

NEUTRAL GROUNDING REACTOR FOR MEDIUM VOLTAGE NETWORKS

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Summary

The different modes of grounding the medium voltage power distribution networks differ from country to another. In France, in the years 1980, the national utility EDF was committed in a reflection on the policy of the neutral grounding of the MV networks in order to increase the power supply availability.

EDF took the decision to define a new neutral point reactor with variable compensating inductance and to replace the existing neutral reactors with fixed inductance values by this adjustable type.

In co-operation with their transformer suppliers they elaborated the specifications for two devices with different maximum reactive fault currents of 600 A and 1000 A. Both are designed to work indifferently in 20 kV or 15 kV networks. After adjustment of the compensating reactor, the resulting fault current under full homopolar tension should not exceed 40 A.

The homopolar capacity of the power distribution network varies according to its topology and its load characteristics. To profit from the advantages of the compensated neutral, the balance between the homopolar network capacity and the inductance of the coil must be maintained.

For the tuning of the reactor inductance, EDF developed a new system. An additional current source is used to inject a homopolar current in the network. Measurements before and during the injection determine the parameters of adjustment for the compensating impedance.

Thus, ALSTOM, an approved EDF supplier, developed and tested a new reactor unit, which gathers the following functions in only one comprising module:

- Neutral point creation by means of a three-phase zigzag winding

- Variable compensating reactor, realised through single-phase self-inductance coils which are coupled in parallel by a commutation system
- Resistor of fixed resistance value, connected in parallel to the inductance coils to create an active component of the fault current
- Single-phase current transformer, to inject the current, which is needed for the system tuning
- Auxiliary cell, provided with load switches for the parallel commutation of the single-phase self-inductance coils. The load switches are controlled by a separated unit, which may be installed in the substation relay building.

ALSTOM underwent successfully the tests of qualification imposed by the EDF-specification. In parallel, an experimentation test phase is carried out on several devices, already in service on site.

The industrial deployment of the compensated neutral of the EDF network begins in 2001. About 1000 to 1200 substations are concerned.

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Introduction

The different modes of grounding the medium voltage power distribution networks differ from country to another. The physical characteristics of the networks, such as network extend, load density, load nature, the quality of the earthing terminals, the network type – air, underground or mixed - led the operators of the various countries to an independent choice of grounding their particular networks.

For the choice of the neutral grounding mode, they have to consider the criteria of tension control during the occurrence of single-phase or multiphase fault currents, the reliability and the sensitivity of protections, the voltage level – simple line-to-earth or phase-to-phase during of the network voltage rise during the defect -, the quality of supply as well as the security of goods and people.

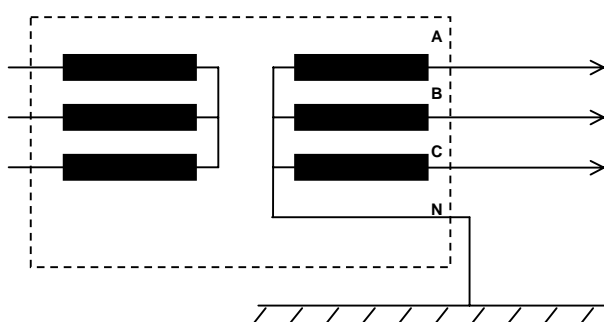
The different modes of neutral grounding

Without being exhaustive, we recall in the following the principal types of medium voltage network grounding applied in various countries of the world:

Direct grounding:

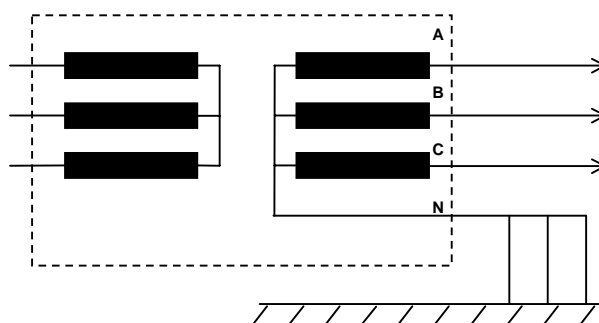
Two alternatives exist, characterised by the different modes of grounding the earthing terminals:

a) direct grounding, neutral not distributed



The insulation level of networks without distributed neutral remains nearly equal to the line-to-earth voltage, the ground potential rise in the proximity of the ground fault are conditioned by the quality of the earthing terminals which must have a very low resistance.

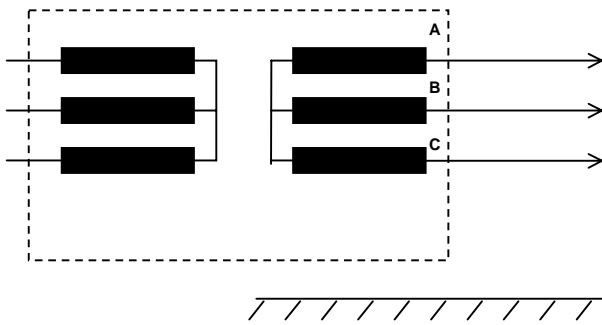
b) direct grounding, neutral distributed



The networks with distributed neutral generally comprise a grounding in many points.

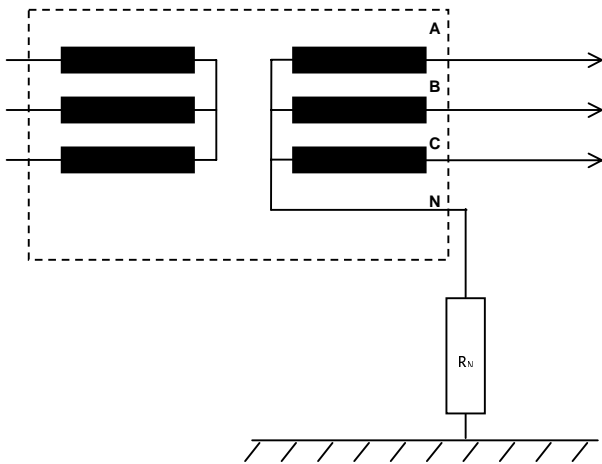
The insulation level of the networks with distributed neutral remains very close to the line-to-earth voltage and the fault current is of strong amplitude.

Neutral point insulated :



The current appearing during a ground fault can only circulate through the capacities between the phase conductor and the ground. It is of low amplitude. Under single-phase fault conditions the voltages of the healthy phases are increased to the phase-to-phase voltage of the network. This has to be taken into account in the definition of the insulation properties of the network.

Neutral grounding by a limiting resistor :

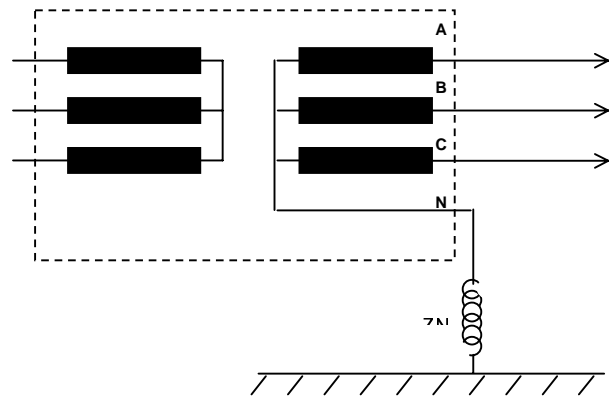


The limiting resistor is inserted between the MV neutral of the HV/MV transformer and the ground of the substation.

The maximum fault current results directly from the resistor value. This current must remain big enough to ensure a sure and rapid fault detection all while maintaining overvoltages in acceptable limits due to personal security.

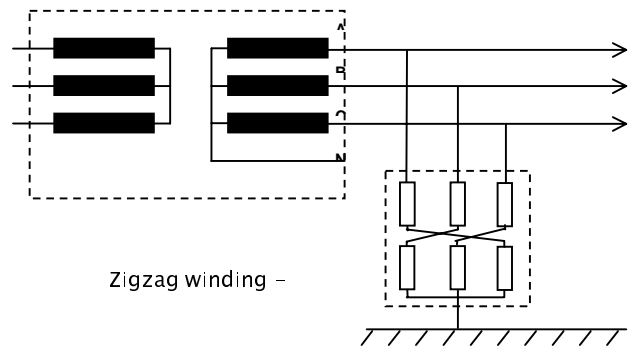
The detection of single-phase fault currents is simple. The insulation level in the case of neutral grounding by a limiting resistor has to be dimensioned for the phase-to-phase voltage of the network.

Neutral grounding by a fixed limiting impedance :



The limiting impedance can be inserted between the MV neutral of the HV/MV transformer of the substation and the ground of the substation. To be independent from the presence of a MV neutral point of the HV/MV transformer of the substation, it is possible to create an artificial neutral point.

This artificial neutral point is most generally realised by means of a three-phase transformer, whose primary winding is zigzag connected and whose neutral is connected directly to the ground of the substation.



This mode of grounding is employed on the MV distribution networks in France since the years 1950. The specification HN 52-S50 of EDF, the national utility of France, thus specified two types of neutral reactors (zigzag winding) for the 5,5kv-10kv-15kv-20kv-30kv networks. A 300 A reactive fault current version is destined for the rural networks with overhead lines, whereas the 1000 A version is gauged for urban networks mainly made of underground cables.

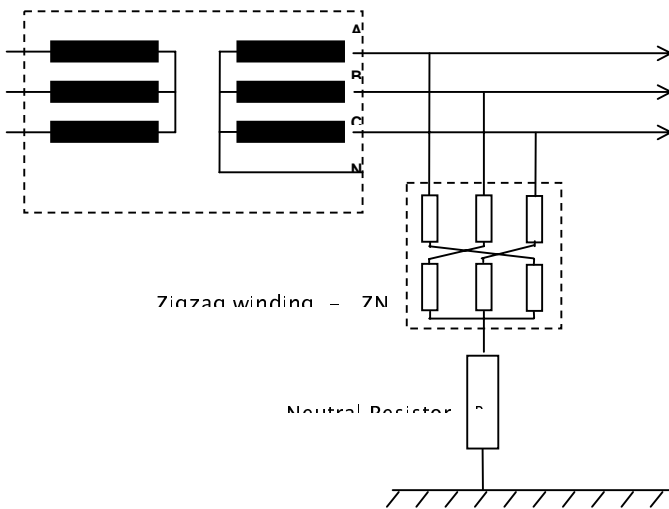
These zigzag neutral point reactors compensate through a constant reactive current the capacitive current of the network in the case of a ground fault. These fault values must remain big enough to ensure a sure and rapid fault detection all while

maintaining overvoltages in acceptable limits due to personal security.

The detection of single-phase fault currents is simple.

The insulation level of the networks with neutral grounding by a fixed limiting impedance has to be dimensioned for the phase-to-phase voltage.

Neutral grounding by connecting in series a fixed limiting impedance and a limiting resistor :



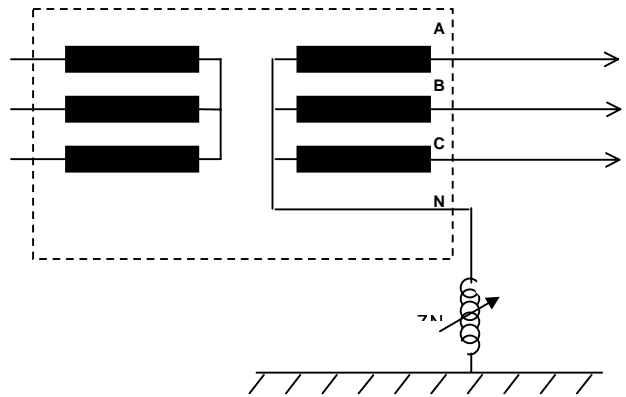
Today, the MV networks of EDF are mainly exploited with 20 kV assigned voltage.

In the years 1980, EDF was committed in a reflection on the policy of the neutral grounding of the MV networks.

The company specifications HM-54-4054 and HM-54-4061 then had to be applied. They contain requirements on the quality factors, dimensions, masses, etc., and they precede already the level of reliability which will be imposed on the future hardware. These constraints had to be validated by performance tests, which reproduce the defects which a zigzag neutral point reactor will meet lasting its life.

To give an example: For the qualification of this hardware, the "300 A" and "1000 A" neutral ground reactors will undergo 1000 application tests of the full zero-sequence voltage with a maximum asymmetry of the current to validate their mechanical behaviour at the generated electrodynamic stresses.

Neutral grounding by a compensating coils :



The compensating coils are variable limiting impedances.

The compensating coils can be connected between the MV neutral point of the HV/MV transformer of the substation and the substation grounding.

The compensating coils can also be connected between the artificial neutral of a neutral reactor and the substation grounding.

The compensating coils are more known under the name Petersen coil, from the name of their inventor.

The compensating coils are adjustable, either manually for the use in fairly stable networks, or automatically for disturbed networks. The ability of adjustment makes it possible to compensate the capacitive current almost completely. After a such compensation the network is "tuned".

The need of compensation adjustment is necessary due to the frequent changes of the network configuration (the load, the length of the exploited network and the share of underground cables of the network). The appropriate value is obtained by an analysis of the network state and the use of an automatic tuning system. Overvoltages are limited to acceptable values due to the tuning range.

The sensitivity and the selectivity of the ground fault detection and particularly the fault resistance makes the fault detection more delicate. This disadvantage often led the operators of this type of network to practise the maintenance of the concerned part of the network during the search and the elimination of the defect.

The insulation level of the networks with neutral grounding by a compensating coil has to be dimensioned for the phase-to-phase voltage.

Grounding by a compensating coil has great advantages. It allows a ongoing evolution of the networks and makes it possible to limit the fault current in the range of optimal values.

It eliminates most of the single-phase fault currents by automatic extinction thus avoiding short power failures.

That's why, for the network operator, a compensating coil is a major asset in view of the continuity and the quality of electric power supply.

The compensated neutral in EDF power distribution networks.

In the years 1980, EDF was engaged to get through a policy of quality improvement of the electric power supply.

While preserving the structures and the conditions of operating the current network, EDF defined objectives such as:

- Fault number reduction
- Reduction of the number and the duration of power failures
- Reduction of fault consequences
- Reduction of voltage hollows
- Increase of the security of people, goods and equipment in the vicinity of the defect

The French rural networks consists of feeders with lengths ranging between 30 and 50 km. Under ground fault condition the capacitive currents can reach a few hundreds amps. A reduction of these values by means of a network topology modification or a grounding improvement of the earthing terminals is not possible for financial and technical reasons.

The French rural networks have undergone significant evolutions during the last years.

To protect the environment, to respect the originality of certain sites, to ensure the safety of the people and the goods and to reduce the network sensitivity in regard of weather events (lightning, storm), EDF transferred a lot of their rural MV overhead lines to underground cables.

The emergence of underground cables in the rural networks increased the capacitive current values under ground fault conditions. In this context, the use of neutral grounding by a fixed limiting impedance shows up its limits. EDF launched a complete inventory and undertook a profound study on all the modes of MV neutral grounding.

An analysis of the advantages and disadvantages of each system made it possible to release new doctrines. The compensated neutral point seemed

to be an interesting solution and compatible with the current networks, while enabling new concepts for fault control, the follow-up of faults and the operational measures in case of a ground fault.

To profit from the advantages of the compensated neutral, the balance between the homopolar network capacity and the inductance of the coil must be maintained.

The homopolar capacity varies according to the topology and the load characteristics of the network. The tuning systems available on the market imply a voluntary modification of the coil inductance in order to generate procedures of calculation and position adjustment of the coil.

In view of the complexity of the automatic tuning systems available and their implementation, EDF decided to developed a new tuning system.

An additional current source is used to inject a homopolar current in the network. Measurements before and during the injection determine the parameters of adjustment for the compensating impedance. This system has the following advantages:

- No inductance variation and thus no variation of compensating coil adjustment is necessary during the calculation.
- The transition time from one position to another is very fast, when a compensating impedance made up of several commutable coils of fixed inductances is used.
- The tuning system may even work during the appearance of a fault.
- The sequences of injection are short and can be frequently repeated.

Having validated this concept, EDF wrote a specification and consulted the manufacturers.

The company specification HN 52 S 25 gathers the criteria, the constraints, the conditions of acceptance and the procedures for testing the compensating reactors.

The compensating reactors are designed to work indifferently in 20 kV or 15 kV networks.

Two types are planned: one type with an adjustment range from 100 to 600 A reactive fault current and another type with a range form 100 to 1000 A.

After adjustment of the compensating reactor, the resulting fault current under full homopolar tension should not exceed 40 A.

To ensure the correct operation of wattmetric and voltmetric homopolar protection systems, an active component of the fault current higher than 20 A is necessary.

The compensating reactor and its control unit (figure 1)

To answer to the EDF specification HN52S25, ALSTOM studied, developed and tested a 20kV–100/600 A and a 20kV–100/1000 A compensating reactor for neutral grounding of medium voltage networks. This reactor gathers several features in only one housing.

Neutral point creation

The creation of the neutral point is realised by means of a three-phase zigzag winding, whose phase inputs will be connected to the three line conductors of the MV network of the substation.

The fixed reactor impedance " Z_0 " has to be very low to avoid a considerable influence on the total impedance value.

Variable compensating reactor

The variable impedance is realised through single-phase self-inductance coils surrounded by a magnetic coat.

These coils are coupled in parallel by means of a commutation system.

The use of 4 different coils allows to obtain 15 adjustment positions which covers the compensation range from 100 A to 600 A reactive fault current.

A whole of 5 coils makes it possible to obtain 31 positions and thus to cover the compensating range from 100 A up to 1000 A reactive fault current.

The impedance values of these single-phase inductances have an approximate arithmetic progression of 1-2-4-8 for the 100-600 A type and an approximate arithmetic progression of 1-2-4-8-16 for 100-1000 A type.

The coils are connected between the neutral point of the three-phase neutral reactor and the substation ground. They are combined and connected in parallel by the commutation system.

Active component of the fault current

A resistor of fixed resistance value is connected between the neutral point of the zigzag winding

and the substation grounding. It creates an active component of the fault current.

Current injection transformer

A single-phase current transformer injects the current, which is needed for the automatic network tuning. The injected homopolar current allows to measure and parameterise the network state and to modify the adjustment of the compensating reactor if necessary.

On the HV side, the current injection transformer is connected between a line terminal and the ground terminal of the substation. On the LV side, there are two LV bushings. The LV circuit is protected by a bipolar fuse disconnecter. The bipolar fuse disconnecter is situated in a switch box, located outside on the front of the tank.

Auxiliary cell for automatic impedance adjustment

The parallel commutation of the single-phase self-inductance coils is carried out by load switches. The auxiliary cell for automatic adjustment comprises as many load switches as there are single-phase coils.

The auxiliary cell for automatic impedance adjustment is provided with:

- A pre-heating system for starting the device under extreme temperature conditions (-25°C).
- A terminal strip for control cable connection.
- Relays for the load switch interlocking and control.
- Mechanical indicators representing the load switch position.

General constitution of de neutral grounding reactor

All these functions (three-phase neutral reactor, variable compensating reactor, active resistor and current injection transformer) are gathered in only one comprising module. They are located in a tank which is provided with cooling fins and filled with dielectric liquid (mineral oil).

The auxiliary cell for automatic impedance adjustment is positioned and bolted on the lid of this tank. The electrical connections between the auxiliary cell and the resistor are carried out by porcelain bushings inside the cell.

The neutral grounding reactor module is connected to the MV network via plug bushings.

The control unit

The control unit of the neutral grounding reactor receives orders from the automatic tuning system. The control unit itself creates the commands for the commutation of the load switches, to couple or to disconnect the single-phase coils of the neutral grounding reactor.

The control unit is a programmed device, which is installed in the substation relay building and which can be removed a hundred meters from the neutral grounding reactor.

A 4-20 mA digital signal forwards all information between the automatic tuning system and the control unit of the neutral grounding reactor.

At automatic control operation mode, the control unit receives only commands of the automatic tuning system. In manual operation mode, the device is under full control of a technician. The commands have to be entered manually by pushbuttons.

The control unit receives information from and transmits information to the neutral grounding reactor and the automatic tuning system.

The "augmente" command for a position change in order to increase the inductive current.

The "diminue" command for a position change in order to decrease the inductive current.

The control unit answers the automatic tuning system this kind of information:

"réglage en cours", indicating that the reactor is carrying out a position change.

"position haute", indicating that the reactor arrived at the position of maximal inductive current.

"position basse", indicating that the reactor arrived at the position of minimal inductive current.

"commande sur place", indicating that the position control of the reactor is exclusively under manual control in the substation control room.

"fonctionnement protection transformateur d'accord", indicating that the protecting fuse of the secondary circuit of the current injection transformer burned through or that the secondary circuit is inoperative due to the opening of the disconnecting switch.

"équipement en défaut", indicating the absence of supply voltage or indicating that the reactor did not finish a position change successfully.

The qualification and experimentation phase

A 20kV–100/600 A and a 20 kV–100/1000 A neutral grounding reactor and their control units built by ALSTOM underwent successfully the tests of qualification imposed by the EDF-specification HN 52S25.

In parallel to these qualification tests, an experimentation test phase is carried out on several devices, already in service on site.

Three 20kV–100/600 A and one 20kV–100/1000 A neutral grounding reactors built by ALSTOM are currently in service on the EDF network.

The industrial deployment of the compensated neutral of the EDF network begins in 2001. About 1000 to 1200 substations are concerned.

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Principal scheme

