Power Quality in Grid with Distributed Generation

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Abstract

The main purpose of this paper is to discuss the basic understanding of power quality in relation to the distributed generation and renewable based distribution generation Due to considerable overlap between two technologies, disturbances affecting the power quality, which are mainly cause by the addition of Distributed Generation on the existing power system network. Injection of the DG into an electric power grid can affect the voltage quality. Distributed generation of different voltage levels when connected to the power system network could influence the voltage regulation, sustained interruptions, harmonics, sags, swells, etc. The role of CPDs in enhancing the integration of renewable and providing quality power through customs power park are described.

INTRODUCTION

The demand of power is escalating in the world of electricity. This growth of demand triggers a need of more power generation. DG uses smaller-sized generators than does the typical central station plant. Distributed generators are small scale generators located close to consumers; normally distributed Generators are of 1 kW to 100 MW [1].

Definition of DG [2]. Distributed generation in simple term can be defined as a small-scale generation. It is active power generating unit that is connected at distribution level.

• IEEE defines the generation of electricity by facilities sufficiently smaller than central plants, usually 10 MW or less, so as to allow interconnection at nearly any point in the power system, as Distributed Resources.

• Electric Power Research Institute (EPRI) defines distributed generation as generation from a few kilowatts up to 50 MW.

• International Energy Agency (IEA) defines DG as "Power generation equipment and system used generally at distribution levels and where the power is mainly used locally on site".

• The International Council on Large Electricity Systems (CIGRE) defines DG as generation that is not centrally planned, centrally dispatched at present, usually connected to the distribution network, and smaller than 50-100 MW. These generators are distributed throughout the power system closer to the loads. The DG penetration in the grid poses new challenges and problems to the network operators as these can have a significant impact on the system and equipment operations in terms of steady-state operation, dynamic operation, reliability, power quality, stability and safety for both customers and electricity suppliers. However as we are only concerned with power quality of the primary and secondary distribution system, we will only consider generator sizes less than 10MW.

II. INTERFACE TO THE UTILITY

Here we are only concerned about the impact of distributed generation on power quality. While the energy conversion technology may play some role in the power quality, most power quality issues relate to the type of electrical system interface. Some notable exceptions include: (a) The power variation from renewable sources such as wind and solar can cause voltage fluctuations. (b) Some fuel cells and micro turbines do not follow step changes in load well and must be supplemented with battery or flywheel storage to achieve the improved reliability expected from standby power applications. (c) Misfiring of reciprocating engines can lead to a persistent and irritating type of flicker, particularly if it is magnified by the response ofthe power system.The main types of electrical system interfaces are synchronous machines, asynchronous (induction) machines and electronic power inverters [2].

Synchronous Machines: Some actual examples of unexpected consequences are:

- The harmonic voltage distortion increases to intolerable levels when the generator is attempting to supply adjustable speed-drive loads.
- There is not enough fault current to trip breakers or blow fuses that were sized based on the power system contribution.
- The voltage sag when elevator motors are being started causes fluorescent lamps to extinguish. Generators must be sized considerably larger than the load to achieve satisfactory power quality in isolated operation.

Asynchronous (induction) machines: Induction generatosr are induction motors that are driven slightly faster than synchronous speed. They require another source to provide excitation. The requirements for operating an induction generator are essentially the same as for operating an induction motor of the same size. The chief issue is that a simple induction generator requires reactive power (vars) to excite the machine from the power system to which it is connected. To supply the reactive power locally, power factor correction capacitors are added. While this works well most of the time, it can bring about another set of power quality problems. One of the problems is that the capacitor bank will yield resonances that coincide with harmonics produced in the same facility. Another issue is self-excitation. An induction generator that is suddenly isolated on a capacitor bank can continue to generate for some period of time. This is an unregulated voltage and will likely deviate outside the normal range quickly and be detected.

Electronic Power Inverters: All DG technologies that generate either dc or non–power frequency ac must use an electronic power inverter to interface with the electrical. The early thyristor-based, line-commutated inverters quickly developed a reputation for being undesirable on the power system. The line-commutated inverters produce harmonic currents in similar proportion to loads with traditional thyristor-based converters.

Besides contributing to the distortion on the feeders, one fear was that this type of DG would produce a significant amount of power at the harmonic frequencies. Such power does little more than heat up wires. To achieve better control and to avoid harmonics problems, the inverter technology has changed to switched, pulse-width modulated technologies [2].

III. POWER QUALITY ISSUES

A major issue related to interconnection of distributed resources onto the power grid is the potential impacts on the quality of power provided to other customers connected to the grid.

A. Voltage Regulation

Over-voltages due to reverse power flow: If the downstream DG output exceeds the downstream feeder load, there is an distance. If the substation end voltage is held to near the maximum increase in feeder voltage with increasing

allowable value, voltages downstream on the feeder can exceed the acceptable range.

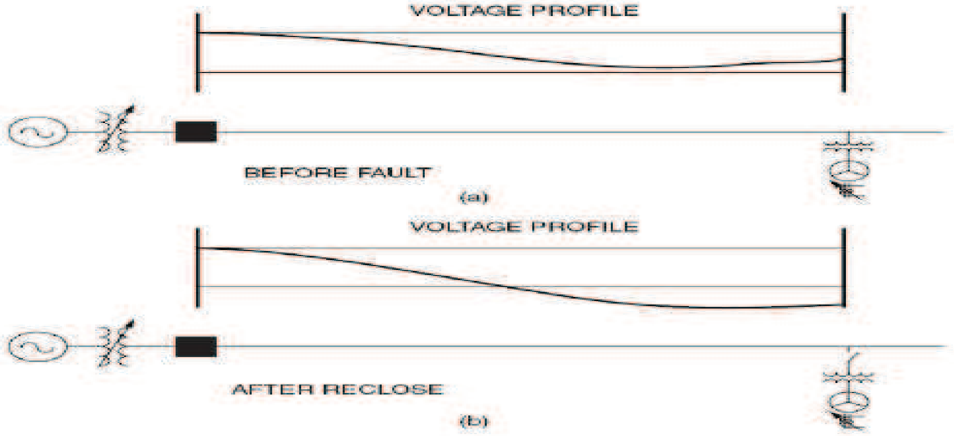

Figure 1. Voltage profile change when DG is forced off to clear faults.

Interaction with load tap changers (LTC) and static voltage regulators (SVR) controls: The presence of DG can cause localized changes in flow patterns, which

When the when the total DG capacity on a feeder becomes significant.This problem is a consequence of the requirement to disconnect all DG when a fault occurs. Fig 1a shows the voltage profile along the feeder prior to the fault occurring. The intent of the voltage regulation scheme is to keep the voltage magnitude between the two limits shown. In this case, the DG helps keep the voltage above the minimum and, in fact, is large are not reflective of the general trend on the feeder. As a result, LTC or SVR can be set such that a good voltage profile may not be obtained .Figure 1 illustrates one voltage regulation problem that can arise enough to give a slight voltage rise toward When the fault occurs, the DG disconnects and may remain disconnected for up to 5 min. The breaker recloses within a few seconds, resulting in the condition shown in Fig. 1b. The load is now too great for the feeder and the present settings of the voltage regulation devices.Therefore, the voltage at the end of the feeder sags below the minimum and will remain low until voltage

commercial loads. Also, it is difficult to make this transition seamlessly and the load may suffer downtime anyway, negating positive reliability benefits of DG.

2. Installing more voltage regulators, each with the ability to bypass the normal time delay of 30 to 45 s and begin changing taps immediately. This will minimize the inconvenience to other customers.

3. Allow DG to reconnect more quickly than the standard

regulation equipment can react. This can be the better part of a minute or longer, which increases the risk of damage to load equipment due to excessively low voltages. which increases the risk of damage to load equipment due to excessively low voltages.When the fault occurs, the DG disconnects and may remain disconnected for up to 5 min. The breaker recloses within a few seconds, resulting in the condition shown in Fig. 1b. The load is now too great for the feeder and the present settings of the voltage regulation devices.Therefore, the voltage at the end of the feeder sags below the minimum and will remain low until voltage regulation equipment can react. This can be the better part of a minute or longer, which increases the risk of damage to load equipment due to excessively low voltages.

Solutions include:

1. Requiring customer load to disconnect with the DG. This may not be practical for widespread residential and small 5-min disconnect time. This would be done more safely by using direct communications between the DG and utility system control.

4. Limit the amount of DG on the feeder.

B. DG Grounding Issue:

A grid-connected DG, whether directly or through a transformer, should provide an effective ground to prevent un-faulted phases from over-voltage during a single-phase to ground fault. Proper grounding analysis of DG will ensure compatibility with grounding for both the primary and secondary

power systems. This analysis must consider

(1) the generator-winding configuration (or inverter arrangement), (2) its grounding point, (3) the interface

C. Harmonic Distortion

Voltage harmonics are virtually always present on the utility grid. Nonlinear loads, power electronic loads, and rectifiers and

inverters in motor drives are some sources that produce harmonics. The effects of the harmonics include overheating and equipment failure, faulty operation of protective devices,

transformer configuration, and (4) grounding of both the primary and secondary power

systems to which the DR is connected(4)

nuisance tripping of a sensitive load and interference with communication circuits. All power electronic equipments create current distortion that can impact neighboring equipment. DG like PV, fuel cells are likely to introduce harmonics problem in the system. Harmonics from DG come from inverters and some synchronous machines. The PWM (pulse width modulation) switching inverters produce a much lower harmonic current content than

earlier line-commutated, thyristor-based inverters [1]. One new distortion problem that arises with the modern inverters is that the switching frequencies will occasionally excite resonances in the primary distribution system. This creates non-harmonic frequency signals typically at the 35th harmonic and higher riding on the voltage waveform. This has an impact on clocks and other circuitry that depend on a clean voltage zero crossing. A typical situation in which this might occur is an

industrial park fed by its own substation and containing a few thousand feet of cable. A quick fix is to add more capacitance in the form of power factor correction capacitors, being careful not

to cause additional harmful resonances [1].

Solutions include:

1. Newer PWM inverters have lower current distortion

2. Use non-resonant switching frequencies

3. Use reactors in the neutral, or generators with a 2/3 coil

winding pitch

D. Flicker

Some energy source (e.g., wind turbine or fuel cell) has some mechanical (or chemical) fluctuations in power output and some electrical equipment (e.g., the dc bus and inverter) does not have sufficient energy storage to smooth out these fluctuations. This will result in fluctuations in the power delivered by a DG and can cause flicker in the power system in a fashion very similar to that caused by load fluctuations [3].

Solutions include [3]:

1. Utility companies try to limit flicker so that it is at a level that cannot be perceived by the human eye. This is accomplished

by designing the power system to be sufficiently robust so that smaller load variations do not create noticeable voltage variations.

2. It is also controlled by imposing limits on the types of loads that are allowed to connect at various points on the system

3. When a larger DR unit is applied on a feeder, rapid response voltage regulators (static VAR compensators) or fast-response reactive compensation using inverter reactive-power capabilities can do mitigation of flicker.

4. Energy storage technologies can be applied to smooth

the output fluctuations of solar and wind energy systems.

E. Islanding

Refers to a condition in which distributed generation is isolated on a portion of the load served by the utility power system. It is usually an undesirable situation, although there are situations where controlled islands can improve the system reliability. Islands may be intentional or unintentional [2]. If an island should occur, it should persist for only a very brief period, unless the aggregate real and reactive output of all the DG supporting the island is close to the load demand. Otherwise, island voltage and frequency will change rapidly and all the DG has to be shut down to prevent this. In case the DG in the distribution system is capable to meet the load demand, DG can be operated in the island mode and continue to energize the distribution system. But the major issues with this type of inadvertent islanding are:

1. The voltage and frequency provided to other customers connected to the island are out of the utility's control, yet the utility remains responsible to those customers.

2. Protection systems on the island are likely to be uncoordinated, due to the drastic change in short-circuit current availability. *Out-of-step reclosing:* Many utilities use an "instantaneous" reclosing practice, where breakers and circuit reclosers reenergize the protected circuit without any intentional delay and this could result in out of phase reclosing of the distribution system.

As a result of out of phase reclosing:

1. Large mechanical torques and currents are created, which can damage the generator or the prime mover.

2. Transients are created which are potentially damaging to utility and other customer equipment.

3. Out-of-phase reclosing, if it occurs at a voltage peak, will generate a very severe capacitive switching transient. In a lightly damped system, the crest over-voltage can approach three times rated voltage.

Prevention [1]:

1. Inverter controls are designed to raise a rising frequency or lower a dropping frequency

2. The power system frequency acts to correct the inverter frequency

3. Without the power system to correct the frequency, the destabilizing signal in the inverter control quickly causes an over- or under-frequency condition, and frequency

relays trip the inverter

4. Load/generation imbalance relies on an intentional and significant difference between the DG output and the local load. DG is operated at constant power factor or

constant reactive power, and not permitted to regulate voltage. When an island forms, the mismatch between the DG and the load will quickly cause detectable voltage and/or frequency variations

F. Protection System [4]

Tradition distribution systems were not designed to have active power generating units in them. Power is supplied by the

transmission system and power flow is mainly unidirectional. But with the DG in the system, power flow can be bi-directional

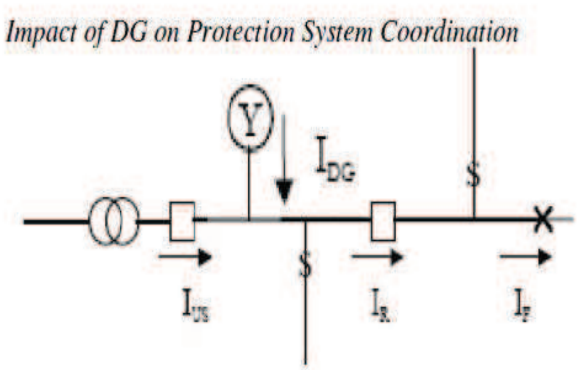

Figure 2. Typical feeder with recloser and fault

In fig 2, IUS is the current from the utility source Fault current seen by the recloser is IR The fault current at the fault location is IF. Without DG, IUS = IR = IF With the DG connected IF = IUS + IDG and IR = IF

However, IR _IUS The condition indicated is not seen in the typical radial distribution system. IUS without the DG does not equal IUS with the DG. With the DG connected, the fault current seen by the recloser (IR) will be greater than without the DG connected. This would normally not cause a problem with the recloser size as long as the new greater IR does not exceed the recloser maximum interrupting rating. However, it is very likely that coordination between the recloser and any down-line fuses will be lost. Because both the recloser and fuses operate faster at higher fault currents, the required margins between the recloser fast curve and the fuse minimum melt curve could be reduced enough to lose coordination. Depending on characteristics of the network and DG, various other protection problems can arise. They are namely:

1. False tripping of feeders (sympathetic hipping)
2. Fuse coordinate with recloser fast-trip varies with DG operation
3. Nuisance tripping of production units
4. Blinding of protection
5. Increased or decreased fault levels
6. Unwanted islanding
7. Prohibition of automatic reclosing
8. Unsynchronized reclosing

Solutions Include

1. Reduction of Reach: Adjust relay to increase reach. Add recloser to add another protection zone. Minimize DG contribution to ground faults
2. Sympathetic tripping: Directional relays, changes to circuit breaker settings
3. Defeat of fuse saving: Larger fuses, minimize DG contribution to ground faults

IV. CONCLUSION

Different issues related to power quality when DR is integrated with the existing power system has been discussed in the paper. It can be concluded from this discussion that when interconnecting DR to the power system, these issues must be considered which could affect power quality and safety. Penetration of DR can be successfully integrated with the power system as long as the interconnection designs meet the basic requirements that

consider not only power quality but also system efficiency and power reliability and safety.

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