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Voltage control ancillary services for low voltage distributed generation

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Abstract

This paper sheds light on the provision of voltage control ancillary services for low voltage Distributed Generation (DG), the need for the creation of the microgrid ancillary services market, since the ancillary service network operation does not include small size energy generation. The limitations facing the participation of DG in the provision of ancillary services, the basis for the creation of microgrid ancillary service market, the gap between the large power plants and smaller sources, as well as useful recommendations to help proffer solution to the problem were considered. This work also embraces the types of ancillary services, micro-grid, distributed generations, voltage control ancillary services, the various types of voltage control service and their usefulness to power system network. The various techniques for voltage control, the relationship between reactive power and voltage control, power factor and power factor corrections as well as their effects on power system were also illustrated.

Keywords: Microgrid, voltage control, distributed generation, market

1. Introduction

Ancillary services are the specialty services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that the supply will continually meet the demand. The term ancillary services refer to a variety of operations beyond the generation and transmission that are required to maintain grid stability and security. Ancillary services refer to those mandatory services required to provide support to the operations of the grid. A number of ancillary services exist, they are supplied by different authorities and certainly may not be the same, and some of the ancillary services are accepted by virtually all the authorities for example, black start, voltage control and frequency control [1]. According to a research in the past [2], ancillary services refer to all those essential services which are usually provided by the grid and which the DSO or TSO also need in order to be able to sustain the stability, integrity and power quality of the distribution or transmission system.

Conversely, another research [3] shows that customers usually demand for energy and capacity but that, it is not only the both of them that are essential for the power system to work effectively, and also essential is a number of grid support services, as they equip the operators of the system with the means required in order to sustain the immediate and continual balance between load and generation, to ensure that the transmission line flows are properly coordinated and also to ensure the control schemes are implemented.

Under normal conditions and also during emergencies, these ancillary services are in demand as they also make provisions for the necessary amenities required for the power system to restart should a situation arises where the balance between generation and load could not be maintained resulting in system breakdown. The numerous types of ancillary services in power systems are as shown in Figure 1.

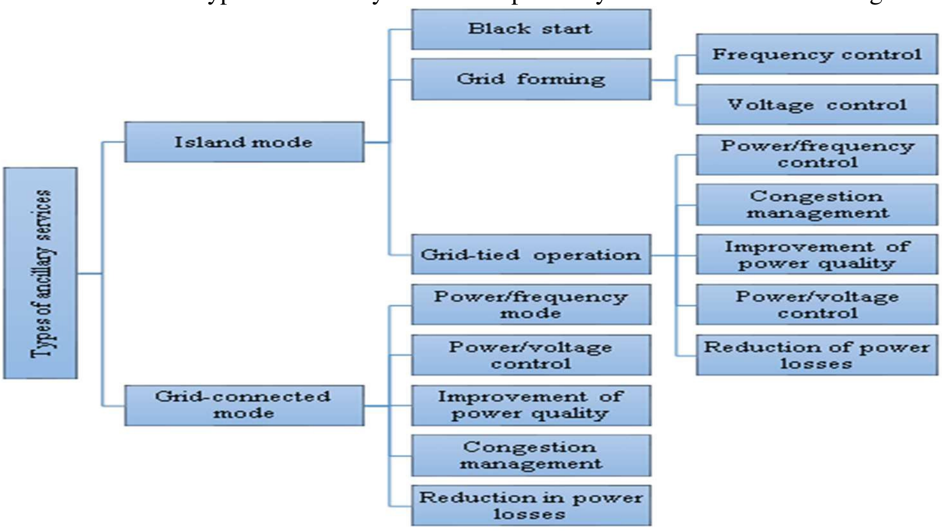

Fig. 1. Types of ancillary services

1.1. Provision of ancillary services to the microgrid

A microgrid is a small small-scale electricity grid, which can function separately or simultaneously with the major electricity grid in the location, it usually requires different sources of energy.

The distribution system of a micro grid is usually composed of sources of energy often referred to as micro sources, means of storage alongside loads that are controllable [4]. Microgrids can be grouped into the following types as shown in Figure 2.

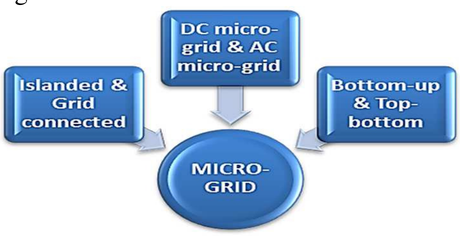

Fig. 2. Types of microgrids

Micro-grid in [5] is made up electrical power generators, some of whose power, is sourced from renewable resources, for example, sunlight and wind, these power generators are referred to as distributed generation, DG. Depending on size and capacity, a micro-grid has some basic functionalities as shown Figure 3.

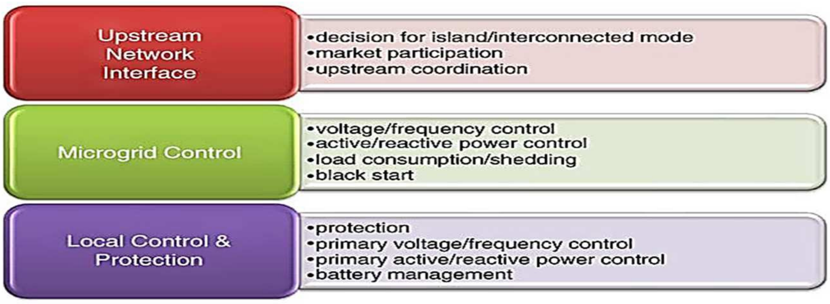

Fig. 3. Microgrid functionalities [6]

Ancillary services can be provided by microgrids as shown in Figure 3 and this is possible if the technical requirements to provide the ancillary services are satisfied by the microgrid [1]. We anticipate that in future, the supply of electricity will depend more on DG, especially from sources of renewable energy, but, at the moment, the power contribution to distribution from DG such as wind and PV are limited, as such do not take part in network operation. DGs are excluded from network operations because of its unstable nature, operational cost and size [7].

1.2. Distributed generation, DG.

Distributed generation (DG) refers to a system or mechanism, which produces electricity near to the consumers with the use of small-scaled power systems. In [8], the energy sources of a DG technology comprises of non-renewable sources of energy, renewable sources of energy and battery storage. The renewable DG is such that you can't predict the stability of power supply since the resources are usually unstable as in [9]. The energy sources are as shown in Figure 4.

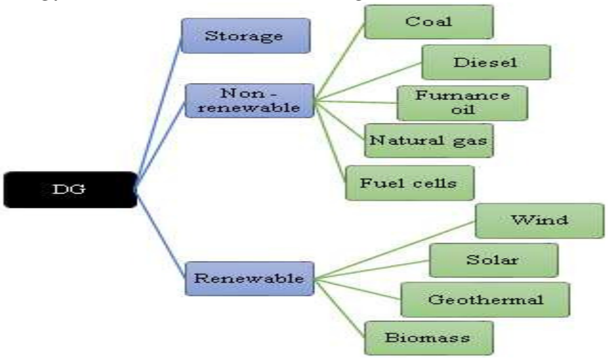

Fig. 4. DG energy sources

It comprises majorly of energy sources that are modular in nature. It usually comprises of renewable energy sources. Because it's usually made up of energy from renewable sources, it has the following advantages: it is friendly to the environment, it can be made available at a much lower cost, and it is more reliable and secured [10]. Generally, DG classification is done on several basis as shown in Figure 5.

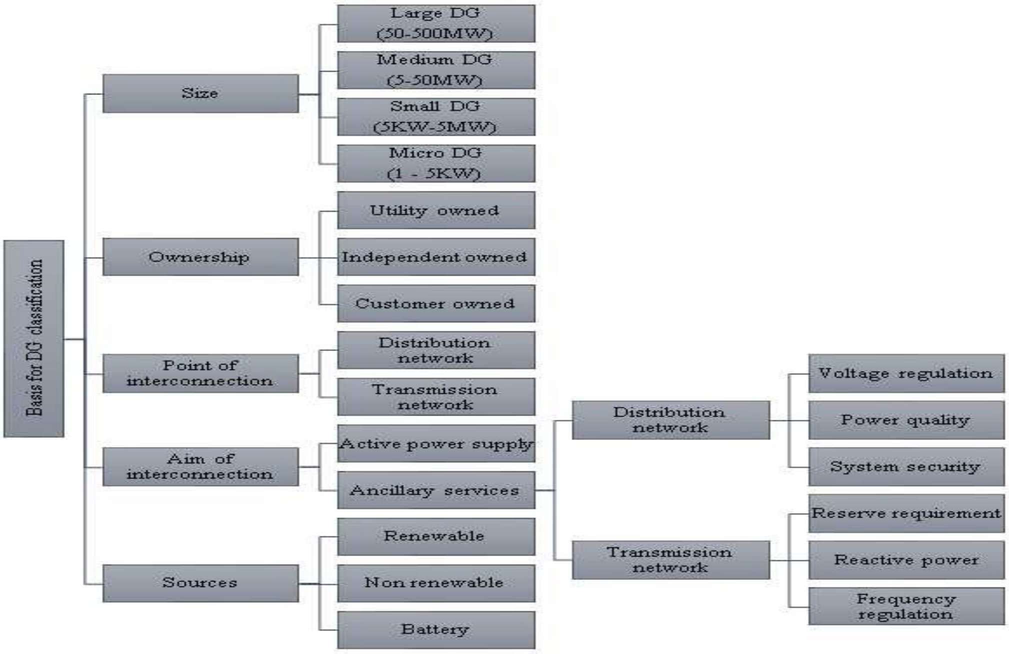

Fig. 5. Classification of DG

DG can be operated as a Utility-connected system or as a stand-alone system usually carried out in an isolated location, such as rural areas where they are used to provide power supply to small buildings, large buildings, industrial site, estate etc. and usually, it is individuals who operate them. DG units give rise to DC power or AC power and these two forms of power cannot be connected together directly and as such the required frequency, voltage magnitude and phase angle are generally derived by means of power electronics interfaces.

With the help of a suitable power electronics interface, each of the various DG units can be linked to the main grid. In some designs, a number of power electronic units are employed and some designs make use of a single power electronics unit to reap some benefits such as minimized losses, simpler design and reduced cost in terms of the control of the system.

It has been observed that DG units comprising of renewable energy sources are better because the sources of energy will not be exhausted in the long run, they are friendly to the environment, energy from the individual sources can be combined to produce a DC voltage as input to DC/AC inverter, which is required for grid connection or connection to a low voltage distribution network [11].

Distributed generation has the potential to provide active power as well as provide ancillary services to the electrical network; In a low voltage network, the DG can operate at a power factor of unity and as such, can be used to check the challenges of voltage regulation as in [12]

This paper focuses on the application of voltage control ancillary service to a low voltage distribution network in hybrid micro-grid and the creation of microgrid ancillary services market.

2. Microgrid ancillary services market

In order to support efficiency and encourage improvement in electrical power services, there is a need for competition among the stakeholders. Participation of distributed energy resources in power generation and provision of ancillary services needs to be supported. Presently distributed energy resources are faced with limitations, some of the factors responsible for the limitations as in [13] include

- Within the European countries, the requirements and naming of the voltage control services is not homogenous, as the voltage control layers are not differentiated.

- The prevailing market structure for ancillary services, supports the supply of ancillary services via programmable generation units i.e. non-renewable energy sources
- As a result of existing regulations, there is a technological limitation to the participation of renewable energy sources.
- Access to participation is limited to the size of the plant as access is restricted only to plants with capacity above 10MVA.

2.1. Need for the creation of microgrid ancillary services market

- A market for microgrid ancillary services can create room for competition among the players and this will result in enhanced efficiency.
- Network operations are required for both low and high voltage distribution systems.
- Power quality and stability is a necessity for every electrical power network.
- Creation of job and investment opportunities.
- To create a basis for DG and microgrid structures
- To increase flexibility.

2.2. Basis for the creation of a microgrid ancillary services market.

Microgrid ancillary services market is grouped based on connectivity, offering, vertical, region and grid type. The different groups also have divisions as shown in the Figure 6

Fig. 6. Basis for the classification of ancillary services market

2.3. Recommendations

Some of the recommendations made to proffer solution to the limitations are as shown below

- Procurement process should be enhanced and reserves activated
- Renewable energy sources should be allowed to participate in the provision of ancillary services whenever possible technically
- The combination of smaller energy units should be engaged and not only big power units
- The gradient should be expressed based on a percentage of the maximum power output and not in absolute values like 10MW.
- Harmonization of the rules for balancing and for using ancillary services across countries in a geographical region, for example Europe, should be carried out.

For a reliable microgrid ancillary services market to function effectively, there must be an audience, usually referred to as the business target audience. The targets in this case are government agencies, transmission system operators, raw materials and equipment suppliers, investor community, utilities, Photovoltaic companies, smart grid software vendors, energy storage vendors, microgrid systems integrators and suppliers.

2.4. Market prospects for microgrid voltage control ancillary services

In the ancillary services market, var utilization is the major product for voltage control, in order for the reactive power needs to be satisfied, the distribution system operator operates a voltage control ancillary services market so that the var needs are distributed between the numerous players whose var bids are accommodated by the distribution system. In this case, the distribution system operator, DSO performs the role of the buyer, and ensures that the market is settled, the major sources of var include microgrids, MV-connected DG units and HV network (if available) [7].

3. Voltage control ancillary services

Voltage control as an ancillary service involves maintaining the set points of the reactive power or the voltage in the network, in order to achieve this, the conditions required in order for a balance between the reactive power demand of the customers and that of the network have to be reached [13]. Voltage control is achieved through the management of reactive power in the AC electrical network, in an electrical network, transmission and distribution equipment absorbs and produces reactive power. For power systems to operate reliably and effectively, voltage and reactive power must be controlled to meet the objectives below as in [14] [15].

- The movement of reactive power in an electrical system from one point to another is reduced in order to cut down XI^2 and RI^2 losses reasonably.
- The stability of the system is improved to ensure that the transmission system utilization is maximized.
- Voltages are within an allowable limit at terminals of each of the equipment in the system.

The function of voltage control has to do with fluctuating load conditions and the corresponding reactive power compensation requirements. Voltage control ancillary services include a fault-ride through (FRT) capability, congestion management, primary voltage control, secondary voltage control and tertiary voltage control. It can be grouped into two categories as in [16] namely

- Distribution system voltage control and
- Transmission system voltage control.

3.1. Distribution voltage control

Distribution voltage control, also known as volt/var refers to voltage control at the distribution level, its main aim is to ensure, energy losses and peak power are reduced while maintaining the voltage within allowable limits for a number of different nominal load systems. Variables of interest include tap changer voltage regulator, capacitors control dead bands, sizes, etc. the voltage on the secondary side of a transformer is measured or regulated with the help of tap changers, and the tap changers are usually controlled with the help of relay controllers.

Transmission System voltage control, on the other hand can be categorized with respect to activation time as shown in Figure 7.

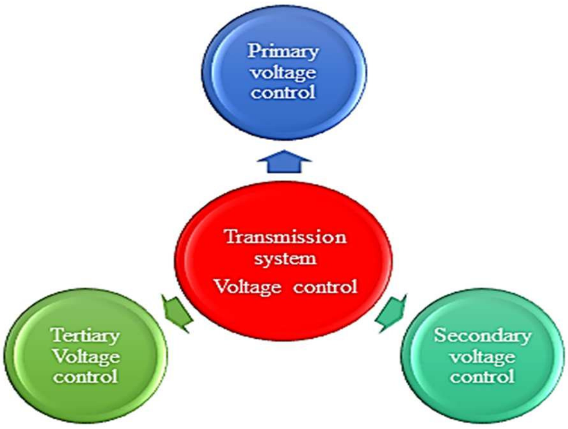

Fig. 7. Categories of transmission voltage control

3.1.1 Primary voltage control

This involves the use of automatic voltage regulators (AVRs) to ensure the voltage of the electrical devices is maintained with respect to their reference value at the point of common coupling. The values involve are normally fixed on a several basis, for example, the maximum amount of reactive power to supply from any of the devices, voltage drops and security requirements etc. This type of voltage control can be operation for 1 minute,

3.1.2 Secondary voltage control

Unlike primary voltage control, this type of voltage control can progress for a minute and can continue for some minutes. Voltage is maintained at specific pilot nodes by coordinating the reactive power resources from the different segments of the network. Once the voltage at the buses becomes out of scope, the voltage regulator set points are adjusted by the system operator to ensure a voltage profile is recovered.

3.1.3 Tertiary voltage control

This type of voltage control has the longest duration of operation, it takes between 10 – 30 minutes and it operates on the entire system. Its primary purpose is to ensure that losses are minimized, the required voltage is maintained, reactive reserves are replaced and the secondary voltage control set point values are provided in order for the operation of the network to be optimized [13]

In a distribution system, the variation in voltage across the line is given as equation (1)

$$\Delta V = \frac{(P_R + Q_X)}{V} \quad (1)$$

Where P and Q stand for the active power and reactive power generated by power source while the resistance and reactance of the electrical line linking the power source are represented by R and X respectively, V stands for the nominal voltage at the power source terminal [17].

With respect to equation 1, any meaningful quantity of electrical power introduced by a power source for instance a DG, will result in an increase/decrease in voltage on the power distribution system especially if the distribution feeder is weak and its impedance is high. Variation in voltage is also influenced by the size of the DG, the voltage regulation method adopted as well as the location.

3.2. Techniques for voltage control

Some of the numerous techniques for voltage control applied in several applications are as shown in Figure 8.

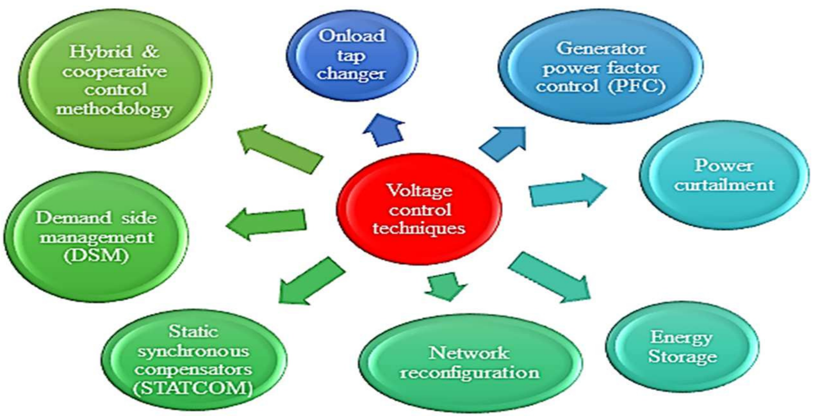

Fig. 8. Techniques for voltage control

Ancillary services over time, have been provided by the conventional generator, because of the need for power generation from distributed energy resources, there is a need for the creation of micro-grid ancillary services.

4. Reactive power and voltage control

In a power system network, when the voltage and current are not in phase, reactive power is said to be present ie it is evident that reactive power exist in a power network when:

- One waveform leads the other waveform
- Power factor of the network is less than unity
- When the phase angle between current and voltage is not equal to 0°

Reactive power is produced when the waveform of current leads that of voltage (often referred to as a leading power factor) and consumed when the waveform of the current lags that of voltage (usually referred to as lagging factor) [18].

A device that consumes power in a manner such that the waveform of the voltage and that of the current are in phase with each other, is said to have consumed real power and zero reactive power but if the current waveform lags that of the voltage, reactive power is said to be consumed. The quantity of reactive power that the device consumed is determined by the phase shift between them. The relationship between real power, P and reactive Power, Q is as given in equation (2)

$$S = P + JQ = V.I^* = VIcos\varphi + jVIsin\varphi \quad (2)$$

Where S represents the apparent power, P is measured in watts while Q is measured in volt-ampere reactive [19]. Reactive power exists as a result of a phase shift between current and voltage curves in power system [20]. The operation of the power system network is affected by reactive power in numerous ways as in [21]

- Loads absorb reactive power and this has to be supplied from some source.
- Transformers and transmission lines absorb reactive power, this has to be supplied from some source, but note that; every transmission line does generate a certain amount of reactive power from the charging of their shunt line, which affects their ability to consume reactive power.
- The movement of the reactive power from its source to sink creates extra heating to the lines and drops in the voltage of the network.
- The production of real power can be restricted by the production of reactive power

4.1. Usefulness of reactive power in power system

In an electrical power network, voltage control is very useful as it ensures that power system devices operate properly to help stop problems such as excessive heating of motors and generators in order to minimize losses from transmission and conversely to sustain the capacity of the electrical system to prevent as well as withstand voltage collapse.

Electrical power often witness under-voltage and over-voltage during operation, this challenge can be checked with the help of voltage/var control. Voltage/var control ensures that the movement of reactive power well as its absorption and production at the different levels in the power system is controlled, it also ensures the voltage profile is maintained within the allowable range and that transmission losses are minimized.

A reduction in reactive power gives rise to a reduction in voltage and conversely, increasing the reactive power increases the voltage. In power system, when the system is faced with a situation where the load exceeds that which the voltage can support, a voltage collapse takes place. In the event a reduction in supply of reactive power, the supply voltage also reduces, there has to be an increase in the current in order to maintain power supply, this results in the absorption of more reactive power by the system leading to more reduction in voltage. If the increase in current is in excess, the transmission line will go off and in the process overload other lines, and hence cascading failure results.

Conversely, if the reduction in voltage is very low, it will give rise to a situation where a number of generators will have to be disconnected from the network automatically to avoid being damaged.

When a power system experiences a reduction in voltage of this nature that is progressive and uncontrollable, it implies that the power system network cannot supply the appropriate reactive power needed by the power system [16]. Other usefulness of reactive power as in [18] are as follows:

- In order for the movement of electrons to be converted into work, reactive power is required by motor loads, etc.
- For active power to perform useful work, the necessary voltage level required, is provided by reactive power
- It helps to regulate voltage.
- For active power to move to a consumer through the distribution and transmission system, reactive power is required.

4.2. Limitations of reactive power

- It cannot travel far
- Production of reactive power closest to the area of need is a necessity
- Its supply is tied closely to its capacity to provide active power
- A source of reactive power at a close proximity to the area need is in better condition to deliver reactive power than a source at a far distance to the area of need.

Consumption and generation of reactive power is attainable with several devices as shown in Figure 9.

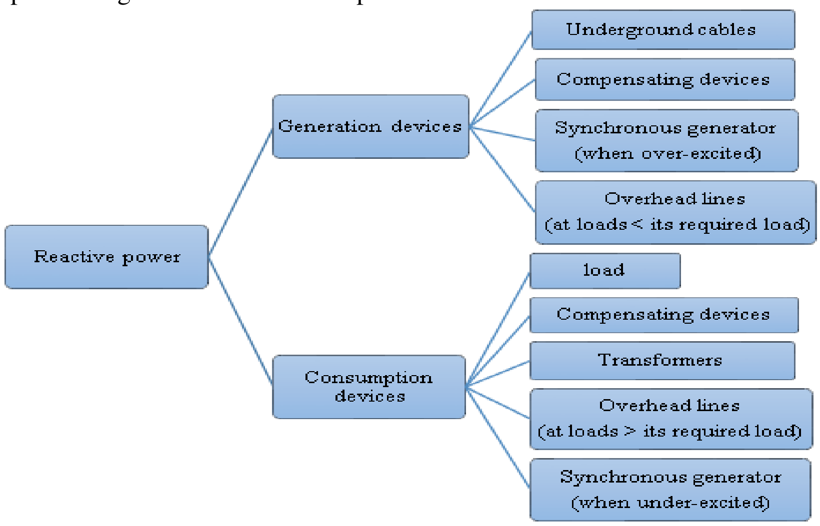

Fig. 9. Absorption and generation of reactive power.

5. Power factor

For an electrical appliance, which operates using AC supply, for example fan, refrigerator, its specification is usually given in wattage, voltage and PF. The voltage rating of the appliance represents its nominal operating Voltage, the wattage rating shows the amount of power required of the appliances when it is switched on while the PF indicates the power factor, which is usually a value between 0.6 and 1. Electrical appliances usually consume power during operation, a larger portion of the used power is converted for its intended activity while the remaining portion is wasted as heat. Power factor as in [22] is defined as the true power (KW) divided by the apparent power (KVA) used up by an AC electrical appliance.

A power factor of unity is the ideal power factor, but in most cases, the PF is less than unity and once it is less than 1, the implication is that, in order for the task at hand to be achieved, more power will be required. The moment the PF is less than 1, the remaining fraction accounts for reactive power.

PF measures the fraction of electrical power that is actually useful in doing work, mathematically, there are two ways of achieving PF and these are:

- The power factor can be calculated using the expression

  $PF = \cos\theta =$ The cosine of the angle between real power and apparent power.
- The power factor can also be calculated as follows

$$PF = \left(\frac{\text{Real\_power}(KW)}{Apparent\_Power(KVA)} \right)$$

Recall the equation (2)

$S = P + JQ$, to find the magnitude of apparent power, equation (2) becomes

$|S|^2 = P^2 + Q^2$ Where $|S| = \sqrt{P^2 + Q^2}$ (3)

$$PF = \cos\theta = \left(\frac{P(KW)}{|S|(KVA)} \right) \quad (4)$$

A network with a PF of unity is an efficient network, it means there is no reactive power and the power is very good for transmission but it is unattainable practically. There are lots of variation in power factor and this is because, the several types of electrical devices which supply or absorb reactive power are connected to the microgrid [23]

Poor power factor in a network indicates a high presence of inductive loads on the network, as inductive loads, for example air conditioning units, AC motors etc. have high demand for reactive power. An AC can have a unity, lagging or leading power factor depending on the electrical devices in the network.

Unity power factor: This implies the current and voltage are in phase, it means the angle between current and voltage in this case is zero and as a result, the cosine of the angle or PF is unity (1). A load with a unity power factor means the load is purely resistive.

Lagging power factor: this is the case with inductive load, in this case, the current vector lags the voltage vector and the power factor varies with the angle of lead and because the power factor is inductive, its sign is positive

Leading power factor: A network PF is referred to as a leading power factor when the current leads the voltage and this is the case with capacitive loads, the power factor varies with the angle of lead and because, the PF is capacitive, its sign is negative.

5.1. Power factor correction

This refers to a technology, which helps to bring the power factor of an AC power system close to unity by providing reactive power of opposite sign, this involves introducing capacitors or inductors that can help to neutralize the capacitive and inductive effect on the system load respectively. For instance, a motor load inductive effect may be cancelled by connecting a capacitor locally, similarly the effect of a capacitive load may be offset by connecting an inductor (reactor) for the purpose of power factor correction [22] [23].

5.2. Usefulness of Power Factor Correction

Power factor correction has several benefits as in [23] as shown in Figure 10.

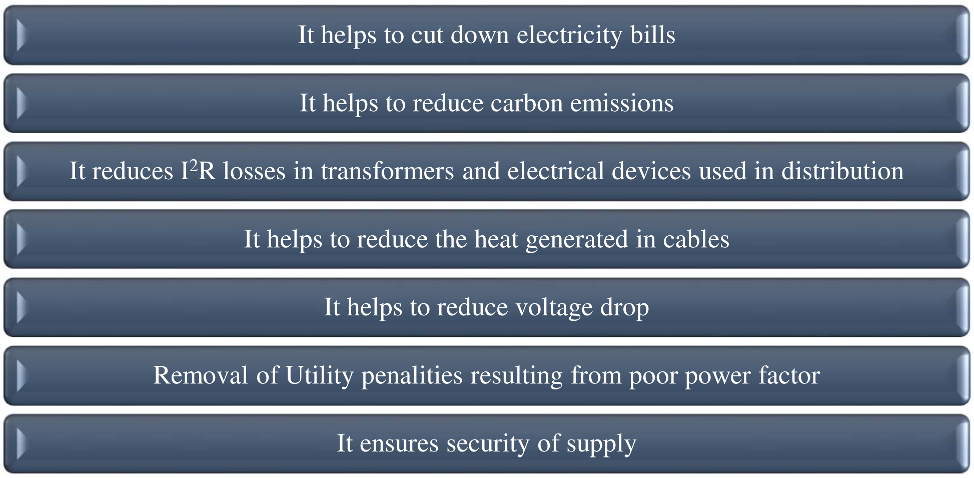

Fig. 10. Benefits of power factor correction

6. Conclusion

Voltage control ancillary services for low voltage distributed DG should be allowed and the creation of the microgrid ancillary services market should be explored and implemented. The limitations facing the participation of low voltage DG in the ancillary services were exhausted and useful recommendations to proffer a solution to the challenge were raised. Future works involve the design of market models for microgrid ancillary services.

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