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Improvement of Reactive Power Sharing and Control in Networked Microgrid

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Abstract

An important task of microgrid is to share the load demand using multiple Distributed Generation (DG) units. The total load demand shared by multiple DG units with different conventional droop control and its variants have been reported in literature. Frequency droop control and voltage droop control methods are introduced to share real and reactive power in microgrid. The power sharing at the steady state is always accurate while reactive power sharing is sensitive to the impacts of mismatched feeder impedance. Due to the mismatched feeder impedance in microgrid, the reactive power sharing errors and power control stability problem occur. For a networked microgrid configuration with linear and non linear loads, the reactive power sharing is more challenging. For improvement of reactive power sharing and control in networked microgrid, a control method is introduced to reduce reactive power sharing errors by injecting a small real power disturbance, which is activated by the low-bandwidth synchronization signals from central controller. The proposed power control strategy has been tested in simulation.
Keywords- Microgrid, Distributed Generation (DG), load demand, reactive power sharing, linear and non linear loads, power quality, active and reactive power sharing.

1. Introduction

The increasing high energy demand along with low cost and higher reliability requirements, are driving the modern power systems towards clean and renewable power. Microgrid technologies are going to be a huge supports for small distributed generation (DG) units on power system. Distributed generation (DG) units in microgrid dispatch clean and renewable power compared to the conventional centralized power generation. Microgrids are systems which operate with different types of loads and micro sources. Due to high penetration of distributed generation (DG) units with different types of loads can cause power quality and power control issues.

The total load demand sharing by distributed generation units should share equal load to maintain power control stability [1]. A voltage and frequency droop control methods are used for sharing active and reactive power from multiple distributed generation units. These distributed generation units are operated by inverters and DC storage units, where a number of parallel inverters are operated [2], [5]. All the distributed generation units are highly responsible for stabilize the system voltage and frequency while sharing active and reactive power in an autonomous microgrid [4].

There are many techniques presented without control interconnection in [5], [9]. Conventionally, they are based on the frequency and voltage droop concept to achieve load sharing. These conventional droop controller methods, however, only work well for linear and mostly resistive load. For nonlinear load, the power transients and load harmonic components cannot be shared properly. For an islanded microgrid, the total loads must be properly shared by multiple distributed generation units in decentralized manner [3], [5]. The real power sharing at steady state is always accurate while the reactive power sharing is sensitive to the impacts of mismatched feeder impedance [3]-[6]. The reactive power sharing accuracy in a simplified microgrid with two distributed generation (DG) units has been introduced in many literatures [7]-[9]. For a networked microgrid configuration with linear and non linear loads, the reactive power sharing is more challenging.

To reduce the reactive power sharing errors in microgrid system, some of improved methods have been introduced [2]-[8]. The control issues regarding reactive power sharing in networked microgrid is more challenging. To improve reactive power sharing and control in networked microgrid, this paper proposed a simple reactive power sharing compensation scheme. For improvement of reactive power sharing and control in networked microgrid, a control method is introduced to reduce reactive power sharing errors by injecting a small real power disturbance, which is activated by the low-bandwidth synchronization signals from central controller. Reactive power sharing errors are significantly reduced with this proposed method. After the compensation, the proposed droop controller will be automatically switched back to conventional droop controller. The proposed compensation method achieves accurate reactive power sharing at steady-state and is effective for microgrids with all types of configurations and load locations.

2. Review of the Conventional Droop Control Method

Most of the wireless-control of paralleled-inverters uses the conventional droop method, which introduces the following droops in the amplitude E and the frequency ω of the inverter output voltage [2],[5].

$$\omega = \omega_0 - D_P.P \tag{1}$$

$$E = E_0 - D_Q.Q \tag{2}$$

Where ω_0 and E_0 are the output voltage angular frequency and amplitude at no load, and D_P and D_Q are the droop coefficients for the frequency and amplitude, respectively.

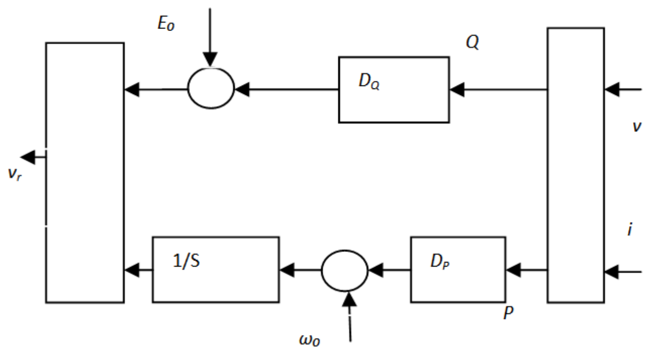

Figure 1: Conventional droop control scheme.

It is well known that if droop coefficients are increased, then good power sharing is achieved at the expanse of degrading the voltage regulation. From Eq. 3 and Eq. 4, we can find the droop coefficients as

$$D_P = (\omega_0 - \omega)/P_{max} = \Delta\omega / P_{max} \tag{3}$$

$$D_Q = (E_0 - E) / Q_{max} = \Delta E / Q_{max} \tag{4}$$

In conclusion, the conventional droop method has several intrinsic problems related to its limited transient response, since the system dynamics depends on the power-calculation filter characteristics, the droop coefficients, and the output impedance. These parameters are determined by the line-frequency, the maximum allowed frequency and amplitude deviations, and the nominal output power. Thus, by using the conventional droop method, the inverter dynamics cannot be independently controlled.

3. Proposed Control Technique

In complex configurations of microgrids, the reactive power sharing errors are caused by a number of factors and its compensation strategy is difficult. Therefore, for improvement of reactive power sharing and control in networked microgrid, a control method is introduced to reduce reactive power sharing errors by injecting a small real power disturbance, which is activated by the low-bandwidth synchronization signals from central controller without knowing the detailed microgrid configuration [1]. This feature is very important to achieve the "plug-and-play" operation of DG units and loads in the microgrid.

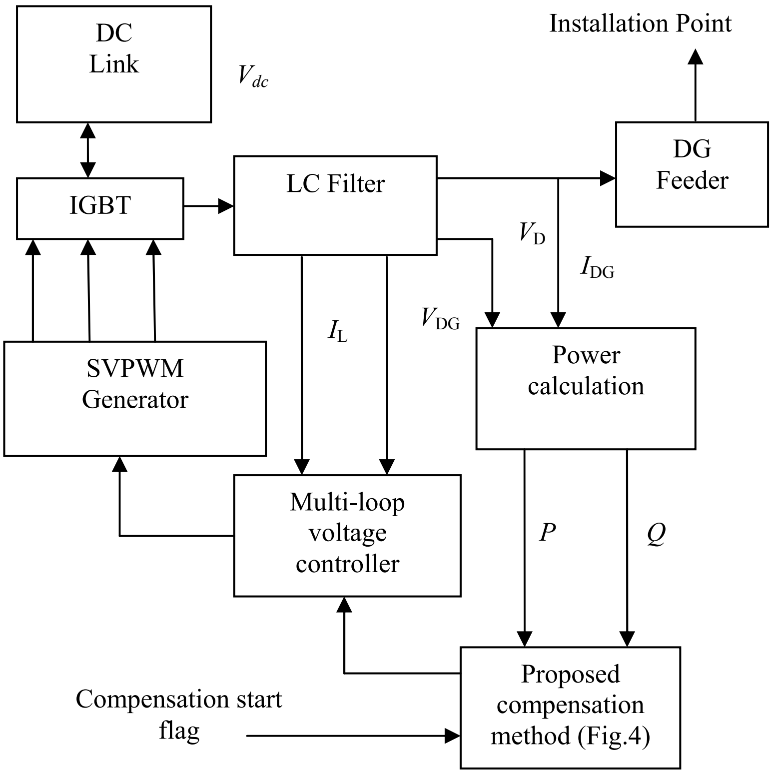

Figure 2: Illustration of microgrid configuration.

Initial power sharing using conventional droop method and power sharing improvement through synchronized compensation method are the two stages of proposed compensation method. In 1st stage of compensation, the conventional droop controller method in Eq. 1 and Eq. 2 are adopted for initial power sharing before receiving the compensation flag signal from central controllers. During this stage, the steady-state averaged real power (P_{AVE}) shall also be measured for use in second stage. The real and reactive powers are measured by first order LPFs for the conventional droop controller in Eq. 1 and Eq. 2. The measured average real power (P_{AVE}) is also saved in this stage for reactive power sharing accuracy improvement control in second stage.

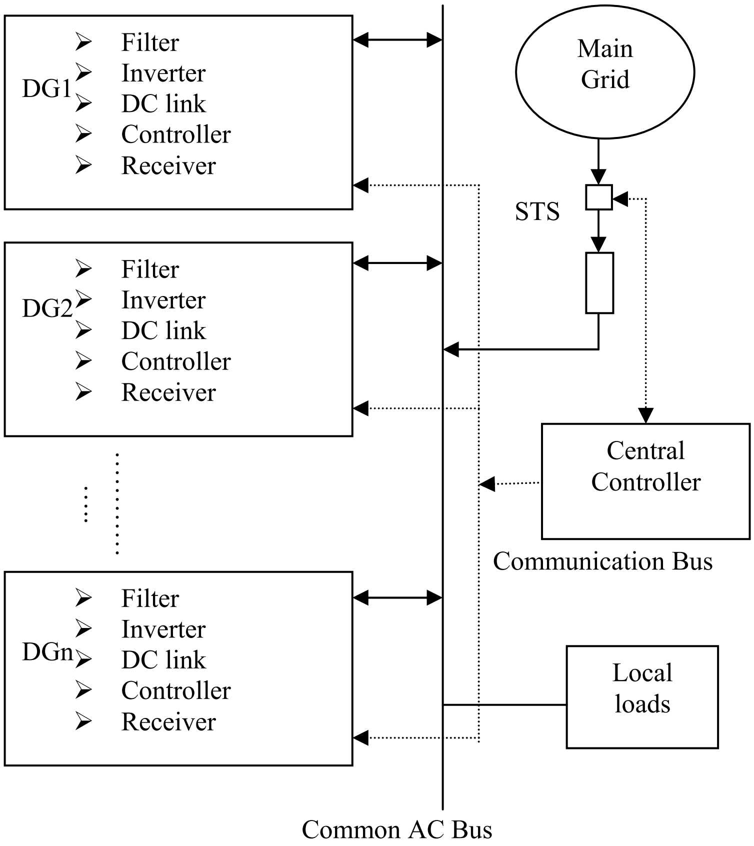

Figure 3: Configuration of the DG units.

In 2nd stage of reactive power compensation, the reactive power sharing error is compensated by introducing a real-reactive power coupling transient and using an integral voltage magnitude control in synchronized manner. Once a compensation starting signal (sent from the central controller) is received by the DG unit local controller, the averaged real power calculation stops updating, and the last calculated P_{AVE} is saved and the used as input of the compensation scheme. During the compensation process, the combination of real and reactive powers can be shown in equation 5 and equation 6.

Table I: DG System Parameters.

Parameter		Values
Interfaced Inverter (Simulation)	Filter Inductor (L_f/R_f)	L:5mH/R:0.2Ω
	Filter Capacitor (C_f)	40uF
	Sampling-switching frequency	9kHz-4.5kHz

Microgrid Parameter (Simulation)	Rated RMS voltage (Line-Line)	208V (60Hz)
	Total Loads	3525W-1425Var
	Non linear load (Diode supplying RL load)	R=500 Ohm, L=250 mH
Droop Coefficients (Simulation)	Frequency droop D_P	0.00125 Rad /(Sec · W)
	Voltage droop D_Q	0.00143 V/Var
	Integration dead-band	6 W
	Integral gain K_C	0.0286 V/(Sec · W)
	LPF time constant τ	0.0159 Sec

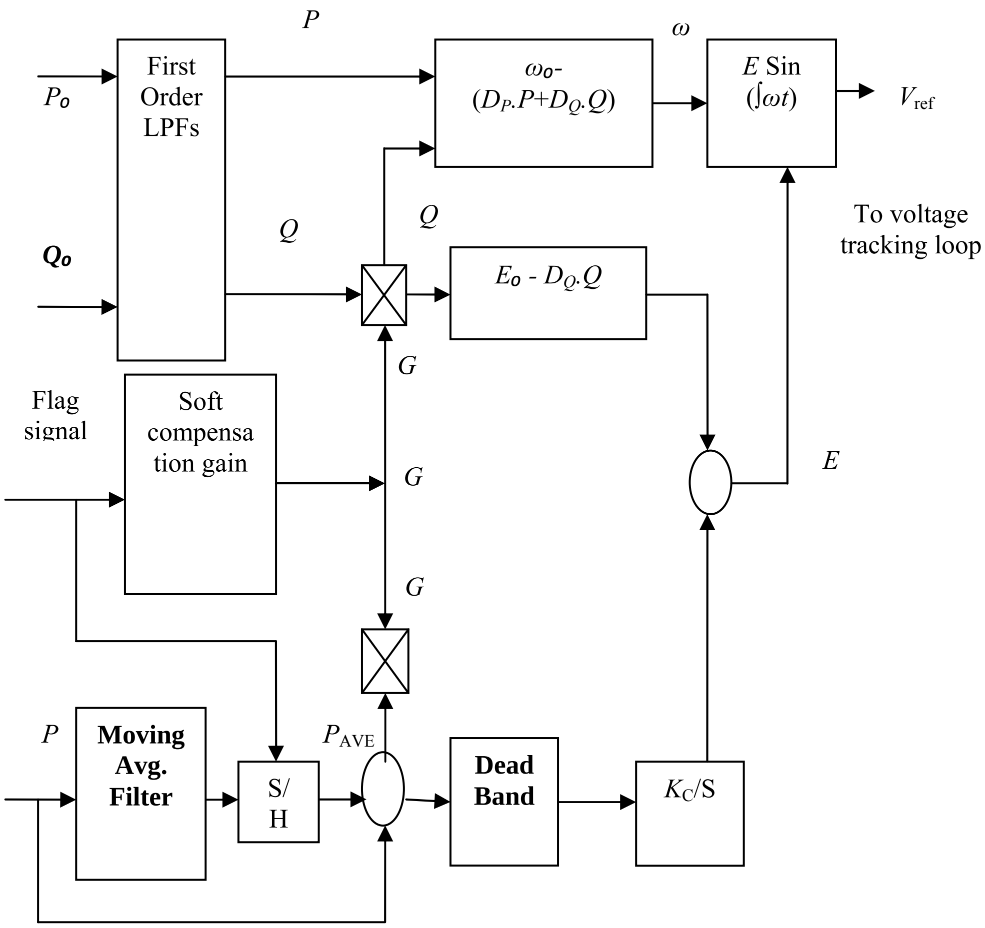

Figure 4: Synchronized proposed compensation scheme

$$\omega = \omega_o - (D_P.P + D_Q.Q) \quad (5)$$

$$E = E_o - D_Q.Q + (Kc/s).\ (P\text{-}P_{AVE}) \quad (6)$$

Where, K_C is the integral gain, which is selected to be the same for all the DG units.

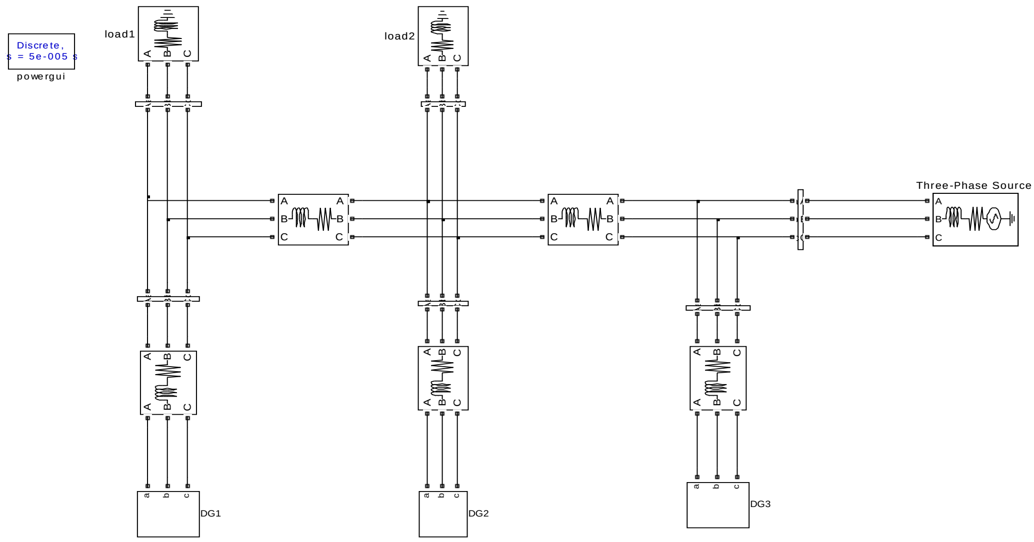

Figure 5: Simulink model of compensation scheme.

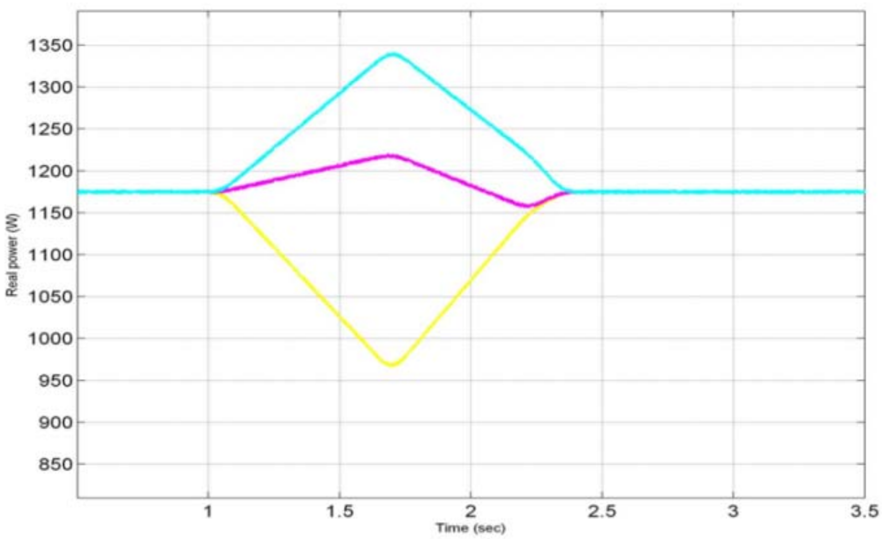

Figure 6: Simulated real power sharing performance in a networked microgrid with linear load (compensated is activated at 1 sec)

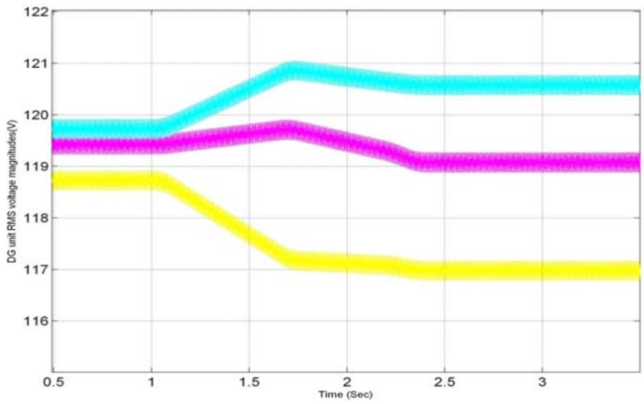

Figure 7: Simulated DG voltage magnitudes.

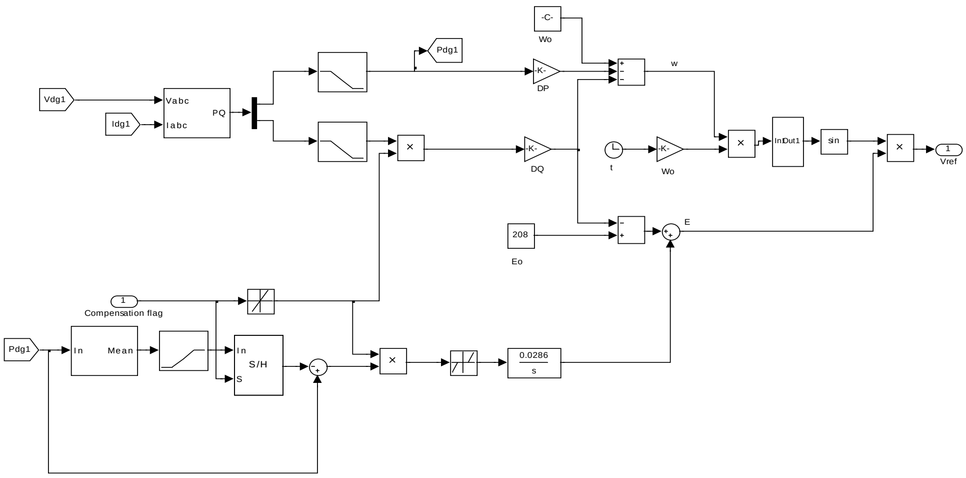

Figure 8: Networked Microgrid in simulation.

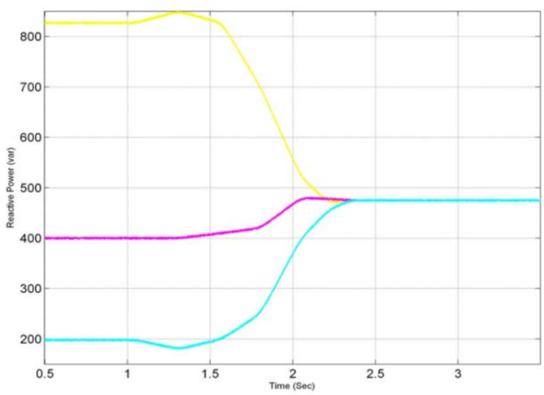

Figure 9: Simulated reactive power sharing performance in a networked microgrid with linear load (compensated is activated at 1 sec)

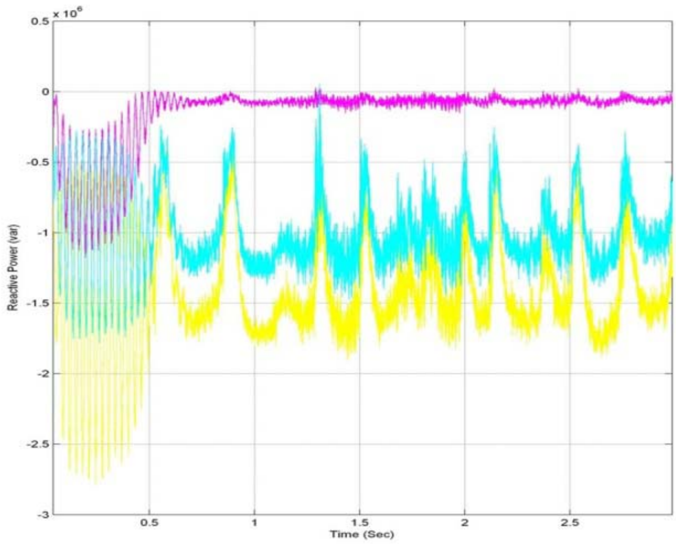

Figure 10: Simulated reactive power sharing performance in a networked microgrid with non linear load (compensated is activated at 0.5 sec).

The real and reactive power is coupled together for the frequency droop control. If there are any reactive power errors, the unequal offsets (D_Q.Q) from different DG units will affect the DG output frequencies, which is subsequently introduce the real power disturbances. This real power disturbance will then cause the integral control term in Eq. 8 to regulate the DG output voltage. With the proposed control in Eq. 7, the DG units providing less reactive power in 1st stage will experience a transient real power increase in 2nd stage. Once the reactive power is shared properly, the DG unit real power flow will go back to its original value with the control of Eq. 5, and the integration control used in Eq. 6 will no longer contribute to the voltage magnitude regulation.

4. Conclusion

Hence, an improved microgrid reactive power sharing strategy was proposed with linear loads and nonlinear loads. With linear load, the method injects a real-reactive power transient coupling term to identify the errors of reactive power sharing and then compensates the errors using a slow integral term for the DG voltage magnitude control. In addition, the proposed method is not sensitive to microgrid configurations, which is especially suitable for a complex mesh or networked microgrid. This proposed control method with non linear loads, the reactive power sharing introduces power transient and unequal power sharing by all DG units.

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