Scheme Of Evaluation
Internal Assessment Test III –May.2019

Sub:	Integration of distributed generation							**Code:**	15EE833
Date**:**	15/05/2019	Duration:	90mins	Max Marks:	50	**Sem:**	VIII	**Branch:**	EEE

Note: Answer Any Five Questions

Question #	Description	Marks Distribution	Max Marks
1	**Define voltage flicker and explain fast voltage fluctuation in wind power** • Definition of voltage flicker • Explanation of voltage fluctuation in wind power	3M 7M	10 M
2	**Explain 2 main sources of unbalanced voltage at transmission level** • Explanation of any 2 main sources of unbalanced voltages	10M	10 M
3	**List the various power quality disturbances developed due to distributed generation** • Explanation of different power quality disturbances	10M	10 M
4	**List the cause of voltage dip in distributed generation.** • Detailed explanation of cause of voltage dip	10M	10 M
5	**What is maximum permissible voltage distortion according to IEEE standard and briefly explain low frequency harmonics in distributed generation** • Voltage distortion is 3% • Explanation of low frequency harmonics	4M 6M	10 M
6	**Summarize high frequency distortion as power quality disturbances** • Explanation of high frequency distortion	10M	10 M

7	**Explain how strong feeders increase the hosting capacity** • Explanation of increasing hosting capacity by using strong feeders	10M	10 M

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Internal Assesment Test - III

Sub:	Integration of distributed generation							Code:	15EE833
Date:	15/05/2019	Duration:	90 mins	Max Marks:	50	Sem:	8	Branch:	EEE(A/B)

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1	Define voltage flicker and explain fast voltage fluctuation in wind power	[10]	CO5	L2
2	Explain 2 main sources of unbalanced voltage at transmission level	[10]	CO5	L2
3	List the various power quality disturbances developed due to distributed generation	[10]	CO5	L2
4	List the cause of voltage dip in distributed generation	[10]	CO5	L1
5	What is maximum permissible voltage distortion according to IEEE standard and briefly explain low frequency harmonics in distributed generation	[10]	CO6	L1
6	Summarize high frequency distortion as power quality disturbances	[10]	CO6	L2
7	Explain how strong feeders increase the hosting capacity	[10]	CO5	L2

The following developments associated with the introduction of distributed generation will have an impact (positive or negative) on the power quality.

- The emission of disturbances by the generator units may result in increased emission levels. This concerns especially harmonics, voltage fluctuations, and unbalance, as well as disturbances due to switching of the generators. The emission by distributed generation will be discussed in all the forthcoming sections. With some exceptions, the emission of power quality disturbances due to distributed generation is not a concern. Flicker due to fast voltage fluctuations and harmonics up to about 1 kHz are mentioned in the literature mostly as serious emission sources; they will be discussed in detail in Sections 6.2 and 6.4, respectively. We will see, however, that the emission of these harmonics and of flicker is limited in most cases. Harmonics at higher frequencies are not so commonly addressed in the literature, probably because of the lack of standards and other information. But several types of interface for distributed generation result in emission at these higher frequencies. Also do several types of distributed generation show more of a broadband spectrum than the existing
3) equipment. The lack of knowledge about the consequences of this indicates

that further studies are essential. Emission of high-frequency distortion (above about 1 kHz) will be treated in detail in Section 6.5.

- Large single-phase generators or many small single-phase generators will result in an increase in the voltage unbalance. This is discussed in Section 6.3.
- The increased strength of the distribution network will limit the spread of disturbances. The impact is different for different types of interface and for different types of disturbances. Synchronous machines are in general more advantageous than other types of interface. The impact can become complex for harmonics because of the frequency dependence of the source impedance. A reduction in source impedance at one frequency may go together with an increase in source impedance at another frequency. We will discuss this further in Section 6.4.
- The shift of generation from transmission to distribution will reduce the strength of the transmission network. This will result in a wider spread of disturbances that originate at the transmission level or that reach the transmission system from a lower level. This could concern voltage fluctuations, unbalance, or harmonics due to large industrial installations, and also voltage dips due to faults at transmission level. The impact of a weakening transmission system on the number of voltage dips is discussed in Ref. 353 in association with the shift of generation due to the deregulation of the electricity market. In Refs. 46, 52, and 391, this is further discussed in association with the shift from large conventional generation to other types of generation. The flicker level due to a large steel installation in Northern Europe increased significantly when a local power station no longer was in operation whenever the steel plant was producing. This is a consequence of deregulation; however, massive penetration of distributed generation will have similar impacts.
- Several types of distributed generation are associated with capacitors or capacitor banks. Also, long cables at transmission and subtransmission levels will result in additional capacitance connected to the grid. This will increase the risk of resonances at harmonic frequencies and shift existing resonances to lower frequencies. At distribution level, the impact appears to be limited to the introduction of resonances at new locations and a shift of resonances to lower frequencies. Resonances around 1 kHz have been reported with solar power installations in domestic environments. Calculations indicate that resonances can be expected around the seventh harmonic due to induction generators equipped with capacitors. The main concern are new resonances, possibly as low as 100 Hz, due to the introduction of long cables at subtransmission and transmission levels. Resonances may also occur in the collection grid of a wind park.

1)

Fast changes in voltage magnitude are referred to as voltage fluctuations or sometimes "voltage flicker." Their main concern is that they result in a phenomenon called "light flicker" with the frequency range between about 1 and 10 Hz. Flicker is a sensation of unsteadiness in the light intensity where the observer notices that the light is not of constant intensity over a longer period, but cannot observe the individual changes. Most people experience light flicker as uncomfortable even if they not always notice the flicker. Studies have shown that even nonnoticeable flicker will result in increased activity in certain parts of the brain. Long-term exposure to flicker will result, for example, in headache and tiredness. The amount of flicker a voltage fluctuation causes for a standard incandescent lamp is quantified by the "flicker severity," P_{st}, where $P_{st} = 1$ corresponds to a level that is experienced as uncomfortable by 95% of persons. The relations between the voltage fluctuations and the flicker and the calculation of flicker indices are discussed in detail in Section 2.4 in Ref. 45.

Light flicker should not be confused with occasional changes or dips in light intensity due to voltage steps or voltage dips. These are observable for voltage steps as low as a few percent of the nominal voltage [377], but are not continuous and do not have the same impact as continuous flicker. The terms "voltage fluctuations" and "rapid voltage changes" are sometimes used with the following meaning:

- *Voltage fluctuations* are continuous changes in voltage magnitude at timescales up to several minutes.
- *Rapid voltage changes* are fast and stepwise changes in voltage magnitude.

Fast variations in generated power may lead to voltage fluctuations. These are a concern for those sources for which the available power strongly varies with time, notably wind power and solar power. Wind turbines produce a continuously varying output. In Ref. 232, three timescales are distinguished:

- Variations with a frequency of several hertz due to the turbine dynamics, the tower resonance, and the gearbox.
- Periodic power pulsations at the frequency at which the blades pass the tower, typically around 1 Hz for a large turbine. These are referred to as 3p oscillations for three-blade turbines. Detailed measurements presented in Refs. 405 and 406 show a range of frequencies associated with the rotation of the blades with respect to the tower—from 1p through 18p.
- Slower variations due to changes in wind speed.

There is some indication that the turbines in a wind park may reach a state of "synchronized operation," thus amplifying the power pulsations due to the tower. The cause of this synchronous operation is not fully clear, but it is thought to be due to interactions between the turbines through the network [232]. Synchronous operation can only be expected for sites with a rather constant wind speed not affected by turbulence due to the terrain. This was often mentioned as a serious problem in the past, but more recently the risk of synchronous operation is perceived as small.

7)

Adding more copper, in the form of more or stronger lines, will in almost all cases result in a higher hosting capacity. Dedicated feeders in case of large units connected to weak parts of the grid are a commonly used solution. Building a completely new feeder, in many cases in the form of an underground cable, could be easier than strengthening an existing feeder. Overvoltages might still occur, but because it is a dedicated feeder, only the generator unit is exposed to the overvoltage. However, this can be fully considered during the design of the feeder and the generator unit.

An additional advantage of a dedicated feeder is that it can be designed to prevent any overloading. The solution is, however, practical only for larger units. For small units, the costs of the new feeder will be too high compared to the total costs of the unit. Also, the costs of the new feeder will be highest when the generator is located further away from the main medium-voltage substation (the one equipped with voltage control). These are exactly the locations where the risk of overvoltage is highest (or, in our terminology, the locations with the lowest hosting capacity).

Rewiring the feeder or parts of the feeder with a thicker wire will be cheaper than building a completely new feeder. It will also be easier to obtain permission for rewiring an existing feeder than for building a new overhead feeder. Rewiring may however cause rather long planned interruptions for existing customers. As shown in Figure 5.14, the impact of the feeder cross section on the hosting capacity is not as big as would at first be expected. The lower cross section results in a lower voltage drop during low load. This partly compensates the increase in hosting capacity due to the lower resistance. However, when using sufficiently thick wires, there is no need for a second voltage boosting. This has the main impact on the hosting capacity.

Network operators in several countries are replacing overhead lines with cables. From a voltage control viewpoint, a cable can be seen as a line that is partially series compensated: that is, the series reactance of an underground cable is less than that of an overhead line. The voltage drop along an underground cable is therefore less than that along an overhead line of the same cross section. This reduces the need for voltage boosting, which gives an increase in the hosting capacity.

Replacing lines by cables with the same cross section, without any further measures, might however reduce the hosting capacity. The voltage drop during minimum load, which is partly due to reactive power demand, becomes less, whereas the voltage rise due to distributed generation remains the same. There is thus less generation needed to reach the overvoltage limit.

The presence of distributed generation, however, impacts the number of dips in several indirect ways:

- Distributed generation connected to the distribution system will locally strengthen the grid, which will result in a decrease of the number of dips experienced by local customers. We will consider this impact in more detail, looking at synchronous machines in Sections 6.6.1 and 6.6.2. The damping effect of induction generators on unbalanced dips is treated in Section 6.6.3.
- Replacement of large conventional power stations by distributed generation will weaken the transmission grid, which will result in an increase of the number of dips experienced by the customers. This has been studied in Ref. 52 for the UK transmission system. It is estimated that 20% distributed generation (assumed constant through the year) will for no customer result in a doubling or more of the number of dips. As the number of dips will vary much more from year to year and due to the lack of any guidance on what are acceptable levels, this is seen as a moderate increase.
- Large penetration of distributed generation will require enforcement of the power system in the form of new cables or overhead lines. Especially the integration of large wind parks into the subtransmission system is reported to require significant amounts of new lines. These lines will result in more voltage dips for customers connected close to these lines. This may especially

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impact large industrial customers that have traditionally been most sensitive to voltage dips. The authors are not aware of any study in which this impact has been quantified.

- The weakening of the transmission system may also result in a longer fault-clearing time and thus longer voltage dips. Distance protection and differential protection are not much impacted by the fault level, over a broad range of fault levels. But overcurrent protection, sometimes used in subtransmission system, may be impacted.
- After fault clearing, rotating machines take a large reactive power. In a weak system, this will pull down the voltage after the fault and result in longer voltage dips. Here, we enter the realm of transient and short-term voltage stability. We will further discuss this in Chapter 8, where one of the conclusions will be that the impact very strongly depends on the system.

Distributed generation does not produce a completely sinusoidal current waveform, just like the majority of other equipment. The harmonics injected into the distribution grid by the generator will result in some increase in the voltage distortion. The emission by distributed generation is, however, smaller than the emission by modern consuming equipment, so the increase in voltage distortion will be small and rarely a problem. This will especially be the case for those frequency components that have traditionally been dominant in power systems: harmonics 5, 7, 11, 13, 17, 19, and so on, as well as 3, 9, and 15 at low voltage. The presence of distributed generation may, however, result in a significant increase in the level of frequency components that have traditionally been small, even harmonics, higher order triplen harmonics, and interharmonics. The permissible levels for these frequency components have traditionally been low, so the hosting capacity could actually turn out to be rather low. Also, these frequencies have traditionally been used for power line communication (PLC), based on the fact that the disturbance levels were low here. Increasing amounts of distributed generation could, therefore, result in interference with power line communication. The interaction between the new equipment and the power line communication is, however, more complicated, depending on the distortion level. See Refs. 370 and 371 for a more discussion on this.

The harmonic emission of distributed generation is low for the frequencies that have traditionally been of concern for harmonics (third, fifth, seventh, up to about 1 kHz). A number of measurement examples and simulation results will be discussed below. The results from the different sources are summarized in Table 6.4.

In Ref. 27, an assessment is made of the hosting capacity when harmonic voltage distortion is the limiting factor. A maximum permissable voltage distortion of 3% (for each harmonic) is assumed, in accordance with IEEE standard 519 [217]. It is further assumed that the emission of a generator unit is equal to the limit in IEEE standard 519 [217] for large customers (short-circuit ratio less than 20). Three typical medium-voltage feeders of different length are considered. A distinction is further made between generation distributed uniformly along the feeder, concentrated at the beginning of the feeder, and concentrated at the end of the feeder. The limits are reached first for triplen harmonics (9, 15, and 33 to be more specific). The results are summarized in Table 6.5, as a percentage of the feeder capacity. High harmonic voltage levels are expected first for triplen harmonics at long feeders when the generation is concentrated toward the end of the feeder.

When interpreting Table 6.5, it should be kept in mind that the actual emission of distributed generators was used nowhere during the analysis. Instead, it was simply
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assumed that the emission is exactly equal to the limit set by IEEE standard 519 for large customers. Without further information about the actual emission, it is difficult to know if these limits are conservative or nonconservative. However, if the network operator imposes the IEEE standard 519 limits on the generators, there will rarely be high levels of voltage harmonics due to distributed generation.

Voltage source converters are known as a source of high-frequency harmonics. The switching frequency and multiples of the switching frequency (1 kHz and up) are present in the spectrum of the current. A systematic approach to determine the amplitude of high-frequency harmonics is given in Ref. 110, where it is also shown mathematically that pulse width modulation leads to groups of frequency components around the integer multiples of the switching frequency.

A problem reported among others in Ref. 125 is that the switching frequency may be close to a system resonance causing a rather large high-frequency ripple on the voltage. Most switching schemes will result in broadband emission, which has also been confirmed by measurements. Resonances cannot be avoided for these higher frequency ranges, so there is a high probability that a resonance will be exited resulting in high voltage distortion. Fortunately, the damping in general increases with frequency, for example, due to the skin effect in the wires. Despite this damping effect, repetitive failure of cable connections has been reported due to high distortion in the kilohertz range. High voltage distortion was in that case due to resonance in a cable connection close to the switching frequency of a power electronics converter connected at medium voltage.

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The German association of network operators (VDN, Verband der Netzbetreiber) gives guidelines for the connection of renewable energy to the grid. This includes the following requirements for the emission per 200 Hz band in the frequency range of 2–10 kHz, depending on the voltage level at which the installation is connected:

- $I_\mu < (16/\mu)$ for connections at 110 kV,
- $I_\mu < (8/\mu)$ for connections at 220 kV, and
- $I_\mu < (4.5/\mu)$ for connections at 380 kV,

where μ is the harmonic order of the center frequency of the 200 Hz band. The current is given in ampere per 1000 MVA.

An increasing level of distributed generation, with power electronics interfaces, will lead to an increasing level of high-order harmonics. There are two schools of thought here: a positive and a negative. The positive way of looking at the problem is that high-frequency disturbances do not propagate far due to their high damping. In addition, high-frequency harmonics can be easily filtered. Some experts, however, warn that the propagation and effects of high-frequency disturbances remain an unknown territory. They call for caution and further studies before installing large amounts of interfaces producing high-frequency disturbances. Potential victims of these high-frequency disturbances are, among others, the capacitors that are common with generator interfaces. The number of studies on high-frequency distortion due to distributed generation is very limited. Some studies have, however, been conducted for smaller equipment with a power electronics interface. Measurements with smaller end-user equipment are much easier to perform and, in the lack of more specific results, some of the conclusions may be applied to distributed generation as well. An overview of emission in the frequency range of 2–150 kHz is given in Ref. 261. Measurements of the interaction between different devices are presented in Refs. 370 and 371. These measurements show that high-frequency currents mainly flow between neighboring devices. The emission from a group of power electronics devices to the grid is small. Simulations and measurements given in Ref. 284 indicate that there is a risk of resonance between EMC filters at higher frequencies. A real case of such a resonance is shown in the paper. According to a recent CIGRE report [95], the harmonics originating from the PWM switching of a DFIG converter or full-size converter are usually filtered sufficiently. This statement is, however, not further documented in the report, neither is there any information in the report about what is "sufficient" in this case.