# The Effect of Fault Resistance on the Earth Fault Characteristics in Unearthed and Compensated Neutral Medium Voltage Networks

Mohamed F. Abdel-Fattah and Matti Lehtonen

*Abstract*--**In unearthed neutral medium voltage network the maximum earth fault current, at zero fault resistance, is limited by the total earth capacitance however for compensated neutral network the maximum earth fault current is limited by the total leakage conductance and the compensation branch. The effect of the fault resistance on the earth fault characteristics, in both unearthed and compensated neutral networks, is investigated in this paper. The investigations include the effect of the fault resistance on the fault current, fault voltage, the transient recovery voltage (TRV) and the rate of rise of the transient recovery voltage (RRTRV). A realistic 20 kV medium voltage network model is used for the required investigations. The network model has been implemented using EMTP-ATP program. Based on the simulation results, it is found that the fault resistance has a significant effect on the earth fault characteristics which is found different in compensated from unearthed neutral networks.**

*Index Terms*--**Earth fault, fault resistance and unearthed and compensated neutral medium voltage networks.**

## I. Introduction

In medium voltage overhead networks of utilities across the world, approximately 80% of faults are transient and 80% of faults involve one phase to earth only (SLGF; single-line to ground fault) [1]. The fault current magnitude, fault resistance and the rate of rise of the transient recovery voltage (RRTRV) can affect the earth fault characteristics including the possibility of self-extinction of the arcing faults. The arc extinction is the process of changing the medium state from a good conducting (arc) state into a good insulating state. The transient recovery voltage (TRV) is the system generated transient voltage during the current interruption process, at zero-current moment [2]. After the arc extinction, the TRV will be generated, in the same time, during the insulation recovery of the medium. If the insulation recovers more quickly than the TRV then a successful extinction occurs. Otherwise the arc reignites again for the following half cycle before the next arc extinction attempt. The possibility of the self-extinction of the arcing faults can be increased by reducing the fault current and/or the rate of rise of the transient recovery voltage at the fault point. The TRV stresses the insulating medium by high electric field, results in a dielectric breakdown and allows the arcing current to flow. The arc reignition usually occurs immediately after zero-current moment due to the possibility of available conducting ions, from the previous conducting plasma (arc). The process of extinction/reignition continues until a successful extinction attempt of the arc. This process is mainly controlled by the competition between the two competitors: the rate of rise of the transient recovery voltage (RRTRV) and the speed of the insulation recovery. Simply, the winner is the fastest one and it will decide the arc behavior. In unearthed neutral medium voltage (MV) network the maximum value of the earth fault current, at zero fault resistance, is mainly limited by the total earth capacitance of the network. However for compensated neutral medium voltage network the maximum value of the earth fault current is limited by the total leakage conductance of the network and the compensation branch (the compensation coil and its susceptance, and the parallel resistance, if connected).

The earth fault current depends on the network zero-sequence admittance and the fault resistance. For the same network, the maximum value of the earth fault current is constant however the fault resistance depends on the network earthing conditions and the fault parameters. The fault resistance might have a significant effect on the earth fault characteristics. The main goal of the paper is to investigate the effect the fault resistance on the earth fault characteristics in both unearthed and compensated neutral networks. The investigations will include the effect of the fault resistance on the fault current, fault voltage, the transient recovery voltage (TRV) and the rate of rise of the transient recovery voltage (RRTRV). A realistic network model is used for the required investigations, based on a typical 20 kV medium voltage distribution network configuration. The network model has been implemented using EMTP-ATP program. The fault resistance can affect the earth fault characteristics, including the possibility of self-extinction of the arcing faults, which will be investigated in this paper for both compensated and unearthed neutral networks.

M. F. Abdel-Fattah is with the Department of Electrical Engineering, Aalto University, FI-02150 Espoo, Finland and with the Department of Electrical Power and Machines Engineering, Zagazig University, Sharqia, PO Box 44519, Egypt (e-mail: mohamed.f.abdelfattah@gmail.com, mohamed.abdel-fattah@aalto.fi).

M. Lehtonen is with the Department of Electrical Engineering, Aalto University, FI-02150 Espoo, Finland (e-mail: matti.lehtonen@aalto.fi).

## II. The Studied Network

Based on the experience of the current situation of the 20 kV medium voltage cable distribution networks, a realistic network arrangement is proposed for the study. The studied network is presented in Fig. 1. The data of the network and urban underground cable feeders are given in appendix, based on the data from [3]–[7]. The mathematical model of the network has been implemented using the alternative transient program ATP/EMTP which is a popular simulation software package mainly intended for transient analysis applications [8]. The ATPDraw, a graphical pre-processor to ATP, has been used to construct the network elements using suitable graphical blocks/symbols, to plot the required figures and to write the required output data files in a suitable form to transfer it to Matlab [9] for any required advanced analysis.

The investigations will be based on different simulation test cases of the medium voltage network including unearthed and compensated network conditions. The behavior of the network can be investigated easily by the comparison of the different test cases. During earth fault, the earth-fault current mainly depends on the earth capacitance of the background network. The other impedances of the network elements are small compared to the earth capacitances and hence can be neglected. Therefore the maximum value of fault current is limited by the network earth capacitance. The investigations of the earth fault characteristics will focus on the behavior of the fault current, transient recovery voltage and the rate of rise of the transient recovery voltage.

The considered fault type is a SLGF (single line to ground fault in phase-a), with a fault resistance of 10 Ω, occurred in the first underground-cable feeder at incidence time of 7 ms of the third cycle (i.e. at 47 ms) and the fault is assumed to be cleared at the zero-current moment. The rate of rise of the transient recovery voltage (RRTRV) will be calculated from the TRV curve, from the slope of the tangent line to the initial curve that starts with zero-voltage and ends with peak-voltage, as presented in [10].

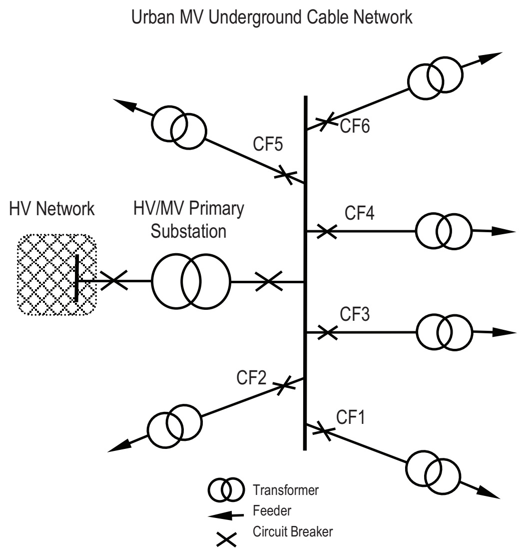


Fig. 1. The studied medium voltage cable distribution network.

## III. The Effect of the Fault Resistance

In unearthed MV network the maximum earth fault current, at zero fault resistance, is limited by the total earth capacitance of the network but for compensated network the maximum earth fault current is limited by the total leakage conductance of the network and compensation branch (the compensation coil and the conductance, considering the parallel resistance if connected). The actual earth fault current mainly depends on the maximum value and the fault resistance. For the same network, the maximum value is constant, however the fault resistance depends on the network earthing conditions and the fault characteristics. The effect of the fault resistance on the fault currents in unearthed and compensated neutral networks is presented in Fig. 2 and the effect of the fault resistance on the initial TRV and RRTRV in unearthed and compensated neutral networks is presented in Fig. 3–4 and the corresponding Figures that present the effect of the fault current are given in Fig. 5–6. The effect of the fault resistance and fault current on the multiplication of TRV and RRTRV, in unearthed and compensated neutral networks, is presented in Fig. 7–8.

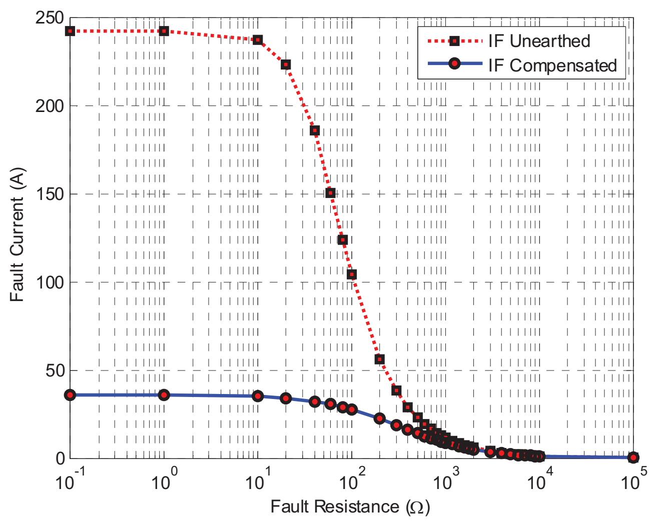


Fig. 2. The effect of the fault resistance on the fault currents in unearthed and compensated neutral networks.

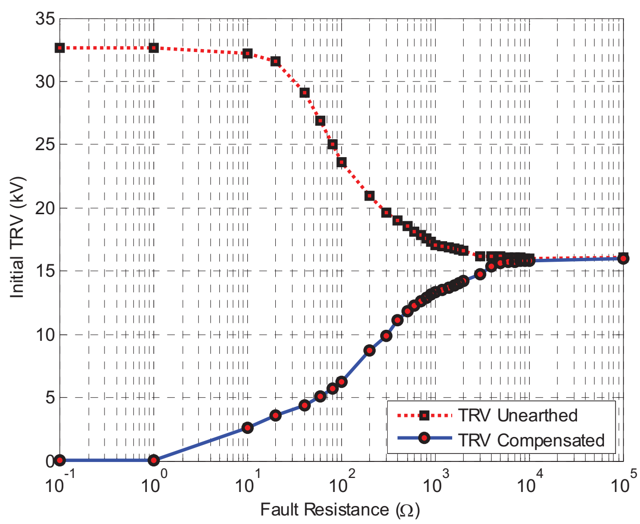


Fig. 3. The effect of the fault resistance on the initial TRV in unearthed and compensated neutral networks.

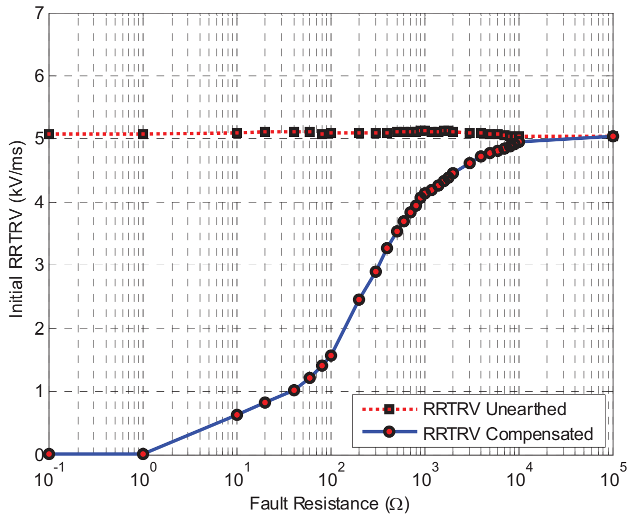


Fig. 4. The effect of the fault resistance on the initial RRTRV in unearthed and compensated neutral networks.

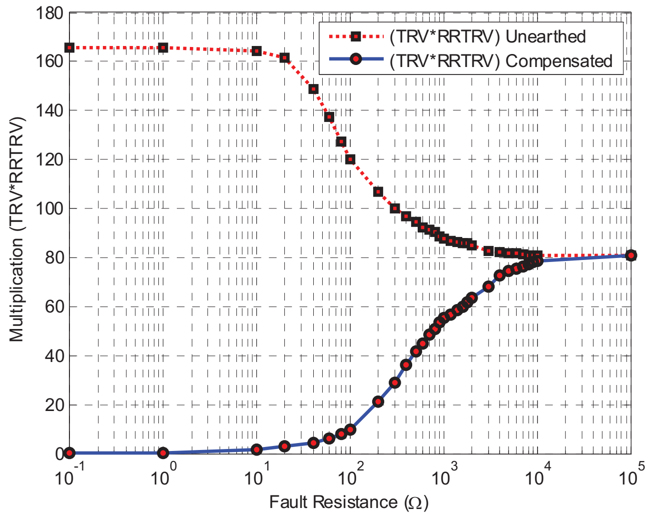


Fig. 7. The effect of the fault resistance on the multiplication (TRV*RRTRV) in unearthed and compensated neutral networks.

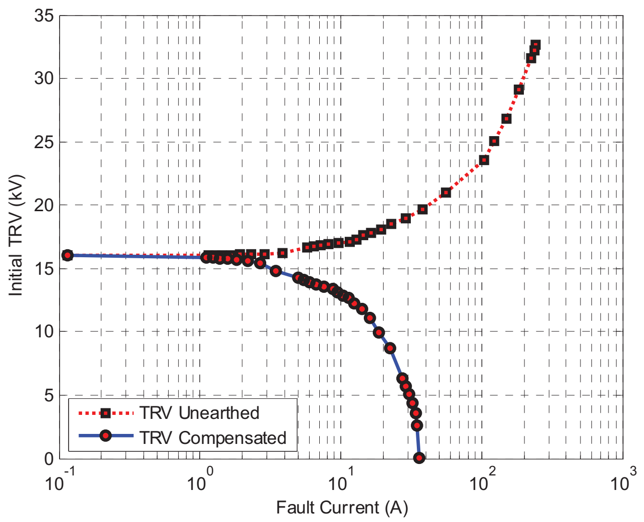


Fig. 5. The effect of the fault current on the initial TRV in unearthed and compensated neutral networks, corresponding to Fig. 3.

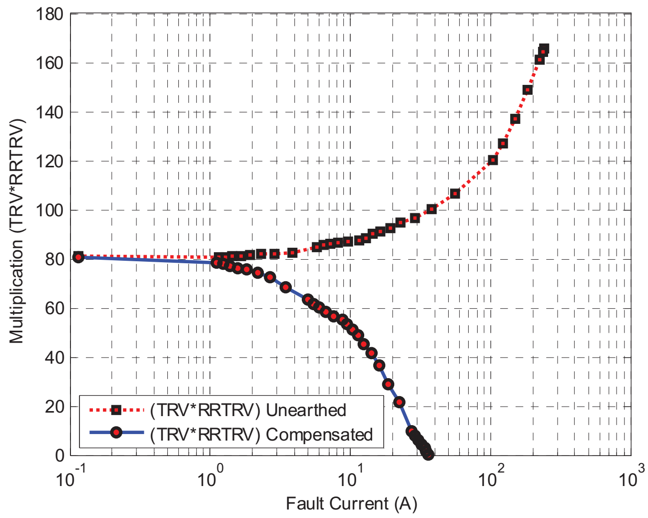


Fig. 8. The effect of the fault current on the multiplication (TRV*RRTRV) in unearthed and compensated neutral networks, corresponding to Fig. 7.

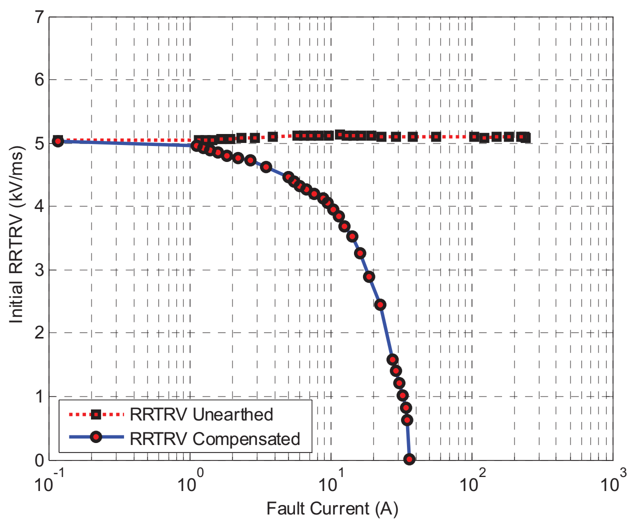


Fig. 6. The effect of the fault current on the initial RRTRV in unearthed and compensated neutral networks, corresponding to Fig. 4.

It can be seen, from Fig. 2, that the fault resistance can affect the fault current in both networks. The significant change can be seen in the range of 10-1000 Ω of the fault resistance and, as expected, the range of the fault current is wider for the unearthed neutral network. The TRV can be decreased with higher values of the fault resistance in unearthed neutral network however it can be decreased with lower values of the fault resistance in compensated neutral network, as investigated from Fig. 3. The RRTRV is almost not affected by the fault resistance in unearthed neutral network however it can also be decreased with lower values of the fault resistance in compensated neutral network, as investigated from Fig. 4. The corresponding values of fault currents, to different values of fault resistances, are shown in Fig. 5–6. It will be beneficial to investigate the effect of the fault resistance on both of TRV and RRTRV, in the same time. The multiplication of the TRV and the RRTRV is proposed to be used. The results are shown in Fig. 7 and the corresponding waveform with respect to the corresponding fault current is given in Fig. 8.

Both Figures present the results with respect to the multiplication of TRV and RRTRV. It can be concluded that, from Fig. 3-8, the effect of the fault resistance on TRV is dominant. The resultant curve in Fig. 7 is similar to the TRV curve in Fig. 3, with different range, and correspondingly the resultant curve in Fig. 8 is similar to the TRV curve in Fig. 5, with different range. The multiplication (TRV*RRTRV) can be decreased with higher values of the fault resistance in unearthed neutral network however it can be decreased with lower values of the fault resistance in compensated neutral network, as investigated from Fig. 7. The two curves for both networks meet at the fault resistance of 10 kΩ, or higher. The minimum value of (TRV*RRTRV) in unearthed neutral network, that can be seen at 10 kΩ or higher, is equal to the maximum value in compensated neutral network.

## IV. Conclusions

This paper has presented the effect of fault resistance on the earth fault characteristics in unearthed and compensated neutral medium voltage networks, including the effect on the transient recovery voltage (TRV) and the rate of rise of the transient recovery voltage (RRTRV). A suitable network model has been used for the required investigations. The mathematical model of the network, based on a typical 20 kV medium voltage distribution network configuration, has been implemented using EMTP-ATP program. Extensive simulations for different test cases have been done to investigate the effect of the fault resistance. Based on the simulation results, an interesting conclusion has been investigated. It is found that the higher values of the fault resistance, starting from 10 Ω, sharply decreases the TRV in unearthed neutral networks, up to 10 kΩ. However, the higher values of the fault resistance, starting from 10 Ω, sharply increases the TRV and RRTRV in compensated neutral networks, up to 10 kΩ. It is strongly recommended to consider this investigation when studying the self-extinction phenomenon of the arcing earth-faults, in unearthed and compensated neutral medium voltage networks.

## V. Appendix

*The urban MV underground cable network data:*
HV/LV primary substation:
Substation transformers: 40 MVA, 110/20 kV
Connection: Star/Delta (Y/Δ) or Delta/Star (Δ/Y)
Reactance = 0.10 pu
MV network total load = 30 MVA
Total feeders' length = 18 km
Feeders = 6 × 3 km (feeder total length)
Feeders' load = 6 × 4500 kVA
LV transformers (20/0.4 kV) = 6 × 5000 kVA = 30 MVA
Connection: Delta/Star-Earthed (Δ/Y┐ )

*Underground cable data:*
AHXAMK-W 3x185Al+35 Cu 20 kV
Conductor diameter = 15.7 mm
Sheath diameter = 37 mm
Cable diameter = 80 mm
Max DC resistance of phase conductor (20˚C) =0.164 Ω/km
Max DC resistance of centre conductor (20˚C) =0.524 Ω/km
AC resistance of phase conductor (65˚C) =0.20 Ω/km
AC resistance of phase conductor (90˚C) =0.21 Ω/km
Inductance = 0.36 mH/km
Operating capacitance = 0.26 μF/km
Charging current (at 20 kV) = 1.00 A/km
Earth fault current (at 20 kV) = 2.90 A/km
Rating current (65˚C) = 330 A.

## VI. References


[1] J. Northcote-Green and R. Wilson, *Control and Automation of Electrical Power Distribution Systems*, Taylor & Francis Group, 2007.
[2] D. L. Swindler, P. Schwartz, P. S. Hamer and S. R. Lambert, "Transient recovery voltage considerations in the application of medium-voltage circuit breakers," *IEEE Transactions on Industry Applications*, vol. 33, no. 2, Mar/Apr 1997, pp. 383-388.
[3] E. Lakervi and E. J. Holmes, Electricity Distribution Network Design, Second Edition, Peter Peregrinus Ltd. - on behalf of - the Institute of Electrical Engineers, London, U.K., 1995.
[4] J. Elovaara and Y. Laiho, Sähkölaitostekniikan Perusteet, Tekijät ja Otatieto Oy, Karisto Oy, Hämeenlinna, Finland, 1993.
[5] Prysmian Cables & Systems Finland. Information on: http://www.prysmian.fi/index.html
[6] E. Lakervi and J. Partanen, Sähkönjakelutekniikka, Gaudeamus Helsinki University Press / Otatieto, Helsinki, Finland, 2008.
[7] M. Hyvärinen, "Electrical networks and economies of load density," Ph.D. dissertation, Dept. of Electrical Eng., Helsinki Univ. of Technology, TKK 146, Espoo, Finland, 2008.
[8] Information at: http://www.emtp.org/
[9] Information at: http://www.mathworks.com/
[10] M. F. Abdel-Fattah and M. Lehtonen, "The effect of network compensation on the transient recovery voltage during earth faults on medium voltage networks," *The EEUG Meeting 2011: European EMTP-ATP Conference*, Ohrid, Macedonia, 26-28 September, 2011.


## VII. Biographies

**Mohamed F. Abdel-Fattah** was born in Qualiobia, Egypt on June 11, 1972. He received his B.Sc. in 1995 with distinction and first class honors from Zagazig University, Egypt and was appointed as a teaching assistant and researcher with the Faculty of Engineering. From the same university, he received his M.Sc. degree in 2000 and Ph.D. degree in 2006 and was appointed as a lecturer with the Department of Electrical Power and Machines Engineering.

Recently, he joined Aalto University, Finland, as a post-doctoral researcher with the power systems group in the Department of Electrical Engineering. His main research activities are related to power system protection, including earth-fault detection, diagnosis and location using transient and fast transient-based algorithms. His current research topic is the development of intelligent protection systems for the self-healing capability of smart grids.

**Matti Lehtonen** (1959) was with VTT Energy, Espoo, Finland from 1987 to 2003, and since 1999 has been a professor at the Helsinki University of Technology (TKK), where he is now head of Power Systems and High Voltage Engineering. Matti Lehtonen received both his Master's and Licentiate degrees in Electrical Engineering from Helsinki University of Technology in 1984 and 1989, respectively, and the Doctor of Technology degree from Tampere University of Technology in 1992.

His main activities include power system planning and asset management, power system protection including earth fault problems, harmonic related issues and applications of information technology in distribution systems.