

# A Review on Impacts of Power Quality, Control and Optimization Strategies of Integration of Renewable Energy Based Microgrid Operation

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**Abstract**—Due to the global demand for energy saving and reduction of greenhouse gas emissions, utilization of renewable energy sources have increased in electricity networks. The negative aspects of this technology are very complex and not well known which affect reliability and robustness of the grids. Microgrids based on renewable energy sources have gained significant popularity, due to the major benefits it has to offer for solving the increasing energy demand. Harmonic distortion in microgrids caused by the non-linear loads is an essential topic of study necessary for the better understanding of power quality impacts in microgrids. The various control techniques utilized to curtail the power quality impacts on micro grids are reviewed in this paper. Also, Optimization based control techniques utilized for power quality improvement in microgrids is discussed in this review.

**Index Terms**—Microgrids, power quality, harmonic distortion, droop control, renewable energy.

## I. INTRODUCTION

Rapid increase in energy demand of the developing nations has put pressure on the availability and cost of all natural resources. In many growing countries, including India, the grid control creates an additional challenge. Due to the highly complicated system of our modern electric grid, the integration of renewable energy sources possess various problems due to the intermittent nature of the source, unpredictable power generation and transmission from rural areas through the weak network. Wind energy is a pioneer among all other renewable energy sources, which has the sun a huge growth and development recently. In all over the world above 28,000 wind turbines are generating profitable. Grid connected renewable energy sources are sensitive to the power quality issues which includes the voltage sag, voltage swell, harmonic distortion, transients, frequency

variations, multiple notches and voltage flicker [1]. Due to the power quality issues, the grid will experience loss of generation which may cause grid instability and insecurity [2]. The integration of renewable energy sources and distributed generation into conventional power systems causes power quality disturbances in the grid. Therefore, power quality monitoring is an essential concern to protect the electrical and electronics equipment [3]. Constantly testing the reliable, steady, effective and economic operation of the grid is essential to maintain the power quality [4]. Among the major issue of power quality issues, harmonic distortion is caused by non-linear loads connected to the electrical power system possess a major challenge [5]. The harmonic current flowing across the microgrid will cause power loss in transmission lines and reduces load capacity.

The microgrid is a cluster of loads and micro sources that act as a single controllable system which injects electrical power to its localized station and regional grid. Over the past 30 years, microgrids played a major role in the world's clean energy conversion and the culmination of the energy improvements. Microgrid includes most of clean energy's valuable technologies like renewable, combined heat and power, systems management, energy storage, energy efficiency and demand response. They can be operated either in the normally interconnected mode or islanded mode [59]. The most familiar voltage quality problems in a microgrid and utility system are the unbalanced grid voltages and the utility voltage sags on the whole system performance. In the modern microgrid, power electronic devices are used for monitoring and compensating the improvement of power quality events [6, 7]. Fig.1 shows a basic arrangement of the microgrid. Microgrid loads are generally classified into fixed and flexible loads. Under normal operating conditions, fixed load should be satisfied whereas flexible loads are controlled by the signals. It could be curtailable loads in response to islanding requirements [8]. In the grid – connected mode, the microgrid injects a power into the utility grid depending on the generation and load demand.

In islanded microgrid, voltage controller is used for lack of utility grid which can work as one grid forming unit. When MG operates an islanded mode, all converter control and local loads manage power with high efficiency. During grid faults islanded system provides uninterruptible power supplies for local loads.

Droop based control methods are widely applied in microgrids which can operate without the need for communication and to avoid a critical information for accuracy basis [9, 10]. The contribution of droop control technique is more efficient to boost the real and reactive power control in grid connected and islanded operation [66].

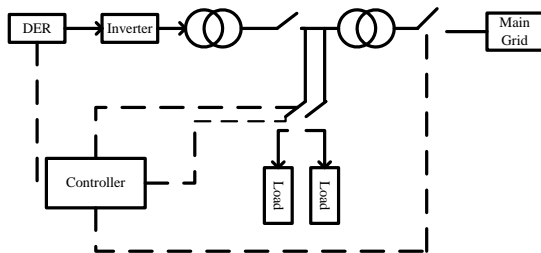


Fig.1. A typical microgrid [8].

In this paper, the feature to evaluate the challenges of the microgrid is discussed, and power quality issues due to harmonic distortion in microgrids are presented. In Section 2, indices of various power quality problems in grid side are illustrated. Section 3 discusses the harmonic detection schemes in various discrete fourier transforms. In Section 4 discusses various droop control techniques in the microgrid, also its merits and demerits are presented in this part. Section 5 indices an optimization technique in the microgrid. In Section 6 and 7 discusses the application of renewable energy sources and discussion & future visions are presented in this part. Moreover, a detailed study of various classification of microgrid has been illustrated in Table 1.

## II. POWER QUALITY ISSUES

Disturbances of power frequency, faulty connections, harmonic distortion, the variation of power factor, electromagnetic interferences are present in power quality problems (70% to 80%) either in the supply of source side or load side [11,12]. To alleviate PQ problem consumers are equipped with various backup instruments distant from the grid supply. This chapter describes the power quality disturbances, also Fig. 2 shows that the classification of grid side power quality issues.

Renewable energy source like hydropower cause a smaller amount of power quality issues compared to other sources like wind and solar energy systems. Power quality issues related to the distributed generation sources (DG's) have been illustrated in Table.2 [11, 73].

### A. Voltage variations

In distribution network, operators have major challenges to compensate the voltage variation due to

variable wind generation and dynamic voltage stability. Voltage variations generally occur from changes in velocity of the wind and generator torque. The deviation of voltage is also affected the real and reactive power of the system [13]. The voltage variation is usually divided into four types which include voltage sag, voltage swell, short interruption and long duration voltage variation.

### B. Voltage sag

Voltage sag is an incidence where the RMS (Root Mean Square) voltage less than the nominal voltage at the power frequency. Sag is caused by sudden changes in loads such as faults, motor starting and sudden increases in source impedance, usually caused by a connection failure [14]. Various type of faults in three- phase grid such as 1 $\phi$  to neutral, phase to phase, 2 $\phi$  to neutral, 3 $\phi$  faults it leads to different voltage sag. Fault location, equivalent network model, properties of the transformer interface, and fault type are the causes of voltage sag at the wind turbine units [15]. IEEE- 519 represents the standards of power quality based on the factors such as distributed generation (DG) costs and voltage sag [60].

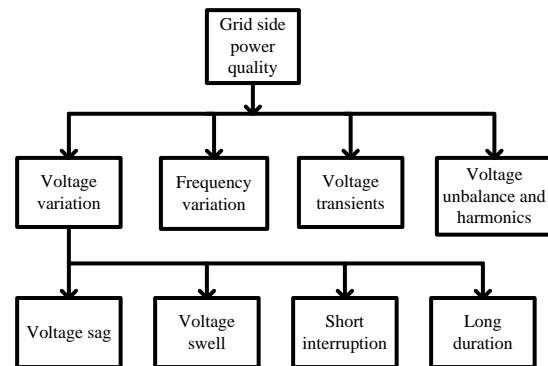


Fig.2. Classification of power quality.

### C. Voltage swell

Voltage swell is a raise in voltage greater than the time range (0.5-30). The main causes of voltage swells are a sudden reduction in load on a circuit with the damaged voltage regulator [16]. In literature [17], voltage swell generates unexpected harmonics of current to the grid by induction melting furnace (IMF) system. Because the voltage swells mainly occur on the faults condition inside or outside of the small steel metal.

### D. Short Interruptions

Short interruptions are the major power quality concern for loads that are fed from the grid. Generally, interruption is defined as the decrease in the voltage supply to less than 10% of nominal for up to one- minute duration. It is typically caused by the reclosing of a circuit breaker, switching to a healthy supply, automatic transfer switches in industrial networks. Short interruptions occur at the point of common coupling (PCC) which is connected to consumers and utility units. Also, based on the load with respect to sag and swells containing its asymmetrical phase angle and magnitude [18].

*E. Long duration voltage variation*

The deviation of RMS variation in the voltage for longer than 1 minute at power frequencies. Long duration variation consists of under voltages and over voltages and sustained interruptions. Less than 90% decrease in RMS voltage at power frequency is defined as under voltage and increase in RMS voltage more than 110 % at the power frequency for longer than a minute can be defined as over voltage. These conditions occur due to load variations in the system, switching of large capacitor banks or due to incorrect tap setting of transformers.

These occurrences reduce the lifetime of the power system equipment. When zero voltage is sustained for longer than a minute, it can be studied as a sustained interruption and necessary action can be appropriated [19, 20]. When the fluctuation occurs in the generation of power from the renewable energy resources because of the changes in environmental constraints [61]. The frequency range of voltage fluctuation in the wind turbine is 10-35 Hz and International Electro-technical Commission IEC-61400 standards indicate the measuring value of flicker meter exactly [1].

Table 1. Classification of Microgrid

	Classification	Integrated level	Impact on utilities	Area of applications	Mode of operation	Quality of power	Observations
1.	Utility microgrid	High	Huge amount of impact on utilities	Quickly developing countries for renewable energy like China, Europe, and Japan.	Grid connected mode	Average	High power quality. High reliability. Robust. Stability could be controlled.
2.	Industrial microgrid	Middle	Small utilities impact	North America, particularly for industrial and institutional application.	Intentional islanded mode or unintentional islanded mode	High	High efficiency. Pollution could be reduced. High power quality. Reliability for sensitive loads.
3.	Remote microgrid	Low	No impacts	Islands, developing countries.	Islanded mode	Low	Maximum power usage for consumers is limited.

Table 2. Causes of power quality problems related to DGs

PQ issues	Wind power	Solar power	Hydro power
Sag	Yes	No	Yes
Swell	Yes	No	Yes
Under voltage	Yes	No	No
Over voltage	Yes	No	No
Voltage unbalance	No	Yes	No
Current harmonics	Yes	Yes	Yes
Voltage harmonics	Yes	Yes	Yes
Interruption	Yes	Yes	No

*F. Frequency variation*

When load increases more rapidly than the generator can react to adjust the power generation, it causes the generators to slow down. Then frequency is in fall condition and decreases when generation is higher than the load. In Fig.3, the utility user interfaces linear and nonlinear loads. In the power system operation, frequency variations are the major issue for power grid companies. An industrial application frequency variation has harmful effects on the modern computer controlled system as it can cause variable operation, system collapse, and computer equipment damage [21]. Generally, the frequency should be maintained based on grid standards. IEEE 1547-2003 standards, grid code fault ride through

condition the output current of the grid converter maintains properly under balanced case [62].

*G. Voltage Transients*

The reason of disturbances is varied in power systems. An electrical transient is a short term excess of voltage/current in an electrical circuit which only lasts milliseconds, which can occur electrical, data and communication circuits. The transmission line switching, reactor and capacitor bank switching are the causes of power system switching events in voltage transients. IEC-61000-4-30 determines the disturbances of transient occurrences should be finding the ability of transient event [63].

### H. Voltage unbalance and harmonics

Voltage unbalance is one of the voltage related compensation. Low voltage (LV) microgrid, voltage unbalance is the general issue, where most of the loads are in single phase load. In literature [22], current and voltage harmonics are compensated by using the active filters. The further functions of active filters such as compensation of current and voltage unbalance, voltage flicker, voltage spikes. Rectifiers, inverters, switch mode power supplies, and energy saving lamps is the sources of harmonics which can easily appear in microgrid [23], but to mitigate the voltage distortion several recent inverters use filters which may give to harmonics at the user end to utilize power electronic based equipment. In [24, 25] voltage unbalance of DG output varies when the overall system changes after the disconnection of microgrid from the main grid. In an islanding mode of operation determines an output of the unbalanced three phase voltage exceeds the threshold value. The general equation of voltage unbalance at the observing time  $t$  is given by,

$$VU_t = \frac{NS_t}{PS_t} \quad (1)$$

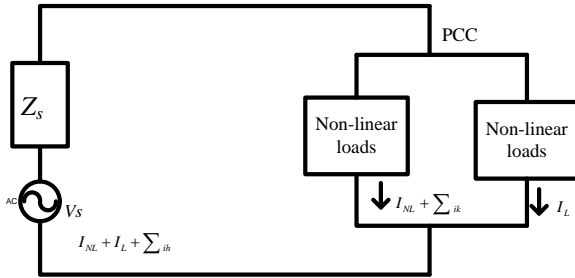


Fig.3. Utility interface [21].

Where  $NS_t$  and  $PS_t$  represent the magnitudes of the negative and positive sequence of the voltage at  $t$ . If negative sequence voltage can be eliminated then voltage harmonics should be affected and tedious calculation of threshold values are the major drawbacks. IEC recommends the voltage unbalance limits should be below 2%. The characteristics of power quality phenomena have been identified in Table 3.

### III. HARMONIC DETECTION SCHEMES

Harmonic Detection Schemes can be categorized into two types which include time domain methods and the frequency domain methods. Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), RMS voltage detection method, Sliding Discrete Fourier Transform (SDFT), the peak voltage detection method are the frequency domain methods [26]. Synchronous Reference Frame (SRF) phase locked loop (PLL), Instantaneous reactive power and kalman filtering are the methods to remove the harmonic components from detecting the three-phase waveforms [27].

### A. RMS Voltage Detection Method

In general, RMS is an equivalent value of dc voltage although RMS voltage is 0.707 times the peak voltage. The supply voltage of the RMS value and the comparison of the value is given to a threshold. An initial phase angle can depend on the residual voltages and durations, also detection capability and probabilistic performance are the negative aspects of RMS voltage methods [28]. The phase angle of supply voltage does not provide information in the event of RMS based methods. The RMS voltage can be derived by [29],

$$V_{rms} = \sqrt{\frac{1}{N} \sum_{i=1}^N V^2[i]} \quad (2)$$

$N \rightarrow$  number of sampled points per cycle.

$V[i] \rightarrow$   $i^{\text{th}}$  sampled voltage.

If the  $N$  value becomes higher, then RMS value could be derived. The sampling  $j$  of the RMS value can be computed by,

$$V_{rms}[j] = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} V^2[j-i]} \quad (3)$$

Assume  $S[j] = \sum_{i=0}^{N-1} V^2[j-i]$ , then

$$S[j] - S[j-i] = \sum_{i=0}^{N-1} V^2[j-i] - \sum_{i=0}^{N-1} V^2[j-i-1] \quad (4)$$

$$= V^2[j] - V^2[j-N] \quad (5)$$

So,

$$S[j] = V^2[j] - V^2[j-N] + S[j-1] \quad (6)$$

The disadvantage of this method is inaccurate calculation because of the low order harmonic distortion and the grid voltage variation ratio should be detected.

### B. Peak Voltage Detection Method

An alternative method of RMS to detect voltage sag is the peak voltage method used for detecting voltage variation ratio of the grid. This peak voltage detection method can be expressed by,

$$V_{peak} = \max |V(t-\tau)|, 0 < \tau < t \quad (7)$$

Where,

$V(t-\tau) \rightarrow$  the sample grid voltage.

$t \rightarrow$  the sampling interval

$\tau \rightarrow$  the instantaneous sample time.

When Low Voltage Ride Through (LVRT) operation is used to verify the ratio of grid voltage variation, the peak

voltage detection method has limited use the half fundamental cycle. Likewise, low order harmonic distortion can detect inaccuracy calculation [57].

Table 3. Characteristics of power quality phenomena [65]

Sl. No	Types	Duration	Voltage magnitude	IEEE & IEC standards	References
1	Voltage Sag	0.5-30 period	0.1-0.9 pu	IEEE 519	60
2	Voltage Swell	0.5-30 period	1.1-1.8 pu	IEEE 519	60
3	Short Interruption	0.5-30 period	<0.1 pu	IEEE-1547	64
4	Under voltage variation	>1 min	0.8-0.9 pu	IEC-61400	1,61
5	Over voltage variation	>1 min	1.1-1.2 pu	IEC-61400	1,61
6	Sustained interruption	>1 min	0.0 pu	IEC-61400	1,61
7	Voltage unbalance	Steady state	0-0.1%	IEEE-1547	64
8	Harmonics	Steady state	0-20%	IEC-61400	1,61
9	Impulsive transients 1. Nanosecond 2. Microsecond 3. Millisecond	<50 ns 50 ns- 1 ms >1 ms		IEC-61000-4-30	63
10	Frequency variation			IEEE 1547-2003	62

C. Discrete Fourier Transform Method

The purpose of DFT is to indicate in a time window to the sample signal in the harmonic components of the digital system. DFT is inaccurate for non – stationary signals [30]. The DFT can be defined as an equation (8),

$$X(k) = \sum_{n=0}^{N-1} x(n)WN^{kn}, (k = 0, 1, 2, \dots, N - 1) \quad (8)$$

Where,

$$WN = e^{-\frac{j2\pi}{N}}$$

D. Fast Fourier Transform Method

Fourier Transform has a lot of limitations on the analysis of short time high frequency and long-time low-frequency signals. Fast Fourier Transform (FFT) is a rapid algorithm of DFT and it decomposes the big point DFT into a small point DFT in this manner computational time can be reduced [31]. Information on the magnitude and phase angle of the harmonic components is provided

by STFT during voltage waveform occurrence [30].

E. Sliding Discrete Fourier Transform Method

Sliding DFT is one among the essential tools for investigating the signals for the harmonic components; also sampling time on DFT performs an N -point. It consists of two cascaded digital filters, combo filter proceeds from second order finite impulse response (FIR). The SDFT algorithm calculates the normalized frequency. The plus point of the SDFT is the simple structure and computational complexity has lower than the DFT and FFT. Z-domain transfer function of SDFT as defined in [32] is given below,

$$H_{SDFT}(z) = \frac{e^{\frac{j2\pi k}{N}}(1-z^{-N})}{1-re^{-\frac{j2\pi k}{N}z^{-1}}} \quad (9)$$

Where, N is the sample count, k is an integer represents k<sup>th</sup> harmonic and 1-z<sup>-N</sup> is the comb filter of FIR. H(z) can be divided into real and imaginary parts.

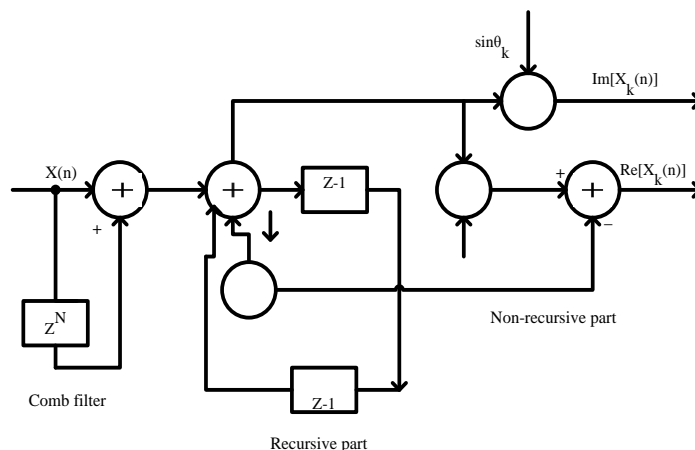


Fig.4. Structure of SDFT [33].

$$\text{Re}[H(z)] = \frac{1 - z^{-N} \left( \cos\left(\frac{2\pi k}{N}\right) - z^{-1} \right)}{1 - 2 \cos\left(\frac{2\pi k}{N}\right) z^{-1} + z^{-2}} \quad (10)$$

$$\text{Im}[H(z)] = \frac{1 - z^{-N} \left( \sin\left(\frac{2\pi k}{N}\right) \right)}{1 - 2 \cos\left(\frac{2\pi k}{N}\right) z^{-1} + z^{-2}} \quad (11)$$

In the above equation, SDFT of real and imaginary parts can be generated using comb filter  $(1-z^{-N})$  and resonator. The schematic diagram of SDFT is shown in Fig. 4 [33].

IV. CONTROL METHODS IN MICROGRIDS

In [34, 35] repetitive controller is a simple learning control method which maintains low total harmonic distortion (THD) in load voltage and grid current. Also, it reaches smooth and continuous transfer of operation mode. In [58], the multilevel inverter is used to enhance the quality of voltage waveform with lower THD. Fig. 5 [36], represents the simplified diagram of a repetitive controller.

Harmonic droop control strategy [37] is performed for every individual harmonic, which maintains the difficulty in the reactive power at the different frequencies. Fig. 6 shows that the  $h^{\text{th}}$  harmonic droop control. The  $h^{\text{th}}$  harmonic frequency should be set as the frequency set point.

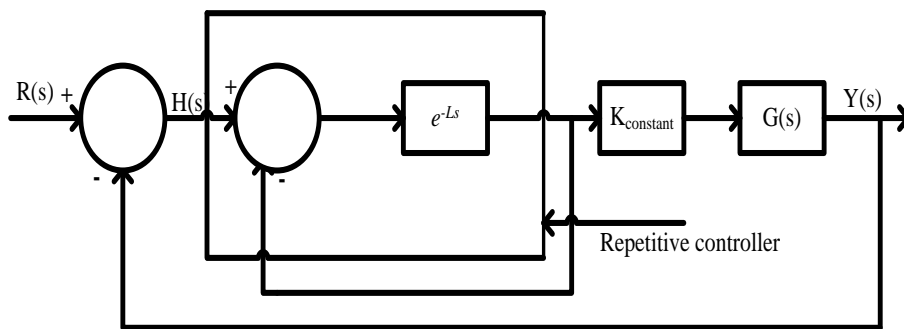


Fig.5. Repetitive controller [36].

The harmonic droop controller equation can be written as,

$$E_h = -n_h P_h \quad (12)$$

$$\omega_h = h\omega^* - m_h Q_h \quad (13)$$

where,  $P_h$  is the real power and  $Q_h$  is the reactive power for  $h^{\text{th}}$  harmonic frequency and  $n_h, m_h$  are the droop

coefficients. The RMS value  $E_h$  and phase angle to be formed by the  $h^{\text{th}}$  harmonic frequency at the reference voltage  $V_{rh}$  generated from the combination of  $\omega_h$ . Harmonic frequency  $\omega_h$  from equation (13) can be combined to  $-m_h n_h$  from  $\omega_{ht}$  with adding the  $\delta_h$ , where  $\omega_t$  phase of the voltage reference. It does not depend on the impedance of the output voltage but may also include resistive, inductive, capacitive or complex.

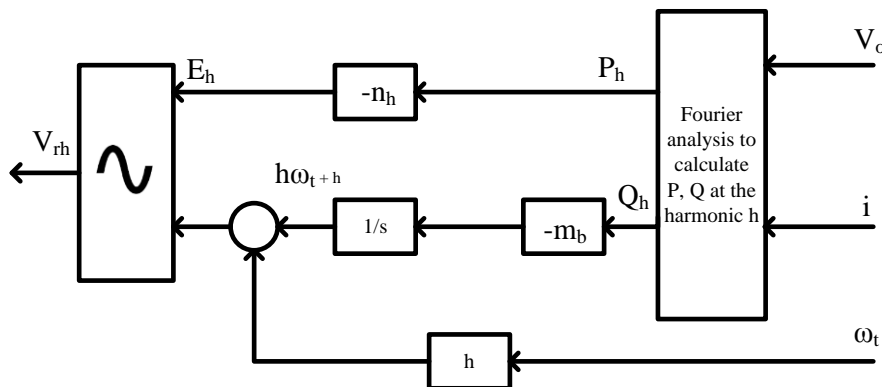


Fig.6. Harmonic droop control [37].

Generally, Adaptive virtual impedance control method [38, 39] is the power flow control method in low voltage distribution grids. Fig.7 shows the basic arrangement of the adaptive virtual impedance control used to extract the

positive and negative sequence at harmonic components. The positive sequence component and other current components cause for the resistive – inductive structure and resistive – capacitive virtual impedance and this

performance of droop controllers is to exalt by the resistive – inductive virtual impedance. The resistive – capacitive blocks provide proper sharing of load current among inverters of negative sequence and harmonic components. Actually, the resistive element improves damping of the system and inductive parts have

decoupled real and reactive power [40]. In the low voltage distribution grid, droop controlled voltage source converter and reactive power sharing can increase the efficiency [39]. An important purpose of virtual impedance is the compensation of harmonics which can reduce the harmonics in the grid voltage.

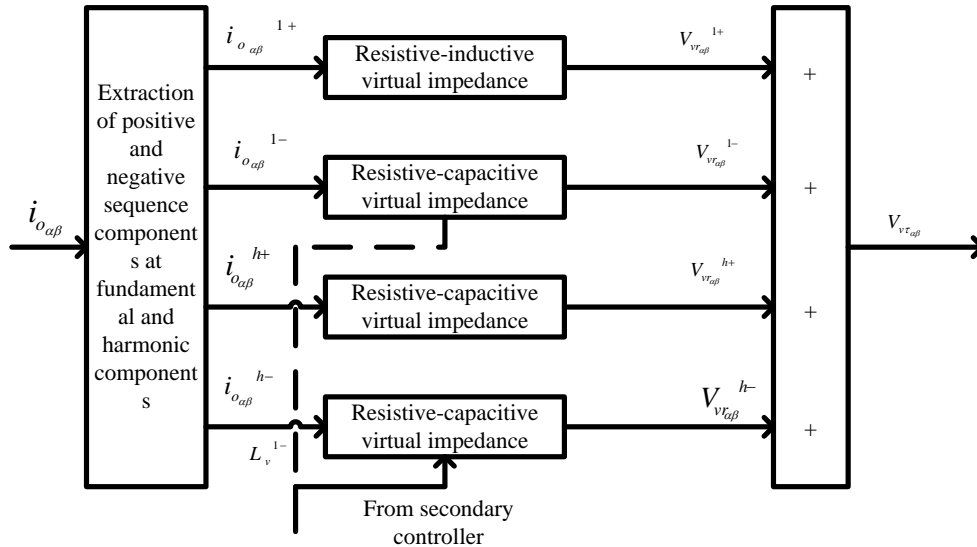


Fig.7. Adaptive virtual impedance.

The voltage controllers [41] adjust the inverter output voltage and it locates to the current controller. Proportional-integral (PI) controller, two degrees of freedom (2DOF) controller, resonant controller, hierarchical control, and repetitive controller are the several controllers used in the voltage controller design. The output voltages of the harmonic distortion while inverter supplies linear and non-linear loads are reduced by using these controllers. The parallel operation of inverters voltage droop control the power angle depends on active power and voltage difference on the reactive power [42].

$$f - f_0 = K_p (P - P_0) \quad (14)$$

$$V_s - V_0 = -K_q (Q - Q_0) \quad (15)$$

In PI voltage control, the system response minimizes the steady-state error with its integral action. The two degree of freedom controller deals with the system deviation and reference variation. The major advantage of this technique is greater robustness. Hierarchical [43] control scheme is a common microgrid which consists of a primary and secondary control level. The DG local

controllers act as the primary control and the central controller acts as the secondary control. This controller sends the reference signal to every DG's properly to reduce the voltage unbalance and harmonic distortion at the microgrid.

In [44], decoupling control scheme is suggested an electric spring (ES) in a microgrid is utilized for the active and reactive power flow control with variable and uncertain renewable energy. By adjusting the shift angle and amplitude of the modulation signal of the ES, the voltage dip and frequency deviation are improved. Integrated power quality controller (IPQC) [45] installed at PCC of the microgrid is recommended to reduce the voltage fluctuation, harmonic high penetration, bi-directional power flow and over current. To improve the source impedance to harmonics for the reason that primary winding shows the high impedance to harmonic also acts as a harmonic isolator. In literature [36], the resonant controller is based on the internal mode principle. It can be expressed as,

$$C(s) = \frac{K_1 \omega_0}{s^2} + \omega_0^2 \quad (16)$$

Table 4. Comparison of control techniques utilized in Microgrid Inverters

Author	Ref.no	Year	Control	Merits	Demerits
Mario Herrán A et al.	35	2014	Repetitive control	<ul style="list-style-type: none"> <li>➤ Simple and efficient learning algorithm.</li> <li>➤ It enables rejection of signals with the high harmonic.</li> </ul>	<ul style="list-style-type: none"> <li>➤ High current distortion can show with small frequency changes.</li> <li>➤ Computational cost is high.</li> </ul>
Qing-Chang Zhong et al, Jinwei He et al.	37, 38	2013, 2015	Harmonic droop control	<ul style="list-style-type: none"> <li>➤ Power sharing and droop control must be reduced an individual harmonic frequency.</li> <li>➤ It avoids the complexity of calculating the reactive power.</li> </ul>	<ul style="list-style-type: none"> <li>➤ It may cause some stability problems.</li> </ul>
Jinwei He et al.	38,46	2015, 2013	Adaptive virtual impedance control	<ul style="list-style-type: none"> <li>➤ In the steady state condition, reactive power of microgrid, power imbalance, harmonic power sharing should be compensated.</li> <li>➤ It reduces noises to the DG units.</li> </ul>	<ul style="list-style-type: none"> <li>➤ Total reactive power demand has some variation during the compensation of harmonic power sharing error.</li> </ul>
Mehdi Savaghebi et al, Jinwei He et al.	43,47	2012, 2015	Voltage control method	<ul style="list-style-type: none"> <li>➤ Less harmonic distortion than the current injected control.</li> <li>➤ Regulates DG unit when feeder impedance depends on virtual impedance.</li> </ul>	<ul style="list-style-type: none"> <li>➤ Sufficient damping to system resonance is not provided.</li> </ul>
Quoc- Nam Trinh et al.	48	2014	Hysteresis control method	<ul style="list-style-type: none"> <li>➤ Simple structure.</li> <li>➤ Fast response.</li> </ul>	<ul style="list-style-type: none"> <li>➤ Switching noises in supply current and load voltage is generated due to the variation of frequency.</li> <li>➤ Control performance is limited.</li> </ul>
Jiefeng Hu et al, Ali Bidram et al.	49,50	2014, 2012	Virtual flux droop control method	<ul style="list-style-type: none"> <li>➤ It can achieve independent power sharing.</li> <li>➤ Simple control structure and without multi – feedback loops.</li> <li>➤ Frequency deviation is lower than the conventional voltage droop.</li> </ul>	<ul style="list-style-type: none"> <li>➤ Cannot handle nonlinear loads.</li> <li>➤ Voltage regulation is not surely supported.</li> </ul>
Mohammad S. Golsorkhi et al.	72	2016	Model predictive control	<ul style="list-style-type: none"> <li>➤ It can improve the power quality by the voltage unbalance limits should be below 2%.</li> <li>➤ Current harmonics should be eliminated.</li> </ul>	<ul style="list-style-type: none"> <li>➤ During high loading condition active power and current overloaded could be prevented.</li> </ul>

## V. OPTIMIZATION TECHNIQUES IN MICROGRID

In real-time, the optimization problem in a microgrid is a complicated concern. The system securities, optimal operation, and reduction of emission are the wide range of microgrid control that needs from one operating mode to other without violating system constraints [83]. The essential characteristics of microgrids are as follows:

In islanding mode of operation, the power quality and stability should be maintained and it requires improvement of control approach which needs to be both generation and distribution side.

Voltage and frequency control problems formed by the transitions from original operation to islanding mode of operation [51]. A brief overview of some of these optimization techniques is shown in table 5.

Fen Tang et al [52], proposed a fundamental synchronization control (FSC) and distortion synchronization control (DSC) algorithms acts as a distributed actuators. In islanded mode, current controlled mode (CCM) and voltage controlled mode (VCM) voltage source converters are used for distributed storage (DS) provides power balance and voltage support. During distorted and unbalanced voltage conditions DSC algorithm is used to achieve a smooth reconnection. The



important advantage of active synchronization is the simple design of parameters which include PLL structure. So, the voltage normalization is feasible.

Ali Maknouninejad et al [42] presented the cooperative distributed optimization to the DGs VAR generation control in a microgrid. The objective of this technique is to minimize the total voltage across the microgrid. The minimization of cost function can be written as,

$$\sum_{i=1}^N f_i, f_i = \left(\frac{1}{2}\right)(1-V_i)^2 \quad (17)$$

The benefits of this optimization technique are the minimization of losses and unified voltage profile. Also, it is possible to determine the low active power losses and stability analysis.

Alessandra Parisio et al [53, 54] implemented a mixed integer linear programming (MILP), a model predictive control (MPC) approach of optimization in microgrid operation. MPC – MILP control economically optimizes the microgrid operation and computational burden by using commercial solvers without decomposition techniques. The application of MPC is to prediction models, operation and security constraints.

Saeed Jazebi et al [55], proposed a shuffled frog leaping algorithm (SFLA) and imperialist competitive algorithm (ICA) are used with discrete particle swarm optimization (DPSO).

Authors proved that the harmonic losses might be reduced after reconfiguration, whereas voltage and current deviation could be satisfied.

Yixi Zhu et al [56] developed a virtual impedance control to determine with the help of genetic algorithm (GA) optimized to reduce the reactive power sharing error. Also, DG units share the loads in MG network that is unbalanced power and harmonic power.

In literature [67], the performance of particle swarm optimization (PSO) algorithm is based on the evolution of particle and combination of the swarm. The equations of search rule with respect to position vector  $X_i$  and velocity vector  $V_i$  can be expressed by,

$$V_i^{k+1} = \omega V_i^k + c_1 r d_1 (X_p b_i^k - X_i^k) + c_2 r d_2 (X_g b^k - X_i^k) \quad (18)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (19)$$

$$\omega = \omega_{\max} - \frac{k \cdot (\omega_{\max} - \omega_{\min})}{N} \quad (20)$$

where  $c_1, c_2$  are positive constants;  $\omega$  is the weight of inertia;  $N$  is the total number of iterations; and  $X_p b_i^k, X_g b^k$  are the best positions based on its own experience. The optimal solution of search space near the boundaries should be difficult to shows the restrictions and limitations on the parameters. Therefore, the damped reflecting method is used to solve the optimal problem near the boundaries which is more consistent and robust [84, 85].

The designs of the inverter- output- controller

optimization have to be rejecting the variation of frequency and voltage disturbances in the microgrid. The principle of controller design should be stable under undisturbed closed-loop system and control of the inverter bandwidth should be a wide range of reference output power. The closed loop controller can be obtained as

$$\tilde{x}(t) = A_{cl} \tilde{x}(t) + B_{cl} \omega(t); \tilde{x}(0) = 0 \quad (21)$$

$$y(t) = C_{cl} \tilde{x}(t) + D_{cl} \omega(t) \quad (22)$$

In the stability criterion, closed loop poles are located in the left half plane which means the matrix  $A_{cl}$  must be Hurwitz. In closed loop system the eigenvalue of  $s$  plane is achieved by the controller criterion, also the convolution operator of  $L_1$  can be minimized by the performance criterion. The  $L_1$  theory of convolution operator can be expressed as

$$\|G\|_1 = \sup_{\omega \in L^\infty} \frac{\|y\|_{\infty, \infty}}{\|y\|_{\infty, 2}} \quad (23)$$

The above equation can be represented by reducing the frequency and voltage disturbances to control the current performance of the inverter.  $\|G\|_1$  has bounded that the closed loop controls system, if the stability criterion is satisfied. This PSO for the inverter controller techniques is only considered the PI controller parameters and it needed more improvement.

In the droop-controller optimization an operation of microgrid should be more efficient and stability of the output of DG control, the reason can be minimized an integrated error cost function with small signal steady state errors. In this optimization technique, the objective function of minimizing an error cost function is integrated time-weighted squared error (ITAE). The operating conditions of stability criterion can be considered as the three conditions such as grid-connected mode ( $J_1$ ), the transition period between grid-connected and islanded mode ( $J_2$ ) and islanded mode ( $J_3$ ). The equation of cost function can be expressed as

$$J = \sum_{i=1}^3 J_i = \sum_{i=1}^3 \left[ \sum_{k=k_0^i}^{k_f^i} [k - k_0^i] \cdot W \cdot |E^i(k)| \right] \quad (24)$$

where  $\tau$  is the performance of the control index,  $k$  is the sampling period,  $W$  is the matrix of the weighting element. The matrix of absolute error  $E^i(k)$  can be represented as,

$$E^i(k) = [\Delta_p^i(k), \Delta_Q^i(k), \Delta_{freq}^i(k)]^T \quad (25)$$

The measurements and references of real and reactive power error can be determined as  $\Delta P^i(k)$  and  $\Delta Q^i(k)$ ,  $\Delta V^i(k)$  is the voltage deviation and  $\Delta freq^i(k)$  is the frequency deviation from the per unit (p.u.) value. In this

technique normally, the p.u. value is 1.0 p.u. The parameters of actual droop control power sharing between DG's can be explained as

$$R_i = R_o \cdot r_i \tag{26}$$

$$M_i = M_o \cdot m_i \tag{27}$$

Therefore the power sharing between DG becomes the ratio of real power is 1/5:1/7 and ratio of reactive power are 1:1. The amount of power sharing between real and reactive power using droop controllers in a microgrid system should be quickly stable in nature.

In [68], optimization based on genetic algorithm (GA) was proposed to improve the stability and easily switching the operation of different modes in a microgrid. The dynamic performance of optimization objective function can be obtained as

$$\min J = \sum_{i=1}^M \left\{ \int_{t_o^i}^{t_f^i} (t-t_o^i) \left[ (P(t)-P^*(t))^2 + (Q(t)-Q^*(t))^2 \right] dt \right\} \tag{28}$$

where  $P(t)$ ,  $Q(t)$  are the real and reactive power in the various operation mode,  $M$  is the microgrid operation mode,  $t_o^i$  is the start time in  $i$  and  $t_f^i$  is end time in  $i$ . The characteristic of GA is global search, stochastic, adaptive and parallel applicable for solving the optimization problem in the nonlinear system. Control parameters for microgrid  $X = [m_p, n_q, K_{p_w}, K_{i_c}]$  which is affecting that small signal steady state stability and high sensitive performance also, control parameters can act as optimal variables. The flowchart of microgrid optimization of a genetic algorithm as shown in Fig.8.

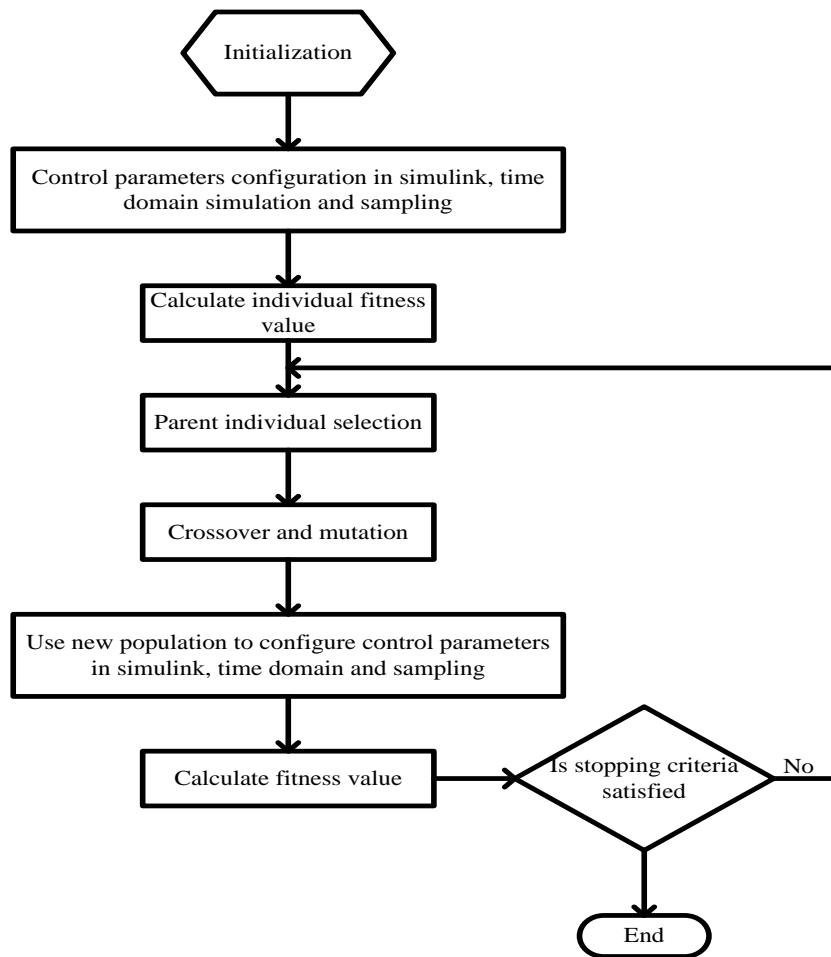


Fig.8. Flowchart of genetic algorithm optimization process.

In [69], consensus algorithm based distributed control methods for DC micro grids was proposed to attain the sharing of information and coordinate multiple distribution units. Consensus algorithm contains continuous control domain and discrete control domain, the model of continuous time (CT) has more accuracy and discrete time (DT) model can act as a digital

communication control network. The continuous and discrete time integrator of consensus algorithm can be expressed as,

$$\dot{x}_i(t) = \sum_{j \in N_i} a_{ij} \cdot (x_j(t) - x_i(t)) \tag{29}$$

$$x_i(k+1) = x_i(k) + \varepsilon \cdot \sum_{j \in N_i} a_{ij} \cdot (x_j(k) - x_i(k)) \quad (30)$$

where,  $N_i$  is the set of agents connected with  $i$ ,  $\varepsilon$  is the constant weight of the edge,  $a_{ij}$  is the connection between the node  $i$  and  $j$ . To conclude the features of control algorithm have more accuracy for sharing of current, the speed of the system should be a high response.

## VI. MICROGRID APPLICATIONS IN RENEWABLE ENERGY

The application of the AC-DC converter in the wind turbines is generally used in islanding operation of DC converters. The DC grid is constructed for both high voltage and low voltage that is called as LVDC grid, it requires regulation of voltage and power control process

should act as the load side control [70]. In DG wind turbine generator is significantly used in the wind power generation systems. In literature [71], the cause of wind speed variation is the fluctuations of power that can be affected by the frequency and voltage stability where the stability of the generated power fluctuation should be controlled by fast and robust methods. The improvement of real and reactive power has control by different approaches to transmitting the output power to the grid with energy storage system (ESS) solutions. The applications of wind power generation systems and hybrid renewable energy sources vanadium redox flow battery (VRB) based ESS systems were used in Australia and Japan. Low maintenance cost, quick response, high capacity is the major advantages of VRB.

Table 5. Optimization methods for power quality improvement in microgrid

References	Year of publication	Category of optimization	Method of optimization	Objectives
74	2013	PSO	Particle swarm optimization for control	To regulate the power sharing between the microgrid and utility under variable load conditions [74].
75	2013	PSO	Particle swarm optimization for frequency and voltage regulation	When the microgrid is operated in islanded condition harmonic distortion, voltage and frequency regulation, power sharing, steady state response and dynamic state response are the parameters could be optimized [75].
76	2010	PSO	Particle swarm optimization based PWM inverter	Using selective harmonic elimination (SHE) technique low order harmonics are eliminated [76].
77	2013	PSO	Particle swarm optimization for stability analysis	To achieve the stability of the microgrid using the minimization of power error based on PSO [77].
78	2016	GA	Non-dominated sorting genetic algorithm II (NSGA-II)	To protect the capability of the grid connected microgrid given by the demand response and to improve the voltage stability of the microgrid [78].
79	2016	HS+GA	Harmony search (HS) and genetic algorithm	To improve the voltage profile, reduction of power loss and increase the reliability based on HS via genetic algorithm [79].
68	2016	GA	Genetic algorithm	To achieve the stability of the microgrid [68]
69	2016	CA	Consensus algorithm	The objective of the consensus algorithm is to voltage restoration and accurate sharing of current in distributed generation [69].
80	2013	ACO	Ant colony optimization	When microgrid is operated in autonomous mode which maintains the voltage and frequency of the microgrid within the limits and minimize the THD [80]
55	2014	SFLA	Shuffled – frog leaping algorithm	To reduce harmonic losses [55].
81	2016	SFLA + FPD	Shuffled – frog leaping algorithm + Fuzzy pareto dominance	FPD and SFLA is used to solve the multi-objective optimization problem in distribution system. To minimize power loss, voltage sag and THD [81].
82	2013	MRGN	Modified recursive gauss newton algorithm	Minimization of error cost function between observed and estimated signal[82].

## VII. DISCUSSION AND FUTURE VISION

Some of the research opportunities in this area which will have an impact on power quality issues and renewable energy system are given below. The generated power from renewable energy sources will be utilized such as solar PV, the wind, battery energy storage system,

etc. should be extended possible [86]. The droop control techniques are based on the measurement of state variable networks. These state variables are mainly used to distribute the distributed generation because they avoid the dangerous communication link [87]. In the overall review, adaptive droop control method provides better sharing of reactive power and voltage regulation. The control strategies of microgrid can be decided the issues

are mentioned by the various topics.

- Integration of RES: The performance of RES such as solar, wind, etc. with droop control methods has a poor response. But we can modify the existing droop control methods to improve the performance of the RES.
- Stability problem: Stability issues such as complex loads, pulsed loads cannot achieve by using the existing droop control methods. The modify droop control techniques should mitigate the problems such as voltage regulation, the frequency of complex loads.

### VIII. CONCLUSION

This paper presents a review on power quality impacts due to harmonic distortion in a microgrid. The current issues owing to the challenges in grid side power quality and microgrid control methods are discussed in this review. The merits and demerits of the controllers utilized in microgrid operation are discussed in detail. Intelligent optimization techniques to improve the microgrid control and operation are focused in detail. This review aims to throw light on the various control strategies available, the operation and performance of the control techniques and the optimization strategies available to improve the performance of control owing to the increasing need and growth of microgrids in future. A model predictive control could satisfy the power quality improvement such as voltage unbalance, total harmonic distortion, stability margin, dynamic performance of islanded microgrids. The heuristic optimization techniques such as PSO, GA, CA, MRGN algorithms are implemented to optimize the lifetime and to maximize the efficiency of the microgrid system. The shortcomings if the technical challenges in the review met will lead to accurate, self-sustained, and reliable quality future grid.

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