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# A Review Article of Load Balancing in Higher Voltage Power Distribution

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**Abstract- Power quality studies for distribution networks are very important for future network expansions realized by utility companies, so the accuracy of such studies is critical. Load data, including information on load imbalance, could have in many situations a significant influence on the correct estimation of many power quality indicators. This paper investigates the impact of load imbalance on several phase imbalance indicators and voltage quality indicators by comparing the values of these indicators, as calculated in a power quality study using, sequentially, different sets of load data characterized by different load imbalances.**

**Keywords- Low Voltage; Distribution Networks; Electricity Load Data; Consumption Profiles; Phase Imbalance/Unbalance; Power Quality Studies.**

## I. INTRODUCTION

Nowadays, modern distribution systems must support the continuous growing and variability of power demand, because of acquisition of new technologies and consumption habits of electrical appliances such as air conditioning systems, television sets, and washing machines.

Although, a balanced distribution system is preferable with similar power in phases, these variable consumption behaviors lead to undesirable unbalance through the distribution system. Therefore, power balance helps to reduce technical losses and improve the use of resources such as capacitor banks and transformers load tap changers. Distribution systems have more users than transmission systems, thus, measuring the consumption and performing load balancing become complex procedures [1].

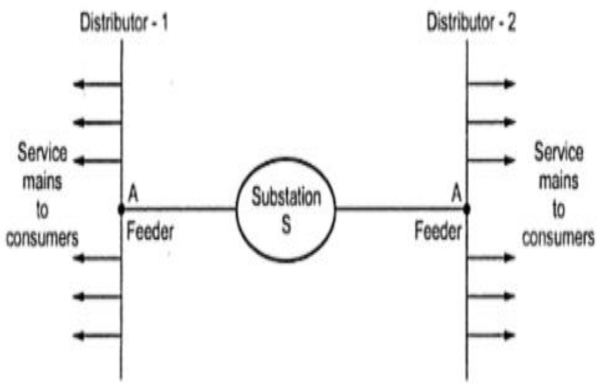


Fig 1. HV distribution.

Consequently, phase-load balancing methods for distribution systems employed in utility companies use nominal loads and diversity factors, assuming power consumption does not change considerably. Hence, electricity providers use theoretical information on regular operating conditions and contingencies.

## II. RESEARCH MOTIVATION

Nowadays, fossil fuels, the main source of our world energy, have been diminished day by day. In addition, the environmental pollution and the global warming concerns cause the increase in the importance of energy saving and loss reduction. So a lot of researches have been devoted to enhancing the efficiency of the energy converter machines.

The most popular shape of energy, electrical energy, is mainly produced in the power plants, transmitted through the electrical networks, and consumed in the load points. Therefore, the electrical network efficiency has a greater role in the energy saving and loss reduction. Electrical networks include transmission and distribution systems. As the transmission voltage is higher than the distribution voltage, the distribution system losses are greater.

The phase balancing results in benefits such as loss reduction, voltage profile improvement, and system reliability enhancement. At LV feeders, single-phase loads make unbalanced conditions and increase losses in the LV feeders. These loads are distributed along the feeder and have different and stochastic behaviors. All of these aspects of the single-phase loads make distribution phase balancing more difficult and complicated. In fact phase balancing is a dynamic combinatorial problem.

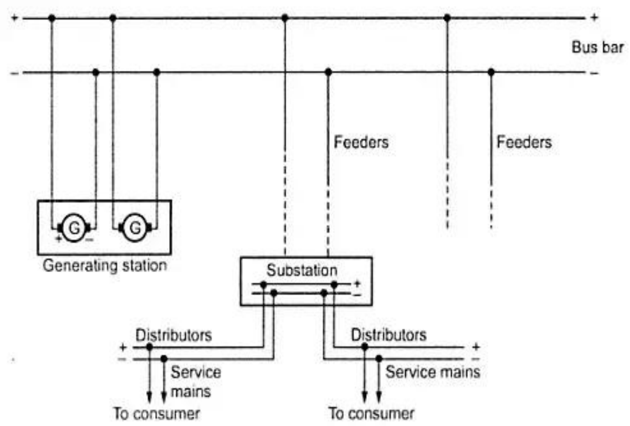

Fig 2. Flow control.

The compensation conduces to maximize the power factor (Q=0) and to active load balancing on the three phases

$$P=3.P_{PHASE}= 3.U^2.G$$

Where U is the rms value of phase-to-neutral voltage, three-phase network by connecting a resistive load (with the equivalent conductance G).

Active and reactive powers flow run on the network phases that supply the ensemble of all three loads are obtained by algebraic addition of active and reactive power previously deducted for the individual supplying circuits. It obtains:

$$P=P_R+P_S+P_T= 3.U^2.G$$

$$Q=Q_R+Q_S+Q_T=0$$

## III. LITERATURE REVIEW

**Victor A.Jimenez,** Phase reassignment for load balance in low-voltage distribution networks: Load balancing is one of the most widely used techniques to reduce losses and improve service quality in low-voltage networks. Many methods have been proposed, including the customer phase reassignment, which has multiple advantages. However, its application represents a real challenge if the data availability is limited (only a few variables from some nodes are measured). This paper presents a new method for load balancing on a three-phase feeder by switching the phase connection of single-phase customers.

It is based on Deterministic Crowding, a variant of Genetic Algorithms with few and easily adjustable parameters. In contrast to related works, we establish an imbalance target value and minimize the number of customers required to switch. The proposed method requires the phase current profiles from only a percentage of the customers, reducing the number of smart meters necessary and the related investment. The method was validated using real data, analyzing different scenarios with different percentages of measured customers compared on the basis of imbalance index, neutral current, and transformer lifespan reduction. Results show a significant improvement in load balancing with few changes, even when only 30% of customers are measured [1].

**Xiaoou Liu,** Automatic routing of medium voltage distribution network based on load complementary characteristics and power supply unit division: In view of the problems of large network scale and low equipment utilization efficiency caused by the lack of consideration of load complementary characteristics in the current distribution network planning, a new practical automatic routing method of medium voltage distribution network considering load complementary characteristics and power supply unit division is proposed.

Firstly, based on the existing conclusions of load clustering and gridding planning, the concepts of feeder block and power supply unit of medium voltage distribution network are redefined, and the framework of medium voltage distribution network planning considering the power supply unit division is proposed. Secondly, the evaluation indexes of feeder block division and power supply unit division considering the load complementary characteristics are proposed, and a centerline swing distance weighted clustering algorithm is proposed, which is used to realize the feeder block division.

Thirdly, considering the annual comprehensive cost of line planning and the outage loss cost based on reliability index, the medium voltage distribution network planning model is established based on the power supply unit division. The automatic routing method is proposed based on ant colony algorithm, which is used to realize the combinatorial solution of the trunk line and branch line. Finally, an example is given to verify the scientificity and practicability of the model and method proposed in this paper [2].

**Omid Homaee,** A practical probabilistic approach for load balancing in data-scarce LV distribution systems using discrete PSO and 2 m + 1 PEM: Unbalanced distribution of single-phase customers among the three phases is an important factor in causing unbalance in low-voltage (LV) distribution systems. This unbalance phenomenon has some important consequences as higher losses in the distribution system, increasing voltage unbalance, and higher neutral wire current. The key challenge is that these networks only have the monthly reading of customers' meters which is called data-scarce distribution systems due to the lack of enough information.

In this paper, a method is proposed in order to have a balanced distribution of single-phase customers between the phases based on particle swarm optimization (PSO) algorithm to reduce the average-load losses (which is calculated losses in the average load of all of the customers and is an attainable data in real-world data-scarce distribution systems). First, a comparative study is performed between two load balancing methods. In the first method, the transformer neutral wire current is reduced.

This method is used generally in electricity distribution companies. In the second method, the balancing is performed in order to reduce the losses in the average-load. Then, a probabilistic approach is proposed in order to manage the uncertainty of single-phase customer's consumption, which is an important issue in low-voltage distribution systems balancing. Numerical studies are performed on a practical system and the results show that the proposed method has higher performance comparing to the first method used by distribution companies. Also, it is observed that by rephasing of some single-phase customers, losses are reduced significantly [3].

**Jianquan Liao,** Voltage stability improvement of a bipolar DC system connected with constant power loads: The constant power loads (CPLs) in direct current (DC) power system have the potential to degrade the stability of the whole system. This paper proposed a virtual resistance damping method that improves the stability of the bipolar DC system connected with CPLs. At first, a stability criterion for the bipolar system is given. After that, a bipolar DC system based on a half-bridge voltage balancer (HBVB) is introduced and its small-signal model is derived. On this basis, a virtual resistance damping method, Capacitor-Parallel-Damping-Resistance (CPDR), is proposed and analyzed.

Moreover, the Lyapunov stability theory is adopted to investigate the impact of unbalanced load on the system stability. It turns out that system stability is determined by the sum of the system output power. This conclusion can significantly reduce the complexity of the bipolar system stability analysis and control loop design. Finally, the simulations and experimentations are performed to verify the proposed idea in this paper [4].

**Bowen Li,** Balancibility: Existence and uniqueness of power flow solutions under voltage balance requirements: In distribution systems, power injection variability due to growing penetrations of distributed energy resources (DERs) and dispatchable loads can lead to power quality issues such as severe voltage unbalance. To ensure safe operation of phase-balance-sensitive components such as three-phase motor loads, the amount of voltage unbalance must be maintained within specified limits for a range of uncertain loading conditions.

This paper builds on existing "solvability conditions" that characterize operating regions for which the power flow equations are guaranteed to admit a unique high-voltage solution. We extend these existing solvability conditions to be applicable to distribution systems and augment them with a "balancibility" condition that quantifies an operating region within which a unique, adequately balanced power flow solution exists. To build this condition, we consider different unbalance definitions and derive closed-form representations through reformulations or safe approximations. Using case studies, we evaluate these closed-form representations and compare the balancibility conditions associated with different unbalance definitions [5].

**Syed Rahman,** Comprehensive review & impact analysis of integrating projected electric vehicle charging load to the existing low voltage distribution system: Electric vehicles (EVs) have remarkably emerged as an alternative for internal combustion engines. With high penetration levels of the EVs, its addition to the existing distribution line infrastructure affects the power quality and grid stability.

Additionally, EV charging loads are characteristically different as they are mobile compared to other fixed node-connected loads. Proposing solutions without considering these factors may result in grid congestion and subsequent over/under compensations. Another emerging dynamics co-occurring in the distribution system is high penetration levels of renewable energy in the utility grid. Although these dynamics pose challenges in stable grid operation, it also gives opportunities for solving some of the grid integration issues of EV loads. Thus, the effect of adding EV charging load to the existing low voltage distribution system must be analyzed by considering different criteria such as grid impact with different EV chargers, mobile nature of EV load, power quality, voltage profile, and spread/peak demand of load curve. This paper presents a detailed report on the impact analysis of EV integration on the component and system levels.

For analyzing the effect on power quality (component level), grid pollution contributed by EV chargers along with possible solutions is elucidated. Detailed discussion on the significance of EV load location, existing load distribution, and nature of EV charging load distribution is presented by considering different feeders and different load curves. These discussions are supported with simulated case studies followed by a review of existing literature for enhanced understanding. Finally, techniques employed to effectively model the mobile nature of EV load and distributed EVs potential to provide ancillary solutions are also explained [6].

**Meng Zhang Yu-Qing Bao,** Voltage control strategy for distribution network with thermostatically controlled loads equivalent energy storage model considering minimum-on-off time: With the large-scale integration of distribution generations (DGs), distribution network (DN) encounters the new challenges in voltage control. Due to some existing conventional voltage regulation equipment in the

DN lacks active power regulation capability, a voltage regulation strategy with thermostatically controlled loads (TCLs) equivalent energy storage model considering the minimum-on-off time is proposed in this paper to alleviate voltage magnitude. Then, a voltage management model incorporating TCLs is developed as a multi-objective optimization model that collectively minimizes demand response (DR) cost, network loss, voltage deviation and voltage overrun penalty. Compared with existing methods, the proposed method achieves lower network loss and maintains safe voltage levels under random load demand and renewable power injection. Finally, the proposed method is verified by testing examples [7].

**Abdelaziz Salah Saidi,** Impact of grid-tied photovoltaic systems on voltage stability of tunisian distribution networks using dynamic reactive power control: Analysis of voltage stability of transmission network with high photovoltaic (PV) integration is a challenging problem because of the stochastic generation of a solar system. Stabilization of the output power is an important criterion for determining the degree of penetration of PV in active distribution networks, considering loading capability. This article describes the effective voltage regulation strategy for the transmission system using the STATCOM module to resolve the drop and the effect aspects on the voltage stability in the transmission network.

This paper analyzes also the influence of the STATCOM control system on preventing the combination of injection voltage STATCOM with harmonics from achieving pure voltage compensation. The proposed test system under analysis is the 53-Bus Tunisian distribution power network integrating 12 MW solar PV plant. Simulation results are added to demonstrate the efficiency of the proposed control technique for enhancing the power system quality based on the Tunisian grid code. Investigation of voltage stability shows that the dynamic behavior of the voltage depends strongly on the short circuit capacity of the power network at the point of PVs integration [8].

**Mario A.Mejia,** Medium-term planning of active distribution systems considering voltage-dependent loads, network reconfiguration, and CO2 emissions: This work proposes a novel mixed-integer linear programming model to address the medium-term reinforcement planning for active distribution networks, taking into account multiple investment options and CO2 emission limits.

The investment plan jointly includes (i) the replacement of overloaded conductors, (ii) the installation of voltage control equipment such as voltage regulators and capacitor banks, and (iii) the installation of distributed energy resources, such as dispatchable and non-dispatchable renewable generators, and energy storage units. Uncertainties associated with the demand for electricity, energy prices at the substation and non-dispatchable distributed generation are addressed through scenario-based stochastic optimization. In contrast to conventional planning methods, the proposed approach models the load as voltage-dependent in order to achieve substantial reductions in energy consumption.

As another outstanding feature, network reconfiguration, which is an operational planning alternative that is normally addressed independently, is incorporated within the planning options. The objective function of the model is aimed at establishing an investment strategy with minimal total costs, but that satisfies the operational restrictions of the network and CO2 emissions cap.

A 69-node system was used to test the proposed model and, the results show that modeling the load as voltage-dependent and integrating network reconfiguration into the medium-term planning actions helps to achieve an effective network that, in addition to being environmentally friendly, has low total planning costs. Finally, the scalability of the proposed method was evaluated using a real 2313-node system [9].

**Waleed Alabri,** Voltage regulation in unbalanced power distribution systems with residential PV systems: Increased integration of rooftop photovoltaic (PV) power generation in a low-voltage power distribution system poses significant challenges due to the severity of voltage unbalance problems and complexities in regulating the voltage. Conventional regulation methods are insufficient to address these challenges due to their inability to deal with the voltage unbalance.

This paper proposes an advanced supervisory control methodology, with the reactive power control and voltage regulation at residential PV inverters, as an effective means of addressing unbalanced voltages in a power distribution system. The uniqueness of the approach is that it simultaneously controls voltage magnitude and voltage unbalance at affected nodes by precise dispatching of reactive power. Several cases were studied by simulating realistic operating conditions on the unbalanced IEEE 37-node test feeder, and results suggest that the proposed approach can manage the voltage magnitude at nodes within voltage unbalance thresholds. Further cases suggest that the application of the proposed methodology could also reduce the operational stress of residential PV inverters significantly, facilitating distribution system with an increased capacity of PV power generation [10].

**Mohammad Eydi,** A novel communication-less fuzzy based control method to improve SOC balancing, current-sharing, and voltage restoration in a widespread DC microgrid: DC Bus Voltage Restoration, proportional current-sharing and SOCs balancing are the leading vital challenges in the field of DC microgrids. It seems that, using communication links and a central controller will solve these problems. However, microgrids under such control system will encounter some drawbacks such as low modularity, flexibility, reliability, and high cost and complexity. Besides, using communication links and the central controller is not reasonable for widespread DC microgrids. In this paper, a novel communication-less control method is proposed. First, the voltage of units is controlled by the droop controller to ensure the system stability. Next, a unit which has the least distance from critical loads is chosen as "sender unit".

The sender unit voltage is set such that the voltage deviation of the sender bus is reduced to zero. Then, this unit injects an AC signal to the DC bus. The frequency of AC signal is determined by a fuzzy controller based on the sender unit SOC and its current. Another fuzzy controller specifies the units' current based on the frequency of AC signal and their SOC. The units' current determination is done such that not only the SOCs are balanced, and the voltage deviation is reduced, but also the current is appropriately shared.

As the proposed method does not rely on communication links, it is applicable on both the single-bus and multi-bus microgrids (compact and geographically dispersed). The stability analysis confirms that the proposed method is strongly stable. Simulation results prove that microgrids controlled by the proposed method have a desirable performance from the standpoint of current-sharing, SOCs equalizing, and DC bus voltage regulation [11].

**Andres F.Moreno Jaramillo,** Load modelling and non-intrusive load monitoring to integrate distributed energy resources in low and medium voltage networks: In many countries distributed energy resources (DER) (e.g. photovoltaics, batteries, wind turbines, electric vehicles, electric heat pumps, air-conditioning units and smart domestic appliances) are part of the 'Green Deal' to deliver a climate neutral society. Policy roadmaps, despite providing a framework and penetration targets for DER, often lack the network planning strategies needed to transition from passive to active distribution networks. Currently, DER's dynamic performance parameters and location identification techniques are not fully standardised. In fact, it can be very ad hoc.

Standardised distributed load modelling and non-intrusive load monitoring (NILM) for equipment manufacturers, installers and network operators is critical to low and medium voltage network management in order to facilitate better balancing, flexibility and electricity trading across and within the power system for mass DER deployment. The aim of this paper is to fill this load modelling and NILM knowledge gap for DERto inform the 'Green Deal' transition and support standardisation.

In the paper, existing load modelling techniques and NILM methodologies are critically examined to inform and guide research activity, equipment development and regulator thinking, as well as network operators. Seven key findings that need urgent attention are identified to support a smooth power system reconfiguration [12].

**Shouxiang Wang,** Non-intrusive load identification based on the improved voltage-current trajectory with discrete color encoding background and deep-forest classifier: With the development of non-invasive load monitoring, we can monitor household appliances' category, operation status, and electricity consumption. Voltage-Current (VI) trajectory feature significantly improves load identification accuracy by representing the voltage and current waveform of appliances in images. However, it cannot reflect power information and has low pixel utilization. To solve this problem, we proposed an improved VI trajectory feature with discrete color encoding background.

First, we added motion and momentum information to original VI trajectory images through color encoding. Then, the active and reactive power information was discretized using the Chi2 method, and the result was added to the background's invalid pixels. Further, we proposed a deep-forest-based VI trajectory classification method to solve the problem of model redundancy of existing image recognition methods.

We also discussed the data imbalance in the VI trajectory recognition problem and proposed a balancing algorithm based on the PixelCNN++ model. The result of case studies shows that the proposed improved feature can effectively improve the classification accuracy. Compared with the advanced image recognition classifiers based on CNNs, the proposed deep forest classifier has higher accuracy, faster speed, and stronger robustness. Moreover, the proposed PixelCNN++ data balancing method is more robust and can generate realistic VI trajectory samples [13].

**Susan Mumbi Kisengeu,** under voltage load shedding using hybrid ABC-PSO algorithm for voltage stability enhancement: Voltage collapse tends to occur due to the voltage instability created during large faults. As a last resort, under-voltage load shedding (UVLS) is performed after all the available power operation and control mechanisms have been exhausted. Load shedding techniques have advanced from the conventional and adaptive methods that are less optimal compared to computational intelligence-based techniques. Recent works have identified hybrid algorithms to give more optimal solutions for UVLS problems with multi-objective functions.

In this paper, a novel hybrid ABC-PSO algorithm, adapted from a software estimation project, is used to perform UVLS on a modified IEEE 14-bus system. Eight overload conditions are imposed on the system ranging from 105% to 140% loading, where FVSI ranking is used in identifying weak buses. The load shedding is then performed following decentralized relay settings of 3.5

seconds, 5 seconds and 8 seconds, which gives an overall 99.32% recovery of voltage profiles. The proposed hybrid ABC-PSO algorithm is able to shed optimal amounts of load, giving an 89.56% post-contingency load, compared to GA's 77.04%, ABC-ANN at 84.03% and PSO-ANN at 80.96%. This study has been simulated on MATLAB software, using the Power System Analysis Toolbox (PSAT) graphical user and command-line interfaces [14].

**Wei Ma,** A centralized voltage regulation method for distribution networks containing high penetrations of photovoltaic power: One of the most significant current concerns in distribution networks is the voltage fluctuations resulting from sharp changes of the active power of photovoltaic (PV) plants. Therefore, this paper proposes a novel worst-case voltage scenarios (WCVSs) based centralized voltage regulation method to suppress the voltage fluctuations of all buses in distribution networks, where the WCVSs are established according to probabilities of bus voltages exceeding the required voltage range.

A mixed integer nonlinear programming (MINP) model is developed to coordinate on-load tap changers (OLTCs), capacitor banks (CBs), and PV plants, aiming at reducing switching operations of OLTCs and CBs, bus voltage variations, operating losses of distribution networks, and active power curtailments of PV plants.

This paper employs the NSGA-II algorithm to find the Pareto optimal set of the established MINP model, and a fast decision-making algorithm is proposed to select the best solution from the Pareto optimal set.

The proposed methods are conducted on a modified IEEE 33-bus distribution network with high penetrations of PV power. Simulation results show that the proposed voltage control methods can not only effectively deal with voltage fluctuation issues in the distribution network, but also reduce the operating costs of the distribution network [15].

## IV. CONCLUSION

One of the biggest problems with distribution systems correspond to the load unbalance created by power demand of customers. This becomes a difficult task to solve with conventional methods. Therefore, this paper uses integer linear programming and Branch and Bound algorithm to balance the loads in the three phases of the distribution system, employing stored data of power demand.

The solution may be used as a planning tool in distribution systems applied to installations with systems for measuring power consumption in different time intervals. Furthermore, in conjunction with communications and processing technologies, the solution could be useful to implement with a smart grid.

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