International Journal of
Science and Engineering Investigations vol. 9, issue 96, January 2020
Received on January 10, 2020 ISSN: 2251-8843

Evaluating the Effects of Inductive Fault Current Limiter and Soil Ionization of High Frequency Grounding System on Transient Recovery Voltage and Rate of Rise of Recovery Voltage in Power Circuit Breakers

Ebadollah Amouzad Mahdiraji[1], Nabiollah Ramezani[2]
[1]Department of Engineering, Sari Branch, Islamic Azad University, Sari, Iran
[2]University of Science and Technology of Mazandaran, Behshahr, Iran
([1]Ebad.Amouzad@gmail.com)

Abstract-In recent years, the use of fault current limiter has been extended in order to limit the current of fault in power transmission lines. Using these limiters near circuit breakers can change the transient voltage of the power circuit breakers when cut off. Installation of the fault current limiter can increase the rate of rise of the transient voltage of the two circuit-breakers to a level that exceeds the tolerable value of the power circuit breaker. On the other hand, given the fact that the transient circuit voltage increase rate, in comparison with the maximum transient voltage, suffers the power circuit breakers much more, it is more important. The simulation results confirm the effect of the proposed idea on improving the transient voltage in the circuit. However, the load on the power circuit breakers depends not only on the cutoff, but also on the increase in the transient voltage. In this paper, by using the EMTP-RV software based on the equivalent model for the induction current limiter for short- line fault, the model of the high frequency grounding system is presented taking into account the effect of soil ionization, current limit factor, stray capacitance and short line spacing. The results of the simulation of inductive FCL electromagnetic transient state show the relationship between the transient voltage rise rate and the transient recovery voltage by using the high frequency grounding system so that we can comprehend the reliable selection of the interrupting characteristics on circuit components and true understanding of the process of transient waves

Keywords- *Fault Current Limiter, High Frequency Grounding System, Lightning Recovery Voltage, Soil Ionization, Power Breakers*

I. INTRODUCTION

Power breakers are the most important control and protection equipment in the power system, the hardest and most important task of which is to diagnose, successfully cut off and isolate the short circuit fault. Switching sparks are always generated simultaneously with a strong CB, which cuts off a short circuit fault. As the RRRV of two isolated contacts becomes larger, the spark extinguishing (possibly with a further arc) becomes harder and CB operational states become more intense. By giving a specific RRRV voltage range, the CB cuts off the two contacts, which are proportional to the oscillating frequency of the switching. Effective factors at intrinsic frequency may include the transmission line structure, FCL position, inductance, and the capability of the main power equipment, as well as the distribution dispersion parameters [1]. When the current is distributed in the distributed power system, the spark is lost between the power breakers while the breaker is free and the system is off. The system is divided into upstream and downstream breakers. At this time, each section, due to internal resistance, inductor, and stray capacitance due to transmission lines and other equipment, generates a series of RLC circuits that have a different natural and damping frequency on each side of the breaker. This difference causes a high-frequency two-breaker voltage, which is referred to as a transient recovery voltage. The peak value of this voltage (TRV) and its rising rate (RRRV) are the two main characteristics of the power breakers, which, along with the short circuit, indicates the capability to disable the breaker [2]. Depending on the type of technology used during the current limiter process, the limiters include power electronics superconductors, polymers, resistors, and arc control techniques. The FCL is arranged in series in the circuit to limit the fault current. After limiting the fault by the limiter, the current is cut off by the breaker. After the cutoff, a transient recovery voltage (TRV) appears at the two ends of the breaker contacts. The placement of the limiter may change the severity of the Breaker action. Today, the use of FCL semiconductor equipment and methods known as active methods has been extended. However, normally, the voltage level of this type of equipment is limited and does not apply to the transmission and super-distribution network. In studies, the highest TRV peak occurs when a non-grounded three-phase fault occurs near FCL and decreases with the increase of the fault location from the location of the FCL installation. In addition, the worst case RRRV condition occurs in a situation where the fault occurs near the FCL, which is considerably reduced by applying methods such as parallel switching with a breaker or using a parallel capacitor with its breaker. The power failure by the power breaker depends on the TRV index. Inappropriate breaker selection is a problem for the power, the most important of which is the short circuit breakdown, because if the breaker is not able to cut the short circuit, it is possible to spread the fault and serious damage to other equipment as well. Therefore, the correct selection of power breakers can increase the reliability of the entire network [4].

In this paper, by using the EMTP-RV software, a study was conducted on a three-phase grounding fault within a 1 km distance from the inductive current limiter, considering the soil ionization of the high frequency grounding system. In this simulation, in order to understand the waveform process correctly, the relationship between the voltage range with the increase in transient voltage and the transient recovery voltage is stated.

II. Analytical Model of Inductive Current Limiter

This type of limiter is connected in series with the CB for operation in the transmission lines and provides approximately zero impedance in normal power network mode. The limiter installation changes the line parameters, which may subsequently create a more dangerous situation for the CB than the non-FCL state. This type of limiter is also the most common limiter type, and is due to its cost-effectiveness and high reliability in high voltage terminals of the transformer, and it can efficiently reduce the fault rate for high-voltage power breakers [5]. In this type of current limiter, a capacitor C_P contains a stray capacitance loop and an additional capacitor in between. The inductive current limiter inductance (L_f) is set in the range of 2.6-23.9. At a frequency of 60 Hz, this suffering inductance shows the same impedance range for an FCL resistor. Also, the C_P capacitor is adjusted between the ranges of 5-100 Nano Faraday. Generally, capacitive equipment may reasonably affect the transient speed of the transmission line, which may be affected by a transient processor that will affect the CB's CB cutoff characteristics. Therefore, investigating the effect of an induction FCL on the RRRV of the power breaker in the series connection should be combined with the current limiter induction FCL stray capacitance. During the process of cutting off the power breaker with a short line fault, the FCL operates at very high current in the limiter conditions of the current with an induction impedance, hence, in the analysis, it can be used as a parallel compound of the inductor with a stray capacitance as shown in Fig. 1 .

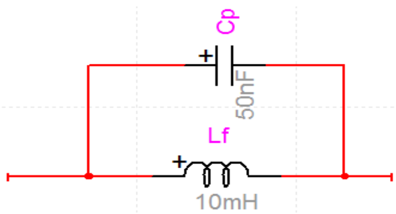

Figure 1. Inductive fault current limiter

III. Impact of Short Line Fault on RRRV Power Breakers

A short line fault is one of the most severe types of faults in testing the capacity of the CB cutoff. The analytical model for the short line fault, regardless of the soil ionization, is shown in Fig. 2, where L_1 and C_1 are respectively the total equivalent capacitance to the grounding and the inductance along the transmission line, respectively.

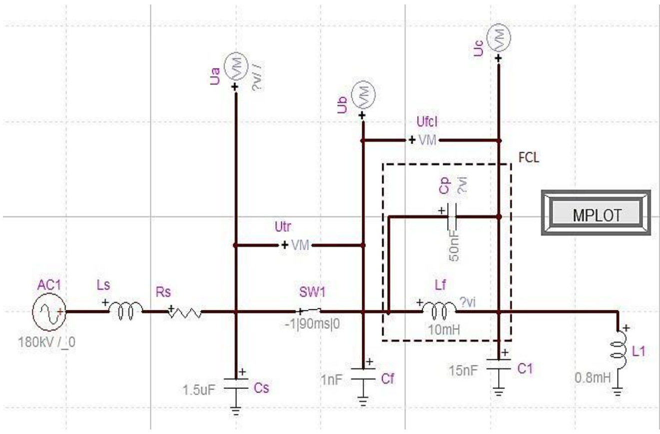

Figure 2. Circuit equivalent circuit for FCL short circuit fault regardless of the effect of soil ionization

The grounding capacitor assembly and the inductance in each unit are C_1 and L_1. If a short line fault occurs at a distance S from the CB, then $L_1 = L_1S$ and $C_1 = C_1S$ are interspersed, then the short-circuit current I_{SS} and the transient voltage rise rate (RRRV) are shown by equations (1) and (2). The calculations are also given with a three-phase short-circuit fault with a 220KV power system and the values of the parameters are as follows [6]:

$U_m = 180KV\ , L_S = 10mH\ , R_S = 0.1\Omega\ , C_f = 1nf\ , C_P = 50nf\ , l_1 = 0.8\, mH/Km$

$$I_{SS} = \frac{U_P}{\sqrt{R_S^2+(\omega L_S+\omega L_f+\omega l_1 S)^2}} = \frac{U_P}{\sqrt{R_S^2+(\omega L_S+\omega L_f+\omega l_1 S)^2}} \quad (1)$$

$$RRRV = U_m\left(\frac{L_S\left(1-\cos\sqrt{\frac{4 l_1 c_1 s^2}{L_S C_S}}\right)}{2s(L_S+l_1 s)\sqrt{l_1 c_1}} + \frac{Z_0}{L_S+l_1 s}\right) \quad (2)$$

IV. Equivalent Circuit of Soil Ionization of High Frequency Grounding System in Short Line Fault

In general, the methods for analyzing the high-frequency model of the grounding system and its dynamic behavior are classified into three theoretical circuit methods, the theory of the transmission line, and the electromagnetic field theory method during the discharge of lightning current. In this paper, the theory of circuit method has been used. A simple and effective way to reduce the voltage range is shown in Fig. 3 for modeling the grounding system at high frequencies in a short line fault.

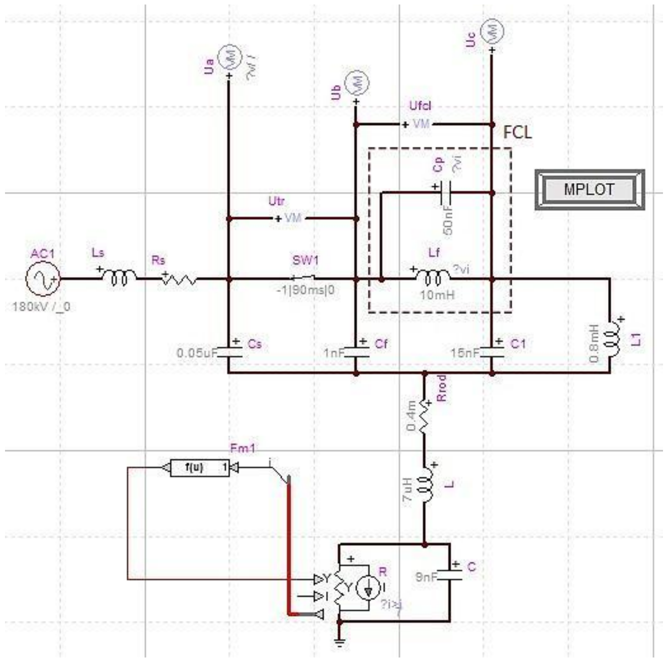

Figure 3. Circuit equivalent circuit for FCL short circuit fault considering the effect of soil ionization

In this circuit, the value of R is determined by the relation (3). In these relationships, the soil's specific strength (in terms of ohm per meter), the length of the surface electrode (meters), the electrode radius (meters), and the depth of the electrode buried per meter.

$$R(\Omega) = \frac{\rho}{2\pi l}\left(\ln\left(\frac{4l}{a}\right) - 1\right) \tag{3}$$

In order to calculate the capacitance of a vertical electrode, it is proposed in equation (4) and it is proposed in equation (5) to calculate the inductance of a vertical electrode. The vacuum permeability coefficient of the soil is usually considered to be the permeability coefficient. In this method, it is assumed that the longitudinal current is uniformly distributed in the electrode. In this paper, the diameter of the rod is 16 mm, the length of the copper rod is 2 meters, and the depth of burial is 0.5 meters. It should be noted that in this research, the high frequency grounding system used is buried vertically [7-11].

$$C(F) = \frac{2\pi\varepsilon l}{\ln\left(\frac{4l}{a}\right) - 1} \tag{4}$$

$$L(H) = \frac{\mu l}{2\pi}\left(\ln\frac{4l}{a} - 1\right) \tag{5}$$

V. THE PROPOSED METHOD ALGORITHM

The considered method in the diagram of Fig. 4 is presented. TRV has various parameters including RRRV and time delay. The RRRV review is very important because it interferes with the other parameters when interrupted by the imposition of a CB. This paper finds an explanation that has a rapid prediction of RRRV over the CB, taking into account the circuit parameters and the current limiter and grounding ionization of the grounding system. In the flowchart T_1, the volatility phase of the source capacitor voltage is T_2, the voltage fluctuation of the FCL is inductive, and T_3 is the fluctuating waves phase fluctuating along the fault line that represents the RRRV wave process. The results of this stage indicate that the transient signals are attenuated on the switching-induced waves. Then, to improve the dynamics of the model, a high frequency grounding system is used. When the injected current to the grounding's rod increases from the threshold of the soil ionization current, the soil around the conductor of the grounding's system changes and positively affects the calculated signals resulting from switching. The output of this flowchart, reducing the amplitude and voltage drop, will improve TRV and RRRV. Advantages of the proposed method in this paper are to improve the level of TRV and RRRV and to achieve a proper understanding of the true wave process.

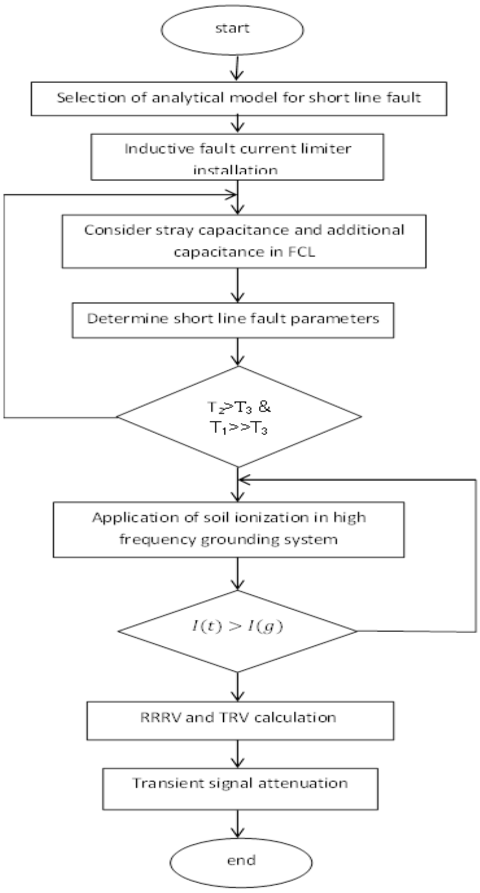

Figure 4. Flowchart of the proposed method

VI. INVESTIGATING TRV AND RRRV CAUSED BY INDUCTIVE CURRENT LIMITER WITH AND WITHOUT SOIL IONIZATION

The system under consideration was simulated for three-phase fault and simulated in the distance of 100 meters from the installation site of FCL in the presence and absence of soil ionization of the high-frequency grounding system using the EMPT-RV software. It should be noted that the simulations performed in the short line fault for different parameters of the source capacitor (C_S = 0.05, 1.5 uf) have been made. In order to determine the FCL, there is no specific relationship to improve the TRV and RRRV and should be done with trial and error. The values of stray capacitances for simulation are: C_P = 10, 50 and100nf. In this simulation, we determine which parameters can reduce the RRRV and TRV values in the power breaker. Fig. 4 and Fig. 5 show the simulated TRV and RRRV diagrams in the absence of soil ionization effect for C_P = 10, 50,100nf and C_S = 0.05, 1.5 uf. The form (6) and Fig. 7 illustrate the simulated TRV and RRRV diagrams for soil ionization of high frequency grounding systems for C_P = 10,50,100nf and C_S = 0.05, 1.5 uf.

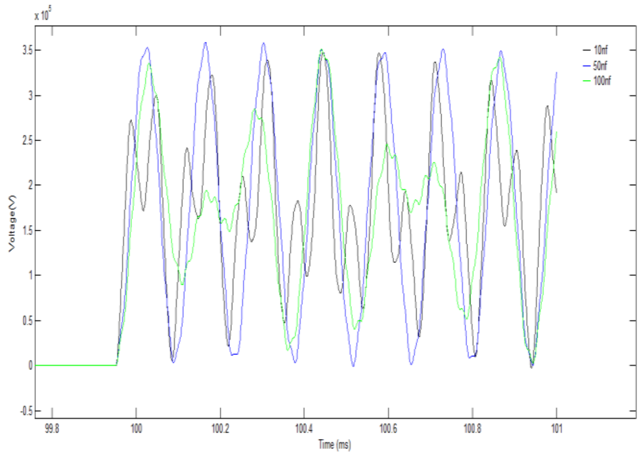

Figure 5. Voltage across the CB in three-phase to ground fault for C_s = 0.05µf and C_p = 10, 50, 100nf in without soil ionization

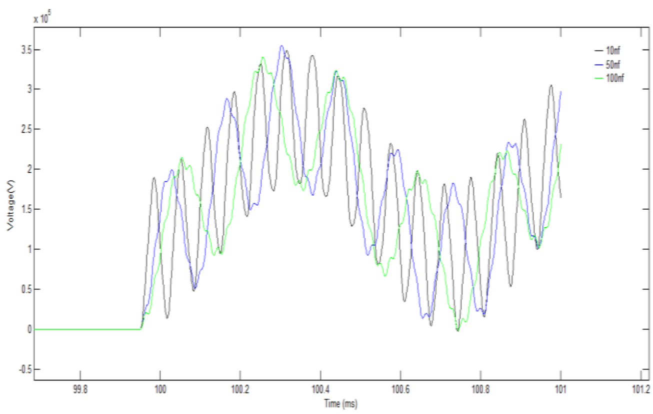

Figure 6. Voltage across the CB in three-phase to ground fault for C_s = 1.5µf and C_p = 10, 50, 100nf without soil ionization

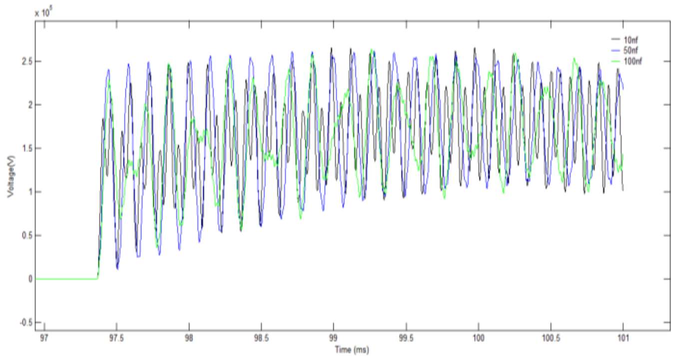

Figure 7. Voltage across the CB in three-phase to ground fault for C_s = 0.05µf and C_p = 10, 50, 100nf with soil ionization

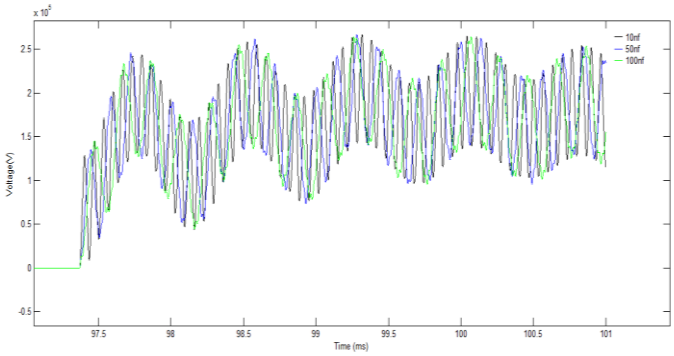

Figure 8. Voltage across the CB in three-phase to ground fault for C_s = 1.5µf and C_p = 10, 50, 100nf by with soil ionization

VII. RESULTS OF SIMULATION ANALYSIS

The results of the simulations show that increasing the capacitance of the dispersion can dramatically decrease the value of the slope of the transient voltage, which this increase in the capacitance of the dispersion can affect the trend of decreasing or increasing the amplitude of the TRV. In addition, one of the parameters that is effective at the slope of the voltage curve is the capacitor at the source side, which, by increasing this parameter, results in a decrease in the RRRV value. Also, in this paper, the effect of soil ionization on the high-frequency grounding system was studied, which results significantly from the decrease in the rate of rise of the transient voltage and a decrease in the peak range of the transient voltage. The presented tables show the values of TRV and RRRV in the 1Km fault, α = 0.5.

TABLE I. TRV AND RRRV VALUES AT DISTANCE 1KM, A = 0.5 WITHOUT CONSIDERING THE EFFECT OF SOIL IONIZATION

C_p (stray capacitance)	*RRRV(KV/US)*		*TRV(KV)*	
	Cs = 1.5uf	*Cs = 0.05uf*	*Cs = 1.5uf*	*Cs = 0.05uf*
10*nf*	347.50	348.67	8.43	5.54
50*nf*	358.56	355.14	4.73	2.67
100*nf*	351.03	340.60	4.35	2.20

TABLE II. TRV AND RRRV VALUES AT DISTANCE 1KM, A = 0.5 WITH CONSIDERING THE EFFECT OF SOIL IONIZATION

C_p (stray capacitance)	*TRV(KV)*		*RRRV(KV/US)*	
	Cs = 0.05uf	*Cs =1.5uf*	*Cs = 0.05uf*	*Cs =1.5uf*
10*nf*	184.42	128.62	2.63	4.28
50*nf*	240.60	135.05	3.43	1.92
100*nf*	229.41	145.67	2.86	1.61

VIII. CONCLUSION

The installation of an FCL induction in the transmission lines has the function of the short circuit current limiter. However, a high RRRV between the CB causes damage to the breaker or leads to a failed breaker. In this paper, considering the different fault scenarios with induction FCL, the relationship between RRRV and the current limiter factor was described. FCL dispersion capacitance, short-circuit fault, high frequency grounding system, and soil ionization effects were represented Also, various factors on RRRV were investigated in detail and compared with the simulation results. In this paper, it was observed that RRRV in the inductive fault current limiter depends on the limiter impedance and limiter current. In the fault current limiter, with increasing impedance limitation, RRRV was significantly reduced. Also for inductive FCL, the RRRV depends not only on L_f but also on the inductor C_P stray capacitance, which has a significant effect on the RRRV of the power breaker. The simulation results show that the RRRV power breaker decreases with increasing dispersion capacitance. We also see, given the orbital shape, that there is a C_P and C_{fcl} capacitor circuit. If the C_P capacitor is not considered in the TRV evaluation, the RRRV will depend mostly on C_{fcl} and because the size of this capacitor is a few nano-Faradays, thus RRRV will be much larger. In another section of the analysis, we considered the effect of soil ionization on the high-frequency grounding system on the short-line fault model so that we saw a significant decrease in the rate of the transient recovery voltage and increase in the transient voltage. Furthermore, with increasing the amount of capacitance of the dispersion, the rise rate of the transient voltage experienced a significant reduction.

REFERENCES

[1] S. Sugimoto, J. Kida, and H. Arita," *IEEE Trans. Power Del.*," 1996, 11(2), 842–847

[2] Hana A Halim, Nur Sabrina Noorpi, Nurhakimah M. Mukhtar, Malaty Amirruddin, *"IEEE computational intelligence", 2013,* 300-305

[3] Wilker V. S. Azevêd , Damásio Fernandes Jr o , Ricardo M. Soares , *"IEEE advanced Topics in Electrical Engineering,", 2013,* 1-6,

[4] Paul Audin Desrosiers, Evenson Calixte and Lein's Maillart Pierre , *"IEEE Conference Power Symposium*", 2007, 63-68

[5] Mohammad Tasdighi,"IEEE north American power symposium",2013, 1-5

[6] Qingmin Li , Jie Lou , and Liang Zou , " *IEEE TRANSACTIONS ON POWER DELIVERY*," 2008, 23(4), 1978-1985,

[7] Imece A, Durbak D, Elahi H, *"IEEE Transaction on Power Delivery*"; 1996, 11(1), 493–506

[8] R. Velazquez. D. Mukhedkar." IEEE Transactions on Power Apparatus and Systems", 1984, 103(6)

[9] Grcev L. IEEE Transactions on Electromagnetic Compatibility, 2009, 51(3), 559–571

[10] R. Marti, F. Castellanos, and N. Santiago, *IEEE Transactions on Power Systems*, 1995, 10(4), 1003-1013

[11] M. Rezaee, Y. Assadi, M.R.M. Hosseini, E. Aghaee, F. Ahmadi, S. Berijani, J. Chromatog. A, 2006, 1116, 1–9.

[12] M. Queiroz, C. Valadão, A. Farias, D. Carvalho, F. Lanças, J. Chromatog. B, 2003, 794, 337–342.

[13] B.J.G. Silva, F.M. Lanças, M.E.C. Queiroz, J. Chromatog. B, 2008, 862, 181–188.

[14] M.D. Oliveira, M.E.C. Queiroz, D. Carvalho, S. Silva, F. Lanças, Chromatographia, 2005, 62, 215–219.

[15] M. Tankiewicz, C. Morrison, M. Biziuk, Talanta, 2013, 107, 1–10.

[16] A. Sarafraz-Yazdi, A. Amiri, TrAc, Trends Anal. Chem., 2010, 29, 1–14.

[17] H. Y. Yuan, Z. C. Fu, and B. G. Wei, Proceedings of the Chinese Society for Electrical Engineering, 2009, 29(25), 111-116

How to Cite this Article:

Mahdiraji, E. A. & Ramezani, N. (2020) Evaluating the Effects of Inductive Fault Current Limiter and Soil Ionization of High Frequency Grounding System on Transient Recovery Voltage and Rate of Rise of Recovery Voltage in Power Circuit Breakers. International Journal of Science and Engineering Investigations (IJSEI), 9(96), 24-28. http://www.ijsei.com/papers/ijsei-99620-05.pdf