Review: Voltage Unbalance Control Techniques for Islanded Microgrid System

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Abstract : Inverter-based distributed generators (DGs) have traditionally been used to mitigate voltage imbalance (VU) in microgrids. It may not be reasonable to rely solely on DGs for VU reduction, especially in islanded microgrids. In microgrids, demand side management (DSM) may be a viable option for VU mitigation. Unbalanced power dispatch from distributed generators (DGs) in a three-phase islanded microgrid with non-stiff grid-supporting or grid-forming distributed generators (DGs) can have a detrimental impact on the voltage quality, stability, and longevity of the DGs. One approach to address such imbalances is to install DGs that can adjust for load imbalances by dispatching unbalanced electricity. Single-phase controlled PQ inverter interfaced DGs are modeled for this purpose in this research. The power stage of the single-phase PQ inverter is approximated to a voltage regulated source using a comprehensive control model of the single-phase PQ inverter.

This paper is reviewing the different techniques for voltage unbalance control of islanded microgrid system. In an islanded microgrid, the DGs may be solar PV system, Wind turbine system but in some cases, fuel cell-based system and biogas based electric energy generation system. This paper will be useful for the complete study of unbalance voltage control of islanded microgrid system.

***Index Terms* – Unbalance voltage control, Islanded Microgrid**

I. INTRODUCTION

Microgrids have been envisioned as effective entities for deregulation of traditional power networks, therefore increasing the penetration of renewable energy systems (RES) in power generating portfolios. However, in microgrids, concerns of reliability, power quality, and power system security have posed obstacles, particularly in the islanded mode of operation, where RES penetration is significant.

Power quality has become a critical concern in microgrids as the number of inverter-interfaced DG units and nonlinear loads has increased [1]. One of the most critical components of power quality concerns is voltage imbalance Voltage Unbalance Control Techniques.

The unequal distribution of single phase loads that are linked either between one phase and the next is the main source of VU. [2], [3] the neutral or in between two stages Furthermore, VU has the ability to Asymmetrical lines and transformers can also cause this open wye and delta, impedances, asymmetrical line faults Non-linear loads, transformer banks, and transformer banks [3]. In the course of a VU, Power systems lose more power and become more vulnerable. to insecurity Power electronic converters, induction motors VU has an influence on variable speed drives (ASDs). Induction motors and ASDs, in particular, suffer from de-rating, mechanical stress, overheating, and a reduction in lifespan. VU produces double frequency power oscillations in power electronic converters, leading in dc-link voltage ripples and an increase in reactive power output.

The best way to reduce VU is to distribute loads evenly throughout phases. [5] describes a network reconfiguration technique that shifts time-variable loads between phases manually or via automatic feeder switching. The goal of the reconfiguration was to reduce distribution system losses, which in turn helped to balance loads between phases. [6] presents an optimization research for rearranging and balancing phases in the distribution transformer's primary side. [7] uses static transfer switches, a central controller, and end-use controllers to dynamically transition residential loads between phases to decrease VU in low voltage networks.

Unlike the previous techniques, the control strategy in this work does not transfer loads from one phase to the next; instead, the phase voltages are balanced by switching the TCLs linked to each phase. Electric vehicles (EVs) have been employed as a DSM entity for VU mitigation in a number of recent research [8]. As a quick demand response, a concept known as an electric spring (ES) that is linked between non-critical loads such as TCLs and the system bus has recently been intensively investigated. This type of ES has largely been investigated for threephase voltage control [9], harmonic suppression of important loads [10], and power fluctuation mitigation. However, because DSM is closely connected to the customers' quality of service, relying just on demand-side mitigation may not always be adequate for VU reduction (QoS).

II. DIFFERENT TECHNOLOGY OF UNBALANCE VOLTAGE CONTROL OF MICROGRID

To accomplish adequate voltage imbalance correction, the author developed [1], a control approach with low bandwidth communications for paralleled three-phase inverters. Voltage/current inner loop controllers, a droop controller, a selective virtual impedance loop, and an imbalance compensator are the key components of the suggested control method.

To further minimize voltage distortion under nonlinear loads, the inner loop controllers are based on a stable reference frame. When providing both linear and nonlinear loads, droop control and a selected virtual impedance loop ensure precise current-sharing. Furthermore, the imbalance factor, which is mostly produced by single phase generators/loads, may be reduced to an exceptionally low amount by changing voltage references according to the amplitude of the negative sequence voltage. Finally, to validate the suggested control approach, an AC microgrid with three three-phase three-leg inverters was tested.

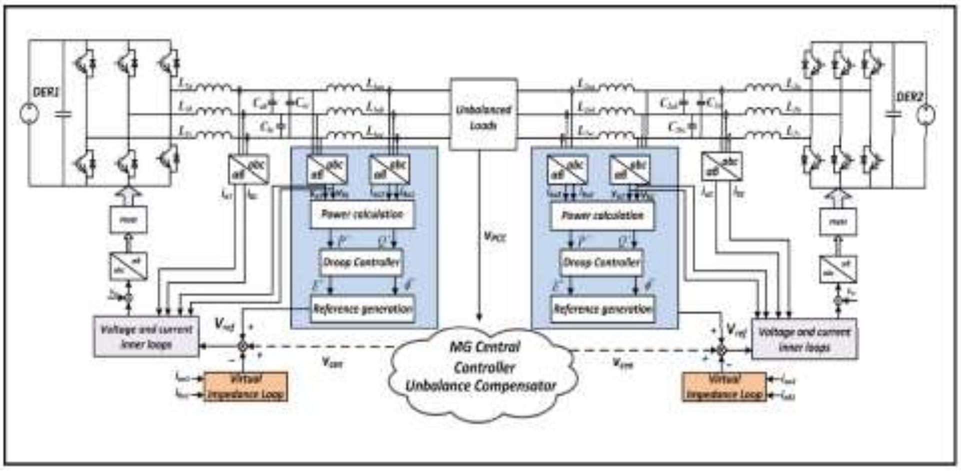

Fig.1. Block diagram of voltage/current inner loop controller, droop controller, unbalance compensator and selective virtual impedance loop [1]

A local controller and a direct voltage imbalance compensator make up the control framework. The local controller is primarily responsible for bus voltage regulation and power sharing accuracy, while the direct voltage unbalance compensator controls the voltage reference to help minimise voltage imbalance at the PCC. Three LCL DG converters linked in parallel and sharing a common AC bus were used to test the control scheme's efficacy. The results of the experiments demonstrate that the negative sequence voltage may be effectively suppressed to the appropriate value while maintaining load sharing accuracy.

Distributed generators (DGs) can be used as distributed compensators in islanded microgrids (MGs) to improve power quality at the consumer end. For voltage imbalance compensation, two-level hierarchical control can be utilized. Droop control and virtual impedance at the primary level can be used to aid positive sequence active and reactive power sharing. Voltage imbalance correction is aided by the secondary level. When distribution line differences are taken into account, however, the negative sequence current cannot be evenly distributed among DGs. Author [2] presents a distributed negative sequence current sharing technique based on a dynamic consensus algorithm to solve this problem (DCA). Unlike the previously suggested techniques, this solution does not require a separate central controller and just requires communication links between nearby DGs. The approach is based on imbalanced system modeling and analysis. The method's efficacy is demonstrated using experimental data from an islanded MG system with three 2.2 kVA inverters.

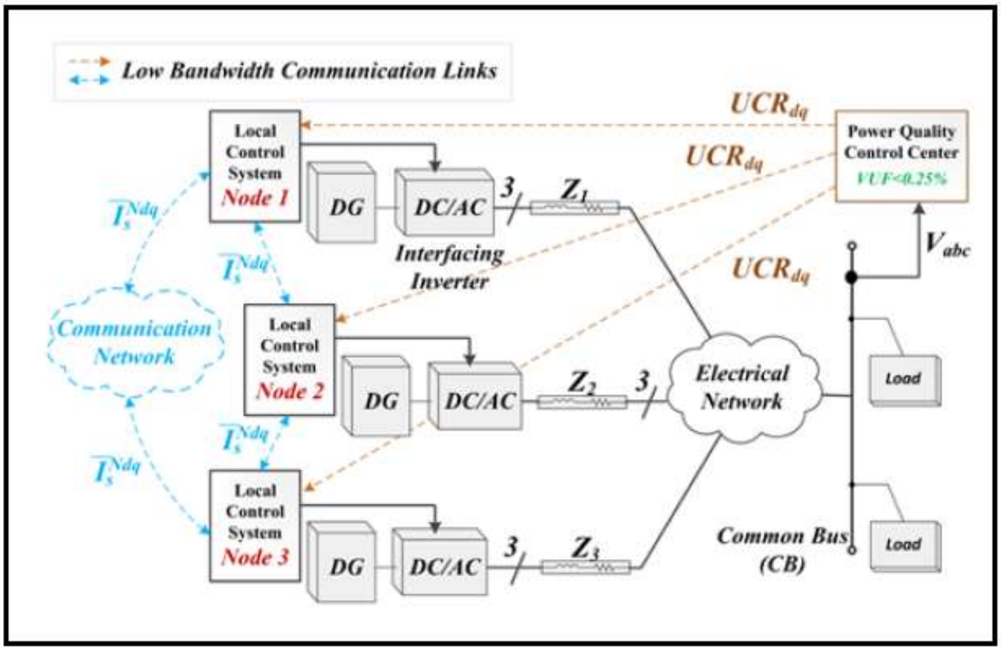

Fig.2. Single line representation of a 3-phase islanded MG [2]

Despite the fact that previous research demonstrated voltage imbalance compensation, the negative sequence current cannot be adequately shared by just using droop control, which might result in an over-current scenario for DGs close to the CB. This technique [2] provides a DCA-based control mechanism to improve existing sharing while addressing the dispersed design of future MG systems. There's also a current sharing loop with a negative sequence.

Compensation and current sharing analyses are used to model the imbalanced system. To test the method's efficacy, the suggested control mechanism is implemented in a dSPACE-based experimental setting. The findings show that the suggested control method can compensate for voltage imbalance while maintaining correct total current sharing between DGs. The online excluding/including unit procedures are also evaluated, demonstrating how such a strategy improves system adaptability. Note that thanks to the distributed nature of the proposed approach, the controller does not need to be implemented in a centralized fashion, which may be dedicated to other management operations of the MG.

A two-level hierarchical control technique for voltage source inverters used to interface Distributed Generators (DGs) in microgrid applications was given to the author [3]. Primary and secondary levels make up the control structure. The primary level is a local controller, which comprises of voltage and current inner control loops to fix the filter capacitor voltage and a virtual impedance loop for voltage harmonics and imbalance compensation, among other things. The central secondary controller sets the virtual impedance to reduce voltage distortion on the sensitive load bus (SLB). Secondary controller is linked to a measuring unit to acquire voltage harmonics and imbalance data at microgrid SLB and broadcasts commands to modify each unit's virtual impedance. It is considered a general example with coupled voltage harmonic and imbalance distortion. Voltage distortion is reduced in this situation by inserting capacitive virtual impedances in the negative sequence of the fundamental component, as well as the positive and negative sequences of major harmonics. Adaptive virtual impedance refers to a system in which the values of virtual capacitances are calculated depending on the necessary voltage quality at the load bus.

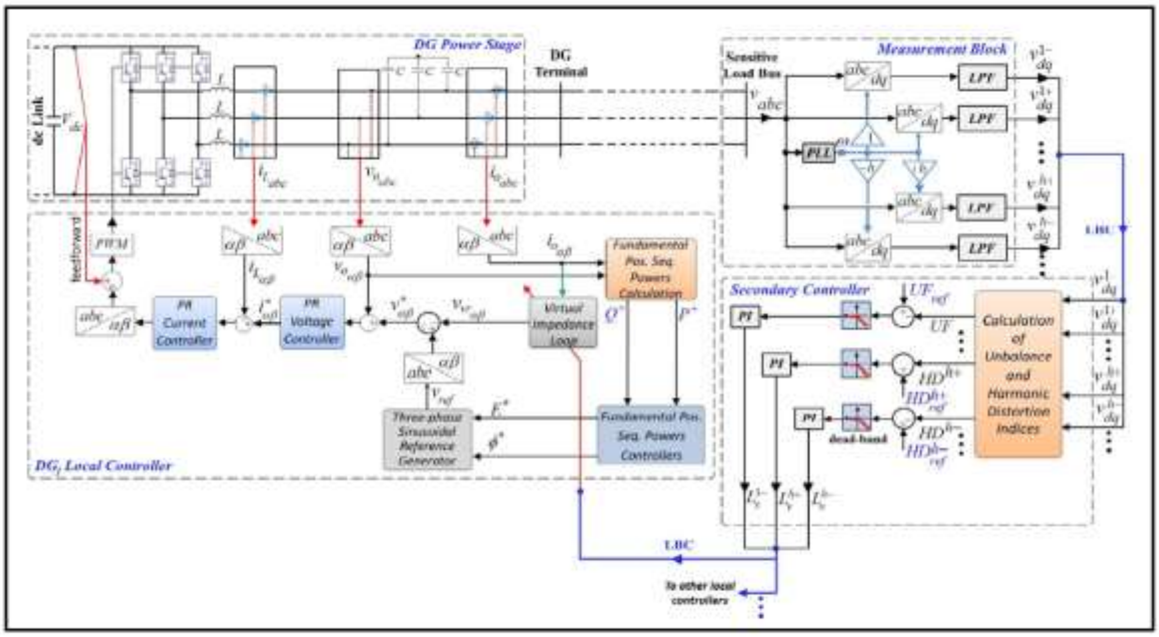

Fig.3. Proposed hierarchical control structure [3]

Based on a hierarchical control framework, an adaptable capacitive virtual method has been presented. The control goal is to reduce voltage quality issues on a microgrid's sensitive load bus to the required level. A central secondary controller determines the values of capacitive virtual impedances for the fundamental negative sequence component and positive and negative components of chosen harmonics, which are subsequently transmitted to the DGs local controllers. The inclusion of virtual capacitances affects the output voltage of DGs, ensuring a good quality of voltage at SLB, as demonstrated by the experimental findings.

To solve uneven power sharing difficulties, the author suggested [4], an improved hierarchical control structure with various current loop damping methods for voltage imbalance and harmonics correction in an ac islanded microgrid. The distributed generation (DG) is correctly regulated to adjust for voltage unbalance and harmonics autonomously while sharing the compensation effort for actual, reactive, unbalance, and harmonic powers. Positive sequence real and reactive power droop controllers, voltage and current controllers, the selective virtual impedance loop, unbalance and harmonics compensators, secondary control for voltage amplitude and frequency restoration, and auxiliary control to achieve a high voltage quality at the point of common coupling make up the proposed microgrid control system (PCC). At fundamental frequencies, an accurate power sharing is achieved by using the proposed unbalance and harmonics compensation (UHC), the auxiliary control, and the virtual positive/negative-sequence impedance (VPI/VNI) loops, and at harmonic frequencies, the virtual variable harmonic impedance (VVHI) loop. Furthermore, the compensation command of the secondary control and auxiliary control is sent from the microgrid control centre (MGCC) to the local controllers of the DG unit using the low bandwidth communication (LBC) technology.

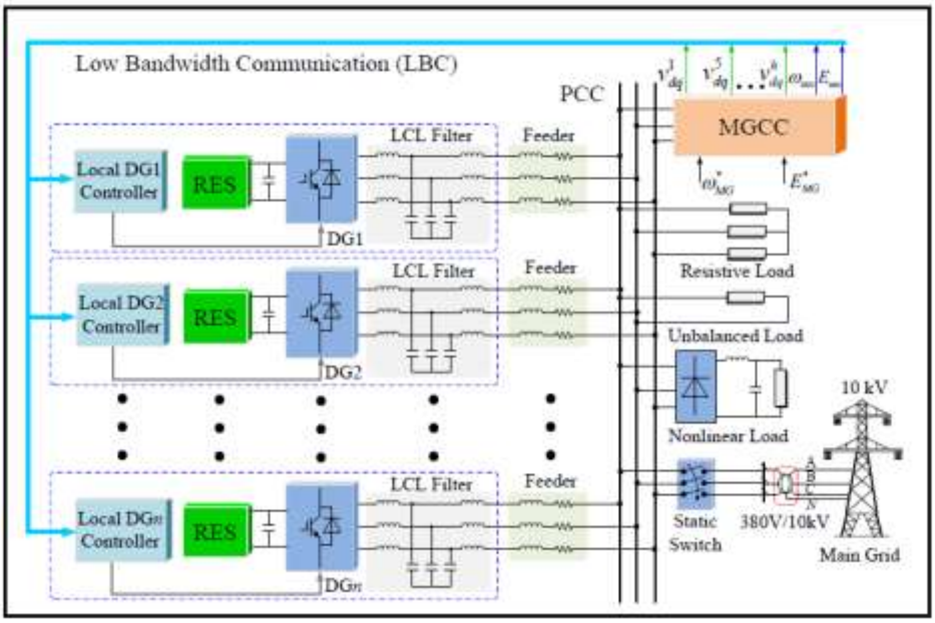

Fig.4. Typical structure of MG with multiple parallel-connected DG units [4]

To correct for reactive, unbalance, and harmonic power sharing faults in a microgrid, the suggested approach uses the selective virtual impedance loop, the local voltage unbalance and harmonics compensation block, and the auxiliary selective compensation of PCC voltage characteristic harmonics. To improve the power sharing of reactive, unbalance, and harmonic power between the DG units, the primary control employs selective virtual impedance at the fundamental positive sequence, fundamental negative sequence, and harmonic frequencies. Individual harmonic component extraction, which is made up of the VPI, VNI, and VVHI, is done using the DSC-SOGI-based sequence decomposition approach. The power controllers employ the basic positive-sequence real and reactive powers to create the DG output voltage amplitude and phase angle references. For the creation of voltage imbalance and harmonics correction reference signals, negative sequence and harmonic powers are used.

Furthermore, the centralised secondary controller is responsible for voltage amplitude and frequency restoration. Auxiliary harmonic correction is achieved by selectively compensating the PCC voltage's distinctive harmonics. Both of them employ the LBC link to provide a suitable central controller control signal for the local primary controller. To show the effectiveness of the increased power sharing methods, the hardware-in-the-loop (HIL) results of the enhanced power sharing scheme under unbalanced and nonlinear load circumstances utilising the dSPACE 1006 platform are presented.

Author was proposed [5], a hierarchical control structure with voltage unbalanced compensation scheme in ac islanded microgrid is proposed to improve Critical Load Bus (CLB) voltage quality and address inac-curate power sharing problems. The hierarchical scheme includes primary and secondary control levels. The primary control mainly contains the power droop controllers, voltage and current controllers, selective virtual impedance loop, and voltage unbalanced compensation. The virtual impedance loop includes virtual positive- and negative-sequence impedance loops at fundamental frequency and virtual variable harmonic impedance loop at harmonic frequencies. The secondary control is designed to restore frequency and amplitude of the CLB voltage. In order to compensate the CLB voltage, an unbalanced compensation is proposed to change the voltage reference of the distributed generation (DG) units. This strategy also employs the low bandwidth communication (LBC) technique to send the proper signals of the secondary control from the microgrid control center (MGCC) to the primary control. To evaluate the performance of the proposed control strategy, simulations are conducted on two islanded microgrid prototype. The results demonstrate the effectiveness of the proposed control structure in the unbalance and harmonic compensation of the CLB voltage and proper power sharing of reactive, unbalanced and harmonic powers among the DG units.

To enhance Critical Load Bus (CLB) voltage quality and solve inac-curate power sharing difficulties, the author suggested [5], a hierarchical control structure with voltage imbalanced compensation method in an ac islanded microgrid. Primary and secondary control levels are included in the hierarchical structure. Power droop controllers, voltage and current controllers, selective virtual impedance loop, and voltage imbalanced compensation are all part of the basic control. At fundamental frequencies, the virtual impedance loop consists of virtual positive- and negative-sequence impedance loops, as well as a virtual variable harmonic impedance loop. The secondary control is used to restore the CLB voltage's frequency and amplitude. An imbalanced compensation is proposed to modify the voltage reference of the distributed generation (DG) units in order to compensate the CLB voltage. The low bandwidth communication (LBC) technology is also used in this strategy to deliver the necessary secondary control signals from the microgrid control centre (MGCC) to the primary control. Simulations on two islanded microgrid prototypes are used to assess the performance of the suggested control method. The findings show that the suggested control structure is successful in balancing and compensating the CLB voltage for imbalance and harmonics, as well as correct power sharing of reactive, unbalanced, and harmonic powers among the DG units.

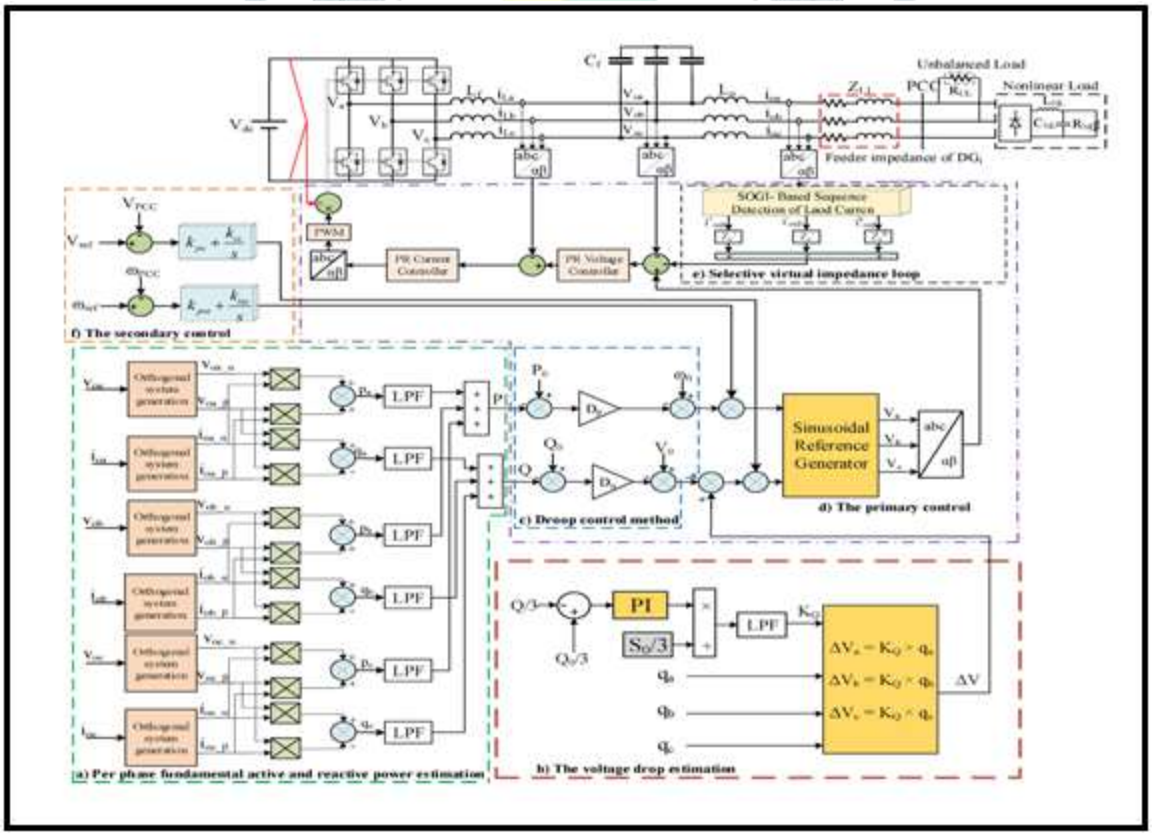

Fig.5. Block diagram of the proposed voltage control strategy [5]

Hierarchical control, comprising primary and secondary control, is used in the proposed method. The droop control technique, unbalanced compensation, and virtual impedance loop make up the main control. At fundamental frequencies, the virtual impedance loop consists of virtual positive and negative sequences, and at harmonic frequencies, the virtual variable harmonic impedance loop. This positive-sequence virtual impedance is thought to help droop controllers operate better. Negative-sequence virtual impedances correct for load voltage distortion and reduce negative-sequence circulating currents between DGs. For improved harmonic power sharing, the virtual variable harmonic impedance loop is utilized. The DSC-SOGI is used to decompose DG output currents and extract fundamental positive and negative sequence currents, as well as prominent harmonic components. The secondary control level returned the PCC voltage's amplitude and frequency to its original levels. The suggested method has been tested in simulations, and the findings demonstrate that it is successful in microgrid deployments.

Voltage imbalance, which has negative impacts on electrical equipment, is one of the primary power quality concerns in low-voltage (LV) microgrids. A new control technique was provided to the author [6] to reduce the voltage imbalance caused by a photovoltaic (PV) system. The PV system mitigates the voltage imbalance by evaluating its terminal voltage in this study, which eliminates load current sensors. Because of the challenges of load current sensors, this may effectively lower the cost and complexity of the compensation system. The suggested control scheme is for a three-phase PV system. The suggested control method creates compensatory reference currents based on the double synchronous reference frame (DSRF) analysis of the PV terminal voltage as the inverter detects voltage imbalance at its terminal. As a result, the microgrid receives compensatory currents from the PV inverter.

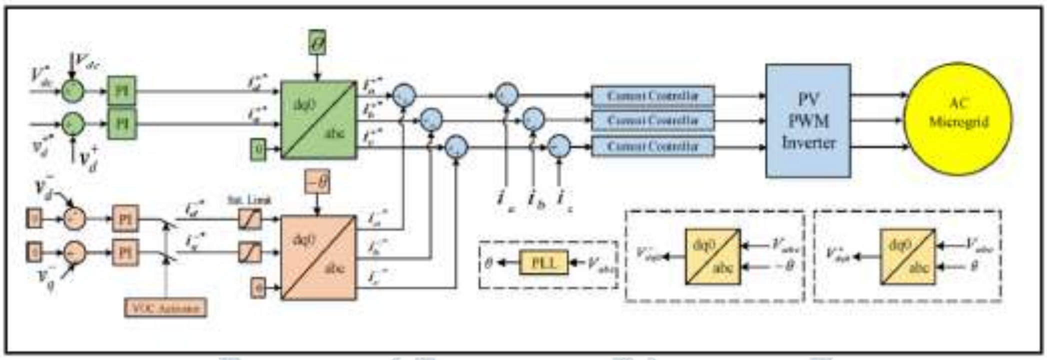

Fig.6. The proposed double synchronous reference frame (DSRF) [6]

In contrast to APFs, the load current sensor was removed, and the compensation method computed the reference currents by evaluating the PV terminal voltage, lowering the cost and complexity. The double synchronous reference frame (DSRF), which detects the positive and negative sequence of the PV terminal voltages, aided the suggested control method. When an unbalanced load connects to the network, the control system detects negative sequence voltages, which indicates a voltage imbalance. The control system calculates the needed negative sequence compensating current based on these voltages in order to decrease the voltage imbalance at the PV terminal. Because this control approach does not need the measurement of imbalanced load current, the compensation system might be used without the use of local load current sensors. Although employing the PV inverter as an active power filter might lower the cost of the compensating system, the suggested control method could cut the compensation cost even further. The PSCAD/EMTDC environment was used to test the control scheme's efficacy. The simulated scenarios confirmed that the PV system could reduce voltage imbalances while unbalanced loads join to or detach from the LV microgrid. While the suggested control approach was designed for islanded microgrids, it may be used to any distribution network experiencing voltage imbalance.

A two-layer hierarchical control system was developed by the author [7] to achieve optimal correction of voltage unbalances in various buses of islanded microgrids. The microgrid voltage and frequency are controlled by the main layer. The secondary layer is utilised to achieve sensitive load bus imbalance correction (SLB).

If the voltage imbalance factor (VUF) at the SLB improves, the VUF at local buses and/or DG terminals may improve as well. In order to adjust the compensation component of each DG source, a complementary section is created and incorporated to the secondary control, while VUF restrictions at DG terminals and local buses are also taken into account. This approach uses a basic but effective solution to achieve multi-power-quality-level control.

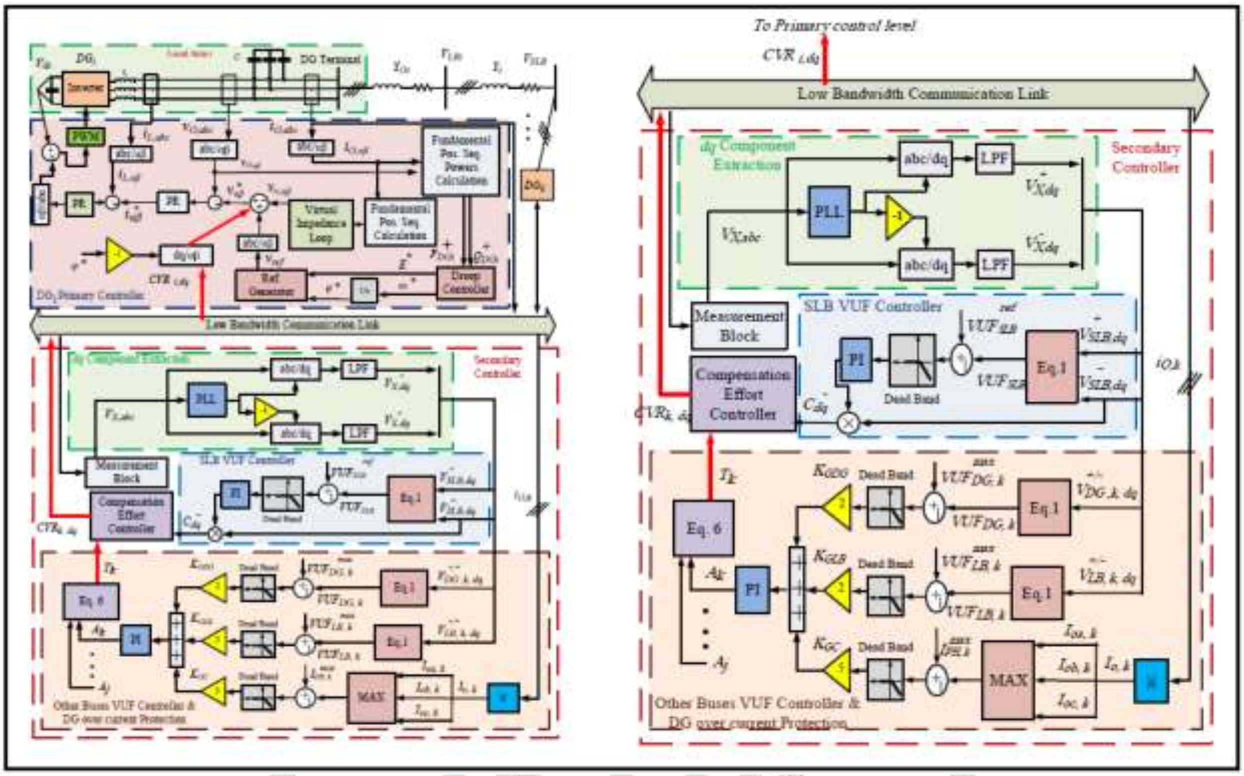

Fig.7. Primary and secondary control for voltage unbalance [7]

The suggested control structure achieves multi-power-quality level control for islanded microgrids with multi-bus and parallel DGs using a simple yet effective method that requires no extra equipment. The suggested controller structure is basic, has minimal mathematical weight, and is independent of network configuration or parameters, making it practical and preserving the DGs' plug-and-play capabilities. Two systems are modelled and simulated as examples. To illustrate its advantages, simulation results are compared to the results of an optimization technique utilised in the literature. The simulation results demonstrate that the suggested approach not only achieves the same outcomes as the existing way, but it also achieves superior results in terms of speed and accuracy in regulating the targets in some situations. All of these useful skills are achieved with a simpler control structure and fewer calculations, and without the use of a complex optimization method or prior knowledge of the system characteristics.

Negative-sequence reactive power conductance (Q—G) droop control is a common way to correct for output imbalance voltages in islanded MGs. Despite this, the conflict between unbalanced voltage compensation and negative-sequence reactive power sharing, which is induced by impedance mismatching of distribution lines and distributed generators, has not been resolved only by Q—G droop control. By properly shifting up and down the Q—G droop characteristic of each DG, the author proposed [8], a distributed cooperative secondary unbalanced voltage control strategy to decrease the output voltage unbalance factor (VUF) of each droop-controlled DG as well as to further enhance the negative-sequence reactive power sharing effectiveness among DGs. In addition, an adaptive VUF weight coefficient method is presented to improve VUF suppression in extreme imbalance circumstances. The author proposed [8], a distributed cooperative secondary unbalanced voltage control strategy to reduce the output voltage unbalance factor (VUF) of each droop-controlled DG as well as to improve the negative-sequence reactive power sharing effectiveness among DGs, by properly shifting up and down the Q—G droop characteristic of each DG. In addition, in extreme imbalance situations, an adaptive VUF weight coefficient approach is proposed to increase VUF suppression.

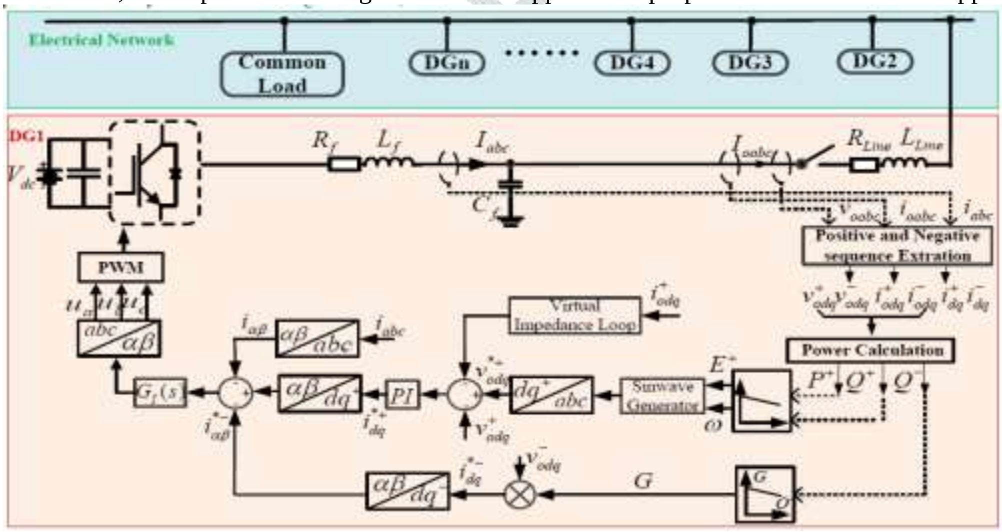

Fig.8. Structure of negative-sequence reactive power-conductance (Q--G) droop control strategy [8]

Each droop-controlled DG interacts with its nearest neighbour to gather all DG information using the suggested SUVC method. In addition, to better suppress VUF under extreme imbalance situations, an approach for adaptively adjusting VUF weight coefficient is presented. Furthermore, a negative-sequences small-signal model of an MG with communication time delay is developed to investigate the system's stability and dynamic performance as a function of several important parameters of the suggested control approach. It has been discovered that when the integral coefficient of secondary layer k rises, the communication delay margin increases. However, an excessively high k will also result in a stability problem. To guarantee system stability and dynamic performance, the secondary layer integral coefficient k should be designed appropriately.

In addition to the conventional power management control, the control flexibility of the power inverters that interface dispersed generation may be used to integrate power quality enhancement features. The author was shown [9] a unique control technique for achieving voltage balance at every node of an AC microgrid, independent of the power network's impedance value. The collaborative method aims to establish a specific share of the balancing currents, avoiding the negative consequences of a single inverter's imbalance correction. A sophisticated version of a proportional resonant controller and a communication connection are used in the control scheme. The technique includes a stability and sensitivity analysis as well as control parameter design instructions. In a laboratory microgrid configuration, the performance of the control concept was successfully tested.

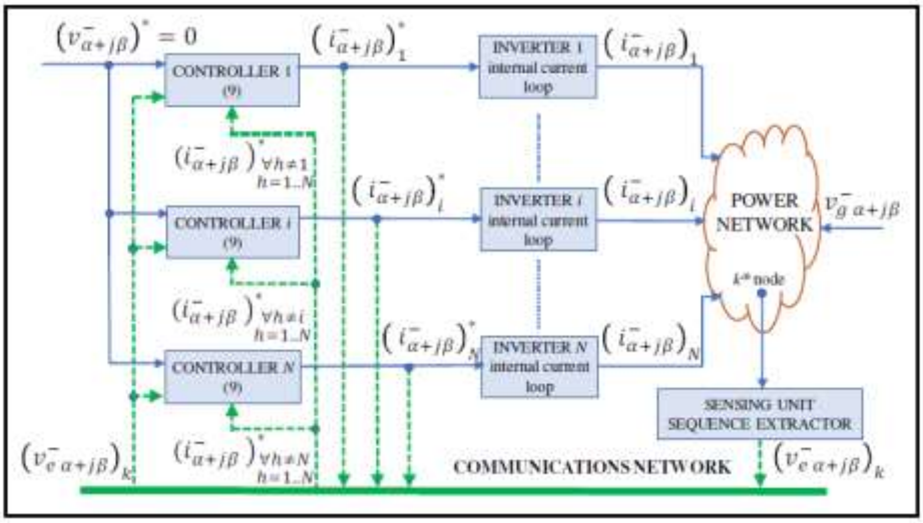

Fig.9. Negative-sequence control scheme [9]

The control parameters were created with the goal of ensuring steady operation and meeting some dynamic requirements. The parameter MT_, in particular, can be set to give a varied contribution of negative sequence inverter currents in order to lower the negative sequence voltages of the inverters. Selected experimental findings show how the AC microgrid's power quality may be improved in a variety of circumstances.

This work inspires a number of new research ideas. First, by incorporating active-power injection curtailment, tolerating a specific voltage imbalance in the sensitive load, or a combination of both, the current distribution algorithm may be further utilised to avoid exceeding the inverters' maximum current. Second, it is possible to eliminate voltage imbalance in several sensitive nodes. Third, as a source of voltage imbalance, the control technique was extended to grid-forming inverters operating in islanded mode and powering unevenly distributed massive single-phase loads. Finally, the investigation of voltage decreases during grid failures in various scenarios (balanced-unbalanced sags, compliance with grid codes, online current limitation).

This technique [10] proposes a synchronous reference frame (SRF)-based decentralised control architecture for parallel inverter operation. Decentralized inverters can share the imbalanced load using the suggested control approach. At the same time, any unwanted voltage unbalances at the inverter output terminal are corrected in accordance with IEEE standard 141-1993.

Based on the positive sequence component (PSC) of the SRF currents, active (P) and reactive (Q) power droops are supplied, and a virtual resistance is simulated concurrently at the inverter output to facilitate load sharing between the parallel-connected inverters. The suggested decentralised control approach is based on inverter terminal data, therefore no inter-communication networks are required. Three fundamental control loops – voltage control, frequency control, and a PLL control – are used to create current-based P=Q-droops and emulate virtual resistance. Because it is designed to function in the SRF, the control structure is basic and devoid of computational complexity and related delays. A closed-loop resonant controller is used to correct the output voltage's negative sequence component (NSC). Comprehensive experimental results on a laboratory test prototype confirm the viability of the suggested technique.

The control structure uses active-reactive (P=Q) power droops based on positive sequence SRF currents in the synchronous reference frame (SRF). The suggested control eliminates instantaneous power computation and its related delays. Simultaneously, it creates a virtual resistance at the inverter positive sequence network's output. Using three fundamental control loops – voltage, frequency, and PLL control loops – equivalent droops based on positive sequence SRF currents are created to integrate P=Q droop with the virtual resistance. Sequences that are positive These controllers employ SRF voltages and currents as references and feedback. Resonant controllers tuned at double line frequency are used to eliminate imbalance at the output line voltage.

While feeding electricity to an unbalanced load, the suggested control technique performs well in terms of load-sharing and voltage imbalance correction. As a result, the suggested control approach may be viewed as a sophisticated solution to the decentralised control of distributed inverters in an islanded microgrid system.

in Matlab/Simulink show the effectiveness of the FTDNN-AVR architecture and its superior stable performance.

III. CONCLUSION

Microgrids have been envisioned as effective entities for deregulation of traditional power networks, therefore increasing the penetration of renewable energy systems (RES) in power generating portfolios. However, in microgrids, concerns of reliability, power quality, and power system security have posed obstacles, particularly in the islanded mode of operation, where RES penetration is significant.

This paper is reviewing the different techniques for voltage unbalance control of islanded microgrid system. In an islanded microgrid, the DGs may be solar PV system, Wind turbine system but in some cases, fuel cell-based system and biogas based electric energy generation system. This paper will be useful for the complete study of unbalance voltage control of islanded microgrid system.

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