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Upgrading Substation Grounding System

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Abstract

Necessity of upgrading the grounding system of the substations:

- Increase in fault level beyond its previous ultimate level due to the expansion of power system,
- Upgrading substations because of aging of equipment, need for modernization and automation, need for expanding the capacity of substations, disturbing the existing ground grid during the upgrading and need to extend the ground loop.
- Changes in safety codes & standards and their requirements

In this presentation addresses the unsafe conditions in substation grounding system, and proposes methods for evaluation and elimination of unsafe conditions will be addressed.

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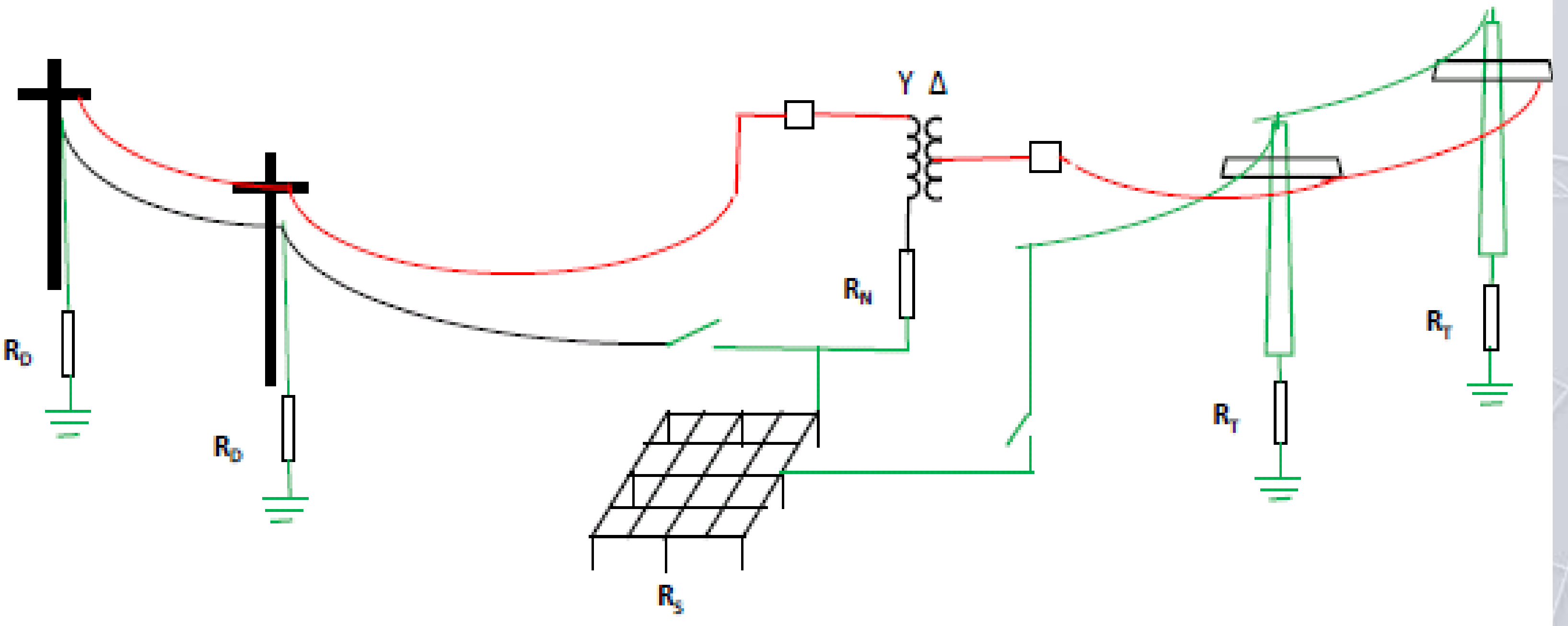
Main objectives of a safe grounding system

- Limiting the potential (with respect to the general mass of the earth) of current-carrying conductors forming part of the system under normal and fault conditions. This objective is essential to the proper operation of the system, and is known as “system grounding”.
- Limiting the potential (with respect to the general mass of the earth) of non-current-carrying metal-work associated with equipment, apparatus, and appliances connected to the system under normal and fault conditions. This objective is essential to the safety of human life and of animals and of property, and is known as “equipment grounding”.

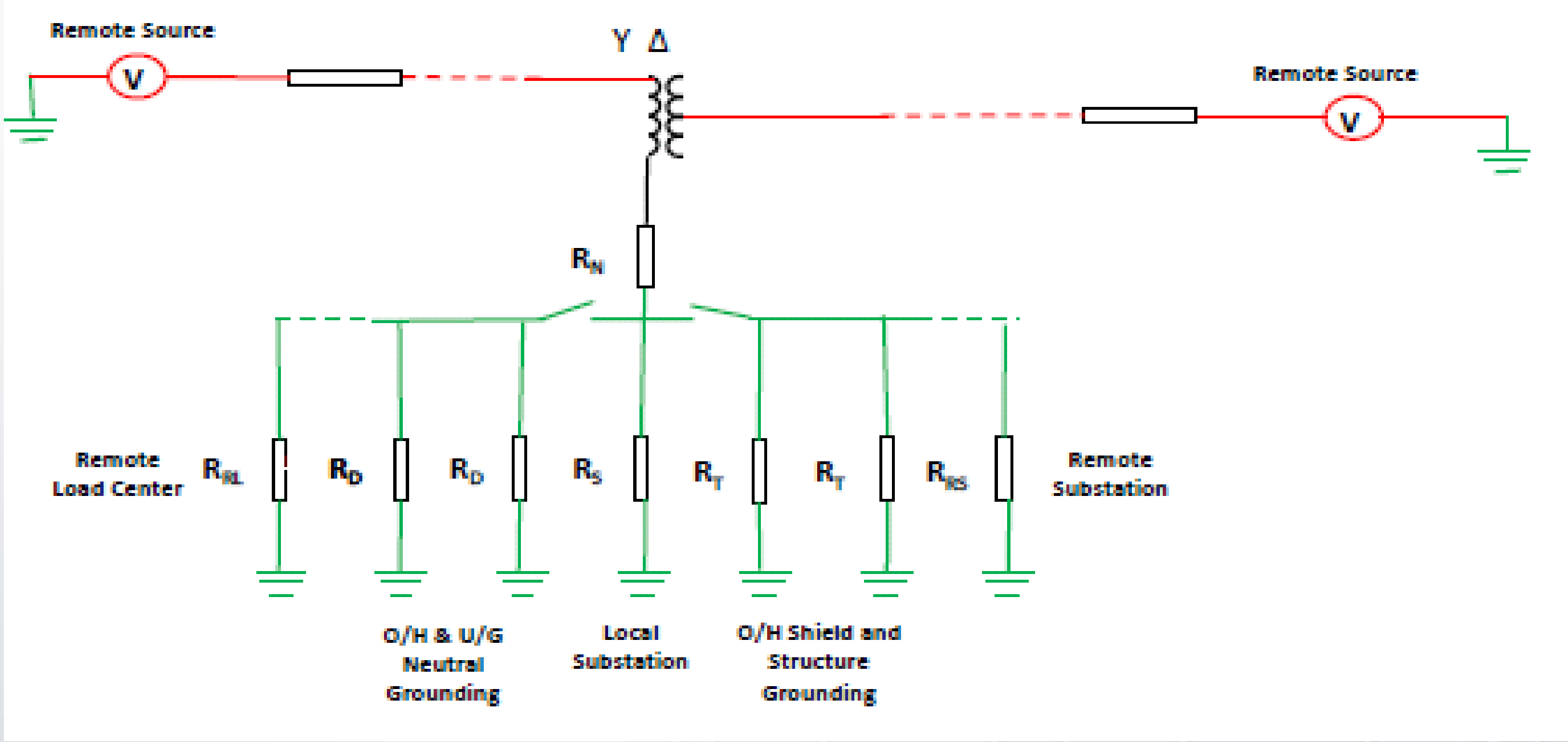
Elements of a substation grounding system

Figure 1: Grounding Scheme of a Substation



Elements of a substation grounding system

Figure 1: Electrical Equivalent of the Grounding System of a Substation



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Basis of a safe and reliable grounding system

1. Good design
2. Proper installation
3. Appropriate maintenance

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1. Grounding system design
.1.A. Ground grid design input

- Site location and layout
- Maximum ground fault current
- Fault duration
- Shock duration
- Soil resistivity
- Resistivity of surface layer

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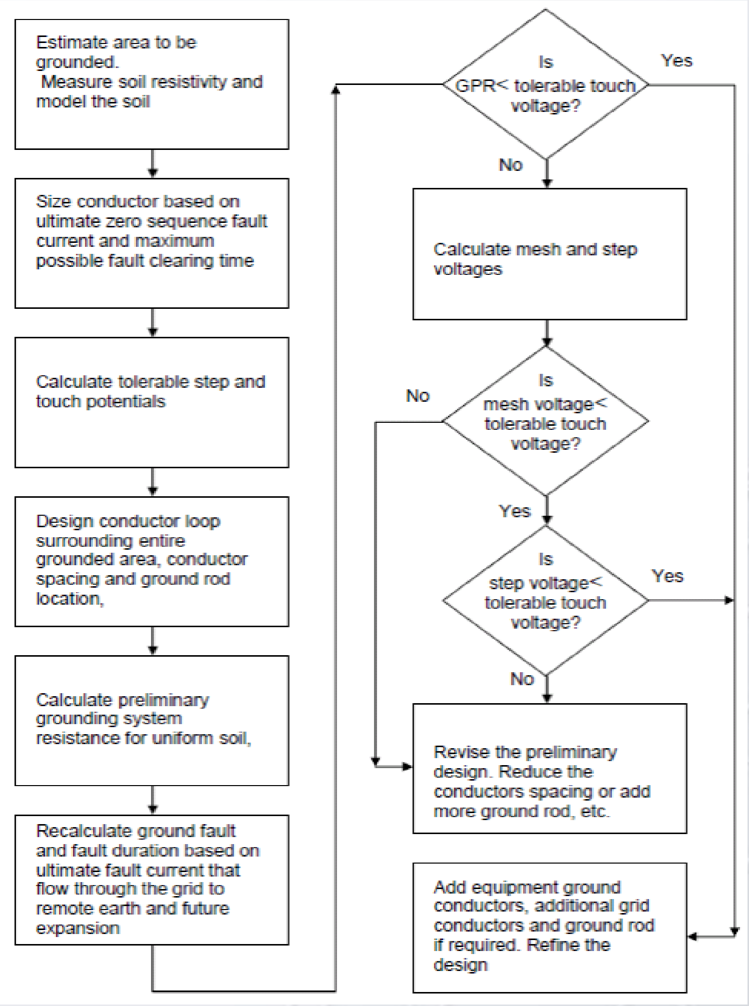
1.B. Ground grid design process



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1.B. Ground grid design process

The following factors play major roles in designing a safe, reliable and economic ground grid.

- Proper measurement of soil resistivity,
- Proper soil modeling,
- Proper estimation of ultimate fault current that flow through the grid to remote earth

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1.B. Ground grid design process

Proper measurement of soil resistivity:

- Take the seasonal variation in soil and its in its electrical characteristics and therefore in ground resistance into consideration.
- Define the climatic condition (temperature, humidity, etc.) and soil condition (moisture, temperature and chemical content) during the test
- Refer to long term studies that have been done on soil resistivity variations in the area of concern for adjustment of the measurement results.

1.B. Ground grid design process

Notes:

1. Where soil resistivity decreases in deeper layers, extending the ground rods deep low resistivity layers, show less seasonal variations of ground resistance,
2. Horizontal ground grid is generally more affected by seasonal variations than long ground rod.
3. Electrode treatments such as chemical backfill may stabilize the grid resistance throughout the year.
4. Changes in the ground impedance may be the direct result of variations in the soil resistivity but could also be the results of permanent changes to the ground electrode itself (corrosion for example).

1.B. Ground grid design process

Proper soil modeling:

Soil model is the basis of grounding system design.

- Variations of measured resistivity when plotted versus probe spacing indicate that the earth is non-uniform, and a two-layer soil model must be used. Using a single-layer model in such a situation cause significant errors in resistivity.
- Calculations based on two-layer soil model usually give correct values for the ground resistance and for the step and touch potentials on the surface of the ground. However, when the soil has a multilayer structure and certain combination of different layers resistivity exist the two-layer model of the soil may give unreasonable results.

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1.B. Ground grid design process

Proper estimation of ultimate fault current that flow through the grid to remote earth:

The ultimate fault current that flow through the grid to remote earth I_g must be must be calculated taking into account:

- The split of ultimate ground fault current I_f for a fault in substation in overhead ground wires, cable sheaths, metallic raceways, distribution neutrals and other grounded conductors leaving the substation,
- All variations in fault type (L-G or L-L-G), location (inside or on various line structures several spans outside the station), on different circuits (HV and LV) and for different system contingencies (parallel bus or transformers operation in substation)

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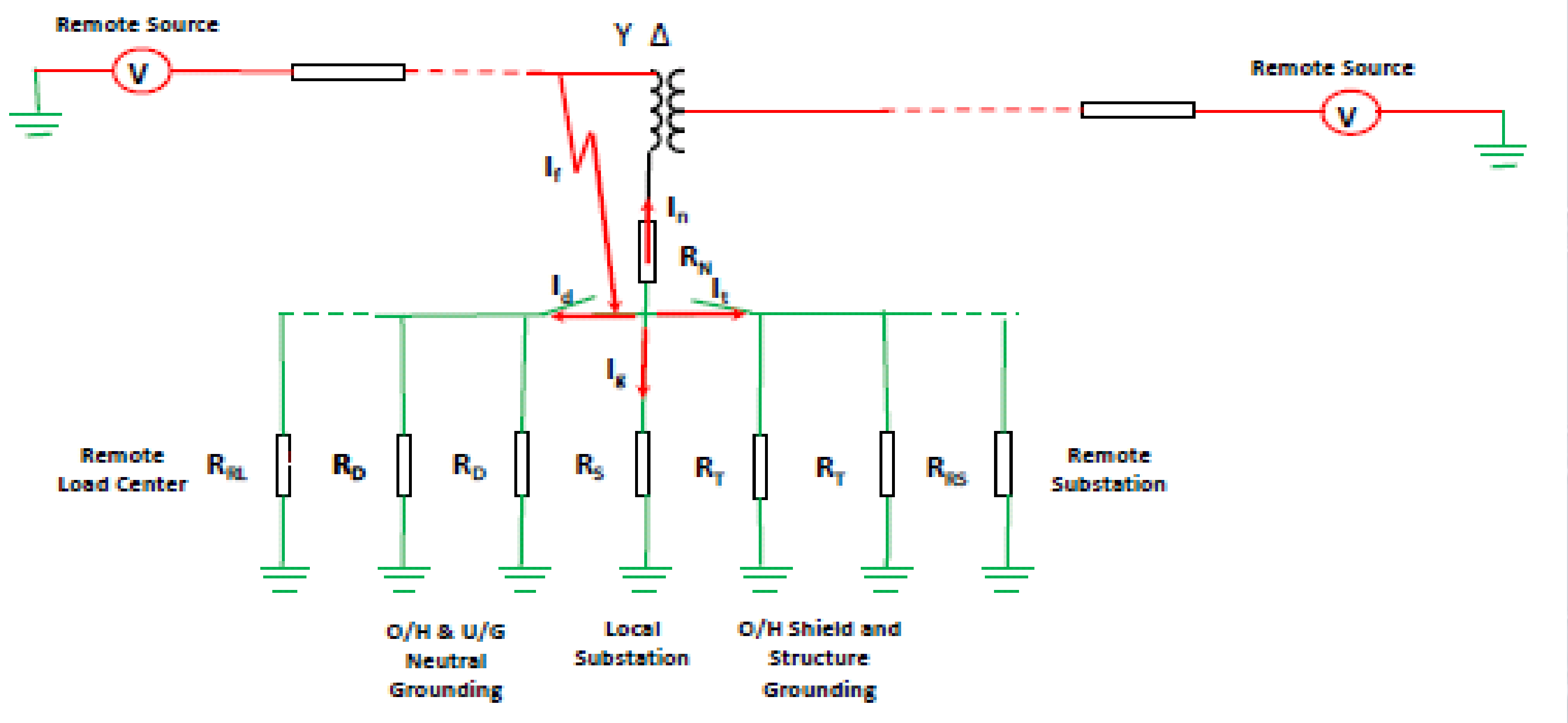
1.B. Ground grid design process

Figure 1: Ground Fault Current I_f Distribution for a Fault in Substation



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.1.C. Design refinement

Ground grid design is an iterative process. If preliminary design calculations indicate that dangerous potential differences can exist within the substation, the possible solutions are:

1. Limiting the ultimate fault current that flow through the grid to remote earth by:

- Changing the fault current split factor by decreasing the footing resistances of towers in the vicinity of the substation,
- Limiting total fault current, where feasible, using impedance grounding approach.

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1.C. Design refinement

2. Reducing the ground grid impedance employing the following remedies:

- increasing the area occupied by the grid and expanding the grid ground outside the fence line,
- deep driven rods or wells where the resistivity of the lower layers are less than upper layers and the available area is limited.
- Reducing the grid spacing
- controlling the perimeter voltage gradients by increasing the number of ground rods at the perimeter, or reducing the grid conductor spacing near the perimeter of the grid
- Placing ground mat, on or above the soil surface, or directly under the surface material, in order to obtain an extra protective measure minimizing the danger of the exposure to high step or touch voltages in a critical operating area or places that are frequently used by people,
- Barring access to areas exposed to high step or touch voltages , where practical, to reduce the exposure of personnel to hazards.

2. Grounding system installation

The following should be taken into consideration in grounding system proper installation:

- Using exothermic welded connection especially for underground. By virtue of its molecular bond, an exothermic welded connection will not loosen or increase in resistance over the lifetime. However the followings will result in blow-back and contaminated welds with voids which in turn create high resistance current paths :
- Poor workmanship,
- Improper type of weld metal,
- Incompatible materials,
- Poorly stored welding material,
- Damaged or dirty mold,
- Improper mold size,
- Improper mold adjustment,
- dirty and greasy conductors.

2. Grounding system installation

- Insufficient compressive forces, incorrect dies, improper installation of connector, dirty and greasy conductor, lack of corrosion inhibitor or inhibitor failure, and deteriorated connections can result in corroded and loose, high resistance current paths where compression connections are used.
- Low clamping forces of most of the corrosion resistance material which can overstress the fastener to yield point or can result in corrosion when low clamping forces is applied, improper installation of connector, dirty and greasy conductor, lack of corrosion inhibitor or inhibitor failure, and deteriorated connections can create high resistance current paths where bolted connections are used.

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2. Grounding system installation

Surface layer material:

Improper surface material can result in decreasing the protective characteristic of surface layer. High resistivity surface material having a minimum 3000 Ω-m wet resistivity are typical selection.

Surface material shall be tested before use.

The washed gravel, usually ¾" crushed rock are preferred selection in comparison with crusher run gravel because of the following properties:

- Reduces the body current significantly more effective in all weather conditions.
- Provides significantly more feet-to-gravel contact resistance.
- Dry out faster following the rain, restoring its insulating properties.

2. Grounding system installation

Post installation measures: In addition to reviewing the grounding system design and inspecting the installation works it is necessary to perform post installation field tests including ground impedance measurement to validate the grounding system design and to evaluate the safety of a ground grid.

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3. Grounding system maintenance

Grounding electrodes are subject to two major types of stresses.

1. The stresses during a fault or lightning.
   - These stresses may break the connection of individual elements and interrupt the continuity, introducing high resistance across bonds.
   - The grounding system may have properly cleared the fault, leaving no obvious indication that it has been compromised. However it may not be able to provide the same level of protection.
2. The second types of stresses are the expansive and persistent forces of corrosion and weather.
   - Stresses due to freezing and soil expansion may break the connection of individual elements.
   - Soil corrosivity which is worse for low resistivity soil constantly wears the grounding electrode away. Metal dissimilarities can accelerate this process.

3. Grounding system maintenance

In addition to ground impedance measurement, which provides a measure of voltage drop across the surrounding soil, the following tests should be performed periodically to evaluate the physical condition of grounding electrodes and to ensure that bonding and grounding of equipment, raceways, enclosures, and fences are properly maintained :

- Visual and Mechanical Inspection,
- Point-to-point ground impedance measurement to evaluate the integrity of ground grid and to determine the resistance between the ground grid and all major electrical equipment, raceways, enclosures, fences, system neutral, and/or derived neutral points. Where the point-to-point resistance exceed 0.5 Ω, shall be investigated

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Changes in grounding system requirements

In addition to the above mentioned variables that impact the grounding system conditions the following factors affect system requirement:

1. Increased available fault current due to new generation or substation expansion.

2. Distribution system grounding impedance reductions due to the distribution system expansion

3. Upgrading and expanding the old substation and disturbing the existing ground grid and deteriorating the surface layer during construction

4. Obsolete design methods, changes in applicable codes requirements

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Upgrading the grounding system

Grounding system upgrade should be based on the result of the ground grid evaluation. If there are new requirements for changes in grounding system or the results of the ground impedance measurement, visual and mechanical inspection, and point-to-point ground impedance measurement/ ground integrity test are not satisfactory then the grounding system may need to be upgraded.

Upgrading the grounding system

the following extra steps shall be taken, in addition to the steps required for designing a new grounding system, to upgrade the grounding system ,

1. Soil resistivity measurements should be conducted at a location outside and near the substation.
2. Computer model of the existing substation should be developed using the measured soil resistivity.
3. The computer model will be valid if the following condition are met:
   A. Calculated grounding impedance and GPR are fairly close to the measured values

   B. The computed touch voltages on are higher than the measured voltages based on the simulated personnel method. However by decreasing the surface layer resistivity it should approach the measured value

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Upgrading the grounding system

4. The validated model should be developed to accommodate all new requirements.

5. The upgrade grounding system design should be checked for meeting all safety requirements of IEEE80-2000 and if required the necessary refinement must be applied.

6. All other measure to be taken as stated above for installation and post installation.

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Challenges for a safe, reliable and economic design

The measurements of soil resistivity, ground impedances, and potential gradients in developed residential, commercial or industrial areas introduce a number of complexities such as difficulties to choose a suitable direction or location for test probes for impedance measurement. It may be necessary to make multiple measurements and to plot trends. Stray currents and other factors usually interfere with the measurements. The measurement technique based on variable frequency may help to avoid interference from stray currents at power frequency and its harmonics

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Questions?

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