163 International Journal of Smart Electrical Engineering, Vol.7, No.4, Fall 2018 ISSN: 2251-9246
EISSN: 2345-6221
pp. 163:168

A Survey on the Impact of Distributed Energy Resources on Power Flow Components

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Abstract

Turning to Renewable Energy Sources (RES) is the most logical politics in securing the modern society from critical changes in earth increasing temperature. However, Distributed Generation (DG) sources could lead to new challenges in electricity network, mainly allocation of DG sources in distribution level of power system will set the existing network under stress of power flow parameters. The generated alternation in lines current, voltage profile and power loss will make a mutation in operator optimal decision. This paper will present a detailed survey on DG impact on power flow components violation. Also, some advanced issues such as difficulty in transformers tap changer, capacitors and power quality problems (i.e. intermediate harmonic interference, transient over voltage) will be addressed by the paper. The research shows a necessity to multi-level load consideration in active distribution networks due to DG existence. The study clarifies main problems in DG application from electricity distribution system operator aspect.

Keywords: Active distribution network, DG impact, Distributed Generation (DG), Power flow components, Renewable Energy Sources.

Article history: Received 09-Oct-2018; Revised 28-Oct-2018; Accepted 05-Dec-2018.

1. Introduction

So far, several definitions have been made in different agencies for distributed products. As defined by the International Energy Agency (IEA), DGs are generating units which can inject power directly to consumers in a local distribution network. According to the International Council on Large Electric Systems (CIGREs) DGs do not dispatch energy in centralized format and typically connect to a distribution network with a capacity less than 50 to 100 MW. Electric Power Research Institute (EPRI) defines a distributed generation as a production with capacity of less than 50 MW. According to the definition of Institute of Electrical and Electronics Engineers (IEEE), a resource that is smaller than the central power plants and is capable of being installed at the place of consuming is called the DG. However, different countries also provide different definitions for distributed sources of production [1, 2 and 3].

With increasing concerns about global warming and environmental pollution, many nations have been trying to reduce carbon emissions under the Kyoto treaty. According to the treaty, carbon emissions should be reduced by 50% by 2050. Therefore, many countries have focused on the use of environmental-friendly resources, including low carbon emissions generators. The use of resources in microgrids will have a significant impact on reducing environmental pollution. The performance of these resources is such that, after assessing the level of contamination released in the environment, they send information to the DGs. In the future, there are likely to be laws and regulations for reducing emissions of greenhouse gases as well as suspended particles in the air [4, 5].

Electric vehicle and central power plants are the largest producers of NOx gases. In addition, large gas turbines and piston engines also contribute to the production of NOx due to their high operating temperatures. Conversely, micro turbines and fuel cells, due to their low combustion temperature, emit less NOx in the air; therefore, their use as scattered sources of production will significantly reduce the combustion of nitrogen and carbon and the hydrocarbon compounds [6].

In spite of DG positive effects on the reduction of carbon associated in power generation sector, its presence in distribution network is not as simple as it seems. Allocation of DG will have direct influence on power flow components such as lines current, voltage profile and power loss. Also, the obtained violation in power quality items (i.e. intermediate harmonic interference, transient over voltage) are the new challenges in active distribution networks. DGs impact on the other components in the distribution network such as transformers tap changer, capacitors is not ignorable. This paper will concentrate on the above mentioned knots caused by DGs and gives detailed overview on DG interaction with distribution network.

The rest of this paper is organized as follows. In section II, DG impact on line current is described, consequently, DG impact on voltage profile and power loss are addressed in section III and IV, respectively. DG operation mode in voltage control and fixed power factor are discussed in section V. Importance of studying various load levels in active distribution networks is presented in section VI. Some advanced issues are focused in section VII. Finally, the research will be concluded in the last section.

2. DG impact on line current

Generally, the purpose of the DGs positioning in networks is to reduce the network load so that the capacity of the lines is released, but in the event of poor engineering design some lines may be overloaded, the research in [7] discuss this concern, hence one of the important studies in the issue of the allocation of DGs is overflow in distribution system lines. The overflow can occur in two ways:

- If the DG is larger than the load placed after it, then part of its current flow goes to the substation. This usually happens when a number of loads are dropped out of the network due to an error.
- In the event that the dedicated DG has been embedded for a particular subscriber, if the load cut-out occurs, the DG flow that moves towards the front of the feeder may exceed the maximum conductor current. Fig. 1 illustrates the case (B) more clearly, a distributed source for feeding the three-phase load on the bus (a) is provided. Under the condition load cut-out, the DG current flows to point-b, and if the line between (a) and (b) is not chosen according to the available capacity of the line, then DG will not be able to transfer energy to point-b, and this line will be overloaded.

So, though, Almost DGs can help reduce the current flow of lines and release their capacity, but in a fraction of poor design, it can cause overloading.

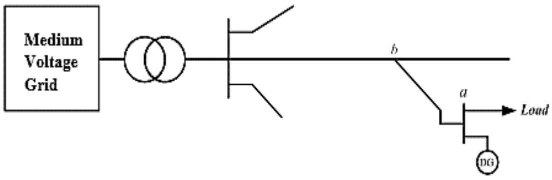

Fig. 1. Connection of DG to a sub branch of a distribution feeder

Each of the mentioned states can cause problems if the current flowed to the feeder is higher than the conductor capacity. Therefore, to solve this problem, it is possible to choose materials between the post and the DG, which have the ability to transfer DG power inversely.

3. DG impact on voltage profile

DGs that are installed in distribution networks and near the load centers can improve the voltage drop because of three reasons:

- By approximating DGs to the loads, the line impedance is decreased and frequently reduces the voltage drop.
- With local feeding, the transfer power from the distribution substation or the sub transmission substation to the end of the feeders is reduced. Consequently, the voltage drop decreases with the reduction of active reactive injectable power.
- The operation in the voltage control mode is beneficial for voltage regulation.

Due to the fact that most DGs deliver a constant power to the network, they help to improve the voltage profile during peak load hours of operation, but at low load level, they will increase the voltage profile by reverse supplying [8, 9].

This is analyzed by a case study shown in Fig. 2. In this figure, a typical DG is attached. According to the figure, the amount of injectable power of the distribution substation will be as follows:

$$S_s = P_s + jQ_s = (P_L - P_{DG}) + j(Q_L - Q_{DG}) \qquad (1)$$

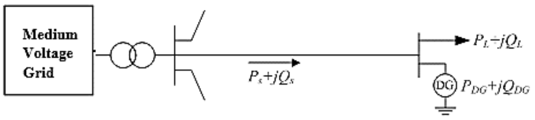

Fig. 2. Connecting a DG source to a load bus

Therefore, the value of the voltage drop is as follows:

$$\Delta V = \frac{r(P_L - P_{DG}) + x(Q_L - Q_{DG})}{V_s} \tag{2}$$

And regarding (2), the following two situations could happen:

- If in the peak hours, the injector power of DG is less than the power consumption of the load, in this case ΔV is positive and as a result, DG acts on improving the load voltage profile and will regulate it close to substation voltage.
- If at low load hours, DG injectable power is greater than the power consumption, then ΔV is negative in this case; the load voltage will be higher than the substation voltage (i.e. load bus over-voltage).

4. DG impact on power loss

Generally, depending on the location of DGs in the network, there are two cases of reduction or increments of power loss are expected:

- DGs reduce network losses by reducing the feeding route. When a DG is selected proportional to the load, it significantly reduces the loss by reducing injectable powers.
- If the DG is too far away from the substation and can deliver power to the substation, or even if its power goes back to the transmission network, then the distribution network losses will increase.

When the DG operates in the voltage control mode, the reactive power is injected to or absorbed from the network to maintain the voltage. If DG's injection power is large and works in leg-phase mode, then it will receive a large reactive power from the network. Therefore, the DG should offer a way to compensate the reactive power provided by the network. Transferring such a great reactive power through the network will increase casualties on the lines. The optimal allocation of DG in the distribution network is studied by [10, 11 and 12].

5. Effect of DG operation modes

DGs can be exploited in two different ways according to their goals and nature:

A) Fixed power factor mode:

In this case, the DG enters the circuit with constant power factor, such as DG of synchronous generators whose active power is constant; hence their constant reactive power is determined by their constant power factor. In power networks, most of the buses are operated under such a mode. The most important factor in using such a situation is the simplicity of operation and reduction of control devices.

The main problem with this functional mode is that in this case there is no control over the bus voltage and if the injection power of DG is larger than the load power, there will be increase in voltage due to reversal current flow on this bus. So, this operating mode is main reason for voltage increase, and since IEEE-1547 [13] does not allow the use of DGs in voltage control mode, this mode of operation is the most common mode of exploitation of DGs.

B) Voltage control mode:

In order to improve the voltage profile, voltage control mode is sometimes used. In this case, the control measurement equipment will determine the size of the voltage and the active power of the bus. Bus unknown items include the amount of injective reactive power and voltage angle. Given that the bus voltage which the DG is connected to it must be constant, therefore, the voltage drop calculations will be somewhat different.

We show the capability of DGs in controlling the voltage of the buses using the following mathematical method. In this method, we can write regarding Fig. 2 for the size of the load bus voltage:

$$V_s - |V_L| = \frac{r(P_L - P_{DG}) + x(Q_L - Q_{DG})}{V_s} \tag{3}$$

In this case, we consider V_s as a reference of network voltage. Now if it is assumed that the size of the bus voltage is equal to the reference voltage, then it can be written:

$$r(P_L - P_{DG}) + x(Q_L - Q_{DG}) = 0 \tag{4}$$

In this case, the following four conditions can arise:

In the case of that the injective active power of DG is smaller than the active power of the load and the load is also inductive (i.e. consuming reactive power), then we have:

$$Q_{DG} = \frac{r(P_L - P_{DG}) + xQ_L}{x} > 0 \tag{5}$$

In this case, DG should be able to inject reactive power to the network.

In the case of that the injective active power of DG is greater than the active power of the load and the load is also capacitive (i.e. generating reactive power), then we have:

$$Q_{DG} = -\frac{r(P_{DG} - P_L)}{x} + Q_L < 0 \tag{6}$$

That is, in this case DG should be able to capture reactive power from the network.

If the active power of the injectable DG is smaller than the active power load and the load is also capacitive, the sign of (5) depends on the value of the parameters, and one of the 1 or 2 statuses can occur.

If the active power of the injectable DG is greater than the active power load and the load is also inductive, the sign of (5) depends on the value of the parameters, and one of the 1 or 2 statuses can occur.

The advantage of this operating mode is that DG can regulate the voltage profile by injection or absorption of reactive power. Also, reactive absorption by DG can cause problems that are referred to in the negative effects of DG on the voltage profile. On the other hand, each DG has a limitation of reactive power production, and this limitation should be observed. Once the reactive power exceeds the limits the DG, DG changes its performance mode from the PV to the PQ function mode.

Given the Standard in [13] prohibits the use of DGs as voltage regulators. Therefore, the use of this operating mode for DG is limited. The disadvantages of using DG in this mode can be summarized as follows:

- Unavailability of DG control by the network operator.
- Feed the location of the fault.

Assume that near the DG location there has been a symmetric three-phase error. The voltage in the error bus is assumed to be zero. Then it can be written:

$$|V_{DG}| - 0 = \frac{r_{Sc}P_{DG} + x_{Sc}Q_{DG}}{|V_{DG}|} \tag{7}$$

Except the reactive power, all other parameters in (7) are constant, so the DG reactive power can be obtained as follows:

$$Q_{DG} = \frac{|V_G|^2 - r_{Sc}P_{DG}}{x_{Sc}} \tag{8}$$

In this regard, the real and imagine sequences of impedance are small, and on the other hand, the size of voltage in the DG bus, in the case of DG action as a synchronous generator is as follows:

$$V_{DG} = E_f - jX_s I_a \tag{9}$$

Where E_f is the generator's inductive excitation force and I_a is the injected current by the generator, which feeds the fault point. In (8), if the generator voltage remains about 1 per-unit, then the reactive power supply should be as follows:

$$Q_{DG} = \frac{1}{x_{Sc}} \tag{10}$$

This will be very large, meaning the generator will strongly feed the fault location. If we follow (9), then I_a as follows:

$$I_a = \frac{E_f}{r_{sc} + j(X_s + x_{sc})} \tag{11}$$

Certainly, for setting the voltage of the generator bus or V_{DG} terminal at about one per-unit, the E_f must be greater than one per-unit. In order to set inductive excitation force more than one per-unit, the injection current according to (11) must be much more than 1 per-unit. This means that, the generator feeds the fault location strongly.

In practice, not only the voltage of the terminal, but also the inductive excitation force will drop sharply and will be much less than 1 per-unit. In fact, the voltage control system increases the excitation current, when the terminal voltage is less than the desired value, due to (11) with increasing of E_f the generator excitation current will be increased. Regarding (9), the increase of the generator current leads to sharp reduction in the terminal voltage, and this cycle can be repeated, so there will be a closed loop that will feed the fault point heavily.

With the agreement of the distribution system operator and DG owner, these resources can be used as a voltage regulator. In this case, they can help with network voltage regulation by injecting or absorbing reactive power; but in general, any DG effort to control the voltage can cause interference with scheme of voltage regulation the same terminal or the neighborhood terminal which managed by the operator. The network operator's voltage control scheme can include the use of capacitor banks, bridge voltage regulators (SVRs), or online tap changer of sub transmission transformers. More information on this interference will be discussed in section VII.

When the use of DG as a voltage regulator is allowed, the DG output reactive power can be changed to adjust the voltage (stabilizing the voltage of a special point at a specified limit). However, the range of DG changes may not be enough to control the wide variation of the voltage. In these cases, DG, like any other PV bus, will change its mode of operation. In fact, the operation in voltage control mode at the joint point of the generator depends on the ratio of the short-circuit power of the DG to the network. If this ratio is small, the DG's effect on the voltage change will be low, and the DG will need to inject or absorb high reactive power to fix its low voltage near the standard voltage level and therefore should be in the low power factor. Accordingly, this will limit its ability to generate active power. In practice of DG applications for voltage control, it should not work at a low power factor.

6. Importance of studying various network load levels

The characteristics of the load in the distribution network are constantly changing, depending on the different seasons of the year and different hours of the day, and usually in the early hours of the night, due to the need for network lighting, the maximum load is experienced, and vice versa at the late hours of the night load is minimized [14, 15]. Decisions are made based on maximum loading for traditional or passive networks in lacking a source of distributed generation that cannot lead to bidirectional power flow. This mode is the worst case in the grid, so if the voltage and current profiles in this mode are in the standard range, these standards will also be met for other load profiles.

With the presence of scattered generation resources and the possibility of bidirectional power flow, the nature of the network changes from passive to active mode; in this case, the current fluctuates in lines, which also changes the voltage profile, so it can no longer be said with certainty if the voltage profile is in standard range in the maximum load, it is also within the standard range in the low load condition.

This issue is usually considered to be more important in the minimum load, this is because that the injectable active power of the DG is usually constant. Due to the reduction in consumption, the extra production of DG can go back to the sub-transmission substation and the current flow in the opposite direction causes the voltage profile changing and in Sometimes an overvoltage will be generated.

Therefore, the power flow for the active networks should be performed in three different statuses:

A) Without DG and with maximum loading

DGs may be dropped out of the network due to repairs, the sellers' refusing to sell to the network, unpredictable errors, and so on. If the network is designed based on the permanent existence of these resources, they may have a voltage drop or an increase in line flow after leaving. In other words, when the resources leave the circuit, due to the increase in current flow rate, from the beginning of the substation to the end of the feeders, the voltage drop will be high and may cause these problems.

B) In the presence of DG and maximum loading

In the peak hours of network loading, we will have a lot of voltage drop and, with the presence of DGs, this voltage drop will be greatly reduced, but if the good coordination between the automatic tap changer of sub-transmission substation, offline tap changer of sub-transmission substation, the location and operating mode of DGs is not managed, a great over voltage in a feeder and extreme reduction of voltage in another feeder can be experienced.

C) In the presence of DG and with minimum loading

Distribution sources and network load have an inverse effect on the voltage profile. In fact, DGs operate in order to increase the voltage profile and the network load in the direction of reducing the voltage profile. Therefore, in the event that the network load is minimized, the network may encounter an increase in voltage. Reducing the load causes the flow of DGs toward the start point of the feeder, and as the reverse flow causes the reverse voltage drop, the terminals close to these sources may encounter over voltages. Of course, some of the studies considers the exit of some of the loads as the minimum load condition for the network.

7. Advanced challenges by DGs

A) Problem of setting transformer tap changer:

When the DG is located on one of the feeders, in order to avoid over voltage at the end of the feeder during low load hours, the transformer tap-changer should be placed on the low taps. Putting the transformer tap on the low points will cause voltage drop in other feeders at the peak load. Consequently, it will be difficult to find an optimal point for transformer tap [16, 17].

B) Transient over voltages:

Abrupt withdrawal of DG sources will cause transient overvoltage [18], which may there is a limit in the time that the primary of the transformers can respond and retrieve the network, in this case, switching capacitors and other reactive power compensators should be applied for retrieving the network voltage.

C) DG Effect on Capacitors:

Capacitors are the most important elements of reactive power compensation in the network, which play an important role in reducing the voltage drop and losses in traditional distribution networks, but the use of this element when the DG is installed in the network will be somewhat challenged because DGs as compensator elements for voltage drop can also lead to over voltage in the network.

One of the important parameters for controlling the voltage is the reactive power flow. In the presence of DG sources, the voltage generally increases, as well as the increase in the voltage due to the installation of capacitors will intensify this situation. In these circumstances, two solutions are proposed to prevent the increase of the voltage from its permissible limit:

- Reactive power consumption by installing the reactor
- The use of DG in the control mode which will consume reactive power at times when overvoltage is experienced.

In both of the above solutions, the stepped-up flow of the reactive power increases the network losses, as well as problems such as overvoltage and the network retrieval after DG abrupt withdrawal.

The coordination between capacitors, reactors, and other reactive power compensators in the network should be highly precisely and prevent the voltage rising or the voltage drop out of the permissible range [19, 20].

D) Network power quality problems in the presence of DGs

Power quality Problems in the active distribution networks include fluctuations, voltage variation, distortion and the harmonics of the voltage and current waveforms, which will be discussed below:

- *Slow or rapid voltage variations*

In case of using multiple DG sources in the network and connecting them to a feeder, the voltage variation caused by all the sources should be considered, therefore accurate power flow of the system is essential. Generally two situations arise:

- For cases where the generation of the DGs is maximal and the network power consumption is minimal, the voltage change at the connection point will be maximized.
- Whenever the production capacity of DGs is in its minimum and the power consumption of the network is maximized, the voltage variation at the junction pint will be minimal.

Therefore, the standards for variation in the voltage of the junction point of DGs into the distribution network feeders for the medium and low voltage networks are set, which are as follows:

According to European standards [21], this value should not exceed 2% -3% in medium voltage (MV) networks, so that the voltage changes of the low voltage (LV) network will not exceed 10%, and the average voltage of each connection should not exceed 5% of the rated voltage, We can compensate the change with regulation in MV/LV transformers tap. The voltage variation in the LV network should stay below 10%.

The rapid change of voltage at the point of DG connection can be created due to the following reasons:

- Switching and connection/disconnection of DG to the network
- Sudden changes in DG output power during operation

To prevent damage to the equipment and loads existed in the network, the size of these changes and the related flicker should be limited. Accordingly, the voltage flicker size in the LV network in the short time scale should be less than 0.75 and in the long period should be less than 1, but for MV network, regarding the network parameters for short term less than 0.7 and for long term is less than 0.9.

- *Harmonics and intermediate harmonics*

The connection of some DG sources such as wind turbines and solar cells to the distribution network requires power electronic devices such as converters that generate harmonics in the MV networks [22].

Considering that the harmonic level of the whole network voltage should not exceed the standard limit, attention should be paid to the potential of production harmonics and intermediate harmonics by DGs.

Also, the increase of harmonics at the connection bus of DGs is very intense and should be limited.

8. Conclusion

In this paper, several definitions of DG sources are presented. The environmental impact of scattered generation sources is undeniable. But studies show that exploitation of DG units requires the adoption of new operating policies in network management. Challenges surrounding the interaction of these units with other elements in the distribution system and their effects on the key components of network load flow are analyzed accurately. Also, the study shows that, unlike the worst-case scheduling strategies (i.e. peak load condition) in traditional networks, this method does not work in modern networks equipped with DGs. Active networks require exploitation studies with the assumption of multilevel load, since the minimum load can be considered as critical as the peak load in such networks.

This study presents a clearer imagination for the networks that are undergoing the modernization process by incorporation of DGs.

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