Mitigating Unbalance Using Distributed Network Reconfiguration Techniques in distributed power generation grids with services for Electric Vehicles: A Review

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Abstract

With rapid movement to combat climate change by reducing greenhouse gases, there is an increasing trend to use more electric vehicles (EVs) and renewable energy sources (RES). With more EVs integration into electricity grid, this raises many challenges for the distribution service operators (DSOs) to integrate such RES-based, distributed generation (DG) and EV-like distributed loads into distribution grids. Effective management of distribution network imbalance is one of the challenges. The distribution network reconfiguration (DNR) techniques are promising to address the issue of imbalance along with other techniques such as the optimal distributed generation placement and allocation (OPDGA) method. This paper presents a systematic and thorough review of DNR techniques for mitigating unbalance of distribution networks, based on papers published in peer-reviewed journals in the last three decades. It puts more focus on how the DNR techniques have been used to manage network imbalance due to distributed loads and DG units. To the best of our knowledge, this is the first attempt to review the research works in the field using DNR techniques to mitigate unbalanced distribution networks. Therefore, this paper will serve as a prime source of the guidance for mitigating network imbalance using the DNR techniques to the new researchers in this field.

Key words: distribution network reconfiguration, phase swapping, unbalance mitigation, electric vehicles (EVs), distributed generation (DG), optimization method.

Highlights:

- Distribution network reconfiguration techniques (distribution feeder reconfiguration, and distribution phase balancing) have been explored in detail.
- Different unbalance indices for mitigating unbalance has been discussed.
- Optimization methods for unbalance mitigation with different objective functions have been surveyed.

1. Introduction

The power system consists of generation, transmission and distribution systems, where the various types of consumer loads connect to distribution systems. The utility providers need to maintain power quality to ensure stable power supply to the consumers. The traditional power system was designed and built for the centralised electricity generation, predominately based on fossil fuels. The electricity demand is increasing day by day, and to meet this growing demand, different energy sources (coal, natural gas, oil, and nuclear energy) are used extensively to generate power. The excessive use of fossil fuel energy sources in the field of electricity production and transport industries is increasing greenhouse gas emission. With advances in technology since the early 21st century, renewable energy sources (RES) such as solar and wind energy have been widely adopted and the penetration of RESs into the power system has increased significantly. The use of technology to distribute RESs such as rooftop solar photovoltaics (PV) panels will continue to increase in years to come. In the broad sense, distributed generation (DG) systems, also known as decentralized generation, embedded generation, or dispersed generation, are small generation units installed at low voltage (LV) distribution grids close to the end users of power. These systems can be powered by both renewable and non-renewable sources (Ackermann, Andersson & Söder 2001; Hadjsaid, Canard & Dumas 1999; Lopes et al. 2007; Pepermans et al. 2005). The distribution network (known as power or utility grids in the traditional power systems), faces more and more pressure to accommodate for an increase of DG systems The typical Power system is as shown in Fig.1.

In the modern world, most loads are single phase nonlinear electronic loads, used in equipment such as air conditioners, switching power supplies, electronic lighting ballasts, and photocopy machines, which are connected through Δ-Y distribution transformers in three-phase four-wire (3P3W3P4W) distribution systems. In a 3P4W distribution system, unequal distribution of loads and PV sources generate a zero sequence current, which also flows through the neutral line (Alam, Muttaqi & Sutanto 2015). Voltage imbalance reduces available capacity due to increased neutral current, higher voltage drops and decreased utilization of network assets, which increases reinforcement cost (Gray & Morsi 2016a; Ma, Li & Li 2016; Sadeghi & Kalantar 2015).

Since DGs have a smaller unit sizes (Ackermann, Andersson & Söder 2001; El-Khattam & Salama 2004; Lopes et al. 2007; Pepermans et al. 2005) and require less area for installation. It is easy to set up DG units especially small scale PV roof-top units and wind turbines. The increasing penetration of DG units into power systems, encourages transport engineers to develop more electric vehicles (EVs) to reduce greenhouse gas emission. The authors in (AGENCY 2017) report that 12 million electric vehicles have been sold and estimated sales will increase by 200 million in 2030. Apart from being distributed loads, PVs can be energy storage units which can discharge While EVs function as distributed loads, they can also act as energy storage units, to discharge electricity to the local load or utility grids as a special kind of DG.

Integration of DG units into low-voltage distribution grids combined with ever increasing loads such as air conditioning devices and unconventional loads (e.g. EV charging loads), raises several issues. (i) DG units and large loads like EVs are connected to a distribution grid rather than the transmission grid and induce three-phase voltage imbalance at LV distribution grids. The distribution service operators (DSOs) have not been concerned with system unbalancing due to difficulty in monitoring real-time load [1]. (ii) Unplanned DG placement and dispatch per node or bus increases network imbalance (Chua et al. 2011; Ruiz-Rodriguez, Hernández & Jurado

2015; Tanabe et al. 2008). (iii) Unequal EV load distribution among the three phases, causes imbalance in LV distribution systems. (iv) EVs are connected to LV distribution grids either as a charging load or acts as a distributed generation source (discharging mode) and uncontrolled EV charging or discharging increases imbalance in LV distribution grids (Jiménez & García 2012; Klayklueng & Dechanupaprittha 2014; Möller, Meyer & Radauer 2016; Putrus et al. 2009; Shahnia et al. 2011).

With the installation of more and more DGs and an increasing number of unconventional loads (e.g. EV charging loads) connected to power systems, the above-mentioned issues must be addressed appropriately to enable practical use of DGs and adoption of EVs. The central issue is the imbalance of distribution networks caused by various factors, including DG units and EVs. The impacts of such imbalance is profound. Following are some examples of significant impacts of unbalance in a distribution grid:

a) Increased network congestion, decreased hosting capacity and reduced power supplying capability at peak load periods.
b) Reduced node voltage and generated harmonics (Liew 1989).
c) Larger DG sizes are required to host unbalanced loads than balanced loads (Hintz, Prasanna & Rajashekara 2016).
d) Unwanted pulsation by unbalanced inductive loads, which creates noise, vibration and malfunction of protective relays.
e) Neutral lines require a larger capacity size than usual due to the overrated current flows caused by system imbalance (Gruzs 1989).
f) Higher neutral to ground voltages (NGV) than standard ratings, which occurs in an ineffectively grounded power system due to asymmetry in distributed parameters and resonance between the distribution capacitance and the Peterson coil ('IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems - Redline' 2007; Alam, Muttaqi & Sutanto 2013).
g) Power-line communication interference (Park et al. 2009).
h) Increased distribution loss, transformer loss through overheating and reduced overall system efficiency (Fukami et al. 2002; Zhang et al. 2013).
i) Increased overall power system operation and maintenance costs (Swapna & Udaykumar 2016).

These impacts demonstrate that severe imbalance in distribution networks can cause deteriorations in power quality. The advent of the smart grid is a promising solution to make more intelligent and reliable distribution grids. The smart grid uses pre-post network information through extensive monitoring devices, communication, and control technologies to operate distribution grid efficiently. The induced smart monitoring system in the smart grid provides valuable information, such as various losses, voltage reduction, harmonic distortions, and levels of voltage imbalance to distribution service operators for analysing the power quality (Depuru, Wang & Devabhaktuni 2011). Therefore, it is highly desirable to mitigate these potential impacts of imbalance in a distribution network to ensure power quality. How to effectively improve power quality and mitigate such an imbalance, is a long-standing challenge research question. Much effort has been devoted to answer this question in the last decade. Table I summaries the review papers related to this research question.

It can be seen from Table I that there is no systematic review on distribution network reconfiguration techniques for mitigating imbalance in distribution networks or grids. Although these reviews touch on specific techniques that may be useful in mitigating imbalance effects in a distribution network, to the best of the author's knowledge, there is no review paper that focuses on mitigating imbalance of an unbalanced distribution grid using Distribution Network Reconfiguration (DNR) techniques. Therefore, this paper aims to bridge this gap by providing a review on imbalanced mitigation techniques based on DNR techniques for a distribution grid, integrated with or without DGs and EVs, to provide new researchers in the field with a holistic view of the available techniques.

The rest of this paper is organized as follows: Section 2 briefly presents the overview of techniques for minimizing the impacts of imbalance in a distribution network. Section 3 summaries the indices for measuring imbalance of a distribution network. Section 4 presents an overview of distribution network re-configuration techniques. Section 5 presents a review on DNR without DG units and EVs. Section 6 presents a review on DNR techniques with DG units and EVs. Section 7 presents a discussion and lists some recommendations. Section 8 concludes the paper and highlights some research gaps.

2. Overview of techniques to minimize impacts of imbalance in a distribution network

In the literature, many practical techniques have been proposed to minimize the impacts of imbalance in distribution networks. These techniques can be classified into two categories: the first category mitigates the network imbalance by incorporating special types of neutral current compensating devices, while the second category is a distribution network re-configuration (DNR) technique. The first category can be further classified into three approaches: (i) Increasing power rating capacity of equipment, (ii) Inducing passive filter or special transformers, and (iii) Installing purpose-built active power filters (APF). Table II lists the description, examples, related articles and drawback for each approach.

The second category can be further classified into two types: distribution feeder reconfiguration (DFR) and phase balancing. Distribution Feeder reconfiguration is a technique to alter the topological structure of the network by changing the candidate switching status (closing tie switches or opening sectionalizing switches) for achieving the desired objective, subject to network and operation constraints. The phase balancing technique alters the phase connection (known as phase swapping or load connection point changes) among phases, to mitigate network imbalance. Both DFR and phase balancing techniques are based on optimization problems modelled as non-linear, non-differentiable, highly combinatorial, and constrained.

Compared with the first category, the second category can reduce the total power loss, voltage or current imbalance and network reliability without procuring new equipment. Therefore, this paper will only consider the second category—the distribution network re-configuration techniques (DNR).

3. Unbalance Indices for measuring imbalance of a distribution network

Several researchers proposed various unbalance indices for analysing imbalance of a distribution system. These research works also showed that these imbalance indices played a vital role to improve power system planning and operations. In this section, a number of imbalance indices that are used for analysing and mitigating imbalance in a distribution network using DNR, are explained during further discussion on mitigating imbalance of a distribution network.

3.1. Load Balancing Index (LBI)

The load imbalance among feeders or overloading due to load variation will decrease a distribution system's efficiency. Overloading feeders and/or transformers increases power loss and decreases the lifetime of equipment. The Taiwan Power Company (Chang, Lee & Lin 2017; Hsu et al. 1993) initiates to mitigate imbalance of loads by reconfiguring the switching states (open/close) of distribution feeders or transformers, based on minimum values of the load error as shown in equations (1) and (2), respectively. Several research works (Dai-Seub, Chang-Suk & Hasegawa 1995; Jin-Cheng, Hsiao-Dong & Darling 1996; Kashem & Moghavvemi 1998; Kuo & Chao 2010; Lin 2003; Qin, Shirmohammadi & Liu 1997; Ravibabu, Venkatesh & Kumar 2008; Roytelman et al. 1996) have been carried out to reduce load imbalance in terms of load balancing index (LBI) as shown in equation (3), which is defined as the ratio of current flows through a branch to the rated current of that branch. The branch can be either a line section, a tie line with the sectionalizing switch or a transformer. Similar work (Babu, Kumar & Teja 2013; Babu et al. 2014; Babu et al. 2017; Ji et al. 2017; Nara, Mishima & Satoh 2003; Xiaoling et al. 2004; Yuehao et al. 2016; Zhou, Wang & Liu 2017) optimized the Load Balancing Index (LBI) as the feeder load balancing index at the system level. The feeder level LBI is shown in equation (4), where n is the number of primary feeders, Y_i is the normalized loading on the feeder (actual loading divided by the loading limit) and Y is the average of the normalized loadings Y_i.

$$\delta_{Load\_Transformer} = Load_{t\_ideal} - Load_{t\_actual} \qquad (1)$$

$$\delta_{Load\_feeder} = Load_{f\_ideal} - Load_{f\_actual} \qquad (2)$$

$$LBI = \Sigma_k \, j_k^{*} \, j_k \qquad (3)$$

Where $j_k = [\frac{I_k^{A}}{\left|I_{k\max}^{A}\right|}, \frac{I_k^{B}}{\left|I_{k\max}^{B}\right|}, \frac{I_k^{C}}{\left|I_{k\max}^{C}\right|}]$

$$LBI = \frac{1}{n}\sqrt{\sum_{i=1}^{n} (Y - Y_i)^2} \qquad (4)$$

3.2 Phase Unbalance Index (PUI)

Several researchers minimized load unbalance in terms of current between phases at the feeder level. Some work (Chia-Hung et al. 2005; Chitra & Neelaveni 2011; Dilek et al. 2001; Jinxiang, Mo-Yuen & Fan 1998; Nicolae, Siti & Jimoh 2009; Sathiskumar et al. 2012; Schweickardt, Alvarez & Casanova 2016; Singh, Misra & Mishra 2016; Ukil, Siti & Jordaan 2008; Ukil & Siti 2008) minimized current deviation between phases in terms of phase unbalance index (PUI), expressed in equation (5), where $I_{j,a}, I_{j,b}, I_{j,c}$ represents current loadings of phases *a*, *b*, and *c* at node j, respectively, and $I_{j,avg}$ represents the average phase current.

$$PUI_j = \min\left[\frac{\max\{\left|I_{j,a} - I_{j,avg}\right|, \left|I_{j,b} - I_{j,avg}\right|, \left|I_{j,c} - I_{j,avg}\right|\}}{I_{j,avg}}\right] \quad (5)$$

3.3 Unbalance Factors

Voltage and current unbalance is a major concern for distribution service operators (DSOs). The level of voltage and current unbalance are usually represented by the terms "voltage unbalance factor (VUF)" and "current unbalance factor (CUF)", respectively. The definition of the voltage unbalance factor used by different communities, is not consistent. The voltage unbalance (VU) is measured in terms of line voltages, as shown in equation (6) based on CIGRE report 1986 (Singh, Singh & Mitra 2007; Siti, Jimoh & Nicolae 2005). The "line voltage unbalance rate (LVUR)" based on NEMA MG1-1993 (Bina & Kashefi 2011) can be defined as the ratio of maximum deviation of line voltage to average voltage and average line voltage, as shown in equation (7). Similarly, the definition of "phase voltage unbalance rate (PVUR)" based on IEEE Std. 141-1993 (Bina & Kashefi 2011) considers phase voltages instead of line voltages as shown in equation (8). On the other hand, IEEE Std. 936-1987 (Bina & Kashefi 2011) defined PVUR as the ratio of deviation between the highest and lowest phase voltage magnitude and average phase voltage magnitude, as shown in equation (9).

The above definitions shown in equations (6)-(8) only considers voltage magnitudes, whereas the definition of voltage unbalance factor (VUF) based on IEEE Std. 1159-2009 considers both the magnitude and the phase displacement of the sequence components, as shown in equation (9). Most of the researchers (Abasi et al. 2018; Coppo et al. 2014; Farahani 2017; Klayklueng & Dechanupaprittha 2014; Knezović & Marinelli 2016; Nicolae & Jordaan 2013; Shahnia et al. 2011; Soltani, Rashidinejad & Abdollahi 2017) defined VUF as the ratio of negative sequence voltage to positive sequence voltage as shown in equation (10), whereas the definition of VUF including zero sequence component is also proposed in the literature (Meyer et al. 2011; Shahnia, Wolfs & Ghosh 2014), as shown in equation (11). The author (Chen, Yang & Yang 2013) examines the above definitions to find suitable indices to define voltage unbalance and recommended the voltage unbalance factor (VUF) as the "true definition" of the voltage unbalance. Different countries have their standard VUF values according to their accepted grid codes. Appendix A lists two tables A and B. Table A tabulates the standard VUF for several countries and Table B shows the power quality standards, specifically for Australia and New Zealand.

$$UB = \sqrt{\frac{1-\sqrt{3-6\lambda}}{1+\sqrt{3-6\lambda}}} \times 100$$

$$where, \lambda = \frac{V_{12}^4 + V_{23}^4 + V_{31}^4}{(V_{12}^2 + V_{23}^2 + V_{31}^2)^2} \quad (6)$$

V_{12}, V_{23}, V_{31} = Line voltage (rms values)

$$LVUR = \frac{\max\{\left|V_{ab} - V_{avg}\right|, \left|V_{bc} - V_{avg}\right|, \left|V_{ca} - V_{avg}\right|\}}{V_{avg}} \quad (7)$$

$$PVUR = \frac{\max\{\left|V_a - V_{avg}\right|, \left|V_b - V_{avg}\right|, \left|V_c - V_{avg}\right|\}}{V_{avg}} \quad (8)$$

$$PVUR_1 = \frac{\max\left(V_a, V_b, V_c\right) - \min\left(V_a, V_b, V_c\right)}{V_{avg}} \quad (9)$$

$$VUF = \frac{\left|V_-\right|}{\left|V_+\right|} \quad (10)$$

$$VUF_0 = \frac{\sqrt{\left|V_-\right|^2 + \left|V_0\right|^2}}{\left|V_+\right|} \quad (11)$$

3.4 Neutral current

Several studies (Abril 2010; Abril 2016; Hooshmand & Soltani 2012a; Hooshmand & Soltani 2012b; Soltani, Rashidinejad & Abdollahi 2017) considered the neutral current, as shown in equation (12) at the supporting feeder as an index of unbalance in a distribution network. The reduced neutral current at the supporting feeder results in a reduction of neutral currents of the network. The neutral current of an ideal balanced system is zero whereas neutral current I_N is a summation of three phase current (I_A, I_B, I_C) at the supporting feeder.

$$I_N = I_A + I_B + I_C \quad (12)$$

The LBI (load balancing index) was used to minimize the overloading effect of power systems' equipment in the 20th century (Hsu et al. 1993). The objective of using LBI was not only to reduce the overloading but also reduce the total power loss. The indices LBI was implemented through a distribution feeder reconfiguration technique using tie or sectionalizing switches by measuring the current of a line, or a branch or a transformer. The LBI mitigates imbalance on the system or network level by assuming loads are balanced among phases. Early in the 21st century, the increasing demand for energy in urban areas motivated academic and industry counterparts to investigate load imbalance among phases at the feeder level. Researchers used PUI (phase unbalance index) to balance loads among phases by measuring current at each phase. Distribution service operators (DSOs) used phase swapping technique to balance loads among phases based on the phase current index PUI. Both indices (LBI and PUI) use current to represent network imbalance. On the other hand, researchers have also used voltage to represent network imbalance, using line voltage unbalance rate (LVUR) and phase voltage unbalance rate (PVUR). Both indices (LVUR and PVUR) are commonly used to investigate the voltage unbalance of a network due to the simplicity of calculation (Chen, Yang & Yang 2013). The unbalancing indices mentioned above, are only considered the magnitude of voltage or current by ignoring the phase displacement. Therefore, the above-discussed indices do not completely represent the network imbalance. To consider both magnitude and phase displacement, the sequence components are considered to represent the unbalance index, Voltage Unbalance Factor (VUF) or Current Unbalance Factor (CUF). The unbalance factor indices are commonly used to investigate the unbalance at each point of common coupling (PCC) in the distribution grid. The increasing penetration of distributed renewable energy sources with electronic converters (such as single phase PV), electronic loads (such as LED lights, photocopy machines, and electric vehicles), and continuously changing single phase loads (which flow current at the neutral wire), may overload the neutral wire in a three-phase four-wire distribution system. The enormous amount of neutral current can be generated by a computer or switch-mode regulator-type loads, even though loads are balanced among phases in a three-phase four-wire distribution grid (Bansal, Bhatti & Kothari 2002). Consequently, the neutral current at the supporting feeder is also an important unbalance index to mitigate imbalance at the feeder level in a three-phase four-wire distribution network. It can be concluded that the unbalance index LBI, is used to reduce imbalance at the system or network level using the distribution feeder reconfiguration technique, whereas the phase balancing technique is used to minimize imbalance at the feeder level using PUI, unbalance factor, and the neutral current. The selection of unbalance indices depends on the control point (VUF at the node/PCC, neutral current at the supporting feeder level, and LBI at the system/network level), and the objective of utility planners or DSOs.

4. Distribution Network Reconfiguration Techniques

The distribution network reconfiguration (DNR) is an operational scheme to control the power flow from the substation to power consumers. Two types of distribution network reconfiguration (DNR) techniques are a) Distribution feeder reconfiguration, referred to as DFR and b) phase balancing. The benefits of the distribution reconfiguration technique are to minimize load imbalance, loss reduction, congestion management, and increase hosting capacity in normal conditions. Furthermore, the distribution network reconfiguration technique can also isolate faulted areas by maintaining continuity of power supply to non-faulted areas. Several researchers proposed distribution network reconfiguration techniques for either mitigating load imbalance (Babu, Kumar & Teja 2013; Babu et al. 2014; Yuehao et al. 2016) or achieving objectives of minimizing both load imbalance and power loss (Dai-Seub, Chang-Suk & Hasegawa 1995; Jin-Cheng, Hsiao-Dong & Darling 1996; Kashem, Ganapathy & Jasmon 1999; Kashem & Moghavvemi 1998; Nara, Mishima & Satoh 2003). The study (Chua et al. 2011; Jiménez & García 2012; Möller, Meyer & Radauer 2016; Putrus et al. 2009; Ruiz-Rodriguez, Hernández & Jurado 2015; Tanabe et al. 2008) shows that DG and EV penetration into a distribution grid increases networks' imbalance. The research work (Ch, Goswami & Chatterjee 2016) proposed simultaneous implementation of distribution network reconfiguration technique and optimal DG allocation (OPDGA) for network imbalance mitigation and power loss reduction. Furthermore, recent research articles (Farahani 2017; Klayklueng & Dechanupaprittha 2014; Liao & Yang 2018; Qiao & Yang 2016; Rodriguez-Calvo, Cossent & Frías 2017; Shahnia et al. 2011; Uriarte & Hebner 2014) paid attention to mitigate unbalance using distribution network reconfiguration technique in a DG-EV penetrated distribution grid. In the following subsections, these two types of DNR techniques are discussed without consideration of whether DGs and/or EVs are involved.

4.1 Distribution Feeder Reconfiguration (DFR)

The usual distribution systems operate in a radial configuration. Various control and protection devices are connected and assume a radial configuration. A distribution system usually consists of several buses, branch elements, controllers, protection devices and switches. The distribution feeder reconfiguration (DFR) technique optimizes the status (open or close) of sectionalizing and tie switches by transferring loads from overloaded feeders to light loaded feeders to minimize load imbalance and maintain a radial configuration. The DFR technique is implemented by closing required tie switches (normally an open switch), and opening required sectionalizing switches (normally a closed switch) to change the status of switches and reconfigure the topology of the distribution system during normal and fault conditions to achieve the desired goals. Fig. 2 shows a three feeder system with an open or closed switch for reconfiguration.

Many researchers (Dai-Seub, Chang-Suk & Hasegawa 1995; Fu-Yuan & Men-Shen 2005; Jin-Cheng, Hsiao-Dong & Darling 1996; Kashem, Ganapathy & Jasmon 1999; Siti, Jimoh & Nicolae 2005; Zou et al. 2011) used the DFR technology to mitigate load imbalance by minimizing the total power loss of the network. Several literature studies used load balancing index (LBI) by balancing feeder loads (Babu, Kumar & Teja 2013; Babu et al. 2014; Dai-Seub, Chang-Suk & Hasegawa 1995; Fu-Yuan & Men-Shen 2005; Hsu et al. 1993; Jin-Cheng, Hsiao-Dong & Darling 1996; Kaboodi et al. 2014; Kashem & Moghavvemi 1998; Lin 2003; Nara, Mishima & Satoh 2003; Qin, Shirmohammadi & Liu 1997; Ravibabu, Venkatesh & Kumar 2008; Roytelman et al. 1996; Xiaoling et al. 2004; Yu-Lung et al. 2004; Yuehao et al. 2016; Zou et al. 2011) and transformer loads (Dai-Seub, Chang-Suk & Hasegawa 1995; Hsu et al. 1993; Jin-Cheng, Hsiao-Dong & Darling 1996; Lin 2003; Qin, Shirmohammadi & Liu 1997) using the DFR technology. The DFR technique (Ji et al. 2017; Qiao & Yang 2016; Tanabe et al. 2008; Tolabi et al. 2014) is also used to minimize imbalance in a DG and EV penetrated unbalanced distribution grid.

The DFR technology is a feasible and popular technique to both academia and industrial communities for maintaining the operation of a radial network. The optimal DFR technique can play a vital role by mitigating load imbalance which improves voltage profile, reduce power loss and quick restoration during the fault.

4.2 Phase Balancing:

Most researchers minimized feeder imbalance but do not consider phase imbalance. Although the feeder reconfiguration techniques can mitigate unbalance at the system level, they cannot mitigate phase imbalance significantly at the feeder level (Hsu et al. 1993). The time-varying characteristics of loads and sources, uneven distribution of single phase distributed sources and loads make the feeder often unbalanced. Phase balancing is a technique to minimize imbalance between three phases in a distribution system. Phase balancing is implemented in two ways: (1) phase swapping or phase re-sequencing and (2) reconfiguring loads among phases.

Phase swapping or phase re-sequencing is an efficient way to re-sequence phases for balancing loads at the feeder. Most researchers (Chia-Hung et al. 2005; Dilek et al. 2001; Huang et al. 2008; Jinxiang, Mo-Yuen & Fan 1998; Kashem, Ganapathy & Jasmon 2000; Knolseisen & Coelho 2004; Knolseisen et al. 2003; Kuo & Chao 2010; Lin et al. 2008; Sathiskumar et al. 2012; Soltani, Rashidinejad & Abdollahi 2017; Tsai-Hsiang & Jeng-Tyan 2000; Whei-Min et al. 2000; Zhu, Bilbro & Mo-Yuen 1999) re-sequenced phases in low voltage (LV) distribution systems at each node or busbar. The phase re-sequencing can be carried out through various ways as shown in Table III. The authors of (Hooshmand & Soltani 2012b; Soltani, Rashidinejad & Abdollahi 2017) take special attention during phase re-sequencing by avoiding the reverse operation of inductive loads, such as motor loads. These studies only consider positive and negative phase sequences. If the existing phasing sequence is considered as {A, B, C} for three phases of the network, the positive phase sequence would be {B, C, A} and the negative sequence would be {C, A, B}. For the time being, the distribution operators have performed manual phase balancing, based on field measurement data and software analysis. The development of the supervisory control and data acquisition (SCADA) system enhanced opportunities for dynamic re-phasing (Soltani, Rashidinejad &

Abdollahi 2017) as shown in Fig. 3. The recent studies (Farahani 2017; Liao & Yang 2018; Meyer et al. 2011) for balancing electric vehicle loads among phases use phase balancing techniques.

Many researchers (Chitra & Neelaveni 2011; Mansani & Udaykumay 2016; Nicolae & Jordaan 2013; Shahnia, Wolfs & Ghosh 2014; Siti et al. 2007; Siti, Nicolae & Jimoh 2006; Ukil, Siti & Jordaan 2008; Ukil & Siti 2008) transferred loads from overloaded phase to light loaded phase using the current deviation between phases or the total power deviation between phases. These studies were undertaken with less number of loads, and assumed small scale distribution systems. The load switching procedure among phases (Shahnia, Wolfs & Ghosh 2014) is shown in Fig.4.

The load switches between phases require switches at the consumer end, whereas distribution service providers will install their switches at the node or bus in phase swapping or re-sequencing technology. The major concern of phase balancing using both techniques, is the number of switches. Although phase swapping requires fewer switches than the loads re-configured per phase method, the phase swapping technique becomes unsuitable for the large distribution system. By considering the limitation of the phase balancing approach, several research works were carried out to reduce the phase moving cost (Huang et al. 2008; Kashem, Ganapathy & Jasmon 2000; Knolseisen & Coelho 2004; Knolseisen et al. 2003; Whei-Min et al. 2000; Zhu, Bilbro & Mo-Yuen 1999) for manual implementation and to reduce the number of switching nodes or buses (Soltani, Rashidinejad & Abdollahi 2017) for dynamic phase re-configuration (DPR). The author (Gray & Morsi 2016b) studies the economic feasibility of dynamic phase reconfiguration technology in EV penetrated low voltage (LV) distribution grids. The economic analysis compares the cost of re-phasing devices (dynamic reconfiguration) and the labour cost, with the service interruption cost (manual reconfiguration). The study proves dynamic re-phasing is an economically efficient technology, compared with manual reconfiguration. These studies also show that the reduced number of switches or phase moves can reduce economic cost but have to sacrifice the performance of the network.

The authors in (Hooshmand & Soltani 2012a; Hooshmand & Soltani 2012b; Navarro, Cruz & Malquisto 2012) proposed implementation of both distribution feeder reconfiguration (DFR) and phase balancing technique simultaneously to minimize the cost of Distribution Network Reconfiguration (DNR). The simultaneous implementation of DFR and optimal DG allocation (OPDGA) technique is proposed in (Ch, Goswami & Chatterjee 2016; Taher & Karimi 2014) whereas sequential implementation of phase balancing, DFR and OPDGA technique is proposed in (Kaveh, Hooshmand & Madani 2018).

The DFR technique was used since 20th century by DSOs to manage demand-generation, mitigate overloading of feeders and transformers, minimize the impacts of faults, and schedule maintenance works in a certain area of a network (Hsu et al. 1993). Several researchers proposed the DFR technique to reduce the total power loss and network imbalance at the medium voltage (MV) and low voltage (LV) network. For two decades, distributed generation (DG) sources are integrated into the MV and LV network to reduce power loss and improve voltage profile. The determination of DGs integration, location and capacity is a challenging task for researchers to maintain stability, voltage profile, and reliability of the network due to time-varying load profile. Usually, the DFR technique is used together with the OPDGA technique to improve voltage profile, and reliability by managing the time-varying load profile.

On the other hand, rising time-varying single phase loads increase phase imbalance in the LV distribution grid, which is not accounted for the DFR technique. Phase imbalances increase power loss, decrease voltage profile and decrease hosting capacity in LV distribution grids. For this reason, researchers also suggested that EVs must be connected to the recommended phases during co-ordinated charging methods. To reduce phase imbalance, researchers also used phase balancing technique for mitigating imbalance, reducing power loss, and improving voltage profile. The phase balancing technique is implemented through two approaches (phase swapping and load switching among phases). The phase swapping approach requires a smaller number of switches than the load switching approach. Therefore, it is recommended that phase balancing using phase swapping approach is efficient in urban LV distribution networks, whereas the load switching approach is efficient in rural LV distribution networks.

5. Unbalance mitigation of a distribution system without DG and EV penetration based on Network Reconfiguration

5.1 Noteworthy Contribution using the Distribution Feeder Reconfiguration technique

In 1975, the author of work (A. Merlin Sept 1975) was the pioneer who proposed the distribution network reconfiguration (DNR) technique for loss minimization. DNR is a technique to alter the topological structure of the network by changing the candidate switching status (closing tie switches or opening sectionalizing switches) for achieving the desired objective, subject to network and operation constraints. In the beginning, several researchers identified that the reduction of the total power loss is closely correlated with load balancing and considered objectives of minimizing power loss and the load balancing index as a multi-objective function. The author of work (Jin-Cheng, Hsiao-Dong & Darling 1996) proposed a systematic iterative solution method for minimizing multi-objectives (the total power loss and load balancing indicator). The author investigated load balancing indicator, power loss and voltage profile with different loading levels of a large scale distribution grid, as shown in Table IV. Though the proposed method reduces power loss and load balancing indicator, voltage profile is not significantly improved.

The study (Kashem & Moghavvemi 1998) proposed the relationship between the load balancing index and the branch sum of the total real and reactive power. The author minimizes the load balancing index using the branch exchanged method. The proposed approach reduces both load imbalance and power loss of the distribution system. Another work (Kashem, Ganapathy & Jasmon 1999) includes the distance between branches into the branch exchanged method for minimizing load imbalance and the total power loss. The proposed distance measurement technique exchange branch is based on the lowest distance, and respective power flows from the centre of a circle. The proposed circle loop is calculated based on power flow and distance, as shown in equation (13).

$$\left[P'_m - \frac{A}{\sqrt{C}}\right]^2 + \left[Q'_m - \frac{B}{\sqrt{C}}\right]^2 = \frac{A^2 + B^2}{C} \qquad (13)$$

Where, A, B, C are constant for a particular loop.

The author of work (Dai-Seub, Chang-Suk & Hasegawa 1995) used a genetic algorithm for minimizing the load balancing index and total power loss. This study proposed Dynamic Parameter Modification (DPM) to control the search space of GA for optimizing the candidate switch and improves convergence speed compared with the classical GA. The author of work (Roytelman et al. 1996) suggests a multi-objective function with suitable weighting factor produces a better result than a single objective function. The phase unbalance index, including the total power loss, considers a multi-objective function (Nara, Mishima & Satoh 2003). This study proposed a criteria-based incremental algorithm for optimum candidate switch reconnection with improved objective function subject to the feeder, transformer capacity and voltage profile constraint. The performance of the incremental algorithm shows better performance than genetic algorithm and branch and bound methods (BB).

Several research works are carried out to minimize unbalance, but they only consider unbalance indices as a single objective function. The author of work (Ravibabu, Venkatesh & Kumar 2008; Zou et al. 2011) used GA optimization methods to minimize objective function LBI (load balancing index) with the optimized number of switching candidates, subject to maximum branch current constraint. Another evolutionary algorithm named particle swarm optimization (PSO) is used for mitigating load imbalance using the distribution feeder reconfiguration (DFR) technique, subject to the radial network structure and the standard bus voltage constraints (Xiaoling et al. 2004). The author of work (Kaboodi et al. 2014) proposed a modified particle swarm optimization (MPSO) algorithm with an interactive fuzzy method, to optimize the multi-objective function subject to network and standard voltage constraints. The multi-objective includes the total power loss, voltage deviation, and load balance. The MPSO algorithm with interactive fuzzy method reached the global optimum solution over other methods (GA, and PSO) and recommend an optimal switch configuration. The ant colony optimization (ACO) method in (Babu et al. 2014; Yuehao et al. 2016) is used to optimize the number of sectionalizing and tie switches for minimizing load balancing Index (LBI). The feeders are balanced by shifting partial loads from overloaded feeders to under loaded feeders using switches in radial network along with graph theory. This study proposed several combinations of candidate switches (open or closed status) to obtain different LBI values. The proposed combinations of feeder switches show the lowest LBI value less than (Civanlar et al. 1988; Ravibabu, Venkatesh & Kumar 2008) . Another study (Babu, Kumar & Teja 2013) proposed a new heuristic search methodology using direct simulation of operator procedures as part of the search process (depth-first search) to minimize LBI. This approach also shows improved performance over those proposed in (Civanlar et al. 1988; Ravibabu, Venkatesh & Kumar 2008). The authors in (Babu et al. 2017; Yu-Lung et al. 2004) presented a methodology to minimize feeders' and transformers' load imbalance by optimizing switching candidates to mitigate loading unbalance using Colored Petri Net (CPN) optimization algorithm. The study (Lin 2003) proposed a heuristic rule-based coloured petri-net algorithm to minimize imbalance. The rules have the pick-up and disconnection stage. The proposed technique decides optimum switching candidates for reducing overload contingency and seasonal load imbalance of Taipower distribution system. This study considers Load balancing index for the transformer as shown in equation (12) and feeder as shown in equation (13) subject to constraints i) deviation of voltage drop and bus voltage fluctuation less than $\pm 10\%$ and ii) neutral current not more than 40 A. The work (Yin & Lu 2009) has carried out financial studies of the Distribution Feeder reconfiguration (DFR) technique. This study optimized the number of feeder switches to achieve multi-objective (the total feeder power loss, total line power loss, and feeder switching cost) considering time-varying seasonal load profile using a binary particle swarm optimization method. This study minimizes the number of feeder switches based on historical seasonal load profile. This study suggests that the feeder changing process should implement 11 times in a year and shows the proposed approach will reduce operating cost by 33%.

5.2 Noteworthy Contribution using the Phase Balancing Technique

In 1997, the phase balancing technique also known as re-phasing/phase reconfiguration technique was introduced by the author of work (Jinxiang, Mo-Yuen & Fan 1998) to minimize the phase unbalance indices (PUI) through a linear objective function using a mixed-integer programming method. The author of work (Kashem, Ganapathy & Jasmon 2000; Zhu, Bilbro & Mo-Yuen 1999) expressed the phase balancing problem as a non-linear integer problem and the phase balancing problem cannot be expressed well as a linear problem. This study optimized the phase unbalance index using the simulated annealing method (SA). Though this study compares the performance of the SA method with the Greedy Algorithm and Quenching Algorithm, the SA algorithm requires higher computational time. Several researchers (Chia-Hung et al. 2005; Dilek et al. 2001) used heuristic algorithms to optimize phase balancing problems. The author of work (Dilek et al. 2001) proposed a heuristic approach to minimize current deviation among phases using phase moves. This study investigates seasonal imbalance and improves imbalance and power loss subject to the maximum number of allowable phase to reduce phase moving cost. Another study (Chia-Hung et al. 2005) used the phase unbalance index (PUI) to mitigate load imbalance by re-phasing technique. The proposed technique using heuristic rules based Backtracking Search Algorithm is applied to a Taipower underground distribution system under conditions of system operation and fault contingency. This study not only mitigates imbalance but also prevents neutral current induced feeder tripping by reducing neutral current.

Later, several researchers paid attention to decrease computational time and optimize phase moves for phase balancing technique. In this regard, the evolutionary Genetic Algorithm (GA) (Tsai-Hsiang & Jeng-Tyan 2000) is used as an optimization method to minimize multi-objective (power loss, average voltage drop, total zero and negative sequence voltage) with the constraint of neutral to ground current of the respective transformer. This improves major key indicators of a distribution grid through phase swapping technology. The authors of work (Knolseisen & Coelho 2004; Knolseisen et al. 2003) used a GA optimization method with the mono-objective approach to minimize the number of phase moving. This study improves voltage drop along feeder, transformer unbalance, and power loss. The optimization of re-phasing cost using the GA is investigated by another study (Whei-Min et al. 2000). The aim of this study was to increase utilization of the open-wye or open-delta transformer in Taiwan distribution system through a re-phasing technique. The phase balancing is considered in this study by following several constraints (maximum branch current, percent voltage unbalance ratio and bus voltage magnitude, according to ANS/IEEE standard). The immune algorithm (IA) (Huang et al. 2008) is implemented to minimize multi-objective (the equivalent cost of neutral current, the labour cost and the customer service interruption cost (CIC)) subject to network and voltage constraints of the network. This study reconnects the laterals and distribution transformers based on optimized results which show the neutral current reduction from 113 A to 58 A as well as lower computational speed than those of the GA. An expert system (Lin et al. 2008) is implemented to achieve the phase balancing strategy by optimizing multi-objective goal (system power loss cost, the labour cost and the customer service interruption cost (CIC), subject to several constraints. This study considers the following constraints: 1) the heuristic rules of system planning and operation must comply, 2) the neutral current of distribution feeder has to be less than the low-energy overcurrent (LCO) relay setting after phase balancing, 3) the customer service interruption cost due to re-phasing work and the labour cost to perform the re-phasing must be justified by the reduction of a system's power loss. This study shows that the proposed method minimizes the neutral current during peak load and fault contingency, which improve the reliability of the distribution system. Self-adaptive Hybrid Differential Evolution (SaHDE) algorithm was proposed for optimum phase re-configuration in (Sathiskumar et al. 2012). The performance of the SaHDE algorithm for minimizing phase unbalance indices shows similar performance, but convergence speed is high compared to that of Differential Evolution (DE) and Hybrid Differential Evolution (HDE) algorithm. The proposed approach reduces the phase unbalance indices (PUI) from 24.25% to 0.66% at 20 hr and shows significant improvement throughout the day. The non-dominated sorting Genetic Algorithm (NSGA-II) (Abril 2016) is implemented to optimize the multi-objective (neutral current, energy loss and the number of reconnection element) of a primary distribution grid using the re-phasing technique. The primary distribution system consists of two circuits in this study for investigating the proposed method. This study shows that the objective of neutral current minimization at several individual points shows better performance than the total neutral current minimization at the feeder of a distribution system. The result of this study enables DSOs to choose allowable phase re-configuration to compromise with the energy loss and the total neutral current of a distribution system. These studies consider manual re-phasing where the labour and service interruption costs are a burden for the DSOs.

The technical enhancement in the field of power system encourages researchers for investigating the performance of the dynamic re-phasing technique. The study (Gray & Morsi 2016b) compares the manual re-phasing cost and the dynamic re-phasing cost per year. The manual re-phasing cost includes the labour cost and revenue loss due to outage, whereas the dynamic re-phasing cost includes equipment (current sensor, static transfer switch with ZigBee receiver) cost and installation labour cost. The result shows dynamic re-phasing at any time throughout the year is cost efficient when compared with manual re-phasing (two times in a year). The authors of work (Kuo & Chao 2010) mitigate load imbalance considering the loading per phase for each transformer using phase swapping technique and also described the automatic data collection method. The authors used Tai-Power distribution automation pilot system (TDAPS), which has the automated mapping/facilities management/geographic information system (AM/FM/GIS) facilities. The network database (loadings per phase per transformer of a feeder, topological map and geographic information) is accounted to select efficient phasing patterns to minimize feeder or distribution loss (by assuming the total power loss is directly related to unbalance) and load deviation between each phase and average phase loadings. Though this study used automatic data collection facilities, the automatic re-phasing implementation is not applied. The authors of work (Soltani, Rashidinejad & Abdollahi 2017) proposed a dynamic phase balancing technique for mitigating the unbalance using the re-phasing switch at each node. This study assumes that the switches with the zigbee receiver were installed at each node and the switches operate, based on the optimized command. The author proposed a framework to determine candidate nodes for reducing computational and implementation time using modified shuffled frog leaping algorithm (MSFLA). The framework will be triggered if the supporting feeder has a neutral current larger than the threshold value and determine the sensitive nodes, which have larger VUF values than the threshold VUF value. The switch of those nodes will operate for balancing phases. This study also discusses another scenario assuming the junction points as the sensitive nodes from the graphical view of the network. The re-phasing approach not only mitigates unbalance but also reduces power loss.

Apart from the re-phasing technique, the phase can be balanced if loads are switched from overload phases to light loaded phases. The author of work (Siti, Jimoh & Nicolae 2005) used the combination of two numerical methods (The Gauss-Newton and Dynamic Leapfrog method) for minimizing power loss and line voltage unbalance. The load is distributed among phases through the load selector switch. When the Gauss-Newton method fails to solve the problem, the dynamic method solves the problem. In this way, computation speed is minimised. The objective of study (Ukil & Siti 2008) was to balance loads among phases if the average load (kW) per phase is above the threshold load (10 kW) considering the South African distribution grid. The load (kW) transfer among phases is determined using Fuzzy logic, and a combinatorial optimization method identifies the respective load points, which are required to transfer to the receiving phase.

Many studies (Chitra & Neelaveni 2011; Nicolae & Jordaan 2013; Siti et al. 2007; Siti, Nicolae & Jimoh 2006; Ukil, Siti & Jordaan 2008) balance loads among phases by phase unbalance index (PUI). The author (Siti et al. 2007; Siti, Nicolae & Jimoh 2006) proposed a heuristic rule-based neural network technique for load switching between phases to minimize load unbalances. This study limits the proposed method within 15 loads and proposes to distribute load groups (5 loads) to each phase, based on their current (A) magnitude difference. Another study (Ukil, Siti & Jordaan 2008) of this author proposed a method to reduce imbalance by minimizing the difference of phase currents compared to the reference current. The reference current is equal to one-third of the total load current. Here, the proposed method of the study searches for an optimum set of 5 loads at each phase so that each phase current is nearer to the reference current.

The author of work (Schweickardt, Alvarez & Casanova 2016) proposed an algorithm named fuzzy evolutionary particle swarm optimization (FEPSO) for minimizing the multi-objective function (the total power loss, voltage deviation, and phase current deviation compared to average current) to obtain optimal load distribution among phases. Multiple objectives were normalized and individual objectives were weighted differently, using the Fuzzy optimization method. The proposed algorithm modifies the weighting factor and adds a constriction factor to the classical PSO. The proposed FEPSO algorithm reduces more neutral current and power loss than PSO and SA methods. Furthermore, this algorithm converges faster than classical simulated annealing (SA) and PSO algorithms. The searching approach for an optimum set of loads requires higher computational time, and the study (Nicolae & Jordaan 2013) proposed a control algorithm of load switching from overload phase to underload phase. The proposed heuristic algorithm rank phases compared to the average phase load. The ranking is used to minimize the number of loads from the overload phases to light loaded phases, until current deviation is minimized. The study (Chitra & Neelaveni 2011) paid attention to minimize the number of load switching. The amount of load imbalance is calculated using fuzzy logic, if the threshold of current deviation between phase current and average phase current is more than 10A. The optimum load point's distribution per phase is optimized using the expert system with minimum load switching. The voltage unbalance factor (VUF) is minimized by load switching among phases in the research work (Shahnia, Wolfs & Ghosh 2014). The proposed algorithm compares the VUF value at any bus, with the threshold of allowable VUF value. If it finds any bus with a higher VUF value, loads are switched from overloaded phase to light loaded phase using the GA algorithm. This process repeats, until the VUF value at each bus is less than the desired VUF value. This study considers 30 houses with 10 nodes or bus, and the maximum VUF value decreased from 2.23% to 0.16%.

Load switching among phases requires additional switches that need to be connected at each load, whereas the re-phasing requires phase switches at each node. The main problem of the phase balancing technique is to minimize the number of switches. On the other hand, the distribution feeder reconfiguration technique ignores phase unbalance at the feeder level. The study (Hooshmand & Soltani 2012b) suggested distribution feeder reconfiguration in the meshed network and phase re-configuration at the radial network for mitigating unbalance. By accounting both problems raised by the feeder reconfiguration and phase balancing technique, the study (Hooshmand & Soltani 2012a; Navarro, Cruz & Malquisto 2012) proposed simultaneous implementation of optimized switching status (open or closed) to reconfigure the network and phase swapping for achieving the desired objectives. This study (Navarro, Cruz & Malquisto 2012) shows that a simultaneous implementation of the re-configuration and phase balancing technique using the GA, reduces power loss and current imbalance. Another study (Hooshmand & Soltani 2012a) considered a multi-objective (minimize power loss, neutral current, phase balance index and re-phasing costs) optimization function, subject to node voltage and maximum branch current capacity constraint. Multiple objectives were normalized through a fuzziffication method. The proposed method used a bacterial foraging- nelder mead (BF–NM) algorithm to obtain an optimum candidate switch for distribution feeder reconfiguration and the optimum number of nodes for re-phasing. This study also found that the BF–NM algorithm performed better than the BF, IA, PSO and GA algorithm, based on convergence speed.

The DNR technique is categorized and discussed in two subsections. The DFR technique mostly considers LBI unbalance index, whereas phase balancing considers unbalancing indices such as PUI, PVUR, and VUF. Moreover, the objective functions, constraints, and optimization methods for solving the DNR problem are discussed in this section. Though the DNR problem is solved using classic algorithms, including mixed-integer non-linear programming and exhaustive search. The Artificial Intelligent (AI) algorithms were found to be efficient in this field. The performance of nature-inspired algorithms (such as genetic algorithms, particle swarm optimization, and ant colony) are compared with physics or society inspired algorithms (such as simulated annealing and tabu search algorithm) for solving the DNR problem and found the efficacy of the natured inspired algorithms. To obtain an efficient solution, the performance of hybrid intelligent algorithms (such as hybrid bacterial foraging - spiral dynamic (BF-SD) algorithm, bacterial foraging-nelder mead (BF–NM) algorithm, heuristic search and expert system, fuzzy set based evolutionary algorithm) are compared. It can be recommended from the above discussion that the DFR at system/network level and phase balancing at the feeder level, that using a hybrid intelligent optimization algorithm would mitigate the systems' imbalance efficiently.

6. Unbalance mitigation of a distribution system with integrated DGs and EVs

Most of the studies that applied the optimal DG allocation (OPDGA) technique for reducing loss and increasing bus voltage, assumes a balanced system for simplifying computations. Whereas some research was conducted for the unbalanced distribution grid. Several studies have accessed the impact of DG integration on the network imbalance of a distribution system. The study (Tanabe et al. 2008) distributes DG's randomly at 12 nodes or buses in an unbalanced distribution grid, and each DG has equal capacity. The study shows that an increased DG size also increases unbalance, although it reduces the total power loss in an unbalanced distribution system. Another study assesses unbalance due to DG placement among phases. (Chua et al. 2011) . The study concludes that the value of the voltage unbalance factor (VUF) increases with an increased PV size, even though loads are balanced among phases. Another case study in [12], shows that the VUF value increases if all loads are in phase A and all PV integrated at phase B. The proposed stochastic assessment method (Ruiz-Rodriguez, Hernández & Jurado 2015) was used to assess voltage unbalance, due to increased penetration of single-phase PV units. This method considers time-varying load, location of the PV and the suitable size of PV in kW at different PV penetration levels. Furthermore, the method investigates the impact of these scenarios on voltage unbalance of a distribution grid in Spain. It is observed from the obtained results that increasing PV size induces unbalance if PV penetration is more than 15%. Both the PV size and PV penetration should be taken into consideration during voltage unbalance assessment.

The study (Tanabe et al. 2008) also used feeder reconfiguration technique for mitigating network imbalance. Authors optimize the candidate switch status (open or closed) for minimizing total power loss, voltage imbalance and current imbalance using a tabu search algorithm. Another work (Tolabi et al. 2014) investigated the performance of placement of different DG types (only active power or reactive power dispatch, both active and reactive power dispatch, active power dispatch but consume reactive power) and feeder switch reconfigurations for minimizing load imbalance, reducing the total power loss and increasing the bus voltage. The multi-objective is expressed as a fuzzified objective function and optimized using the bees algorithm. Several scenarios have been investigated, and the obtained results show that simultaneous placement of DGs (only active power dispatch) and reconfiguration using the proposed hybrid fuzzy- bees algorithm, mitigate the highest load imbalance. The author of work (Ji et al. 2017) converted the non-linear feeder reconfiguration problem to the second-order cone programming (SOCP) model. The enhanced SOCP model is used to minimize the multi-objective (the total power loss and load balance) of an IEEE 33 bus distribution system. The obtained results show that the enhanced SOCP model reduces 18.30% load imbalance and 39.10% power loss of the network.

The research works in (Ding & Loparo 2016; Umar, Firdaus & Penangsang 2016; Vítor & Vieira 2016) includes voltage or current imbalance with the total power loss in the multi-objective function and investigates the efficacy of the optimal placement and DG allocation (OPDGA) technique in an unbalanced distribution grid. The author of work (Umar, Firdaus & Penangsang 2016) used the optimal DG allocation (OPDGA) technique, and proposed to minimize power loss, voltage imbalance and harmonics within constraints values (balanced demand-generation, bus voltage, and total harmonic distortion) using a GA optimization method. Another study (Vítor & Vieira 2016) shows optimal DG placement and sizing for minimizing the line voltage unbalance rate (LVUR) and improving the bus voltage using GA. This study shows that LVUR is minimized from 7.15% to 6.17% after optimal DG placement, which does not show significant improvement. The obtained results of (Ch, Goswami & Chatterjee 2016) suggest that the best performance is achieved through the simultaneous placement of DGs, VAr sources and network reconfiguration. This proposed method in (Ch, Goswami & Chatterjee 2016) considers power quality indicators (the total power loss, harmonic distortion, unbalance and the voltage sag) as a multi-objective function and optimized the DG placement and reconfiguration problem using branch exchange method. The author of work (Taher & Karimi 2014) placed DG units at optimum nodes in an unbalanced distribution system (IEEE 25 node or bus) and optimized the candidate switch for network reconfiguration using the GA to mitigate voltage and current imbalance, improve voltage at different bus and reduce power loss. Though the proposed methodology improves the total power loss and voltage, the voltage and current imbalances are not minimized significantly. For real-time operation, the author of work (Zhai et al. 2018) proposed a dynamic network reconfiguration technique using the remote-controlled switch in an IEEE 34 node unbalanced distribution grid. The DG units are connected at Node 8 and Node 34. This study mitigates the imbalance by reconfiguring the optimized candidate switch status using the MILP (mixed integer linear programming) method at each hour. The dynamic reconfiguration shows that the total power loss and network imbalance are reduced at each hour by the following time-varying load profile.

The commonly used feeder reconfiguration has one well-known problem: it ignores the phase imbalance issues at the feeder level. The study (Kaveh, Hooshmand & Madani 2018) investigates the efficacy of sequential implementation of the phase balancing, optimal DG placement technique, and the feeder reconfiguration technique. The optimum nodes and phase sequence, optimum candidate switch status (open or closed) and optimum DG nodes are determined using the proposed hybrid bacterial foraging - spiral dynamic (BF-SD) algorithm with the minimum value of the multi-objective function (the total power loss, average voltage drop, neutral current of the feeder and re-phasing cost). The study considers three scenarios: 1) identifies candidate nodes and optimized phase sequence for phase balancing, 2) keeps the phase balancing (scenario 1) and identified optimum nodes for DG placement, and 3) keeps the phase balancing (scenario 1), DG nodes (scenario 2) and obtain candidate switch status (open or closed) for reconfiguration. The amount of neutral current is reduced from 220 A to 6 A using the phase balancing technique (scenario 1) whereas the amount of neutral current increases from 6 A to 7.99 A after DG placement (scenario 2). On the other hand, the proposed sequential implementation of phase balancing, optimal DG allocation (OPDGA), and feeder reconfiguration (scenario 3) reduces the neutral current from 7.99 A to 6.7 A. Scenario 3 reduced the total power losses and improved node voltage more than scenario 1 and 2.

With the increasing negative impacts of greenhouse gas emissions, climate change, and increasing fuel price; more and more people are considering electric vehicles (EVs) for their transport needs. The integration of EVs as a charging load into the low voltage (LV) distribution grid induces challenges for the distribution service operators (DSOs). Many studies (Jiménez & García 2012; Möller, Meyer & Radauer 2016; Putrus et al. 2009) investigates the impact of plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs) on distribution grids and observe that increasing penetration of EVs violates bus voltage limits and voltage imbalance. The study in (Shahnia et al. 2011) investigates the impact of EV charging locations on feeder imbalance and identified that EV penetration at the end of the feeder decreases imbalance more than EV penetrations at the beginning of the feeder. Correspondingly, another study in (Klayklueng & Dechanupaprittha 2014) investigates the phase balancing problem due to EV charging and observed that the EV integration in one phase (lack of planning) increases voltage imbalance by 3.44 times than random distribution of EVs among phases.

Both renewable energy sources-based DG's and EVs proliferation into the LV distribution grid is increasing day by day. The balancing of DG's power and EVs charging loads also pose a challenge for DSOs. The study (Uriarte & Hebner 2014) presents a technique of EV integration when a PV unit feeds power to the grid. This technique can reduce the power loss in distribution networks and improve a network's imbalance. The work in (Möller, Meyer & Radauer 2016) shows the integration of distributed PV units and EVs in LV grids increases voltage imbalance in distribution feeders and power imbalance at the transformers. The authors of (Rodriguez-Calvo, Cossent & Frías 2017) investigated the effect of PV and EV units at different unbalanced loading levels on energy loss and voltage profile of a distribution grid. Increasing penetration of PV solar power and the EVs' charging loads into LV distribution grids shows a higher degree of imbalance which violates voltage constraints, reduces network hosting capacity and increases energy losses. Another study (Uriarte & Hebner 2014) shows that incorporation of PV units and EVs in a distribution grid causes increased transformer over-loading, power losses, and current imbalance.

Several researchers used electric vehicles storage benefits through Vehicle to Grid (V2G) technology for mitigating unbalance, by injecting power to the respective phases. On the other hand, several researchers (Liao & Yang 2018) balance phases through co-ordinating the EV charging method. The study (Farahani 2017) proposed a method where EVs will take variable charging power and inject variable discharging power to a certain phase for solving phase imbalance problems. The evolutionary particle swarm optimization (PSO) algorithm is used to minimize the voltage unbalance factor. The solution of phase balancing in (Farahani 2017) suggests the optimal phase re-configuration and the amount of charging/discharging power for each EV. Another study (Qiao & Yang 2016) shows load balancing through a distribution feeder reconfiguration of an EV penetrated unbalanced distribution grid in the UK.

The rapidly growing penetration of EVs into the LV distribution grid can introduce overloading in the system, and the DFR technique can be used to balance loads of the network by relocating loads to another feeder in the network. The co-ordinated EV charging method is presented for mitigating imbalance at the feeder level through the time of use and optimal point of connection among phases (phase balancing), for respective EVs. It is observed from the above discussion that the DGs penetration into LV distribution grids increases network imbalance. Therefore, it can be recommended that the phase balancing technique for optimizing EV loads and DG sources would mitigate the network imbalance.

7. Discussion and Recommendation

Network imbalance is a challenging issue for the distributed power network which must be addressed for its reliable and secure operations. From the above discussion, it is observed that the increasing time-varying residential single-phase electronic loads such as LED lights, photocopy machines, air conditioner, and refrigerators induce imbalance into the LV distribution grid. The single-phase or three-phase converter-based intermittent DGs also contribute to produce networks' imbalance. The co-ordinated EV charging/discharging method is recommended for minimizing imbalance, but the research work (Xu & Chung 2014, 2015) shows that the uncertainty of EV users creates a significant risk when maintaining co-ordinated charging or discharging. Therefore, it is necessary to maintain the dynamic distribution network re-configuration in a distribution grid to mitigate network imbalance. From the work that was listed in Sections 3-6, it can be observed that the network imbalance problems have been tackled using various distribution network reconfiguration (DNR) techniques by solving optimization problems with different objectives and constraints, using different optimization methods. Table V shows the taxonomy of the reviewed work and summarizes the used objectives, unbalance indices, type of the DNR techniques, and methodologies for mitigating unbalance in the distribution grid.

Most of the research studies have been carried out using the unbalance index (LBI) with power loss since the 20th century. The unbalance index LBI is used to balance loads among feeders, whereas PUI is used to balance loads among phases. The unbalance factor (VUF/CUF) is introduced to represent a network's imbalance accurately, by considering both magnitude and phase displacement of voltage/current, whereas previously used indices (LBI, PUI, LVUR, PVUR, and VU) only considers the magnitude. Therefore, recent studies utilize the VUF and neutral current to represent networks' imbalances. Though most researchers use unbalance indices as a single objective function, several researchers recommend using the unbalance index with multi-objective functions such as reducing power or energy loss, voltage drop, and re-phasing cost. From the rigorous survey conducted in this paper, it can be summarized that unbalance indices are selected, based on the objective of DSOs. It can be recommended that minimizing multi-objective unbalance indices (VUF at the PCC, neutral current at the supporting feeder level, and LBI at the system or network level) would mitigate the network's imbalance efficiently.

The implementation of a distribution network reconfiguration (DNR) technique is economically cost-efficient, whereas the number of switches is the major concern for larger distribution systems. As the number of the switches increases, the system's cost and design complexities also increase. The phase balancing technique through phase swapping requires a smaller number of switches than loads switching among phases. It can be recommended to implement the DFR at the system or network level and the phase balancing technique at the feeder level simultaneously, to reduce the DNR cost in a distribution system.

The increasing penetration of inverter-fed DG units in distribution networks, worsens the imbalance problem in power systems. Several studies have recommended that the implementation of DNR techniques for mitigating imbalance is not an efficient solution for DG integrated distribution networks, whereas the simultaneous implementation of distribution network reconfiguration (DNR) and optimal DG allocation (OPDGA) technique is proven as an efficient method.

The network imbalance is increased severely, when an un-coordinated EV charging or discharging is employed. To mitigate this problem, coordinating EV charging and discharging are recommended by utilizing: a) time of use (ToU) tariff, and b) optimal EV connection among phases to balance them. However, it is challenging for EV users to maintain scheduled time, which causes un-optimal EV connection among phases, as well as an imbalanced demand generation. For this reason, it is recommended to use the DNR technique to re-sequence EV loads among phases in a DG-EV penetrated distribution grid.

Minimizing the unbalance indices (VUF at the PCC and the neutral current at the supporting feeder) is also advisable, using the simultaneous implementation of the DFR, phase swapping and OPDGA technique. This would be an efficient solution to mitigate the network imbalance in a higher penetrated DG-EV distribution grid. If the network has less EV penetration, the joint optimization of the EV load switching among phases and DGs dispatch can efficiently solve the network imbalance problem.

Although the Distribution Network Reconfiguration (DNR) approach has gained a lot of attention from researchers for optimizing power distribution systems, the gaps to improve the performance of DNR, based on previous research works still exists. These gaps are to:

- Compare the different reconfiguration techniques (Feeder reconfiguration, phase balancing through phase swapping or load switching among phases), and methodologies (simultaneous and sequential methodologies) based on performances and economic perspectives.
- Improve the operational performance, including network imbalance of dynamic distribution network reconfiguration technique considering load and generation uncertainty, fault condition, and communication failure etc.

- Compare the distribution network reconfiguration (DNR) technique with other unbalance mitigation technique based on cost and network imbalance.
- Apply distribution network re-configuration techniques with different types of voltage regulators, EV charging loads, distributed generation sources such as EV battery storage, combined heat and power (CHP) sources, PV solar, BES and wind plant etc. to improve the performance of the distribution system.
- Extend the distribution network reconfiguration (DNR) technique to improve stability and network imbalance of a DG-EV integrated distribution grid.

8. Conclusion

As the characteristics and nature of imbalance problems in modern power grids are changing due to the integration of new loads and generators, improved solutions are required to address this problem. The optimal balance of demand-generation among phases and feeders in a network is challenging to manage due to the uncertainty of EV user's, intermittent nature of DG sources, and frequently changing single-phase loads. Therefore, mitigating the network imbalance is still an emerging topic and needs an immediate solution. This paper has conducted a thorough review and compared the performance of available techniques to mitigate the network's unbalance of a distribution grid integrated with or without DGs and EVs. It discusses the commonly used unbalance indices and their strengths and limitations. The unbalance indices with other key performances such as power loss and voltage drop is considered as an optimization problem. Both classic and artificial intelligent (AI) optimization algorithms have been used, with AI algorithms producing the best performance. The details of the DNR technique and its feasibility for the utility planners and DSOs are discussed in this paper. The selection of unbalance indices and the DNR technique depends on the penetration of electric vehicles (EVs), DGs, and the time-varying nature of loads and generation. The joint optimization method using the DNR technique and the OPDGA technique is recommended to achieve the best performance in a DG-EV penetrated distribution grid. Though several researchers proposed an efficient methodology to mitigate the imbalance using the DNR technique at real time, the challenges associated with the implementation cost and data reliability is not considered. On the other hand, the load-generation forecasting error due to EV charging or discharging uncertainties and indeterminate DG's generation, will rise with an increasing penetration of DG and EVs, as well as inducing more imbalance to the network. Therefore, the review work in this paper to mitigate imbalance using the DNR technique would be a guideline for utility planners and DSOs, to manage the impacts of the increasing surge of DGs and EVs in networks.

Appendix

Table A: Standard VUF for different countries (Perry 2014)

Country	VUF (%)	Code
USA	<3	ANSI C84.1
USA	2	IEC (Banerjee 2008)
USA	1	NEMA-MG-1 [79] ('NEMA Standards Publication MG 1-2009, Motors and Generators' 2009)
Germany	2	At transmission and distribution voltage level
Scotland	2	Great Britain grid code
France	2	RTE at transmission voltage level

Brazil	2	At transmission and distribution voltage level
Canada, Hydro Quebec	2	At distribution voltage level
England & Wales	2	At distribution voltage level
New Zealand	2	AS 4777 ('Network standard' 2015)
Australia	2	Less than 10 kV ('National Electricity Rules Version 107' 2018)

Table B : Australian Standards (AS) and New Zealand Standards (NZS) ('Network standard' 2015)

Standard	Purpose	Specification
AS 4777	Energy system connection to grid via inverters	$\Delta V = +10\%, -6\%$ V
		VUF = 2%
		Difference between phase currents $\Delta I = 20\ A$
		P.f : 0.95 lagging to 0.8 leading.
AS/NZS 61000.3.100	Steady state voltage limit in public electricity systems	Nominal : 230 V
		Minimum : 216 V
		Maximum : 253 V

Figure captions

Fig. 1. The schematic diagram of a power system.

Fig. 2. Sample distribution feeders with open/close switch.

Fig. 3. Sample of dynamic phase swapping technique.

Fig. 4. Sample of individual load switching among three phases.

Table captions

Table 1: Overview of reviews

Table 2: Approaches in category 1 techniques

Table 3: Valid re-phasing sequence.

Table 4: Performance with different loading levels

Table 5: Taxonomy of the reviewed work.

Table I: Overview of reviews

Research group	Focused topics	articles	notes
Kalambe & Agnihotri et al.	The total power loss minimization technique in distribution network.	(Kalambe & Agnihotri 2014)	Bibliography review.
Sultana & Khairuddin et al.	Optimal DG allocation (OPDGA) and sizing to minimize the total power loss, and voltage stability.	(Sultana, Khairuddin, et	Reviewed single/multi-objective planning variables and optimization algorithms.

		al. 2016)	
Pesaran H.A, Huy & Ramachandaramurthy et al.	Optimal DG allocation (OPDGA) and sizing technique to minimize power loss, improving voltage profile, stability and power generation cost.	(Pesaran H.A, Huy & Ramachandaramurthy 2017)	Discussed corresponding objectives, constraints, methodologies and optimization algorithms.
Sultana & Mustafa et al.	The distribution network reconfiguration (DNR) technique for improving reliability and the power loss.	(Sultana, Mustafa, et al. 2016)	Discussed the Distribution feeder reconfiguration technique, and methodologies.
Badran et al.	The DNR and OPDGA technique for reducing the total power loss.	(Badran et al. 2017)	Discussed different methodologies, and optimization algorithms.
Sreenivasarao, Agarwal & Das et al.	The neutral current compensation technique using various transformers and active power filters.	(Sreenivasarao, Agarwal & Das 2012)	Discussed the efficiency and comparative study of different techniques.
Kütt et al.	The impact of EV charging on voltage unbalance.	(Kütt et al. 2013)	Discussed the effect of EV charging.

Table II: Approaches in category 1 techniques

Approach	Description	examples	articles	drawback
1.	Mostly used practices	Oversizing the neutral conductor. Separate neutral conductor for non-linear loads.	(Gruzs 1990; Hiranandani 1998)	Extra cost (Sreenivasarao, Agarwal & Das 2012).
		De-rating the distribution transformer	(Gruzs 1990; Hiranandani 1998)	
2.	Passive approach (Passive filters and special designed transformers)	Passive harmonic filters	(RodrÍguez et al. 2009)	Bulky and expensive (Sreenivasarao, Agarwal & Das 2012). The amount of compensating neutral current depends on transformer impedance, location of transformer and source voltage (Sreenivasarao, Agarwal & Das 2012).
		Synchronous machine as filter	(Fukami et al. 2001)	
		Scott- transformer	(Li & Crossley 2014)	
		T-connected transformer	(Singh, Jayaprakash & Kothari 2008)	
		Star-hexagon transformer	(Jayaprakash, Singh & Kothari 2008)	
		Zigzag transformer with single phase series/shunt Active Power Filter (APF).	(Hurng-Liahng et al. 2005)	
		Star-delta transformer with single-phase half-bridge PWM.	(Enjeti et al. 1993)	
3.	Active approach	Three H-bridge shunt APF topology.	(Quinn & Mohan 1992; Quinn, Mohan	The 3P4W four leg APF topology shows greater control flexibility over H-bridge and

	(Special designed Active Power Filter)		& Mehta 1993)	3P4W capacitor midpoint APF topology (Sreenivasarao, Agarwal & Das 2012). But the integration of electronic hardware has its own losses, cost and may inject harmonics (Sreenivasarao, Agarwal & Das 2012).
		Three phase-four wire capacitor midpoint APF topology.	(Jou et al. 2008) (Salmeron et al. 2004)	
		3P4W four leg APF topology.	(Quinn & Mohan 1992; Quintela et al. 2011; Salmeron et al. 2004; Singh, Al-Haddad & Chandra 1999; Sreenivasarao, Agarwal & Das 2012)	

Table III: Valid re-phasing sequence.

Phase	**Re-phasing sequences**
3-phase	(A,B,C,N)/(C,A,B,N)/(B,C,A,N)/ (B,A,C,N)/(C,B,A,N)/(A,C,B,N)
1-phase	(A,*,*,N)/(*,A,*,N)/(*,*,A,N)
	(B,*,*,N)/(*,B,*,N)/(*,*,B,N)
	(C,*,*,N)/(*,C,*,N)/(*,*,C,N)

Table IV: Performance with different loading levels (Jin-Cheng, Hsiao-Dong & Darling 1996)

Loading		Power loss	Load balancing	Voltage
50%	Before	137.76 kW 1134.29 kvar	1.075	0.949
	After	127.09 kW 1088.64 kvar	1.024	0.954
100%	Before	506.84 kW 4173.99 kvar	3.975	0.907
	After	471.48 kW 4050.47 kvar	3.804	0.916
150%	Before	1062.93 kW 8778.12 kvar	8.344	0.872
	After	992.44 kW 8546.76 kvar	8.015	0.884

Table V: Taxonomy of the reviewed work.

Reference	Unbalance Indices				Objective Function	Type of Distribution Network Reconfiguration Technique			Methodology
						Feeder reconfiguration	Phase balancing		
	LBI	PUI	UF	Neutral current			Phase swapping	Loads switching among phases	
(Babu et al. 2014)	√				LBI	√			Ant Colony Optimization algorithm.
(Yuehao et al. 2016)	√				LBI	√			Ant Colony Optimization with graph theory
(Babu, Kumar & Teja 2013)	√				LBI	√			Genetic Algorithm.
(Jin-Cheng, Hsiao-Dong & Darling 1996)	√				The total power loss and LBI	√			Heuristic Search.
(Kashem & Moghavvemi 1998)	√				LBI and stability index	√			Branch exchanged method.
(Kashem, Ganapathy & Jasmon 1999)	√				Load Unbalance current Index + Loss minimization	√			Branch exchanged method.
(Dai-Seub, Chang-Suk & Hasegawa 1995)	√				Total power loss and LBI.	√			Genetic Algorithm.
(Nara, Mishima & Satoh 2003)	√				Total power Loss and LBI.	√			Incremental Algorithm.
(Roytelman et al. 1996)	√				Power loss, voltage drop, service interruption cost and LBI	√			Heuristic Search.
(Qin, Shirmohammadi & Liu 1997)	√				LBI	√			Fuzzy approach.
(Lin 2003)	√				LBI	√			Colored petri net Algorithm.
(Ravibabu, Venkatesh & Kumar 2008)	√				LBI	√			Genetic Algorithm.
(Kuo & Chao 2010)		√			PUI		√		Heuristic search
(Xiaoling et al. 2004)	√				LBI	√			Particle Swarm Optimization (PSO).
(Jinxiang, Mo-Yuen & Fan 1998)		√			PUI		√		Mixed integer Programming.
(Dilek et al. 2001)		√			PUI		√		Heuristic Search.
(Chia-Hung et al. 2005)		√			PUI		√		Backtracking search Algorithm.
(Chitra & Neelaveni 2011)		√			Total power loss and PUI			√	Fuzzy logic and combinatorial expert system.
(Sathiskumar et al. 2012)		√			PUI		√		Self-adaptive Hybrid Differential Evolution (SaHDE) algorithm
(Schweickardt, Alvarez & Casanova 2016)		√			Power loss, voltage deviation, and PUI			√	FEPSO (Fuzzy Evolutionary Particle Swarm Optimization)
(Nicolae & Jordaan 2013)		√			PUI			√	Heuristic search
(Soltani, Rashidinejad & Abdollahi 2017)			√		Voltage Unbalance Factor (VUF)		√		Modified shuffled frog leaping algorithm (MSFLA)
(Shahnia, Wolfs & Ghosh 2014)			√		Voltage Unbalance Factor (VUF)			√	Genetic Algorithm.
(Hooshmand & Soltani 2012a)		√		√	Total power loss, neutral current, PUI and re-phasing cost.	√	√		Bacterial Foraging- Nelder Mead (BF–NM) algorithm.
(Hooshmand & Soltani 2012b)				√	Neutral current, Average voltage drop, re phasing cost, Power loss cost.	√	√		Bacterial Foraging - Particle Swarm Optimization (BF-PSO).
(Fu-Yuan & Men-Shen 2005)	√				Total power loss and LBI	√			Genetic Algorithm.
(Yu-Lung et al. 2004)	√				LBI	√			Colored petri net Algorithm.
(Kaboodi et al. 2014)	√				Total power loss, voltage deviation and LBI.	√			MPSO with interactive fuzzy method.
(Kashem, Ganapathy & Jasmon 2000; Zhu, Bilbro & Mo-Yuen 1999)	√				LBI and Phase swapping cost.		√		Simulated Annealing.
(Tsai-Hsiang & Jeng-Tyan 2000)			√		Voltage Unbalance, Total line loss and average voltage drop.		√		Genetic Algorithm.
(Knolseisen & Coelho 2004; Knolseisen et al. 2003)		√			Voltage drop, power loss, number of phase moving cost and PUI		√		Genetic Algorithm.

	(Huang et al. 2008)				√	The equivalent cost of neutral current mitigation, the labour cost and the Customer service Interruption cost (CIC)		√		Immune Algorithm
	(Lin et al. 2008)				√	System power loss cost, the labour cost, the Customer service Interruption cost (CIC), and neutral current.		√		Heuristic search and expert system.
	(Siti et al. 2007; Siti, Nicolae & Jimoh 2006)	√				LBI			√	Heuristic rule based Neural Network Technique.
	(Navarro, Cruz & Malquisto 2012)		√			Total power loss and PUI.	√	√		Genetic Algorithm.
	(Abril 2016)				√	Energy loss and neutral current.		√		Non-Dominated Sorting Genetic Algorithm (NSGA-II).
	(Tanabe et al. 2008)			√		the total power loss, voltage and current unbalance	√			Tabu search algorithm
	(Farahani 2017)			√		Voltage unbalance factor (VUF)		√		Particle Swarm Optimization (PSO).
	(Qiao & Yang 2016)	√				LBI	√			Expert system.
	(Ji et al. 2017)	√				the total power loss and load imbalance	√			Second-Order Cone Programming (SOCP)
	(Zhai et al. 2018)			√		the total power loss and voltage unbalance	√			MILP (Mixed Integer Linear Programming) method
The joint optimization of the DNR and the OPDGA Tachnique	(Ch, Goswami & Chatterjee 2016)			√		the total power loss, harmonic distortion, voltage unbalance and the voltage sag	√			Branch Exchange method
	(Tolabi et al. 2014)	√				load imbalance, the total power loss and bus voltage.	√			Hybrid Fuzzy- Bees algorithm
	(Taher & Karimi 2014)			√		voltage and current unbalance, voltage at different bus and power loss.	√			Genetic Algorithm
	(Kaveh, Hooshmand & Madani 2018)				√	the total power loss, average voltage drop, neutral current of the feeder and re-phasing cost.	√	√		hybrid Bacterial Foraging - Spiral Dynamic (BF-SD) algorithm
	(Umar, Firdaus & Penangsang 2016)			√		minimize power loss, voltage imbalance and harmonics	√			Genetic Algorithm
	(Vítor & Vieira 2016)			√		line voltage unbalance rate (LVUR) and bus voltage	√			Genetic Algorithm

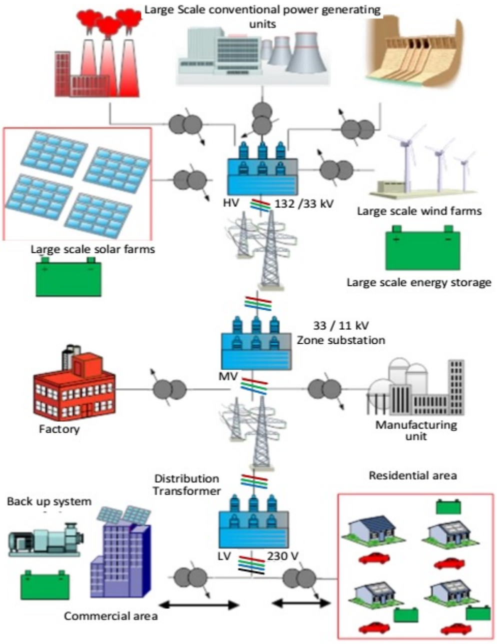

Fig.1. The schematic diagram of a power system

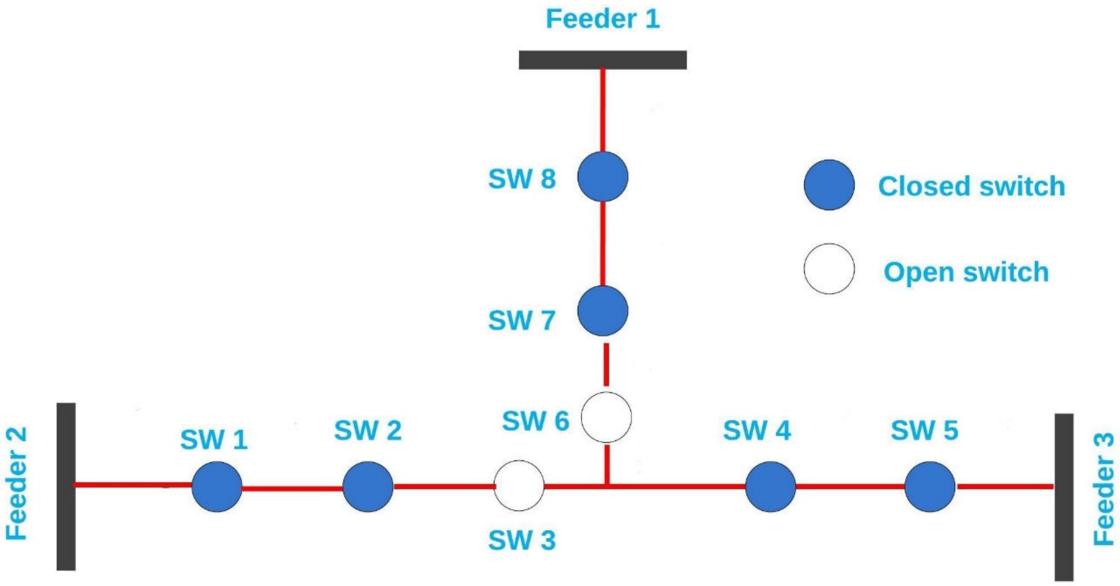

Fig.2. Sample distribution feeders with open/close switch

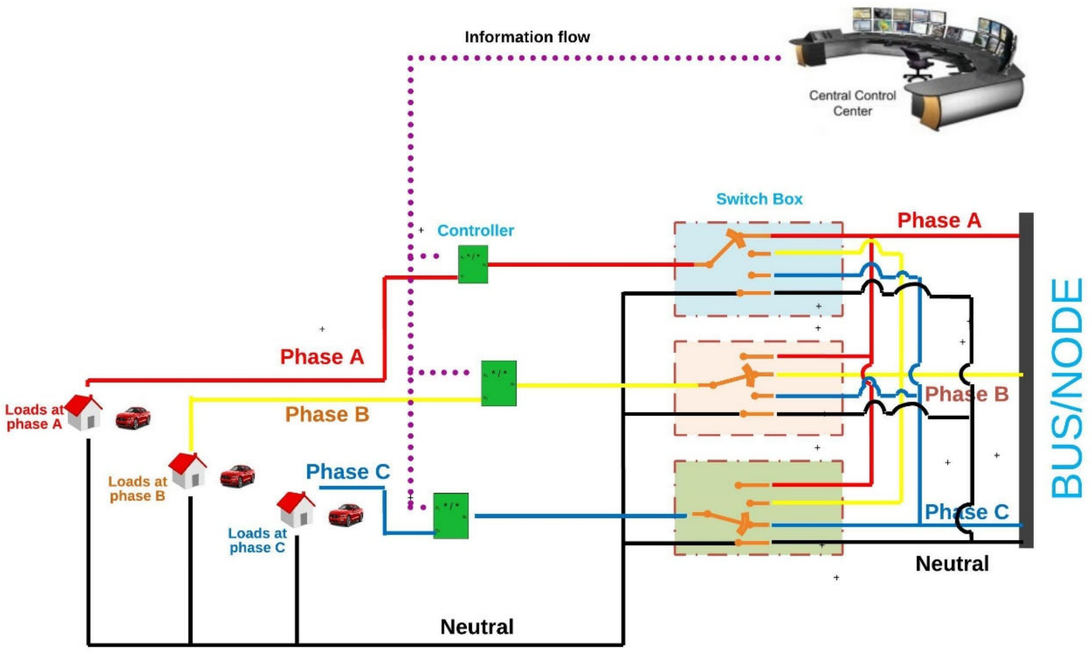

Fig.3. Sample of dynamic phase swapping technique

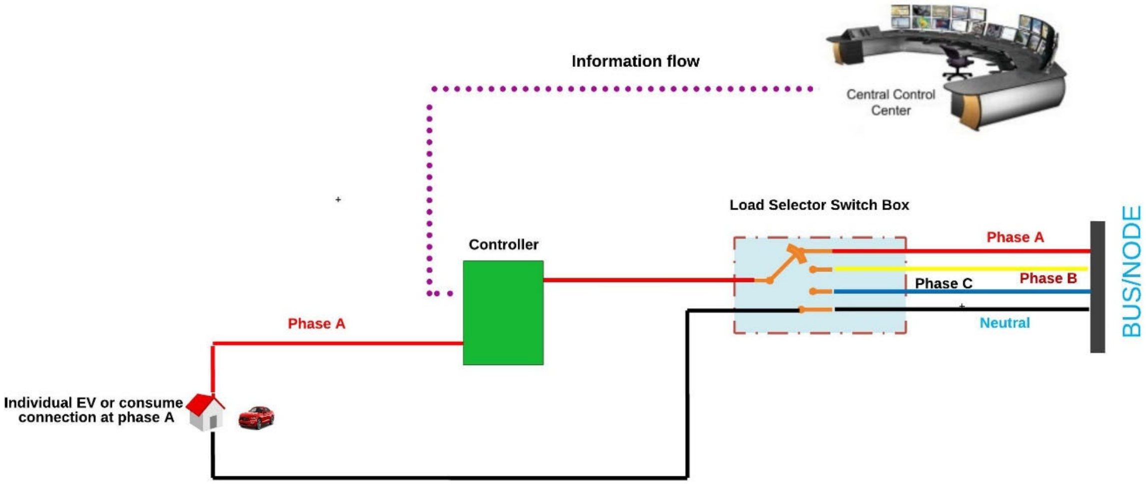

Fig.4. Sample of individual load switching among three phases

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