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Effect of DGs on Power Quality of Distribution System: An Analytical Review

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***Abstract* – This article offers an overview of distributed generation (DG) in distribution systems (DS). The primary goal of this study is to assess the performance of DGs in DS. Due to the rise in electrical energy consumption, it is anticipated that DG sources would be essential to DS. Future power generating networks have a bright outlook on consideration of DG's potential for utilising alternative energy sources. The quality of power systems is a crucial concern for energy providers and consumers. In order to decrease reliance on fossil fuels for the production of electricity, distributed generations are gaining importance in the energy supply networks in many countries. Distributed generators are small units that generate electricity close to customer sites. These DGs use renewable energy methods such as wind energy, solar energy and geothermal energy. The incorporation of DGs into a conventional power supply system evolves in a number of side effects, including an increase in the number of short circuits, higher power losses, a decrease in the quality of the energy produced, voltage transients, problems with voltage stability, coordination issues regarding voltage regulation and protection, the possibility that system protection will not function correctly, and the fact that there is less residual current input as a result of the DG bidirectional power flows. This review paper discusses the impacts of the penetration of DG into DS and provides various strategies to mitigate these effects.**

***Keywords* – Distributed generation, distribution system, power quality, voltage transients.**

I. INTRODUCTION

Generation, transmission and distribution are the three processes that must be completed before the power can be used by its ultimate consumer in a conventional electric power system. Each of these stages must be completed before the electricity can be used. To overcome the economics of scale and environmental concerns, the power is initially generated in big generating plants situated in remote, lightly populated locations far from loads. Transformers, overhead transmission lines and underground cables are utilised to carry out the second stage. Final stage is distribution which connects the source to the consumers. This step is one of the most crucial steps of the power structure since its dependability determines the ultimate power quality. The electrical power system is illustrated in Fig. 1 [1].

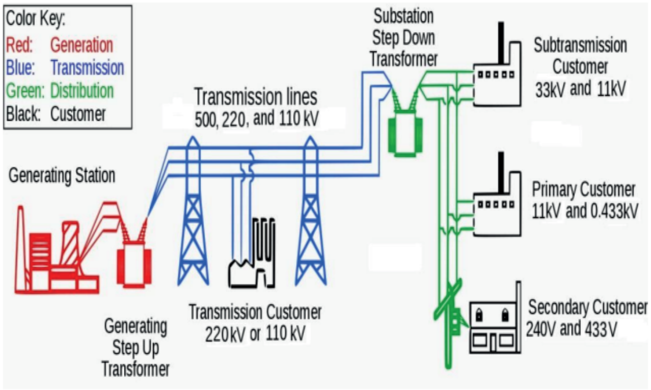

Fig. 1. Electric power system.

A distribution network utilises both overhead lines and underground cables and is comprised of several components, such as busbars, switches, circuit breakers and transformers. As power consumption has steadily increased over the past years, the distribution network has been increasing resulting in congestion. Initially, distribution systems were built to facilitate a unidirectional power transfer from higher to lower voltage levels. As load demand densities grow, distribution network complexity and difficulties will increase. Losses of power and voltage control are the primary issues in distribution networks.

The term "distributed generation" (DG) refers to the practice of utilising a number of smaller production units that have been strategically positioned across the electric power system in close proximity to load centers. It is one of the recent developments in power systems that are being employed to accommodate the increasing demand for energy. This continually growing demand for electricity results in the reduction of non-renewable power generation sources. The present liberalized electricity market is unsuited for these sources because of the high costs associated with operating them and the negative impact they have on the environment. The primary goal of utility companies is to meet the needs of their consumers by delivering power in a way that is safe, efficient and cost-effective. In this context, DG offers potential clarification to these issues. DGs are characterised by their small-scale units which may be powered by both non-renewable and renewable energy sources, and need a smaller land area for installation [2].

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Because of these properties, they find widespread applications in electrical distribution systems (DSs). In addition, DG units that are positioned in the most effective manner reduce the amount of system losses while also improving voltage safety and stability, system dependability, power quality and voltage profile. Moreover, DGs are effective in reducing voltage sags and harmonics to a large degree. Consequently, the integration of DG into DS is extremely advantageous for both the utilities and the users [1]. In addition to these benefits, it also has a number of drawbacks, particularly if it is not positioned in the most optimal areas. Problems with stability, frequency, power quality and protection might result from its presence. In addition, the development of modular DGs demands a cheaper initial investment, less time for construction and less area than traditional methods. As a direct consequence, DG has emerged in recent years as the most popular subject of research.

In recent times, issues pertaining to the environment, the economy and technology have arisen in relation to electrical systems. The utilisation of DG units presents a workable solution to alleviate such issues. Because of the deregulatory changes in the electrical industry, the participation of these units has become even more important. In addition, units of DGs are viable possibilities for DS managers to choose from. It would be done to fulfill the essentials of their customers [3]. The outcomes of the research conducted on the topic clearly support the idea that the DG placement and size in DS have a significant impact on the environmental, economic and technological goals of DS. DG allocation refers to the process of determining the ideal dimensions for DGs in terms of size, position and type in DS. In addition, the installation of adequate DG in acceptable locations and of suitable sizes would significantly reduce the amount of system losses. DGs avoid the requirement of moving bulk power since they generate electricity closer to the load centers that they serve. This reduces the strain that is placed on the electric transmission networks. The use of DGs is often regarded as the most cost-effective strategy for bringing electricity to rural locations with high distribution and transmission expenses. DGs increase the variety of energy source options, which in turn increases industry competitiveness, improves power quality and lowers the price of electricity for end customers [4].

Despite these advancements, DGs continue to face a number of obstacles. DSs were first built and intended to only be able to manage the flow of electricity in one particular way. However, the insertion of DG units resulted in bidirectional power flows, which significantly disrupted and affected the operation of the protective relay. In addition, the islanding phenomenon may take place in DSs that contain DG. Islanding causes dangerously high voltages and significant power losses and it also puts the crew and the general public in danger. It is possible that stability issues might be caused by improper DG location and size. When utilising DG in DSs, it is therefore necessary to take into consideration all of the aforementioned variables.

II. LITERATURE REVIEW

DG refers to the production of electricity by alternative generating sources located near the consumer areas. This system is coupled to the source network at the point of common coupling (PCC). This coupling is made to limit the augmentation of the existing electric transmission system. Power networks are expanding rapidly in the domain of DG due to profitable features, environment-friendly impacts, and reliability requirements, amongst other factors. At the distribution level, in today's reorganised electricity system, there is a significant development in the usage of DGs. This is because of the obvious benefits which include an increase in the dependability of the supply, an improved voltage patternand a decrease in the amount of loss that occurs during transmission. The utilisation of energy derived from renewable sources is becoming increasingly significant due to the fact that it encourages sustainable living and, with a few notable exceptions (such as the burning of biomass), does not pollute the environment. It is possible to employ renewable sources in either large-scale or small-scale applications, depending on the location and the availability of the resource. Massive-scale applications may be carried out in areas with plentiful resources [5].

Over the past few years, a great amount of attention has been dedicated to the power quality challenges, both by scholars and by professionals. Improvement in power quality has become a major concern for power sectors and power companies in the modern era. This is primarily attributable to the increased sensitivity of electrical devices, the negative side effects of modern equipment, the growing demand for electricity of a high quality, the tendency of producers to prioritize customer satisfaction, and the ability of consumers to evaluate power quality. Power quality pertains to an overarching framework that encompasses a variety of subcategories, including huge and brief disturbances, voltage sag, voltage swell and reliability concerns [6]. On the utility side, switching operations, faults, and lightning are the principal causes of power quality difficulties. On consumer side, there are multiple obstacles such as nonlinear loads, poor grounding, electromagnetic interference, and static electricity. All industrial, commercial, and residential consumers may be affected by the issue of power quality. Figure 2 depicts the findings of a study carried by Georgia Power Company on the factors of power quality difficulties from the utility and consumer perspectives [7], [8].

Figure 3 depicts a market research and analysis study completed by the GreenTree Global team on the primary factors impacting power quality, market size, and trends for 2018–2021 [9]. This indicates that voltage dips, transients, and spikes constitute over 50% of the factors of power quality deterioration.

The grid experiences several power quality difficulties such as voltage dips, swells, harmonics, load shedding, etc. Some power quality difficulties may have a negative impact on the protection system, resulting in defective protective devices. These variables also influence the different measuring devices and monitoring systems. Voltage disturbances are a major power quality concern requiring regulation. Voltage regulation is contingent upon the generator excitation mechanism and reactive power correction [10].

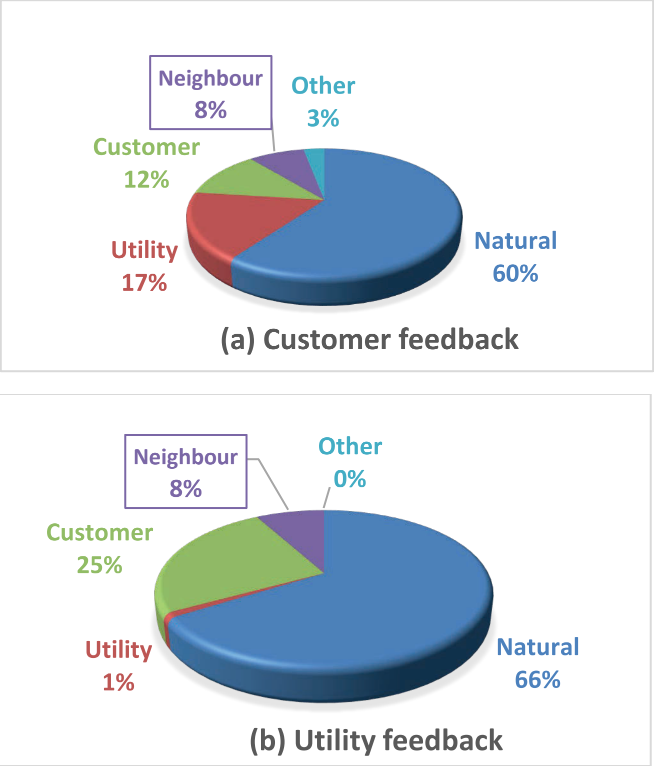

Fig. 2. (a) Customer and (b) utility feedback results of a study conducted by Georgia Power on the factors of power quality issues.

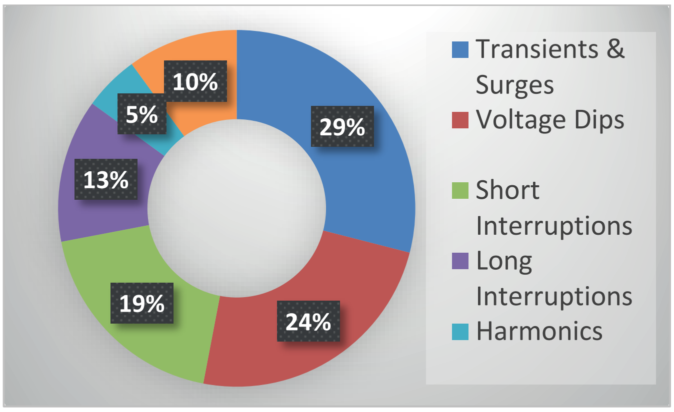

Fig. 3. Major power quality issues epresented by GreenTree Global team.

The utilisation and incorporation of DG units, which can maximize the penetration of green energy into the utility network, raise concerns about voltage and frequency stability. This is because DG systems can increase the amount of green energy that is used. Inefficient utility network systems are characterised by frequent occurrences of voltage distortions as well as variations. Voltage harmonics may yield due to the ripple currents that are generated by the power electronics converters. As a consequence, the distorted voltage waveforms might be achieved. As a result of the proliferation of DG and the benefits it confers on transmission and distribution networks alike, this phenomenon is now recognised as a persistent challenge for the operation of power systems and the planning of their further growth. DG affected difficulties are one of these things that have to be taken into account. In this context, the effects of dispersed generation on the dependability of distribution networks are one of the most significant concerns that should be researched not only by scholars but also by those responsible for the planning of distribution networks [11]. Therefore, distribution network designers need to take into account the influence that DGs have while they are working on developing the system.

A number of studies on reliability evaluation in distribution networks linked with DGs have been carried out in recent years. Placement of distributed resources has been investigated in past works, with the goals of enhancing voltage profile, cutting power loss, and bolstering system dependability being the primary centers of attention [12]. When distribution networks were seen as a market place in previous publications, reliability evaluations were carried out [12].

Because it is feasible to put DGs at several different points along a feeder, it is necessary to develop an analytical method for determining how reliable a feeder is when it contains DG in several different points along the feeder. DG refers to the integration of renewable energy sources (RES) at the distribution level. Owing to the greater involvement of intermittent RES with DS, the utility company is concerned because this may represent a danger to the network in terms of stability, voltage control, and power-quality concerns [13].

Therefore, the DG systems are expected to conform with rigorous regulatory and technical frameworks. This gives assurance to the safe, dependable, and effective performance of the whole network. Because of recent developments involved in power sector, DG networks can readily be regulated, which improves the network performance and provides greater power quality [12], [14]. DG is the most emerging technology in power networks that is being utilised to serve the ever-increasing demand for energy [12], [13]. A universally acknowledged definition of DG does not exist since the term encompasses a wide variety of technologies and applications. Notations such as “embedded generation”, “dispersed generation” and “decentralized generation” are used in various nations. DGs are thought of as an electrical source that is coupled to the power network at a point that is either extremely close to or at the location of the customer. In comparison to centralised power plants, DGs are considerably smaller in size. It is the intention of the scattered generation that has been implemented in the radial and mesh system for there to be no production of electricity in either the DS or at the loads that are local. This introduction may play a major part in enhancing the power flow and voltage pattern of the overall system [15], [16]. Depending on the parameters of dispersed generation and the operational characteristics of the distribution system [17], [18], the implications of this form of generation may appear as negative or positive consequences. Table I outlines the significant DG studies conducted by various authors.

TABLE I
SUMMARY OF DG RESEARCH

Sources & Objectives	**Techniques**	**Obtained Results**	**Demerits**
To increase DG resilience and lower their computational run time. To get the lowest possible network loss configuration in DS [20].	Genetic Algorithm, Enhanced Reconfiguration scheme	Results demonstrated the effectiveness of the suggested method for determining ideal switch status, DG unit sizes, and placements in a shorter amount of time.	This work was primarily focused on energy dissipation minimization and runtime reduction; however, for improved power networks in the future, more elements should be examined.
To determine the best size and placement of DGs for improved voltage stability [21].	Chaotic Artificial Bee Colony (CABC)	Decreased reactive and actual power losses and improved voltage pattern of the system.	More factors affecting DG performance must be investigated and validated.
To determine the best distribution of Distributed Generation in DS. To endorse the efficiency and practicability of Kill-Herd on radial DS using 118, 69, and 33 buses [22].	Kill-Herd (KH) Technique	Examined the complicated problem of size of DG and placement for energy loss reduction in radial DS. Reduced loss of power by putting DG in the most advantageous position.	The ideal tuning of some input parameters led to local convergence, which was caused by improper parameter selections.
To ensure that the DG system has the appropriate level of overcurrent relay coordination. To prevent unneeded power outages and the malfunctioning of relays, while the DG is being penetrated [23].	Global Sensitivity Analysis (GSA), Particle Swarm Optimisation (PSO)	GSA demonstrated superior performance in terms of relay coordination.	Combining several distinct strategies will lead to greater results, but first, further progress should be made.
To calculate ideal sizing of DG and position by taking voltage stability in DS into account [24].	Teaching learning, dependent optimization method, PSO, GA	Analysed test system performance with and without DG installations. With optimal DG positioning, improved performance was achieved.	There is a need for more research that takes into account various types of DG. In addition to DGs, fixed capacitors can be used to obtain better results.
To determine the best DG distribution and network reconfiguration for radial DS. To improve the convergence and precision of optimization strategies [25].	Intelligent search dependent teaching learning optimization	Increased solution quality while decreasing CPU time. The rearrangement of the network boosted the objectives of DG installation.	For optimally arranging distributed resources with intermittent generation, more research is required.
To analyse the technical aspects that influence DG integration. To investigate optimization techniques for determining appropriate DG allocation [26].	Harmony search, Ant colony, GA, hybrid heuristic schemes	Offered the most recent publications on the implementation of various optimization strategies for resolving the DG allocation problem in power system networks.	There were no dynamic distribution networks in use. Therefore, dynamic models must be utilised for future DG planning.
To limit DS loss through proper DG resource sizing. To increase voltage profile [27].	Ant-lion Optimization (ALO)	ALO demonstrated superior performance by reducing power losses and achieving an improved voltage profile.	There is a need for more research that considers various transmission buses in order to get better outcomes.

III. TYPES OF DISTRIBUTED GENERATION

A. Photovoltaic Systems

Solar energy generation is one of the most promising and quickly developing renewable energy sources in the world. Utilising photovoltaic solar cells, solar power is the transformation of solar radiation into electricity. Photovoltaic effect is responsible for this conversion in the solar cell. Inputs are typically produced in the megawatt range. The energy of solar panels is transformed to alternating current by the inverter. On the other hand, it does have a few drawbacks, such as being dependent on the weather and having intermittent availability throughout the day and night. In addition, a huge involvement level of PV paired with changes in load demand generates power variations, in addition to unpredicted voltage spikes, issues with voltage regularity, and increased energy losses in the distribution systems.

B. Wind Turbines

Wind turbines generate power from wind energy. Wind is a very fluctuating source that cannot be stored; hence, it must be managed in accordance with this property. In the most prevalent arrangement, the generating system outputs an AC voltage that varies with wind speed. Due to the changing nature of wind speed, the produced voltage must be converted to DC and back to AC using inverters. However, wind turbines with a constant speed are directly linked to the grid. The intermittent nature of wind power production and the high initial investment costs are the primary drawbacks associated with wind power. Furthermore, several issues may arise in the power distribution networks as a consequence of strong wind production occurring concurrently with off-demand [19].

The convergence of EVs with RES has also been looked at in various recent research studies which reveals that the grid incorporation of electric vehicles (EVs) needs improvisation. A state-of-the-art schematic framework developed in high impact research works implies better charging capability, long operating duration and minimum power loss through the storage devices. Various benefits can be achieved by EVs to include low operating expense, the reduced CO_2 emissions and services to the grid by using the proper infrastructure. The grid and electric vehicles will exchange power using V2G technologies. V2G technologies can provide a variety of services to the grid, including support for clean energy sources, load balancing and other ancillary services. Implementing V2G technologies will eliminate a number of problems, including vehicle battery loss and effects on delivery parameters.

IV. IMPACT OF DISTRIBUTED GENERATION ON POWER QUALITY

As it has been stated that the integration of DGs with the distribution system may create overvoltage or undervoltage, the issue arises as to what degree this statement is accurate. Distributed generation is meant to sustain and enhance the system voltage. Furthermore, several DG technologies, such as solar and wind generators, have an intermittent power production. As a consequence, voltage fluctuations take place, which, in turn, lower the overall quality of the electricity that is supplied to customers. In addition, there have been reports of over-voltage and under-voltage in distribution networks that use DG as a result of the incompatibility of DGs with the various techniques that are currently used to regulate voltage. In most cases, voltage regulators, capacitors, and the changing of the taps on transformers are used in order to accomplish the task of regulating the distribution networks. These techniques were developed for the flow of radial (unidirectional) power and showed a high level of dependability and effectiveness in the past. However, in modern times, the installation of DGs in distribution networks has had a significant influence on the performance of voltage control systems. This is because DGs have brought a meshed (bidirectional) power flow to the networks. On the other hand, the integration of DG had a significant impact on the distribution networks.

This is due to the fact that DG makes a contribution to the reactive compensation for voltage control, frequency regulation, and they operate as spinning reserve in the event that the fault indices of the main system are exceeded [28]. Various power quality issues of AC system are shown in Fig. 4.

It is important to position DG units in locations where they will have the most impact on lowering losses. The purpose of this method of DG allocation is to reduce the power losses (both active and reactive) that distribution networks experience as a result of its installation close to load centers. Several studies, the majority of which were published before, revealed that the placement of a DG unit and the size of the unit generator both played a vital role in the reduction of power losses. Consequently, the unique position of a DG within a dispersed network and the DG specific capacity that results in the least amount of power loss are determined as the optimal location. The DG allocation approach closely resembles the capacitor allocation procedure for reducing power losses. The primary distinction between the two methods is that DG units have an effect on both real and reactive power, whereas capacitor banks solely affect the flow of reactive power. It has been demonstrated that in the event of networks undergoing increasing power losses, deploying a relatively small distributed generating unit that is strategically connected to the network may result in a significant reduction in the amount of power losses [29].

Integration of DG into electrical distribution networks can potentially have severe consequences, particularly for large-scale systems if not efficiently managed. The primary disadvantages of DG are outlined below [30]:

- The integration of DGs may result in over-voltage and voltage profile problems, mostly owing to mismatched synchronization with the electrical supply facilities.
- When a DG is linked to a network, the short circuit levels change. Therefore, relay settings should be modified and if DG is disconnected, relay settings should be returned to their original condition.
- Power losses are reduced as a consequence of DG power injection; but, depending on the network structure, the penetration level, and the type of the DG technology, this decrease in power losses may be offset by an increase in power losses in the distribution system.

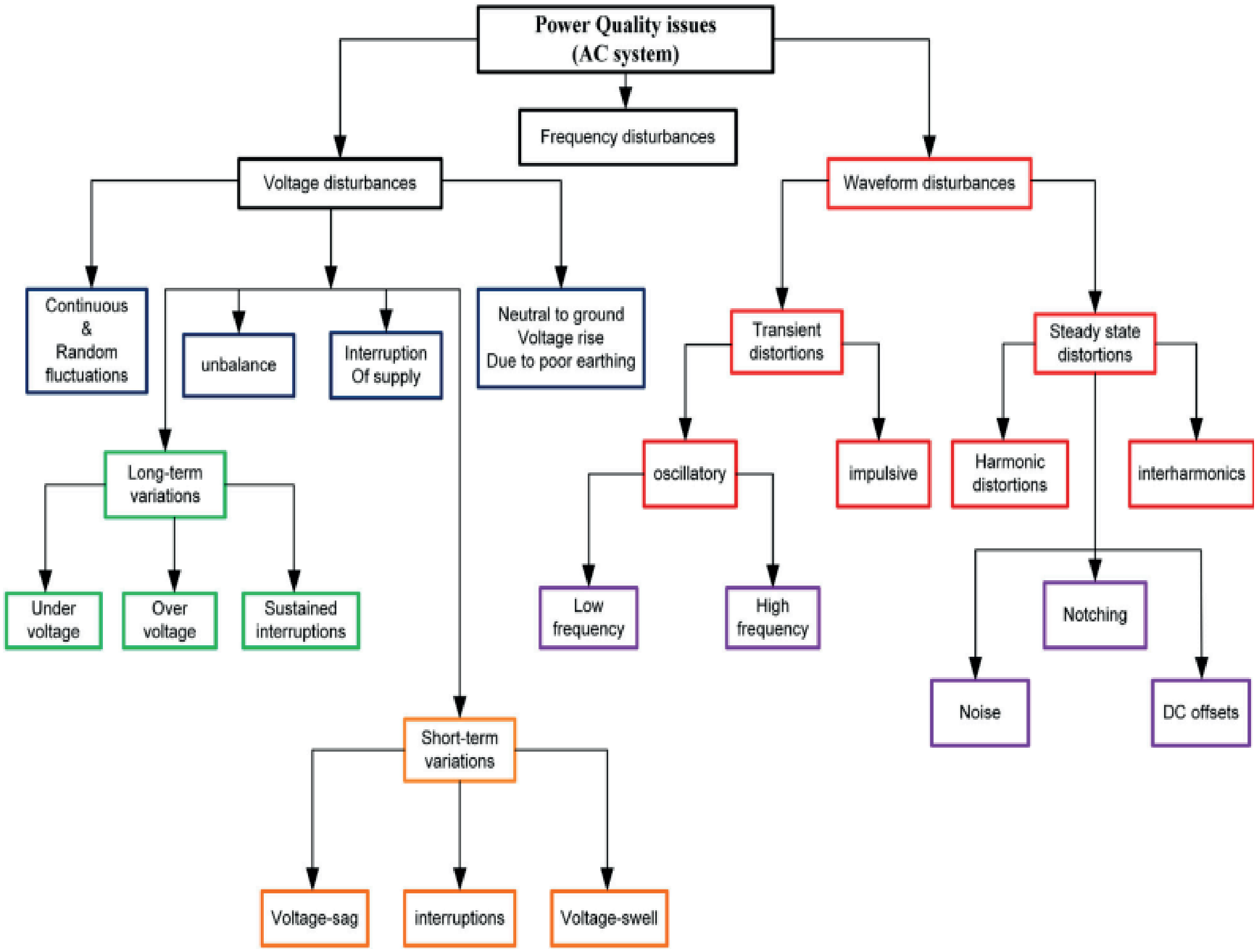

Fig. 4. Classification of power quality issues.

Installations of DGs are dependent on the reliability of the distribution network. After a significant disruption, the DG should be able to maintain its synchronization. Additionally, a widespread adoption of DG results in a reduction of the overall system inertia. The system frequency will become highly sensitive to disturbances if the principal control is not applied with a rapid acting, unless it is applied.

V. CONCLUSION

The use of DGs has a more significant effect on energy loss, voltage instability, distortions, short circuits, and the safety of islands and networks. There are several benefits of having decentralized generation, one of which is the ability to generate power in close proximity to where it is used. The diversity of power sources, the decrease of power dissipation in the system, which has resulted in an efficient energy market, the utilization of renewable energy resources, and the savings of energy are all contributing factors to the expansion of the energy supply. The release of greenhouse gases, most notably carbon dioxide, as a result of the combustion of fossil fuels is also an eliminated prospect with the adoption of DGs using RES. Even though these and other additional benefits of DGs and energy resources may be easily identified, DGs and energy resources are not always economically viable. The cost of energy and the actions taken by the national government to encourage the use of DG resources will have a significant impact on the company's capacity to remain profitable. However, in the near future, widespread recognition of the advantages of DGs will be accepted.

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