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REVIEW ON VOLTAGE SAG STUDIES FOR DISTRIBUTION GRID INCLUDING RENEWABLE ENERGY SOURCES

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Abstract

Several types of power quality problems can be observed in power network. These power quality problems include voltage unbalance, voltage flicker, voltage sags and swells, interruptions, and voltage and current harmonics. Voltage sag is one of the vital power quality issues. This problem can cause a decrease in power grid voltage over a short time horizon. The aforementioned problem is caused by various types of short circuits and the widespread use of sensitive devices. These problems have a significant impact on power systems. In this review article, the different ways to prevent voltage sag have been presented by considering literature studies. Concerning voltage sags in radial and mesh grids, the equipment used, and methods have all been taken into account. In these studies, the articles about voltage sag-related problems have been put into groups based on certain criteria. These criteria include the consideration of uncertainties in electricity demand or renewable sources. The recommendations related to the voltage sag studies have been presented. These suggestions are based on the inclusion of electricity consumption and renewable energy source uncertainties. The future works have been mentioned by considering these load and renewable system uncertainties.

Keywords: Voltage Sag, Power Quality, Uncertainty, Renewable Energy Sources

YENİLENEBİLİR ENERJİ KAYNAKLARI DAHİL EDİLEREK DAĞITIM ŞEBEKESİ İÇİN GERİLİM ÇÖKMESİ ÇALIŞMALARI ÜZERİNE DERLEME

Özet

Güç şebekesinde çeşitli güç kalitesi sorunları gözlemlenebilir. Bu güç kalitesi problemleri arasında gerilim dengesizliği, gerilim titremesi, gerilim çökmeleri ve yükselmeleri, kesintiler ve gerilim ve akım harmonikleri bulunur. Gerilim çökmesi önemli güç kalitesi problemlerinden biridir. Bu problem, elektrik şebekesi geriliminin kısa bir zaman aralığında düşmesine neden olabilir. Bahsedilen problem, çeşitli kısa devrelerden ve hassas cihazların yaygın olarak kullanılmasından kaynaklanmaktadır. Bu problemler, güç sistemlerinde önemli bir etkiye sahiptir. Bu derleme makalesinde, gerilim çökmesini önlemenin farklı yolları literatür çalışmaları dikkate alınarak sunulmuştur. Radyal ve ağ şebekelerdeki gerilim düşmeleri ile ilgili olarak, kullanılan ekipman ve yöntemlerin tümü dikkate alınmıştır. Bu çalışmalarda gerilim çökmesi kaynaklı problemler ile ilgili makaleler belirli kriterlere göre gruplara ayrılmıştır. Bu kriterler, elektrik talebindeki veya yenilenebilir kaynaklardaki belirsizliklerin dikkate alınmasını içerir. Gerilim çökmesi çalışmaları ile ilgili öneriler sunulmuştur. Bu öneriler, elektrik tüketimi ve yenilenebilir enerji kaynağı belirsizliklerinin dahil edilmesine dayanmaktadır. Bu yük ve yenilenebilir sistem belirsizlikleri dikkate alınarak gelecekte yapılacak çalışmalara değinilmiştir.

Anahtar Kelimeler: Gerilim Çökmesi, Güç Kalitesi, Belirsizlik, Yenilenebilir Enerji Kaynakları

Cite

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1. Introduction

Power quality issues in power systems can be classified into several categories. These are voltage unbalance, voltage flicker, voltage sags and swells, interruptions, and voltage and current harmonics [1]. The voltage sag phenomenon is a prominent issue of power quality. This problem is defined as a drop in system voltage over a short period of time [2 – 4]. The voltage swell is defined as a rise in voltage over a short period of time [5]. This problem may happen because of vulnerable power electronics-based loads and faults. They play an important role in the power system [6 – 9]. When voltages fall below a critical level, sensitive loads may be damaged [10 – 13]. The bus voltages commonly decrease when they violate the predefined level. This is due to the increase in fault-related voltage sag issues and sensitive demands in the power network [14 – 17]. The continuity of power quality for end users may be negatively influenced by these problems [18 – 20]. It is critical to remember that the required power quality can be provided. In other words, the required equipment can be connected to the power network while facing the voltage sag problem [21 – 25].

Therefore, the power system company can take the necessary precautions to reinforce the network, considering the voltage sag-related issues. In this manner, the integration of flexible AC transmission systems (FACTS) reduces the economic concerns caused by the voltage sag in distribution systems [26, 27]. On the other hand, reconfiguring the network using optimization approaches such as the genetic algorithm (GA) and the tabu search algorithm (TSA) is another way of dealing with this problem [28, 29]. It is worth noting that the fault location is one of the important parameters needed for the voltage sag analysis [30]. Moreover, the placement of dynamic voltage restorers (DVRs) [31, 32], power quality monitors (PQMs) [33], fault current limiters (FCLs) [34], and open unified power quality conditioners (OUPQCs) [35] are various means of minimizing the voltage sag problems in the power networks. However, distributed generation (DG) systems can exhibit the desired behavior as well. They mitigate the voltage sag issues and support the power networks in problematic cases [36 – 38].

The voltage sag has been investigated together with the DGs in some papers in the literature [39 – 42]. In [39], researchers have looked at the optimal way to use DGs for reducing voltage sag and power losses and improving the distribution network's voltage profile. It is important to remember that the best DG interconnection can reduce voltage sag and power loss and keep system voltage stable. By installing DGs, the network reconfiguration has taken into account a number of goals, such as problems with voltage sag and drop in [40]. The reconfiguration has been handled along with voltage sag by taking DG allocation into account in distribution networks in [41]. By the way, optimal DG interconnection can be used to get the financial benefits of voltage dips, renewable energy sources, and grid network losses. When figuring out how to solve the optimal DG allocation and size problem, these benefits have been taken into account in [42].

In this review paper, voltage sag-related problems in radial and mesh power networks have been investigated. The equipment used and the approaches in the different applied methodologies have been considered. The categorization of these studies has been performed based on the uncertainties in demand or renewable systems. The inclusion of demand uncertainties and renewable system intermittencies has been recommended in the studies related to the voltage sag.

2. Literature Review

In this section, the literature review has been classified. This classification is based on the equipment placements, power grids, proposed methods, load uncertainty, and renewable uncertainty. The various approaches used in the literature studies have been presented when voltage sag-related issues have been encountered. The classification of these approaches has been demonstrated in Figure 1 and presented in the proceeding subsections.

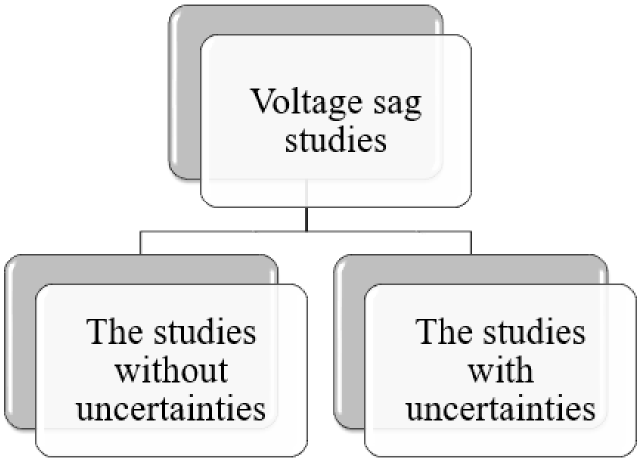

Figure 1. The classification of voltage sag studies.

2.1. The Studies That Do Not Consider Uncertainties

The power systems face the financial results of the voltage sag event. Thus, FACTS devices must be used in both low-voltage and high-voltage power systems. FACTS devices preserve the power electronics-based devices damaged by voltage sag issues. Utilizing these devices is the economically advantageous decision. They consist of distribution static compensator (D-STATCOM) and static var compensator (SVC). The design of these devices prevents voltage sags from causing significant economic damage. In [26], the analytical method with FACTS devices has been used to reduce the economic problems caused by voltage sags. These problems result from various kinds of faults in the practical distribution network. From the owners' and users' points of view, the problem of voltage sags remains important. The multi-objective formulation, which includes economical and technical issues, has been proposed to solve the static compensator (STATCOM) placement problem in [27]. In the related study, the evaluation of voltage sags has been implemented using an analytical method. The optimal placement of the aforementioned device has been achieved by utilizing strength pareto evolutionary algorithm with shifting density estimation (SPEA2/SDE) in interconnected grids.

Reconfiguring the network with GA has solved the economic issues caused by voltage sags in [28]. The vulnerable power-electronics-based devices are exposed to voltage sag events. These devices have been considered for evaluating economic issues. These problems have been reduced by optimally reconfiguring the distribution grid. The voltage sags have also been taken into account when reconfiguring power networks in [29]. These problems have been solved by reconfiguring mesh networks using TSA. Determining the location of the fault is critical for ensuring a reliable distribution network. In this manner, an analytical method has been utilized to evaluate the voltage sags based on measurements in [30].

By using an index in the distribution network, DVR allocation has reduced voltage sag in [31]. In [32], the minimization of voltage sags on load has been taken into account. This has been done for the evaluation of DVR capacity and placement in the optimization framework. The reliability of electricity consumption has been considered while minimizing the economic problems related to the DVR's size. The index, which indicates the amount of voltage sag issues affecting electricity load, has been improved. In the radial system, GA has handled the formulation of the problem. Using integer linear programming (ILP), the PQM placement has been considered in terms of voltage sag issues in [33]. This problem has been handled considering the short-circuit places for various grid configurations. The voltage sag issues resulting from fault problems are expected to rise. This is due to the power grids' gradually increasing consumption. The resulting fault-related currents may cause the power grid devices to be damaged. These currents can be alleviated by using FCL devices. In [34], the financial and technical objectives have been considered by implementing multi-objective evolutionary algorithm with decomposition (EA/D), particle swarm optimization (PSO), and non-dominated sorting genetic algorithm (NSGA-II). FCL size and placement have been optimized for minimizing fault-related currents. Mesh grids have been used to implement multi-objective optimization algorithms. Improving power quality is unavoidable in order to prevent insufficient current and voltage in distribution systems. In this context, OUPQC devices are useful for these insufficiencies and voltage sag issues. In [35], the analytical method has been performed to observe the applicability of these devices. The method is based on backward forward sweep load flow (BFSLF). The distribution grids have been strengthened during the voltage sag-related events.

In power systems, DG interconnection can also minimize voltage sag. In [36], the goals have been the costs of voltage dips, power network losses, and DG units. The optimal DG allocation has been determined by improving power flows and bus voltages. This problem has been handled by a GA-based multi-objective approach, which has been applied to distribution and mesh grids. The required DG optimization plan can reduce the effects of voltage sag issues on vulnerable loads. The DG trip impacts have been qualified by introducing the different trip types in cases of voltage sags in [37]. The density evaluation of voltage sag problems has been applied to sensitive loads and DGs. With the use of PSO in cases of voltage sags, plans for DG and vulnerable loads have been made considering economic problems. Voltage sag has a negative impact on vulnerable power electronics-based devices. These problems can be minimized by ensuring optimal DG interconnection in distribution networks. In this manner, a PSO-based methodology has been utilized to determine optimal DG system allocation and capacity in [38]. This has been applied to minimize voltage sags influenced by different types of faults. The costs of the DG systems, voltage dips, and grid losses have been parts of the objective function. The radial distribution network's bus voltages and line flows have been preserved. Voltage sags cause economic problems for vulnerable loads. Because of this, they play an important role in distribution grids. The optimization of DG placement and capacity has been performed in [39]. Voltage sag issues have been minimized by the differential evaluation (DE) approach. Bus voltages, power flows, and line losses have been improved in radial networks. With the aid of growing technologies, the required power can be provided to the grid by the DG units. The distribution system reconfiguration has been performed with DGs. The multiple objectives, including voltage sags and drops, have been considered by applying shuffled frog leaping algorithm (SFLA), GA, and PSO in a radial system in [40]. The predefined voltage level can be maintained for vulnerable devices in the distribution grids. The short circuits give rise to voltage dip events in these grids. In order to minimize the voltage sag-related issues, both DG allocation and radial grid reconfiguration have been implemented in [41]. The binary particle swarm optimization (BPSO) approach has been implemented to minimize the voltage sag issues. In [42], a PSO-based methodology has been used in conjunction with an expert system to optimize DG placement. Voltage sag and power network losses have been considered. Short-circuit currents are expected to increase in DG-connected distribution grids. The FCLs could minimize these currents to prevent the grid elements from being damaged. In this manner, the technical and financial objectives have been considered for FCL placement in distribution networks in [43]. The technical objectives are short-circuit currents and voltage sags, whereas the financial objective is FCL cost. Vulnerable loads can be used to plan voltage sag minimization while taking the area of vulnerability (AOV) and expected sag frequency (ESF) into account. The AOV and ESF have been considered in cases of short circuit-related voltage sag issues in the mesh grid with wind turbine (WT) in [44]. The distribution grids are expected to include the maintenance of power quality. The installation of DG units on the grids can affect DOCR management. The objectives related to voltage sags and protection devices have been minimized in [45]. The parameters of FCL and directional overcurrent relay (DOCR) have been optimized by applying GA to the distribution grid. In the aforesaid grid, FCL, DG units, and vulnerable device nodes exist.

2.2. The Studies That Consider Uncertainties

The performance of a radial grid can be developed by SM. The analytical method has been used to obtain the fault locations using smart meter (SM) in [46]. The steady-state voltage sag-based issues are commonly considered for resolving grid technical issues. The required equipment can be applied by taking into account transient problems in the radial systems. Furthermore, transient issues may have an impact on vulnerable elements in power grids. The NSGA-II has been applied to determine the size and placement of energy storage (ES) units and switch elements in [47]. The DG integration is needed because line losses and electricity loads are increasing in the radial grids. The appropriate allocation of renewable generators may enhance the performance of these grids. The operation of these grids may be negatively affected unless the expected precautions are taken. The bus voltages and line losses have been considered for suitable DG allocation by applying GA in [48]. The fuzzy integrated models have been proposed by taking into account increasing demand and voltage sag on the radial system.

In the distribution grid, problems with line loss, voltage sag, and stable voltage can be seen. These issues may arise from uncertainties in electricity consumption and WT systems. Energy storage devices can be utilized to prevent these issues. The improvements in line loss, voltage profile, and voltage stability have been planned in [49]. In the multi-objective formulation, both the allocation and capacity of superconducting magnetic energy storage (SMES) and WT have been taken into account. The formulation of the problem has been handled by applying equilibrium optimizer with loss sensitivity factor (EO/LSF), PSO, and GA. The voltage drop and sag issues can both be improved by ES. The two stages have been taken into account for the ES planning in [50]. In the first stage, GA and Monte Carlo Simulation (MCS) have been used to get the optimal placement and capacity of ES by minimizing financial goals related to ES and voltage sag. A post fault network reconfiguration (PFNR) approach has been performed to guarantee the optimality of the initial stage results by considering the financial objectives related to WT, demand, and ES in the second stage. This approach is based on optimal power flow (OPF).

The voltage sag-related studies can be categorized into two groups. The first group does not consider load or renewable uncertainties. However, the second group considers the uncertainties in demand or intermittencies in renewable units. The review of voltage sag studies has also been illustrated in Table 1.

Table 1. The literature review concerned with the voltage sag.

References	Placement	Power Grid	Proposed Method	Load Uncertainty	Renewable Uncertainty
[26]	FACTS devices: D-STATCOM, SVC	Practical distribution system	Analytical approach based on impedance matrix	✗	✗
[27]	STATCOM	Mesh network	Multi objective SPEA/SDE	✗	✗
[28]	✗	Generic distribution system	Single Objective GA	✗	✗
[29]	✗	Mesh networks	Single Objective TSA	✗	✗
[30]	✗	Radial distribution network	Fault location method based on impedance	✗	✗
[31]	DVR	Radial distribution system	Thevenin's Superposition method	✗	✗
[32]	DVR	Radial distribution system	Single objective multi population GA	✗	✗
[33]	PQM	Mesh network	Single objective ILP	✗	✗
[34]	FCL	Mesh networks	Multi objective EA/D, PSO, NSGA-II	✗	✗
[35]	OUPQC	Radial and practical distribution networks	BFSLF	✗	✗

Table 2. The literature review concerned with the voltage sag (continued).

References	Placement	Power Grid	Proposed Method	Load Uncertainty	Renewable Uncertainty
[36]	DG	Mesh and radial networks	Multi objective GA	✗	✗
[37]	DG	Mesh network	Multi objective PSO	✗	✗
[38]	DG	Radial network	Multi objective PSO	✗	✗
[39]	DG	Radial and practical distribution networks	DE, Real coded GA	✗	✗
[40]	DG	Radial network	SFLA, GA, PSO	✗	✗
[41]	DG	Radial network	BPSO	✗	✗
[42]	DG	Mesh network	PSO	✗	✗
[43]	DG, FCL	Radial and practical distribution networks	Multi objective PSO	✗	✗
[44]	WT	Mesh and practical mesh networks	Bisection search method	✗	✗
[45]	DOCR, FCL, DG	Practical distribution network	Multi objective GA	✗	✗
[46]	SM	Practical distribution system	Fault location method	✓	✗
[47]	ES	Practical radial distribution network	NSGA-II	✓	✗
[48]	DG	Radial distribution network	GA	✓	✓
[49]	WT, ES	Radial distribution network	EO/LSF, PSO, GA	✓	✓
[50]	WT, ES	Radial distribution networks	GA with MCS, OPF based PFNR	✓	✓

3. Discussions

Nowadays, the uncertainties of electricity loads and renewable systems can be observed in active power systems. The desired power grid analysis can be carried out by considering the variations in parameters. When there are uncertainties in optimization problems, the active distribution systems have problems with voltage sag. Therefore, the voltage sag minimization problem can be studied together with the uncertainties [51]. The aforesaid uncertainties include loads and renewable units. The desired power quality can be maintained in the distribution networks. The prominence of including the uncertainties in the voltage sag studies has been presented in Figure 2.

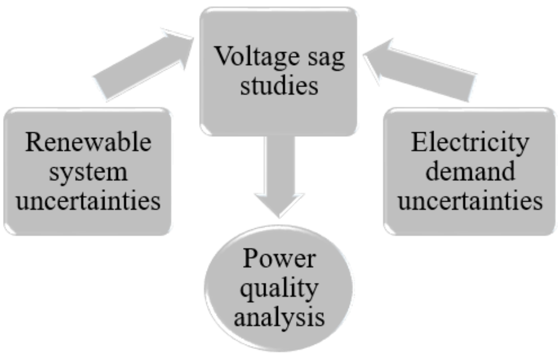

Figure 2. The prominence of uncertainties in the voltage sag studies.

The power grids are adversely influenced by the voltage sags as a result of the growing installation of vulnerable devices. Power quality studies need to be done before renewable units and sensitive equipment can be connected to the grid. Thus, it is thought that the optimal renewable units can be connected to power grids that have problems with fault currents and voltage sags. The solutions to the voltage sag problems can be adopted while optimally reinforcing the active power grids for power quality. The electricity loads are in anticipation of power quality improvement. In the event of a power grid voltage sag, proper renewable unit installation is advised [52]. The factors for handling suitable grid plans on the active power grids have been given in Figure 3.

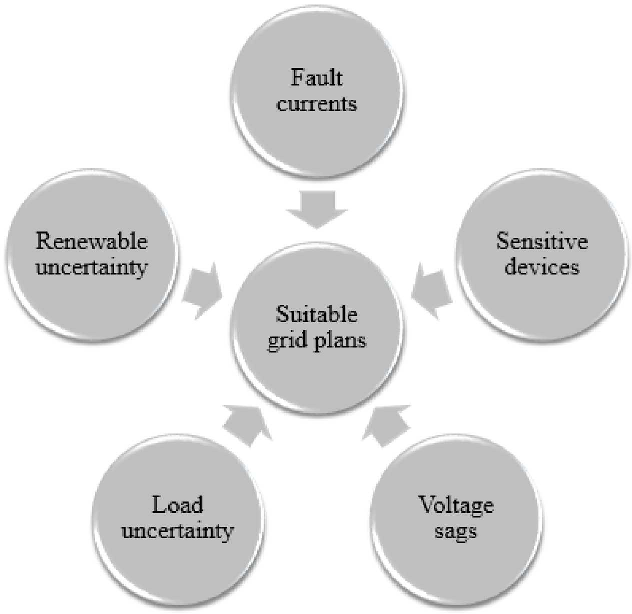

Figure 3. The factors for handling suitable plans on the active power grids.

Power systems are being investigated for significant power quality issues. The implementation of renewable energy in various fields is increasingly being considered in power quality studies. It is important to note that optimally connecting renewables to the grid is required to prevent voltage sag. Nevertheless, the limitations on the voltage sags may be violated because of the increasing vulnerability of the demands on these grids. Thus, the technical voltage sag issues can be considered while evaluating the optimal installation of renewables for power quality. Suitable grid plans can be handled on active power grids to solve these technical problems by taking electricity load and renewable uncertainty into account. Both renewable units and sensitive loads can be considered in an active power system. In this case, using the appropriate methods, the optimal renewable installation based on voltage sags can be obtained. Thus, it is important to note that renewable intermittencies play a significant role in voltage sag issues on active power grids [53, 54].

4. Conclusions

In this review paper, voltage sag-related problems in radial and mesh power networks have been examined. The equipment used and the approaches in the different applied methods have been considered. The categorization of these studies has been applied based on the uncertainties in demand or renewable systems. In practice, the uncertainty of renewable units means that voltage sags must be carefully interpreted in terms of power quality. With the proper power grid analyzers, voltage sag problems can be looked at when getting the optimal renewables. As a result, the renewable and electricity demand uncertainties can heighten the importance of this issue. Uncertainties in renewable energy resources and electricity consumption elevate the problem to the level of a complex design. By reducing voltage sags, the literature investigations can be moved to the novel grade. Power quality can be maintained by designing the optimal renewable interconnection. The future work will consider the inclusion demand uncertainties and renewable system intermittencies in the voltage sag-related studies. In active power networks with uncertainties, voltage sag analysis will be performed by including various types of faults and vulnerable loads.

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