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A Review on Different Control Strategies for Parallel Inverters Control in Microgrid

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ABSTRACT: In this paper different control methods are applied for parallel operated inverter systems. Control strategies for parallel operation of inverters in microgrid are operated either in grid connected mode or standalone mode which are analysed and explored in order to get merits and demerits of the control schemes. This review paper gives clear idea about present development in power supply systems along with the need of power electronic devices.

KEYWORDS: Parallel inverters, Microgrid, Grid connected mode, standalone mode.

I. INTRODUCTION

Present days energy sources like renewable energy and distributed generation (DG) are mostly connected to main grid via power inverters. While systems are not connected to the main grid is also act as microgrid (MG) called as islanded MG [1]. High power ratings of electronic devices are available with several numbers of inverters to operate in parallel to get high-power and for low-cost applications. Critical customers need high reliability and redundancy operated parallel inverters is also another reason. While sharing the active and reactive power the system maintains voltage and frequency by all the DGs in an autonomous MG. Network can be complex when the load sharing can be done without communicating between converters are the most desirable option and can span over a large geographic area. Frequency droop characteristics is the most common approach to achieve this for parallel converters to control locally to delivering desired real and reactive power to the system [2]. Frequency and the fundamental voltage magnitude are the two independent quantities controlled by achieving their real and reactive power share. The inverters change its behaviour often from voltage to current sources when operate in grid-connected mode [3]. New growth in MGs because coordinated approach can be provided for the integration of DG. The development of converter-based microgrids are been increased by increasing the amount of small-scale power sources which are not directly coupled to the electrical network. MGs can operate both modes like in grid connected and islanded mode. The DG units are grid which follows current-control strategies when operated in the grid-connected operation. Maximum power point tracking strategy generally determines the state of the electrical network for individual unit delivering power by DG units. Based on the state of the electrical network the power modification reference including the ancillary services provided by the DG units, in order to support voltage in case of voltage dips and reactive power. The DG units are responsible for the voltage control and the power balancing and sharing when the MG is operated in the islanded mode. Hence, it requires a grid forming control strategy for it. As traditional power systems compares with MG having different characteristics, different operation and control methods have been developed. For uninterrupted power supply, Communication-based control strategies are mainly developed to achieve good results in islanded MGs. But communication links are costly and impractical especially in large MGs. When compared with the case where the primary controls of MGs is required without communication which reduces reliability of the system due to this link forms a single point failure [4].

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II. DROOP CONTROL THEORY

In MG, more micro sources are interconnected so the system stability and reliability is attained only by the voltage regulation. In order to reduce the reactive power oscillations and voltage fluctuations we use voltage regulator. Whenever several DGs are connected to MG then the system become complex even though the power sharing between them with the help of droop control scheme. Droop control scheme has advantage that it can permits smooth disconnect and connect to complex system [5].

In the droop control scheme, we can control active and reactive power sharing by using the frequency droop and control reactive power sharing by using the voltage droop. By regulating the active and reactive powers we can employ the frequency and voltage respectively. The below equations are shows the conventional droop control scheme.

In a transmission line, the real and reactive powers are designed as:

$$P = \frac{E_1 E_2}{X} \sin \delta \quad (1)$$

$$Q = \frac{E_1^2}{X} - \frac{E_1 E_2}{X} \cos \delta \quad (2)$$

In the aforementioned equations (1) & (2), Resistance is neglected for an overhead transmission lines as it is much lower than inductance. Also the power angle δ is lesser, consequently, $\sin \delta = \delta$ and $\cos \delta = 1$.

$$\delta = \frac{XP}{E_1 E_2} \quad (3)$$

$$E - E_0 \cong \frac{XQ}{E_1} \quad (4)$$

From the equation (3), the power angle δ depends on the real power and it can be controlled through the real power (P). From the equation (4) the E_1 can be controlled by regulating the reactive power (Q). The power angle and the frequency are interlinked, by adjusting the frequency we can regulate the power angle. Finally, we can understand the voltage and the frequency of the MG are manipulated by adjusting the reactive power and real power. By observing equations (5) and (6) we can understand frequency and voltage droop regulation

$$f = f_0 + K_p (P - P_0) \quad (5)$$

$$E = E_0 + K_q (Q - Q_0) \quad (6)$$

Where f , E = The new operating frequency and voltage; P , Q = The new operating Active and reactive power; f_0 , E_0 = Base frequency and voltage; P_0 , Q_0 = set4points for the real and reactive power; K_p , K_q = Droop constants.

Droop control theory is explained in the block diagram as illustrated in Fig. 1. In order to control the frequency and output limit the functions of the droop control block is used.

The central controller delivers the inputs such as the system frequency and the output of power generation, or feeder flow and set points.

Inputs are local measurements of frequency and power output or feeder flow and the set points are provided by the central controller. The output of the current controller is current reference signal of the d-axis [5].

In grid connected mode, the grid frequency is constant and rated so that the output power and feeder flow are also be constant. When the system is disconnected from the main grid, the unbalanced power will be automatically corrected by droop control scheme. By this control method we gain the steady state rated values.

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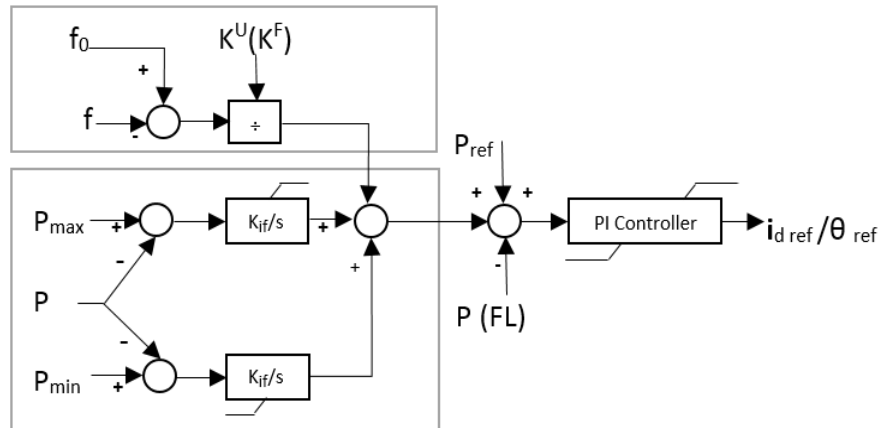


Fig.1. The Droop control block diagram [5].

III. CONTROL SCHEMES

This paper discusses about different control schemes for the parallel inverters. In [1] control scheme for conventional limits are reveals the inherent. In adopted power ratings to the conventional droop control scheme which is proportional for accurate load share in parallel-operated inverters with same p.u impedance has been proved. For the inverters the same voltage set-point had generated by the droop controllers. Proportional load sharing error is obtained as a result due to difficulty to meet both the conditions practically. A Robust droop controller as shown in Fig.(2), is then proposed without meeting these two requirements in this paper to achieve accurate proportional load sharing and to reduce the load voltage drop due to the load effect and the droop effect. Load voltage can be maintained within the desired range around the rated value. The strategy is robust against different types like parameter drifts, disturbances, noises, component mismatches, feeder impedance and numerical errors. In this paper the quantified error is measured load voltage is the only shared error. When measuring the voltage there are errors like a fundamental trade-off between the sharing accuracy and voltage drop appears. In order to avoid errors or reduction of errors can be achieved by the setting in global power sharing of accurate frequency and rated voltage.

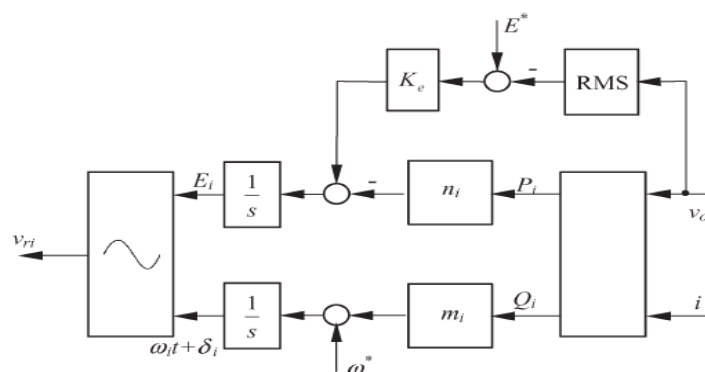


Fig.2. Robust droop controller to achieve accurate proportional load sharing [1].

In order to achieve accurate proportional sharing the mentioned above two conditions are not required in the robust droop control strategies. Compensating the voltage drops due to the load effect can also be done by this control strategy maintaining the voltage of load within their desired rated value. Quantitative analysis of the error in power sharing has been carried out thoroughly. This paper demonstrated various experimental results but here very effective strategy was proposed was proposed which was shown in [1]. In paper [2] author proposed high gain droop angle

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control instead of commonly used traditional frequency droop provides good load sharing in the weak condition and the overall system was not stable. In order to get the better load sharing in the system, author introduced a supplementary loop around the primary loop. Because of implementation of the supplementary loop control we can reduce the high gains that are obtained in primary loop control. Overall the system stability is increased by using supplementary loop. The supplementary droop control loop as illustrated in Fig. 3, to stabilize the system for a range of operating conditions while ensuring satisfactory load sharing.

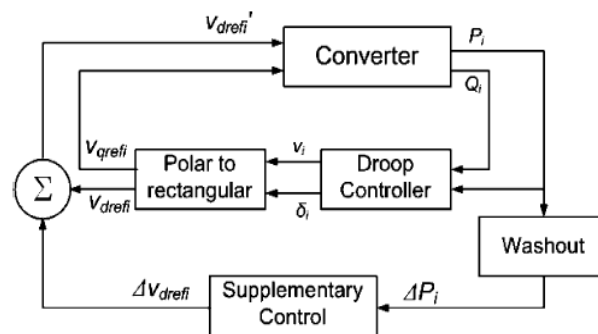


Fig.3. Supplementary droop controller configuration [2].

In this paper [6] author proposed a controller for a system of inverters operated in parallel. The inverters are voltage source inverters connected by a standard UPS systems. The controller is simple and very low cost but it will work very efficiently. The parallel operation of the inverters can be possible by taking same phase reference to all the inverters which are operated in the system and the voltage control loop control each inverter and the system will give good characteristics. The phase difference between the inverters output voltage is zero due to each inverter getting the same phase reference. So, the synchronization of all the inverters output voltages is getting very easily. In this paper [7] two inverters operated in parallel. Each inverter can be controlled by a individual controller. In this author investigated the active and reactive power sharing in the inverters, which are connected in parallel. By adjusting voltage and frequency we can achieve good power sharing. There is no communication between the inverters.

In this paper [8] a circular chain control method is implemented I multi-module inverters operated in parallel. In this system the configuration of the control technique for all modules are similar. Each module having two control loops in which a PI controller was placed for inner loop through which the system dynamic response was expedited and outer one is a voltage control loop. In this paper [9] current-limitation control scheme was implemented for multi-module inverters operated in parallel. Each inverter in this system having voltage and current loops with master and slave modules, in which master module receive current commands which were generated by voltage controller. The slave modules with idle running condition. In this[10] paper sinusoidal pulse width modulated inverters connected in parallel in which the proposed control strategy is auto master-slave control technique. From this control strategy the dynamic response becomes faster and load current sharing of the each inverter unit is precise. The inverter which share more load power is master inverter and remaining inverters are slave inverters in the system. In distributed AC power system the above control strategy gives good load sharing between the parallel inverters. In this [11] paper an enhanced droop control technique is exhibited for parallel inverters in order to achieve accuracy of reactive power sharing in a low voltage MG. Here control strategy was implemented by adding rotary-coordinate transformation and sine-virtual active power frequency droop control scheme. In this paper [12] set of inverters operated in parallel in islanded mode, in which each inverter connected to main controller unit as shown in Fig. 4. The presence of impedance imbalance in interconnected cables causes the reactive power sharing in the system is not accurate. The control method which was implemented in this paper provides good reactive power sharing accomplished by the infrequent voltage measurement at PCC. Because of the infrequent voltage measurement we can get a new gain value that is replaced traditional voltage-reactive power droop control method.

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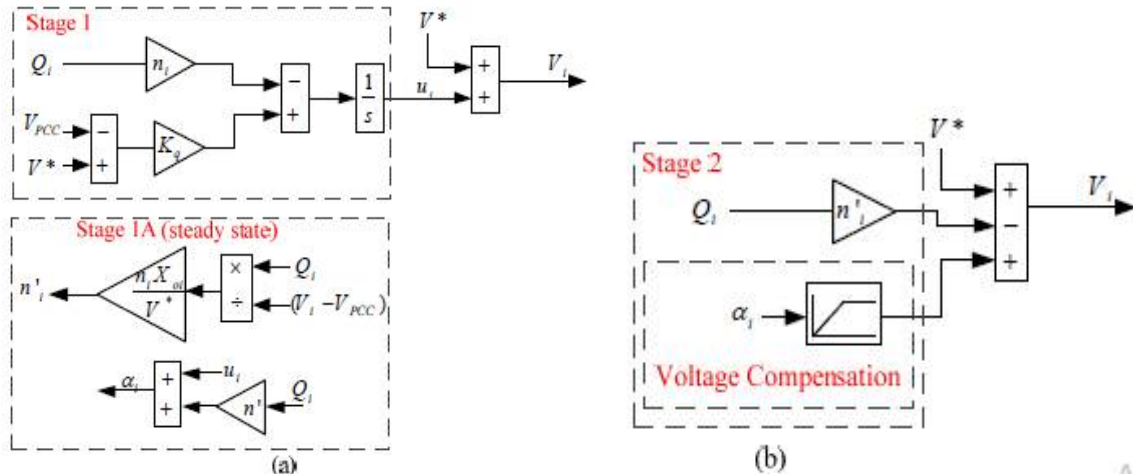


Fig.4. (a) Stage 1: Accurate power sharing. (b) Stage 2: Voltage compensation [12].

In [13], the system enhanced with a secondary controller for a three phase inverter which is operating with a diesel generator in standalone mode. There is no communication between the inverter and diesel generator. The system can share the load proportional to their power ratings under balanced and unbalanced conditions, because of presence of the secondary controller, system can achieve constant frequency and voltage profile in steady state condition and the circulating currents are also minimized to greater extent. In [14], the author proposed parallel operating inverter system with various aspects and characteristics and also proposed different methods for system implementation. In this paper [15], the author proposed control technique for two single phase inverter units interfaced with linear and nonlinear loads. Here no communication between the inverters. This control strategy enhances the expandability, switching redundancy and also increases reliability of the system, because of feature of the control, which compensate the non-uniformity of the inverter units and the effect of imbalance in the line impedance. In this paper [16], set of inverters operated in parallel in islanded mode of operation. In order to get the stability of the system a novel load sharing controller is proposed. This is also a decentralized control technique. Two inverters are connected to a common load is tested in this paper. The proposed controller gives good dynamics when the load is varying. In this [17] paper, inverter is the only choice for the interfacing the distributed generator and the main grid. In the grid many inverters operating parallel so, in this paper proposed another technique that ensures the stable operation. Primarily inverter should be regulating the grid voltage and share the load power accurately. The load is not always a linear load, because of the non-linear loads the voltage waveform quality may change and system will be unbalance. To avoid the aforementioned problems a control technique is proposed. The control method gives control task separately in the frequency domain. Accurate power sharing and grid voltage regulation can be controlled centrally and the command signals are distributed via low bandwidth communication link as shown in Fig. 5. From the simulation results we can conclude the advantages of the proposed control technique are maintain voltage stability while large variations in the load and avoiding circulating currents during steady state and transient conditions.

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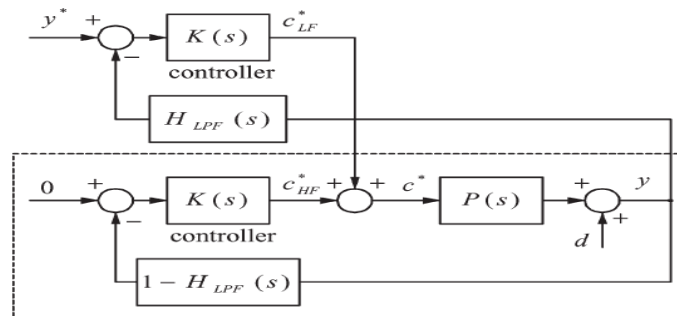


Fig.5. Distributed control method [17].

In this [18], a power sharing control strategy has been proposed, the control sharing is based on networked control. In this system the circuit configuration has two control loops, in which the modules are similar. The output voltage is regulating by using the inner loop and outer loop is regulating the accurate power sharing. Low bandwidth communication method is used to get superior load sharing and the system is also robust while the communication fails. In the networked parallel connected system, the dynamics of the active and reactive powers are described by using a state space model and also develop a methodology for stable operation when the delay time and data dropout in the networked parallel inverter system. In [19], a novel load sharing control technique has been proposed for parallel inverters. Conventional droop control method can effectively use in steady state conditions only. When the load sharing at transient condition is not possible by using conventional droop control scheme. In this the other proposed a controller, which will give better load sharing in the case of transient conditions also. By observing the experimental results we can understand the significant improved dynamic response of the system.

In this [20], author proposed a technology that is complete paralleling control method, which will be used for the connection of the parallel inverters. The algorithm used in this paper is very effective even though there is no communication between the inverters, still the operation is very acceptable. The communication between the inverters enhances the performance, reducing the total harmonic distortion and better power sharing between the inverters. The model which was proposed in this paper is an islanded mode of MGs [21], gives a solution to the reactive power sharing in the system and the harmonic distortion in the voltage at the point of common coupling (PCC). Here two level of control loops are presented. The primary level is basic droop control and the secondary level is to achieve active and reactive power sharing to restore the frequency and voltage perturbations. Two different loops used (capacitance virtual impedance loop and voltage compensation loop) to dampen the voltage harmonics at PCC. In this [22] the control strategy is fully decentralized and it need not any communication between the individual UPS units. In these two inverters operated in parallel, the active power is regulated by using active power frequency droop method and the reactive power is regulated by using reactive power voltage droop method. The algorithm involved in this method is simple for two inverter system. If the no. of inverters in the system is increasing the algorithm also extended to get the stable operation of the system. In this [23] a novel control method has presented for voltage source inverter, so the inverters can operate in islanded mode of operation or grid connected mode also. The control has mainly two functions, valuation of the grid parameters be the first function and the second one is a droop control method. Because of the above two functions the control scheme can effectively inject active and reactive powers to the grid. Finally we could understand the scheme which is used in this paper used for distributed generator voltage source inverters for MGs.

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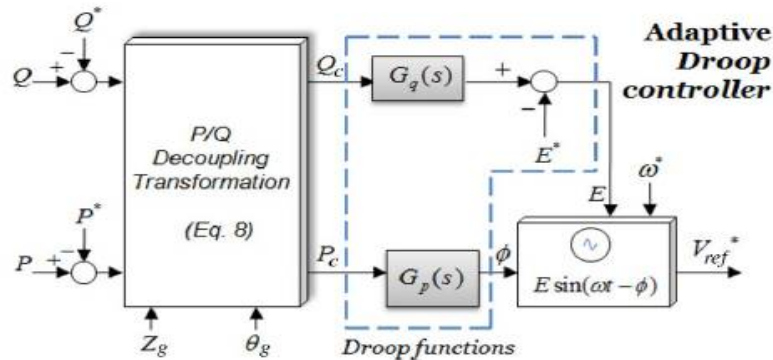


Fig.6. Block diagram of the adaptive droop control [23].

IV. CONCLUSION

As a part of the earlier discussion, it is observed that the control strategies studied have their own characteristics and limitations in achieving certain objectives. The progress in control strategies over the past years is clearly seen in the awareness towards the current work. Because of its discovery and application in MG and distributed energy condition, parallel inverter control captivated researchers towards this work. The work includes droop techniques which exhibit a better performance in the aspects of auxiliary services such as system impedance, harmonic power sharing along with appropriate voltage and power control. The power quality requirement of MG is satisfied with a multi loop control approach of droop control which operates in combination with auxiliary control loop. This makes the capability of droop controlled parallel inverter to manage the MG in both grid connected and standalone modes. The technical challenges in connection to the MG are mentioned which are nothing but the shortcomings of the control mechanism in various aspects like communication, power sharing methods, stability margin in nonlinear environment. A reliable quality and self-sustained future grid will be achieved if the shortcomings are curtailed and the challenges are addressed properly.

Adapting a single control scheme for all applications is very much tedious in practical conditions. However a vivid knowledge and profound consideration of these control techniques is very useful in refining them and in turn it will refine the design. This also helps in improving the design and implementation of future distributed modular grid architectures which require various methods that will fit exactly with the system requirements.

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