)

where $m_1$ and $m_2$ are droop coefficients of $\text{DG}_1$ and $\text{DG}_2$, respectively.

Hence, the frequency deviation and power sharing between DGs for load change in islanding operation is obtained.

$$\Delta f = -\frac{m_1 m_2}{m_1 + m_2} \Delta P_{\text{load}}$$ (3A)

$$\Delta P_{\text{DG}_1} = -\frac{m_2}{m_1 + m_2} \Delta P_{\text{load}}$$ (4A)

$$\Delta P_{\text{DG}_2} = -\frac{m_1}{m_1 + m_2} \Delta P_{\text{load}}$$ (5A)

REFERENCES


