Microgrid synchronization using power offset through a central controller

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Abstract: A high penetration of renewable energy in power systems gives rise to the inverter based distributed generators (DG) in the current microgrid system. With the ability of microgrid to operate in both islanded and grid connected mode, a robust and reliable coordination and synchronization between the DGs and the utility grid is crucial to provide a seamless transition between operation modes. Droop based technique is the most popular method in microgrid system, however, voltage or current transient are present during mode transition. A power offset synchronization technique is proposed to provide a seamless transition between modes of operation. The results show that the mode transition is smooth and seamless without any voltage or current transients.

1. Introduction

Typical microgrid systems consist of multiple distributed generators (DG), power storage and multiple loads connected in parallel. With renewable energy such as solar are becoming more widespread in power systems, inverter based DGs have grown in popularity and plays an important role in the current generation of microgrid system [1]. Since these inverters are electronically commutated, coordination and synchronization are a crucial in the microgrid system to maintain system reliability and operation [2].

Microgrid DGs can operate with or without the utility grid. In grid connected mode, the DGs operate in grid supporting mode where the DGs support the grid by injecting current into the grid to supply the loads [3]-[5]. Both the voltage and frequency are regulated by the utility grid. When the microgrid operates independently without the need of the utility grid, it is known as islanded mode. In islanded mode, the DGs have to established their own voltage and frequency [6]-[10]. This mode is also known as a standalone mode and coordinating between the DGs are important to avoid instabilities in the microgrid system. It is preferred for a microgrid system that can operate in both grid connected and islanded mode for a more robust distribution network. Coordination and synchronization between the DGs to provide seamless transition between these modes is important to reduce the current and voltage fluctuations in the system [11].

Phase locked loop (PLL) are mainly used in microgrid to provide frequency and voltage tracking for the DGs in both grid connected and islanded mode [12]-[15]. As for DGs controls, the most common way for a DG to work in both modes is to use two distinct controllers to cater for each mode [16]-[18]. One controller regulates the voltage and frequency output for it to work in islanded mode, while the other controller regulates the output current injected to the grid. Only one controller is active at a given time. Switching in between these controllers introduces voltage or current spikes during transition due to the different control parameters between the controllers. In [19], a large leader DG,
which is the closes DG to the point of common coupling (PCC) are used to synchronize the other DGs through the use of droop technique. In [20], low bandwidth communication is implemented between the DGs and a secondary controller is used to provide synchronization signals. In [21-22], a P-w and Q-V droop control are implemented with the use of communication through a central controller for synchronization.

Most researchers focus on using the droop technique with a secondary or central controller to provide the synchronization signals required for the DGs. However, the transition between islanded and the grid connected mode causes current and voltage transient during transition. Furthermore, the droop technique encompasses drawbacks such as poor power sharing performance, frequency variation and sensitive to changes in line parameters [23]. In this paper, a synchronization technique based on power offset is introduced to provide seamless transition and synchronization between modes of operation. A microgrid central controller (MGCC) and a secondary controller are used as a synchronization and power sharing platform.

2. Proposed microgrid system

A microgrid system is proposed as in figure 1, where the system consists of 3 DGs, common load, MGCC and a secondary controller. Each DG is connected to the PCC through line impedance and an interfacing inductance to make the line behave more inductive in nature. Each DG is controlled by the MGCC where the DG reference active power P and reactive power Q are calculated independently by MGCC.

![Diagram of proposed microgrid system](image)

**Figure 1.** The proposed microgrid for grid connected and islanded operation.

Based from the AC power flow through an impedance as in figure 2 where the line is mostly inductive, it is well known that the DG active power can be adjusted by varying the DG power angle $\alpha$ while the DG reactive power can be adjusted by varying the voltage output of the DG. The overall control for each DG is shown in figure 3 where P and Q generated by the DG are controlled through the P and Q controller. The controller adjusts the voltage amplitude and phase angle of the DG reference generator. The inverter primary control consists of an inner current control [22] with an outer voltage control.
Power offset synchronization

Transitioning from islanded mode to grid connected mode requires the voltage, phase and frequency on the PCC to match the main utility grid before connection to avoid a high power surge and damaging the DGs. For a PQ controlled DG, a synchronization signal to correct for voltage, phase, and frequency is required. This will introduce multiple signals to be transmitted through the low bandwidth communication lines and slows down system response. Since each DG in the microgrid are controlled using P and Q references, changing these power references allows the DG to change its phase angle and voltage output to meet the new set references. Thus, by introducing a power offset in each DG power references, the phase and voltage on the PCC can be adjusted to match the utility grid without affecting the DGs P and Q generation. The addition of power offset are managed by the MGCC where the P and Q power references for each inverter is calculated as

\[ P_{ref} = \frac{P_{offset} + P_{DG1} + P_{DG2} + \cdots + P_{DGn}}{n} \]  

\[ Q_{ref} = \frac{Q_{offset} + Q_{DG1} + Q_{DG2} + \cdots + Q_{DGn}}{n} \]  

Where \( n \) is the number of available DGs in the microgrid system. The \( P_{offset} \) and \( Q_{offset} \) are regulated through a PI controller which the controller inputs are obtained from the secondary controller. The P and Q power offset are only applied during synchronization with the grid in islanded mode. During normal operation, MGCC sets both the power offsets as zero so that the power sharing scheme between DGs is implemented. The secondary controller calculates the PCC phase and voltage difference with respect to the utility grid by using PLL and Clarke transformation respectively. The voltage and phase difference is calculated as

\[ \Delta V = \sqrt{(V\alpha_{grid}^2 + V\beta_{grid}^2)^2} - \sqrt{(V\alpha_{pcc}^2 + V\beta_{pcc}^2)^2} \]  

\[ \Delta \theta = \theta_{grid} - \theta_{pcc} \]
The synchronization with the utility grid is completed when $\Delta V$ and $\Delta \theta$ are approximately zero and thus $P_{\text{offset}}$ and $Q_{\text{offset}}$ are also converging to zero. At this moment, MGCC will close the utility grid switch ($G_{\text{SW}}$) and connect the utility grid with the PCC of the microgrid. Equation (1) and (2) are still applied by the MGCC even after successfully connected to the grid to avoid large voltage and current transient during grid connection. MGCC then switches to grid connected mode by utilizing equation (5) and (6) for P and Q reference for each DG. The $P_{\text{offset}}$ and $Q_{\text{offset}}$ term are removed since it is only used during synchronization and replaced by $P_{\text{grid}}$ and $Q_{\text{grid}}$ so power can flow from the utility grid to PCC.

$$P_{\text{ref}} = \frac{P_{\text{grid}} + P_{\text{DG1}} + P_{\text{DG2}} + \ldots + P_{\text{DGn}}}{n+1}$$  \hspace{1cm} (5)$$

$$Q_{\text{ref}} = \frac{Q_{\text{grid}} + Q_{\text{DG1}} + Q_{\text{DG2}} + \ldots - Q_{\text{DGn}}}{n+1}$$  \hspace{1cm} (6)$$

3. Results

Simulation of the proposed microgrid system is constructed in Matlab Simulink as in figure 4. The parameters used in the simulation are specified in table 1. Note that the different values of line impedances and interfacing inductances are used in the simulation. This helps to show the performance of the proposed system for DG with different line impedance. All other parameters including the LC filter, PQ controller and primary controller are the same for all DGs.

![Figure 4. Matlab Simulink simulation of the proposed microgrid system.](image-url)

| Description                  | Parameters | Values              |
|------------------------------|------------|---------------------|
| Interfacing inductance       | $L_{\text{int1}}$, $L_{\text{int2}}$, $L_{\text{int3}}$ | 2mH, 4mH, 4mH       |
| LC filter (all)              | LC         | 1mH, 30μF           |
| DC voltage bus               | $V_{\text{dc}}$ | 500V                |
| Line impedance               | $L_{\text{lin1}}$ (R_{L1}, X_{L1}), $L_{\text{lin2}}$ (R_{L2}, X_{L2}), $L_{\text{lin3}}$ (R_{L3}, X_{L3}) | 0.171Ω, 0.0429Ω, 0.684Ω, 0.1716Ω, 0.342Ω, 0.0858Ω |
| P controller gain (all DG)   | $K_p$      | $1 \times 10^{-3}$  |
| Q controller gain (all DG)   | $K_q$      | $5.0 \times 10^{-4}$|
| Voltage controller gain (all DG) | $K_v$, $I_v$ | 5, 800              |
In figure 5, at $t<0.3s$ all the DGs are initially operating in islanded mode and $G_{SW}$ is open. Using equation (1) and (2) with the P and Q offsets are zero, the DGs operate in equal power sharing mode supplying the common load of 10kW and 2kVar. At $t=0.3s$, the grid synchronization is started and P and Q power offset are applied. Figure 6 shows the voltage and phase difference between PCC and utility grid. With a negative phase difference, a negative P offset is injected while a positive Q offset is injected to correct for the positive voltage difference. A slight increase in power is observed due to the increase in voltage amplitude on the PCC to match with the grid voltage.

At $t=0.5s$, $G_{SW}$ is closed hence connecting the utility grid to the PCC. Note that equation (1) and (2) still applies which allow for power sharing only between DGs while $P_{grid}$ and $Q_{grid}$ is zero. From figure 7, it is observed that during when the $G_{SW}$ is closed, no current transients are present on both the grid and load currents during connection. At $t=0.55s$, MGCC switches to using equation (5) and (6) where P and Q for the utility grid is included in the power sharing with the DGs. Equal power sharing is
applied for all DGs including from the utility grid. It is observed that the power for all the DGs and the grid reached the calculated $P_{\text{ref}}$ and $Q_{\text{ref}}$ setpoint.

At $t=0.9s$, the transition from grid connected mode to islanded mode occur. During transitioning, the DGs promptly have to increase their P and Q power to cater for the disconnection of the utility grid and MGCC will revert to using equation (1) and (2). All the DGs can quickly reach their respective P and Q reference power and there is no current fluctuation or transients for the load current during transition.

4. Conclusion

A microgrid grid synchronization method is proposed by using P and Q power offset to adjust the DGs phase angle and voltage amplitude to provide smooth transitions between modes of operation. The proposed method is able to quickly synchronize the voltage and phase with the grid without compromising on power sharing and drooping of the frequency. Furthermore, the method allows for smooth and seamless transitions in between operation modes without any transients. Individual P and Q control for each DG can be maintained for different line impedance in both islanded and grid connected modes and during synchronization.

References

[1] Bifaretti S, Cordiner S, Mulone V, Rocco V, Rossi JL, Spagnolo F. Grid-connected microgrids to support renewable energy sources penetration. Energy Procedia. 2017 May 1;105:2910-5.

[2] Tan D, Novosel D. Towards a (more) electronic transmission and distribution (eT&D). CES Transactions on Electrical Machines and Systems. 2017 Jul 7;1(1):15-25.

[3] Mousavi SY, Jalilian A, Savaghebi M, Guerrero JM. Coordinated control of multifunctional inverters for voltage support and harmonic compensation in a grid-connected microgrid. Electric Power Systems Research. 2018 Feb 1;155:254-64.

[4] Bullich-Massagué E, Aragüés-Penalba M, Prieto-Araujo E, Sumper A, Caire R. Optimal feeder flow control for grid connected microgrids. International Journal of Electrical Power & Energy Systems. 2019 Nov 1;112:144-55.

[5] Abusara MA, Sharkh SM, Guerrero JM. Improved droop control strategy for grid-connected inverters. Sustainable energy, grids and networks. 2015 Mar 1;1:10-9.

[6] Rokrok E, Shafie-Khah M, Catalão JP. Review of primary voltage and frequency control methods for inverter-based islanded microgrids with distributed generation. Renewable and Sustainable Energy Reviews. 2018 Feb 1;82:3225-35.

[7] Andishgar MH, Gholipour E, Hooshmand RA. An overview of control approaches of inverter-based microgrids in islanding mode of operation. Renewable and Sustainable Energy Reviews. 2017 Dec 1;80:1043-60.

[8] Azeem F, Narejo GB, Shah UA. Integration of renewable distributed generation with storage and demand side load management in rural islanded microgrid. Energy Efficiency. 2018:1-9.

[9] Chen M, Xiao X. Hierarchical frequency control strategy of hybrid droop/VSG-based islanded microgrids. Electric Power Systems Research. 2018 Feb 1;155:131-43.

[10] Husna AW, Roslan MA, Mat MH. Droop control technique for equal power sharing in islanded microgrid. International Journal of Power Electronics and Drive Systems. 2019 Mar 1;10(1):530.
[11] Micallef A, Apap M, Spiteri-Staines C, Guerrero JM. Single-phase microgrid with seamless transition capabilities between modes of operation. IEEE Transactions on Smart Grid. 2015 Jul 2;6(6):2736-45.

[12] Chauhan PJ, Reddy BD, Bhandari S, Panda SK. Battery Energy Storage for Seamless Transitions of Wind Generator in Standalone Microgrid. IEEE Transactions on Industry Applications. 2018 Aug 6;55(1):69-77.

[13] Zeng Z, Shao W. Reconnection of micro-grid from islanded mode to grid-connected mode used sliding Goertzel transform based filter. IET Renewable Power Generation. 2017 Apr 11;11(7):1041-8.

[14] Hong YY, Liu CY, Chang YR, Lee YD, Ouyang DC. Synchronisation of two separate zones in a standalone microgrid. The Journal of Engineering. 2017 Jun 23;2017(7):300-5.

[15] Meegahapola L, Laverty D, Jacobsen MR. Synchronous islanded operation of an inverter interfaced renewable rich microgrid using synchrophasors. IET Renewable Power Generation. 2017 Nov 28;12(4):407-14.

[16] Talapur GG, Suryawanshi HM, Xu L, Shitole AB. A reliable microgrid with seamless transition between grid connected and islanded mode for residential community with enhanced power quality. IEEE Transactions on Industry Applications. 2018 Feb 21;54(5):5246-55.

[17] Singh B, Pathak G, Panigrahi BK. Seamless Transfer of Renewable-Based Microgrid Between Utility Grid and Diesel Generator. IEEE Transactions on Power Electronics. 2017 Nov 28;33(10):8427-37.

[18] Wang C, Liang B, He J. An enhanced power regulation and seamless operation mode transfer control through cooperative dual-interfacing converters. IEEE Transactions on Smart Grid. 2017 Apr 5;9(6):5576-87.

[19] Arafat MN, Elrayyah A, Sozer Y. An effective smooth transition control strategy using droop-based synchronization for parallel inverters. IEEE Transactions on Industry Applications. 2014 Nov 12;51(3):2443-54.

[20] Hou X, Sun Y, Lu J, Zhang X, Koh LH, Su M, Guerrero JM. Distributed hierarchical control of AC microgrid operating in grid-connected, islanded and their transition modes. IEEE Access. 2018 Nov 21;6:77388-401.

[21] Das D, Gurrala G, Shenoy UJ. Transition between grid-connected mode and islanded mode in VSI-fed microgrids. Sadhana - Academy Proceedings in Engineering Sciences. 2017 Aug 1;42(8):1239-50.

[22] Lee CT, Jiang RP, Cheng PT. A grid synchronization method for droop-controlled distributed energy resource converters. IEEE Transactions on Industry Applications. 2013 Jan 25;49(2):954-62.

[23] Khaledian A, Aliakbar Golkar M. Analysis of droop control method in an autonomous microgrid. Journal of applied research and technology. 2017;15(4):371-7.