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Review on the Coordination and Energy Management of Microgrids Broad Based on PQ Controller and Droop Control. Some Useful Information Is Given in This Paper

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Abstract

The integration of distributed Energy Resources (DER) is challenging electrical network quality which is the main vital and ubiquitous all over the world. Coordination and energy management of microgrids in grid connected and in islanded mode is one of solutions of distribution power quality with best reliability, and stability to ensure power system resilience. In this review, the coordination and energy management of microgrids broad based on PQ controller and droop control some useful information is given in details and analyzed. Additionally, possible structures, options and control methods of DER units are presented which is followed by the descriptions of system controls and energy management strategies. Eventually, future trends of microgrids are discuss, point out how this concept can be a key to select a best method of coordination and managing microgrids for future researchers in order to tackle some challenges based on power quality.

Subject Areas

Electric Engineering

Keywords

Control Strategies of Microgrid, Droop Control, PQ Controller, Energy Management System

1. Introduction

A microgrid is made up by an interconnected loads and distributed energy resources within clearly defined electrical boundaries that acted as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode to provide a customized level of high reliability and resilience to the grid disturbances [1]. This advanced, integrated distribution system addresses the need for application in locations with electric supply and/or delivery constraints, in remote sites, and for protection of critical loads and economically sensitive development. Microgrids should be composed by different micro sources namely PV, Microturbine, wind turbine, battery storage, supercapacitors fuel cell etc. The micro source such as wind power and photovoltaic cells, which output power is influenced by the weather, have obvious intermittent [2]. Control of microgrids becomes a critical issue for ensuring reliable operation of the microgrid and each AC and DC microgrids have different hierarchical controls, but those could be generalize into three levels by referring to the hierarchical control which are classified as follows: (1) the primary control is based on the droop method, including an output-impedance virtual loop; (2) the secondary control allows the restoration of the deviations produced by the primary control and to improve power quality via unbalance and mitigation of harmonics in network; and (3) the tertiary control manages the power flow between the microgrid (MG) and the external electrical distribution system [3]. The PQ controller and droop control should be able to control and manage power properly in both operating mode, grid-connected mode and stand-alone mode. Microgrid in stand-alone mode would lead to more challenges, particularly when the imbalance of generation and consumption happen because of flexible load and DERs. An integration of energy storage system into the PQ controller and droop control will improve the controller performance; meanwhile, DC link capacitors support the voltage regulation and energy management has a strong impact on power system stability which will lead to the coordination of charging and discharging constraints against overcharging and deep charging and increase lifetime of some storage devices such as battery and so on ;sometimes the storage devices aforementioned can be used as back-up system in case of the main micro sources become incapable to reach load demand. Microgrid loads are commonly categorized into two types: fixed and flexible. Fixed loads cannot be altered and must be satisfied under normal operating conditions while flexible loads are responsive to controlling signals. Flexible loads could be curtailed in response to economic incentives or islanding requirements consist of distributed generation units (DG) and distributed energy storage systems (ESS) which could be installed at electric utility facilities and/or electricity consumers' premises [4], [5]. This paper shows a review on Coordination and energy management of microgrids broad based on PQ controller and droop control. The paper is organized as following. Section II gives a brief review of droop control with different aspect with respect to the form of power transmission and distribution within a microgrid. Section III, which is followed by PQ controller with different structures, Section IV, Conclusion and future trends of microgrids.

2. Literature Review

2.1. Characteristics of Droop Control

An integration of multiple renewable resources can be considered as microgrid and can also behave like smart grid according to the different electrical apparatus incorporated in that. Power system industry use a control technology which has been available many decades called droop control. Droop control can be divided into two broad categories namely conventional droop control and modified droop control [5]. In electrical power system analysis, most of generators operation based on power transfer, frequency and impedance of line mean while some countries use 60 Hz whereas other countries use 50 Hz. Each resources need power electronics interface to transfer the energy to the common bus through impedance of line. The general equations based on the above statements are written as follows.

$$P = \frac{EV}{X}\sin\phi. \tag{1}$$

$$Q = \frac{EV\cos\phi - V^2}{X}. \tag{2}$$

By considering the value of power angle and trigonometric rules, we can derive the following clarification of phase shift when power angle is very small $\sin\phi \approx \phi$. And the $\cos(\cos) \approx 1 - \frac{\phi^2}{1} = 1$, the Equations (1) and (2) become

$$\phi \approx \frac{PX}{EV} \tag{3}$$

and

$$QX \approx V(E - V). \tag{4}$$

after deriving the aforementioned equation we can conclude that active power depends upon angle meanwhile reactive power mostly depends upon to the output voltages [2]. So the droop control can be defined from amplitude and frequency of inverter output voltages and **Figure 1** is representing equivalent diagram of two parallel inverters by considering different parameters namely transmission lines, voltage of each inverters from sending up to the receiving end and angles.

Table 1 lists typical line parameters. It proves that the line impedance of the high voltage system is inductive due to its value of inductance which is bigger

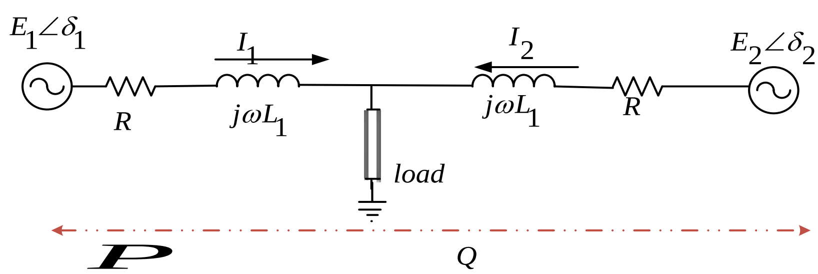

Figure 1. Equivalent diagram of two parallel inverters [24].

Table 1. Typical line parameters [6], [22].

Line type	$R\left(\Omega\cdot\text{km}^{-1}\right)$	$X\left(\Omega\cdot\text{km}^{-1}\right)$	R/X
Low voltage line	0.642	0.083	7.70
Medium voltage line	0.161	0.190	0.85
High voltage line	0.060	0.191	0.31

than the value of resistance, and the low voltage system is near pure resistive because of the value of resistance is bigger than the value of inductance meanwhile medium voltage is also inductance due to the value of inductance the aforementioned characteristics of each line will be shown and summarized in **Table 1** due to the voltage level, therefore, the traditional droop characteristics cannot be applied in the low voltage microgrids, it needs improvement.

2.2. Characteristics of Conventional Droop Control

Due to the standard, the frequency and the voltage amplitude are controlled by respecting the real and reactive power generation of the system. For this reason, the power sharing strategies in microgrid is succeeded by the output power generation according to its distributed generator's power rating**.**

2.2.1. Conventional Droop Control with a Pure Inductance Line

Means $\omega L \gg R$ this forms the frequency and voltage are increasing meanwhile active and reactive power also increase. The reactive power is not varying whereas the changing of ϕ is making active power also change. This **Figure 2** is presenting how voltage E is varying at the same time active and reactive power change based on the following control equations [7]:

$$f = f_0 - K_P\left(P - P_0\right). \quad (5)$$

$$V = V_0 - K_q\left(Q - Q_0\right). \quad (6)$$

Figure 2 is showing the voltage and frequency that has some limitations based on standard where the active power increase meanwhile frequency drop whereas reactive power increase meanwhile voltage drop. Therefore the above Equations (5) and (6) are sketched as follows.

2.2.2. Conventional Droop Control with a Pure Resistive Line

This characteristic of is similar to the above but the difference is based on value of phase which is small and vary between $-90^\circ < \phi < 90^\circ$ and $\cos\phi \approx 1$, $\sin\phi \approx \phi$ thus the droop equations are modified as follow as $P \approx \frac{E\left(V - E\right)}{R}$, $Q \approx -\frac{VE\phi}{R}$ then $R \gg \omega L$ so **Table 2** is the summary of the benefits and drawbacks of conventional droop with a pure resistive line by comparing benefits and drawbacks of conventional droop control.

2.2.3. Conventional Droop Control with Complex Impedance

The active power and reactive are increasing in clockwise and anticlockwise ac-

Table 2. Traditional and modified droop control.

Type of droop control	Equations	Benefits	Drawbacks	Reference
Conventional droop control	$f = f_0 - K_P(P - P_0)$ $V = V_0 - K_q(Q - Q_0)$	✓ No communication wires between distributed energy generations (DER). ✓ Easily to adjust the coefficients. ✓ Has more reliability and stability margin. ✓ Applicable for low voltage	✓ Boundary based on sign of voltage and frequency	[1]
Droop modified	$V = V_0 - K_P(P - P_0)$ $f = f_n - K_q(Q_0 - Q)$	✓ Active power is decreasing due to the variation of R. ✓ Economically this system can provoke much losses in transmission	✓ Q is increasing due to the variation of ϕ. ✓ Active power is independent on ϕ	[7]

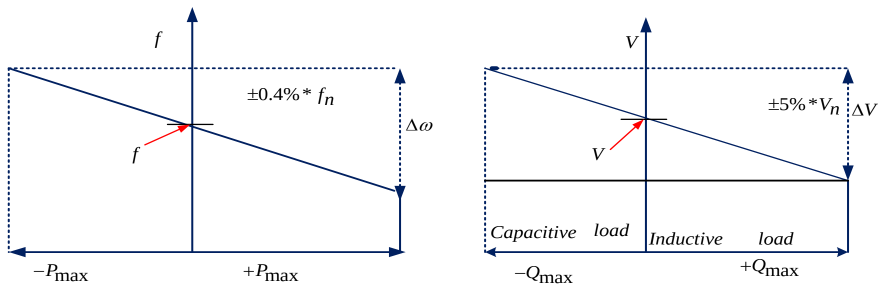

Figure 2. Droop characteristics based on pure inductive line [23].

cording to the variation of angle ϕ this type of droop control has some enhancement on microgrid where it can facilitate the decoupling of active and reactive power in terms of controls. In addition, it has some improvement based on voltage regulation. Whereas it has some negative impact on microgrid stability where line impedances should be calculated in advance by observing the variation of active power and reactive power where active and reactive power can be calculated by using Equations (7) and (8) [8].

$$P \cong \frac{U}{Z}\left[(E-U)\cos\phi + E\phi\sin\phi\right]. \tag{7}$$

$$Q \cong \frac{U}{Z}\left[(E-U)\sin\phi + E\phi\cos\phi\right]. \tag{8}$$

2.3. Type of Droop Control Modified

Assumptions suitable in high voltages transmission are not applicable in microgrid whereby the value of resistance should be included in calculations and the droop modified is based on changing some parameters of conventional droop control in the following paragraph will describe all type of droop control modified.

2.3.1. A Modified Droop Control Method for Parallel Operation of VSI's in Microgrid

In order to enhance dynamics response of parallel connected inverters, the traditional droop control is improved by adding derivative terms on traditional droop. This method is capable to achieve best performance. By any means, it is not easy to track a suitable coefficient for the derivative term in the supplemental droop equations and can be given as follows:

$$\omega = \omega^{*} - m_{f} - n_{f}\frac{\mathrm{d}P}{\mathrm{d}t}. \tag{9}$$

$$E = E^{*} - m_{e}Q - n_{e}\frac{\mathrm{d}Q}{\mathrm{d}t}. \tag{10}$$

Table 3 is describing the benefits and drawbacks of modified droop control method for parallel operation of voltage source inverter's (VSI) in microgrid by comparing with conventional traditional droop control.

2.3.2. Droop Control Modified with Adaptive Transient Droop Gain

This type of droop control modified is combining static droop characteristics and transient droop control at the same time. The transient droop function use some derivatives of active power and reactive power and added to droop functions in order to reduce an oscillations of power sharing between micro sources. To figure out the problems related to the power oscillations and voltages we need to add an adaptive transient droop gain m_d on conventional droop control as follows:

$$\omega_0 = \omega_n - \omega_P P - m_d\frac{\mathrm{d}\delta}{\mathrm{d}t}. \tag{11}$$

By replacing $\frac{\mathrm{d}\delta}{\mathrm{d}t}$ by its value we get new equation which is:

$$\omega_0 = \omega_n - m_P P - mdp\frac{\mathrm{d}P}{\mathrm{d}t} + mdQ\frac{\mathrm{d}Q}{\mathrm{d}t}. \tag{12}$$

where mdp and mdQ are adaptive derivative gains in the voltage frequency droop control characteristics. Equation of voltage and reactive power are modified also by adding adaptive transient droop gain n_d to the equation of traditional droop control

Table 3. Traditional and modified droop control.

Type of droop control	Equations	Benefits	Drawbacks	reference
Traditional	$f = f_0 - K_P(P - P_0)$ $V = V_0 - K_q(Q - Q_0)$	➢ No communication signals between units. ➢ Best modularity ➢ Best reliability and stability ➢ Ubiquitous and applicable in different micro sources	➢ Load rely on frequency, voltage and amplitude deviations ➢ Impedance of line will affect P ➢ Q sharing between micro sources. ➢ It has Poor transient ➢ suitable for pure inductive line	[1]
Modified	$\omega = \omega^{*} - m_f - n_f\frac{\mathrm{d}P}{\mathrm{d}t}$ $E = E^{*} - m_e Q - n_e\frac{\mathrm{d}Q}{\mathrm{d}t}$	➢ Fast transient response ➢ Precision and accurate regulation ➢ Reduction of overloading and underloading	✓ Hardly to track the suitable coefficients for derivative term that ensures stability of the system. ✓ Frequency are leading toward to the nominal value	[9]

$$V = V_0 - n_q Q - n_d \frac{\mathrm{d}\delta}{\mathrm{d}t}. \tag{13}$$

By inserting the value of n_d we get new equation which can be shown below:

$$V_0 = V_n - n_q Q + n_{dP} \frac{\mathrm{d}P}{\mathrm{d}t} - n_{dQ} \frac{\mathrm{d}Q}{\mathrm{d}t}. \tag{14}$$

Benefits of droop control modified with adaptive transient droop gain

- ✓ Droop coefficients are broad based on small signal stability
- ✓ Variation of voltage output magnitude and angle are varying in vice-versa.
- ✓ Remarkable changing of damping modes power sharing strategies
- ✓ Circulating current and power oscillation are reduced completely

Drawbacks of droop control modified with adaptive transient droop gain

- ✓ Implementation of this method need a prerequisite of small signal stability
- ✓ It is hard to track the value of derivative terms of active power and reactive power
- ✓ Variations of voltage, frequency and reactive power are not presented [10].

2.3.3. Robust Droop Multiple Loop Control Method

This type of droop control is the same as conventional droop control but the aforementioned droop has been added with outer robust power and the inner voltage and current loop. This type of control consider the influence of output impedance and line impedance in order to improve a reliability and robustness of power sharing between two parallel inverters. The simplified diagram of two parallels inverters are shown in this **Figure 3** where E_i is the amplitude of the inverter output voltage e_i, Q_i is the phase deviation between e_i and u_L. Considering the output impedance and line impedance [11], active and reactive power can be respectively expressed as:

$$P_i = \frac{1}{Z_{0i} + Z_{linei}} \left[\left(E_i U_L \cos\phi_i - U_L^2 \right) \cos\beta_i + E_i U_L \sin\phi_i \sin\beta_i \right]. \tag{15}$$

$$Q_i = \frac{1}{Z_{0i} + Z_{linei}} \left[\left(E_i U_L \cos\phi_i - U_L^2 \right) \sin\beta_i - E_i U_L \sin\phi_i \cos\beta_i \right]. \tag{16}$$

where $Z_{linei} = R_{linei} + jX_{linei}$ is the line impedance $Z_{0i} = R_{0i} + jX_{0i}$ is the equivalent output impedance of inverter, and E_i is the impedance angle between Z_{0i} and Z_{linei}. In the low-voltage microgrids $R_{linei} \gg X_{line}$, so $\sin\phi \approx \phi$ and $\cos\phi_i = 1$. **Figure 3** is schematic diagram of robust power droop controller where all equations of robust power droop controller are written and inserted in

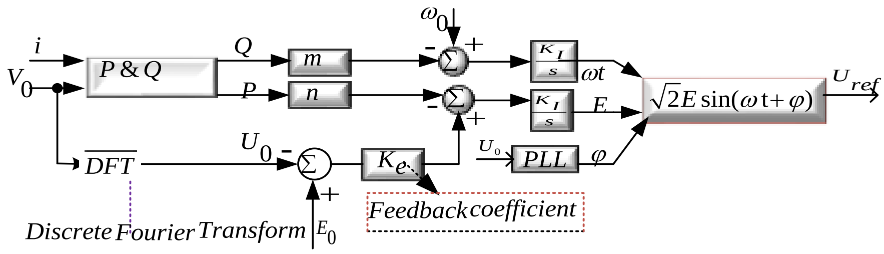

Figure 3. Schematic diagram of the robust power droop controller [11].

diagram meanwhile Table 4 is short statement of robust power droop controller about sorting out the benefits and drawbacks of robust power droop controller over benefits and drawbacks of conventional droop control.

2.3.4. Droop Control with Low Pass Filter Modified

In power system stability and control, frequency of system is vital signal because of many apparatuses should operate at the range of nominal frequency according to the standard of IEE and other research institutions. As aforethought, common controllers have not presented any solution to resolve frequency drop in the VSIs. The purpose of proposed control method is returning frequency to the nominal value. The new control method should reduce the overshoot and oscillation of response. The modification of low pass filter by adding zero and pole on low pass filter will automatically change the output value but the output signal is still remaining in standard. Regarding frequency will go towards instead to decrease due to the variation of load [12].

2.3.5. Sine Virtual Active Power-Frequency Droop Control

The droop control modified can decouple active and reactive power through rotating orthogonal transformation, and extend conventional droop control to low voltage microgrid. This type of droop modified called sine virtual active power frequency droop control may restrict the maximum power of inverters without adding droop controlling unit of amplitude limits, and can enhance the accuracy of reactive power sharing. By considering rotating orthogonal transformation matrix T, the active and reactive power can be transformed into the virtual active power and virtual reactive power via the coordinate transformation. T for rotating coordinates orthogonal transformation matrix can be expressed as:

$$T = \begin{pmatrix} \frac{X}{Z} & -\frac{R}{Z} \\ \frac{R}{Z} & \frac{X}{Z} \end{pmatrix} = \begin{pmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{pmatrix}. \tag{17}$$

the active and reactive power inject into the bus by every inverter can be writen as:

Table 4. Conventional droop control modified and robust droop multiple loop control.

Type of Droop control	Equations	Benefits	Drawbacks	References
Traditional	$f = f_0 - K_P(P - P_0)$ $V = V_0 - K_q(Q - Q_0)$	➢ No communication signals between units ➢ High stability ➢ Best reliability ➢ Best profitability	➢ Suitable for inductive line ➢ Modification during grid connected mode are needed. ➢ Voltage and frequency depend on coefficients settings.	[1]
Robust Droop multiple oop control	$P_i(s) = (E^* - U_L)\frac{U_L}{R_{0i}} \Big/ \left(1 + \frac{nU_L}{R_{0i}}\right)$ $Q_i(s) = (\omega_0 - \omega^*)\frac{E_i U_L}{R_{0is}} \Big/ \left(1 - \frac{mE_i U_L}{R_{0is}}\right)$	➢ High transient response. ➢ High stability and reliability ➢ An accuracy of power sharing ➢ Tracking of voltage	✓ Power will depend on voltage instead of to depend on frequency vice versa. ✓ Reactive power will depend on frequency.	[11]

$$P = \frac{U}{R^2 + X^2}\left[R\left(U - V\cos\delta\right) + XV\sin\delta\right]. \tag{18}$$

$$Q = \frac{U}{R^2 + X^2}\left[X\left(U - V\cos\delta\right) - RV\sin\delta\right]. \tag{19}$$

By combining Equations (18) and (19) thus yield

$$\begin{bmatrix} P' \\ Q' \end{bmatrix} = T\begin{bmatrix} P \\ Q \end{bmatrix}. \tag{20}$$

Sine virtual active frequency droop control can be represented as follow as:

$$\omega = \omega_0 - k\sin\left(l\left(P' - P_0\right)\right). \tag{21}$$

This modification has done by changing only power and frequency equation thus the Figure 4 proves the sine droop control and general diagram.

Sine virtual active power-frequency droop control is robust and feasible to be implemented. This control method has a strongest enhancement on large microgrids whereas traditional droop control is little bit incapable to control the power sharing strategies between micro sources [13].

2.3.6. Angle Droop Control

Angle droop control is a conventional droop control whereby the frequency has been replaced by angle and its tremendous are shown clearly where the frequency drop are less than the droop control with frequency and stability margin are very good. In addition, the variation of output power is very low than the power from traditional droop. Eventually, this control method has best frequency regulation and good stability margin by comparing to the conventional droop techniques Figure 5 is implementation of the equations of angle droop control and schematized in the following figure meanwhile Table 5 is brief of drawbacks and

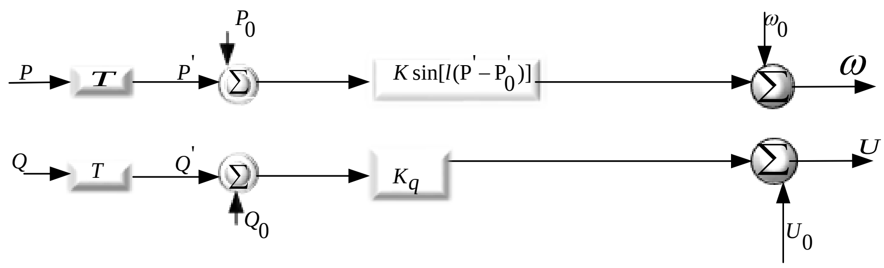

Figure 4. Block diagram of sine droop control.

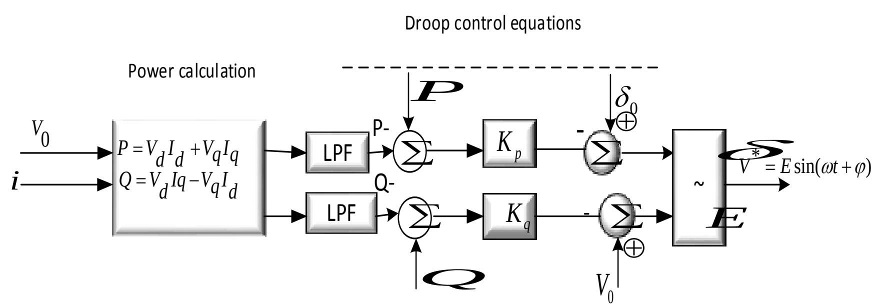

Figure 5. Angle droop control.

Table 5. Conventional droop control and angle droop control.

Type of droop control	General Equations	Advantages	drawbacks	References
Conventional droop control	$f = f_0 - K_P(P - P_0)$ $V = V_0 - K_q(Q - Q_0)$	Easy to be implemented No need of a communication cables between microsources	Low inertia Poor dynamic response	[1]
Angle droop control	$\delta = \delta_0 - K_P(P_0 - P)$ $V = V_0 - K_q(Q_0 - Q)$	Stabilizes the operation mode of the droop control that have higher. Constant frequency regulation. Best stability margin. More robust and effectiveness	□Requirement of GPS. Poor performance of active and reactive power sharing between units	[14]

benefits of angle droop control by comparing the benefits and drawbacks of conventional droop control [14].

2.3.7. Droop Control Based Synchronized Operation

The feasibility of this control method has two main clue namely: error reduction operation and voltage recovery operation. The power sharing performance is improved by the sharing error reduction operation, which is highly activated by the lower band width synchronization signals. However, the error reduction operation will be available in reduction of output voltage amplitude. Moreover, the voltage recovery operation is proposed to compensate the decrease. In this control, communication is compulsory even it is very simple to be implemented however, the plug-and-play is reserved. Eventually. The improved droop control equations can be written as [15] [16].

$$\omega_i = \omega^* - K_P\left(P_0 - P\right). \tag{22}$$

$$E_i\left(t\right) = E^* - n_i Q_i\left(t\right) - \sum_{n=1}^{K-1} K_i Q_i^n + \sum_{n=1}^{K} G^n \Delta E. \tag{23}$$

where K denotes the time of synchronization event until time *t*. where G^n is the voltage recovery operation signal at the *n*-th synchronization interval, G^n has two possible values: 1 or 0. If $G_n = 1$, it means the voltage recovery operation is performed.

<u>Benefits droop control based synchronized operation</u>

- ➢ Improved power sharing system
- ➢ Not put-on by the physical parameters
- ➢ Sturdy to communication delay

<u>Disadvantages droop control based synchronized operation</u>

- ✓ Requirement of low bandwidth communication
- ✓ Hardly to be implemented

2.3.8. $Q - \dot{V}$ Dot Droop Control Method

This control method is based on relationships between a reactive power Q and the variations of output voltage $\dot{V}$ in order to improve the reactive power sharing strategies. The proposed control method $Q - \dot{V}$ can avoid this coupling dependence. The change rate of voltage will lead continuously until the desired Q flows, and its performance cannot be much affected by the line impedance

[15]. The $Q-\dot{V}$ droop controller can be expressed as:

$$\dot{V}=\dot{V}_0-K_q^*\left(Q_0-Q\right). \tag{24}$$

$$V^*=V_0+\int_t^{t+1}\dot{V}_x \mathrm{d}\tau. \tag{25}$$

where K_q is the droop coefficient, $\dot{V}_0$ is nominal voltage, $\dot{V}$ is set to zero, is set to zero and related to the reactive power of distributed generation, and Q_0 is the reactive power set point at the nominal value. In steady state the $\dot{V}$ should be reset back to zero in order to prevent the variation of output voltage magnitude. Eventually the $\dot{V}$ restoration mechanism has been designed as:

$$\frac{\mathrm{d}Q_0}{\mathrm{d}t}=K_{res}*Q_R*\left(\dot{V}_0-\dot{V}\right). \tag{26}$$

The control diagram of proposed $Q-V$ and droop control and the distributed generation (DG) control block diagram are shown in Figure 6. The control method of proposed droop control and the distributed generation block diagram are shown in this Figure 6.

<u>Benefits of $Q-\dot{V}$ dot droop control method</u>

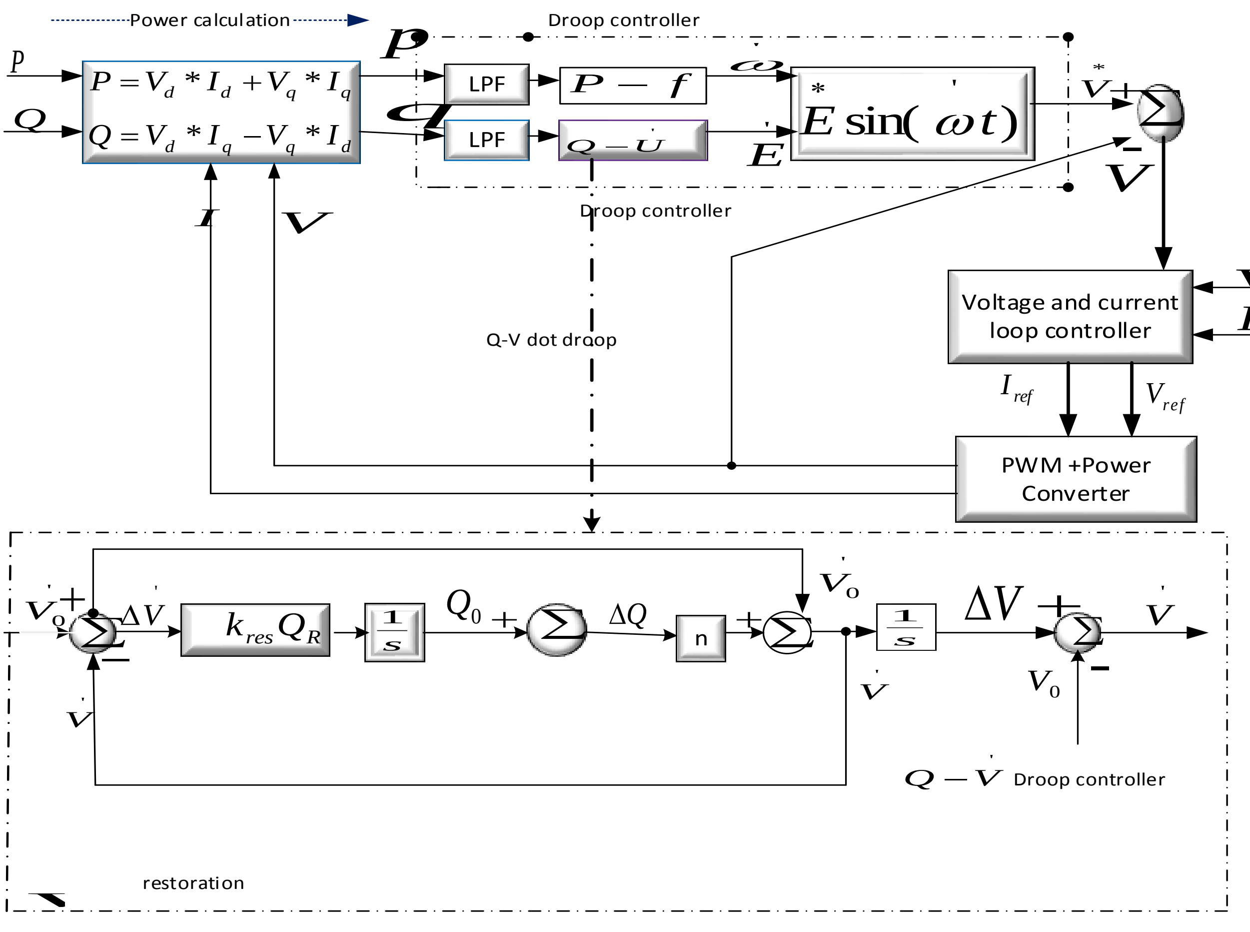

Figure 6. $Q-\dot{V}$ droop controller and the control block diagram of single distributed generation The output results are related to the initial conditions of the voltage change rate. Inspite of the system is stable and the steady-state solutions may be it does not exist.In addition ,the power sharing performasnces are not crucial superior to those of conventional methods.

- ✓ Restoring process of voltage with a local control loop
- ✓ Prevention of coupling dependability.

Disadvantages of $Q-\dot{V}$ dot droop control method

- ✓ Depend upon the initial conditions
- ✓ The controller is not possible in real microgrid applications.
- ✓ Steady-state solution may be not available.
- ✓ Stability of the controller through a microgrids is not good.

2.3.9. State of Charge Based on Droop Control

The main purpose of this control method is to enhance dynamic performance of the system and sort out the problem related to the sharing power in the distributed energy storage system and to improve the life time of some storage devices [17]. The state of charge is one way to recognize time for charging and discharging according to the criteria determined by a designer and for some storage devices can be used in backup system when the main micro sources become incapable to satisfy the load demand [1]. The energy storage units with highest SoC generate more active power than the lowest Soc. But the SoC-based droop control, the frequency gradually deviate from its nominal value. So, an auxiliary control has been integrated in order to restore the frequency and amplitude of the AC bus voltage so this effect, made the frequency and amplitude of the point of common coupling to be restored [17].

2.3.10. Arctan Droop Control

In this type of droop control modified the power frequency droop slope has been replaced by arctan based algorithm. In order to carry out the arctan based algorithm, the microgrid operators should make sure if the frequency of the system is in accepted range according to the standard. In fact the determination of droop coefficients is based on frequency constraints meanwhile using a fixed gradient. Presently fixed gradient droop is not a curve neither an angle it is just a straight line. Therefore, the differential of gradient (concavity) is all the time zero. The arctan droop permits variation in both gradient and concavity of the power profile. The gradient varies via the power boundaries and it is feasible to achieve natural frequency bounding with no dependence of a secondary or tertiary level controller. Scientifically arctan droop control supplies an adequate best control than the gradient of droop about power set point. In addition, it has best desirable horizontal asymptotes which is a smooth function over the domain being used [18]. Eventually it has existing function libraries in highest level coding languages and the general equations of droop can be written as:

$$f = f_0 - \frac{a_p}{\pi}\left(\arctan\left(\rho\left(P' - P_0'\right)\right)\right). \tag{27}$$

And is equal to

$$\omega = \omega_0 - 2a_p\left(\arctan\left(\rho\left(P' - P_0'\right)\right)\right). \tag{28}$$

Benefits of Arctan droop controller

- Naturally the frequency is the range of $\left(f_0+\frac{a_p}{2}\right)$ and $\left(f_0-\frac{a_p}{2}\right)$ Hz.
- Reduction of an angle until it reaches as the same as droop control.
- Best performance of controlling power sharing scheme.
- The system is more robust and more stable.
- No need of communication wires.

<u>Drawback of Arctan droop controller</u>

- ✓ The system is more complex
- ✓ In terms of economy the system is costly

2.3.11. New Perspectives on Droop Control in ac Microgrid

The main idea behind on this type of droop control is modification of $P-\omega$ by adding proportional derivative. Whereas $Q-V$ are added a coefficient of virtual impedance in order to improve reactive sharing mechanism. Therefore, this type of droop modified has some advantages and drawbacks which are listed below [19]:

<u>Advantages new perspectives on droop control in ac microgrid</u>

- Reactive power sharing accurately
- Enhancement of transient process
- Robustness regarding parameters system

<u>Drawback new perspectives on droop control in ac microgrid</u>

- ✓ Requirement of high bandwidth for controller is the main challenges
- ✓ Frequency deviation is small

2.4. Control Modes for Distributed Generations

The selection of control strategy depends upon the types of micro sources installed in the microgrid. If the energy from micro sources are influenced by weather for instance PV array and wind turbine generator etc. Those types of micro sources should be operated by PQ controller even though PQ controller cannot work alone where it needs voltage, frequency, reactive power and non-reactive power reference from droop controller which is called Vf. Vf Control is composed by three loops which are power, voltage and current loop. Therefore by using dqo transformation the current loop takes direct-axis reference current i_{dref} and quadrature-axis reference current i_{qref} from power loop and voltage loop as well. In power control loop, the reference active power follows the change of frequency. V/f control could adjust the reference power of distributed generations according to the voltage and frequency of micro-grid by respecting the standard. If the microgrid is composed by large storage capacity, the best control strategy is pure droop or fictitious impedance, since the load following is shared among micro sources [1].

Type of PQ Controller

PQ controller must achieve a specific quality in order to control micro sources. In the structure of PQ controller, the active and reactive power should be decoupled to get the reference value of the inductor current i_{dref}, and i_{qref} which will be compared with the actual values. The steady state error signal passes through PI or PID controller of the instantaneous current loop as the inverter bridge modulation voltage signal. PI or PID controller has a capacity of keeping steady state error zero by adjusting its values, and the dispatched generation of the PQ control receive the support of the frequency by the soft phase locked loop. Active and reactive power reference are the reference values of the active power and reactive power; then ω is the frequency; current reference from direct axis and reference current from quadrature axis by power decoupling and i_{dref}, i_{qref} are the d-axis and the q-axis current reference value by the power decoupling; V_d and V_q are the modulated voltage of the d-axis and the q-axis by the current loop control [1]. The schematic diagram of PQ controller is presented by **Figure 7**.

1) PQ controller based on conventional Proportional Integral (PI)

This type of PQ controller is composed by two loops which are power and current loop. Moreover, PQ controller can be realized by decoupling process where PI controller has been used for getting a steady state error zero. The adjustment of PI controller will produce i_{dref} and i_{qref} as input for current loop. The structure of this PQ controller is drawn in **Figure 8** and schematized as follows:

2) PQ control strategy based on multivariable PI-controller

Contrary to the PQ controller conventional PI-controller that composed by feed forward signals to minimize the coupling between two axes, moreover the

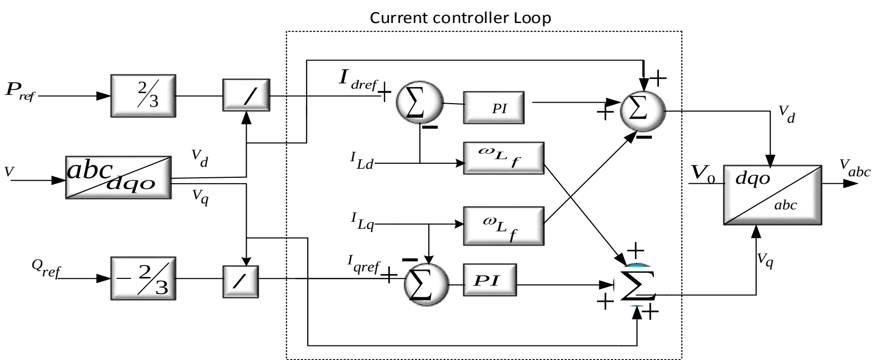

Figure 7. Schematic diagram of PQ controller [1].

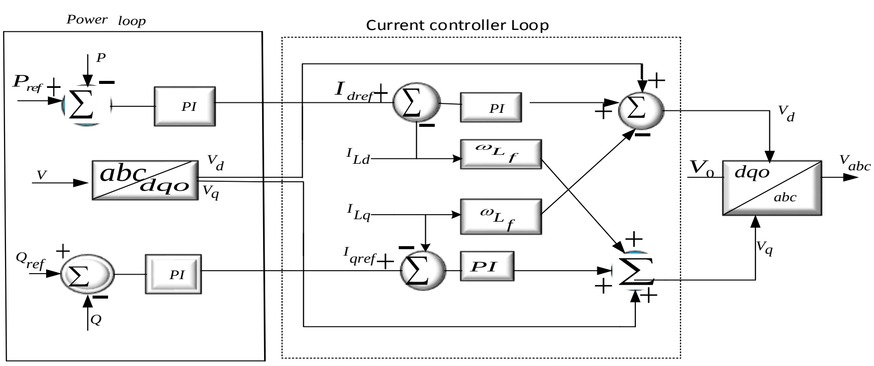

Figure 8. Schematic diagram of PQ controller [7] [20].

multivariable current controller the plant inversion technique has been implemented and schematized as follows according to the Figure 9 [21].

3) Another type of PQ controller

The purpose of PQ control is to supply constant active and reactive power at a desired power factor. The reference values of power are determined by a local or central controller from the microgrid control center. This schematic diagram can be implemented as a voltage controlled current source. Current or voltage components in direct axis $(I_d \& V_d)$.And in quadrature axis $(I_q \& V_q)$ with inverter terminal voltage are calculated based on specific method [21]. Therefore the Table 6 is comparison of benefits and disadvantages of each type of PQ controller.

3. Future Trend and Conclusion

This academic review presents eleven (11) droop control modified and four type (4) of PQ controllers for controlling microgrid. The Essential operating principles of each of the strategy has been emphasized. The advantage and drawbacks of each controller has been found out as reliable scientific evidence which determine the choice of optional control strategies of microgrid. Therefore, the results of this work have provided a state-of-the-art review of research efforts in microgrid control systems for future researchers willing to do a research about microgrid. Eventually, type of PQ controller architectures for microgrids power energy managements, and voltage and frequency regulation has been described, and highlighted that modern microgrid has to become intelligent and more

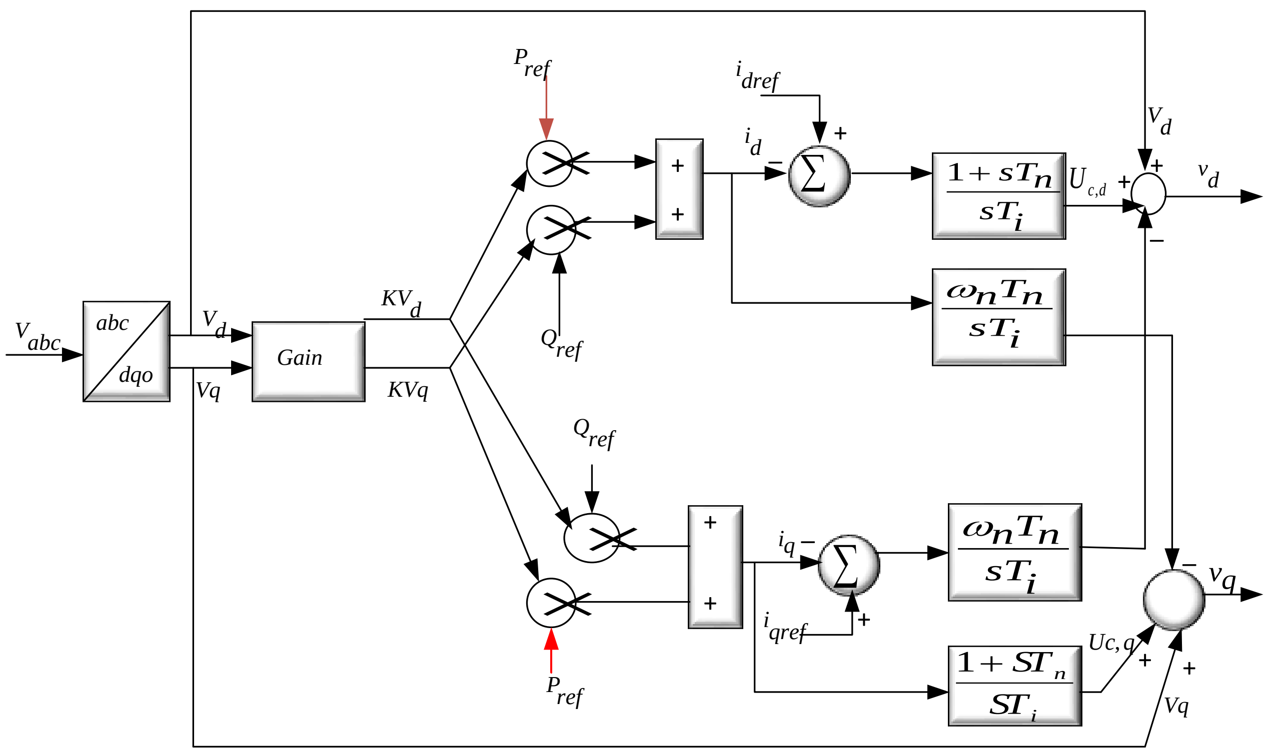

Figure 9. Schematic diagram of the PQ controller based on multivariable current controller.

Table 6. Benefits and disadvantages of each type of PQ controller [1], [21].

Type of PQ controller	Benefits	Disadvantages
PQ controller.	❖ Suppression of transient fluctuation of voltage and frequency are not perfect. ❖ Best correctness and effectiveness way to manage microgrid in different way such as islanded mode and connected to the utility grid.	❖ Propagation of steady state error ❖ Problems related to the best stability and reliability. ❖ Propagation of steady state error in the system
PQ controller based on PI controller	❖ Suppress the transient fluctuation of voltage and frequency. ❖ Improvement of stability and reliability ❖ Not need of communication between units ❖ Good dynamic responses ❖ Maintenance of economic operation	Inexpensive economically Easily to design it Adjustment of PI controller need some are very complicated
PQ controller based on multivariable PI-controller	➢ Fast dynamics response ➢ Less transient ➢ Best capability of decoupling active and reactive power ➢ Rejection performance of disturbance ➢ Better tracking of the reference values	✓ Expensive economically ✓ Hardly to be implemented ✓ More difficult to adjust of PI controllers incorporated in voltage and current loop and it needs more skills about design of filters
Another Type of PQ controller	➢ Don't have zero crossing detection, ➢ The computation of active and reactive power go smoothly. ➢ The simplicity of the algorithm ➢ Performance of shifting between states are seamlessly without any interruption, seamlessly.	✓ Poor dynamic response ✓ Low inertia ✓ It is very hard to design and to implement this PQ controller

flexible by the help of telecommunication system based on broadband technology. The significance of the load characteristics for microgrids operation and control are demonstrated and deeply explained. Under the impact of load and line, characteristics has been analyzed; several different load sharing strategies among distributed energy resource (DER) units has been compared for instance reactive and active power managements. Three robust controllers namely conventional droop control, droop modified and PQ controller has been shown their benefits and drawbacks against each other.

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