QUID 2017, pp. 1044-1050, Special Issue N°1- ISSN: 1692-343X, Medellín-Colombia

EVALUATION OF BEHAVIOR OF FAULT CURRENT LIMITERS ON POWER QUALITY OF DISTRIBUTION NETWORKS WITH PRESENCE OF DISTURBED GENERATION

(Recibido el 17-05-2017. Aprobado el 11-08-2017)

Nader Rezai
Islamic Azad University,
Graduate Student, Department of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahr-e-Rey Branch,Tehran, Iran

Amir Ahmarinejad
Islamic Azad University
Assistant Professor, Department of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahr-e-Rey Branch,Tehran, Iran.

Resumen: Hoy en día, los problemas de calidad energética son uno de los problemas más importantes en las redes de distribución, que han atraído en gran medida la atención de investigadores e ingenieros eléctricos. La principal y última razón para prestar atención a la calidad del poder en el sistema de distribución puede ser cuestiones económicas. Los estudios de calidad de la energía indican que entre el 80% y el 90% de las quejas de los suscriptores de la compañía de energía se deben a la falta de potencia debido a la falta de voltaje, y la principal razón de la falta de voltaje son las fallas de cortocircuito. Por lo tanto, el limitador de corriente de falla es una solución conveniente y económica para resolver este problema. En este trabajo se utiliza FCL en el sistema de distribución y cuando se produce un fallo en la barra colectora 5, los cambios de voltaje y corriente se observan utilizando un limitador y sin utilizarlo.

Palabras clave: Limitador de corriente de falla, Mejora de la calidad de la alimentación, Sistema IEEE 9-Busbar

Abstract: Today, the power quality problems are one of the most important problems in distribution networks, which have largely attracted the attention of researchers and electrical engineers. The main and final reason for paying attention to the quality of power in the distribution system can be economic issues. Power quality studies indicate that between 80% and 90% of subscriber complaints from the power company are due to the lack of power due to the lack of voltage, and the main reason for the lack of voltage is short circuit faults. Therefore, the fault current limiter is a convenient and economical solution to solve this problem. In this paper, FCL is used in the distribution system, and when the fault occurs in the busbar 5, voltage and current changes are observed using a limiter and without using it.

Keywords: Fault Current Limiter, Improving the Power Quality, IEEE 9-Busbar System

Citar, estilo APA: Rezai, N., & Ahmarinejad**, A.** (2017). Evaluation of behavior of fault current limiters on power quality of distribution networks with presence of disturbed generation. *Revista QUID (Special Issue)*, 1044-1050.

1. INTRODUCTION

Across the world, power networks are the vast networks that, for various reasons, there is always the possibility of disturbance in them. In general, three reasons can be noted for the increasing attention to this issue: 1) The sensitivity of current electrical equipment has increased in comparison with previous equipment and power quality changes, 2) Increasing the subscriber awareness towards the topics of power quality, 3) Connecting networks to one another and forming larger networks has been caused to damage the equipment leading to more adverse effects. On the other hand, electric power consumers are able to function in a specific range of power quality. In order to evaluate the quality of the electric power and carry out measures to improve it, it is necessary to have sufficient knowledge about the disturbances causing the decrease in the power quality of the electric power. To this end, disturbances are classified into different groups and each group has its own specific characteristics, and restrictions are imposed for each of them in accordance with the standards. These limitations are considered in order to keep the power quality through an acceptable level for consumers. To maintain these limitations, there should be continuous monitoring on the quality of electrical power. As a result of this monitoring, the disturbances, defects and problems of power supply are recognized and the way opens to improve the quality of electric power (McQueen, 2015).

Subscribers of distribution networks have always been affected by voltage range variations such as short-term and long-term drop, short term and long term fluctuations, short term and long term volatility and power outage. In the annual report of the power distribution company, the greatest percentage of problems on the network is related to the voltage drop in high power grids. Therefore, the first issue is the service and maintenance of the equipment, which is very effective in generating power quality and raised the reliability indicators. Then, the voltage drop problem was considered in several medium pressure feeders performed activities and calculations on them practically (Shahram, 2012), (Hadjidemetriou, 2015).

The issue of electrical energy quality or power quality is one of the issues that have been seriously addressed by consumers of electrical networks in recent years. It is estimated that the damages caused by power quality disturbances in the United States is estimated to be about $ 100 billion annually. Therefore, the investment to deal with these disturbances is much less than the damage done. New distribution systems are susceptible to various disturbances in the network and their performance can easily be disrupted. These abnormalities can cause serious damages as mentioned above. Therefore, the investments and studies are very much considered today to improve the quality of power and prevent the above-mentioned damages (Alireza, 2015).

2. LIMITERS FUNCTIONS on SERIES and PARALLEL RESONANCE

The limiters effect on series and parallel resonances:

2.1 Basics of series resonance

Suppose that in the circuit of Fig. 1, the existing inductor and capacitor are perfectly ideal. In this case, the impedance of the inductor and the impedance of the circuit can be expressed as follows (Tian, 2016):

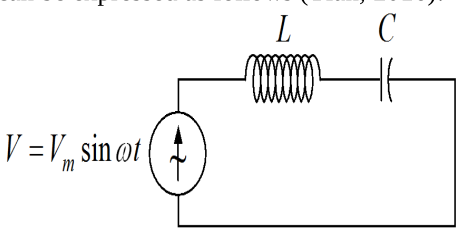

Figure 1. An ideal LC series circuit with sinusoid simulation

$$X_L = j \times 2\pi f \times L = j\,\omega L \,. \quad (1)$$

$$Z = X_L + X_C = j\,(\omega L - \frac{1}{\omega C}) \,. \quad (2)$$

So, for resonance occurrence:

$$\xrightarrow{Z=0} \omega L = \frac{1}{\omega C} \Rightarrow \omega = \frac{1}{\sqrt{LC}} \,. \quad (3)$$

$$f_{res} = \frac{1}{2\pi\sqrt{LC}} \Rightarrow Z_{res} \approx 0 \Rightarrow I_{res} \Rightarrow \max \,. \quad (4)$$

That, in above relation:

f_{res} is the adverse frequency. When the circuit operates at this frequency, the current flows from orbit or I_{res} maximizes. Note that with respect to frequency variations, total impedance can show both inductor behavior and capacitive behavior.

2.2 Basics of parallel resonance

As before, the inductors and circuit capacitors of Figure 1 are ideal. So it can be written in order to calculate the total circuit impedance (Tian, 2016):

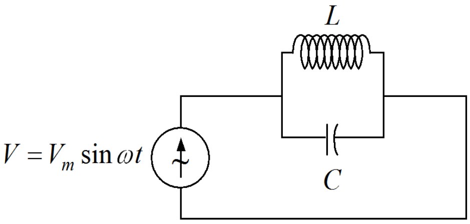

Fig. 2. An ideal LC parallel circuit with sinusoid stimulation [5]

$$Z_{Total} = Z_L \parallel Z_C = \frac{j\omega L \times \frac{-j}{\omega C}}{j\omega L - \frac{j}{\omega C}} = \frac{j\omega L}{1 - LC\omega^2} \quad (5)$$

.

In this case, the resonance frequency is calculated similar to Equation 5. With the difference that in parallel resonance it is expected that the circuit impedance will be infinitely (open circuit). As a result, the current passing through the circuit will be zero.

3. APPLICATION OF RESONANCE PHENOMENON IN FCL

Note that in normal mode, the resonance in the circuit should be occurred. In the case of 50 Hz power supply in Iran, the FCL should be at this frequency in the state of resonance and the frequencies should be increased to limit the flow of fault. For example, consider the circuit of Fig. 3 at 50 Hz with values

$$R_{ls} = 0.25\Omega, L_{ls} = 200\text{mH}, C_{ls} = 50.66\mu\text{F}$$.

The circuit conversion function is equal to [6]:

$$H(j\omega) = R_{ls} + j\left(\omega L_{ls} - \frac{1}{\omega C_{ls}}\right) \Rightarrow \begin{cases} |H(j\omega)| = \sqrt{R_{ls}^2 + \left(\omega L_{ls} - \frac{1}{\omega C_{ls}}\right)^2} \\ \angle H(j\omega) = \tan^{-1}\frac{\left(\omega L_{ls} - \frac{1}{\omega C_{ls}}\right)}{R_{ls}} \end{cases} \quad (6)$$

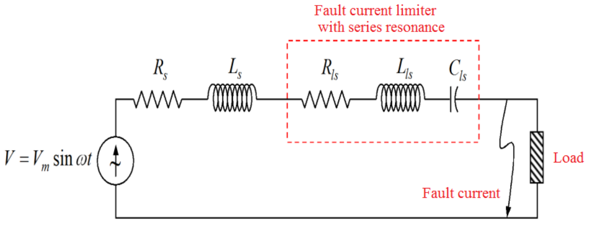

Figure 3. limiting fault current using series resonance

The frequency of resonance can be calculated based on the equation 7:

$$\left(\omega L_{ls} - \frac{1}{\omega C_{ls}}\right) = 0 \Rightarrow \omega = \frac{1}{\sqrt{L_{ls}C_{ls}}} \Rightarrow f_{res} = \frac{1}{2\pi\sqrt{L_{ls}C_{ls}}} \quad (7)$$

.

In resonance mode, the FCL impedance value will be equal to 0.25Ω, and in fault mode, the impedance value will increase by more than 100 times. This also applies for the parallel resonance circuit. For example, the real and imaginary parts of the FCL conversion function of Figure 4 are:

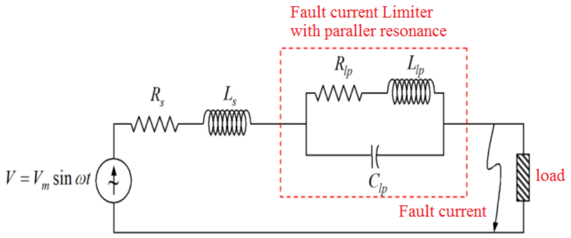

Figure 4. limiting fault current using parallel resonance method

$$\begin{cases} |H(j\omega)| = \frac{\sqrt{R_{lp}^2 + [\omega L_{lp}(1-\omega^2 L_{lp}C_{lp}) - \omega C_{lp}R_{lp}^2]^2}}{(1-\omega^2 L_{lp}C_{lp})^2 + (\omega C_{lp}R_{lp})^2} \\ \angle H(j\omega) = \tan^{-1}\frac{\omega L_{lp}(1-\omega^2 L_{lp}C_{lp}) - \omega C_{lp}R_{lp}^2}{R_{lp}} \end{cases} \quad (8)$$

.

The frequency of resonance can be calculated based on the Equation 9:

$$\angle H(j\omega) = 0 \Rightarrow \omega = \sqrt{\frac{1}{L_{lp}C_{lp}} - \frac{R_{lp}^2}{L_{lp}^2}} \Rightarrow f_{res} = \frac{1}{2\pi}\sqrt{\frac{1}{L_{lp}C_{lp}} - \frac{R_{lp}^2}{L_{lp}^2}} \quad . \quad (9)$$

4. PRESENTATION OF THE MODEL

Since one of the factors for the reliability of the output results is based on the standard of the studied network, in this paper, an IEEE 9-busbar network is used to test the results. The diagram of this network is shown in Figure 5. (Tian, 2016).

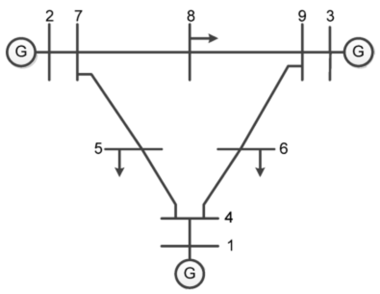

*Figure 5. IEEE 9-busbar network (*Panchbhai, 2016*)*

4.1. Power network implemented in MATLAB

The full specifications of power grid resources are shown in Table 1

Table 1. The full specifications of the standard of IEEE 9-busbar system with disturbed generation *(*Panchbhai, 2016*)*

Type of equipment	Parameter	Value
Source No.1 connected to busbar No.1	Voltage	16.5 kV
	Power	247.5 MVA
	Frequency	50 Hz
	Initial phase	0
Source No.2 connected to busbar No.2	Voltage	18 kV
	Power	192 MVA
	Frequency	50 Hz
	Initial phase	0
Disturbed generation (DG) connected to busbar No.3 including 6-turbine wind farm	Voltage	13.8 kV
	Power	6 * 1.5 = 9 MVA
	Frequency	50 Hz
	Initial phase	0

Also, the specifications of system bars are shown in Table 2.

*Table 2: T*he specifications of system bars (standard) [7]

Specification of bar	Parameter	Value
Indicator Ohm bar connected to busbar 5	Voltage	230 kV
	Ohm power	125 MW
	Indicator power	50 MVAr
Indicator Ohm bar connected to busbar 6	Voltage	230 kV
	Ohm power	90 MW
	Indicator power	30 MVAr 0
Indicator Ohm bar connected to busbar 8	Voltage	230 kV
	Ohm power	100 MW
	Indicator power	35 MVAr

Simulation run

In this study, it is assumed that the fault is applied in the busbar No.5 and in the bar. First, the single phase fault in the ground in phase A will be applied to the system. Finally, we validate the effect of FCL on the network by analyzing FFT and examining the quality characteristics. In the busbar 5 and 0.2 to 0.25 seconds, the phase A hits the ground. The fault pulse duration is drawn in Figure 8.

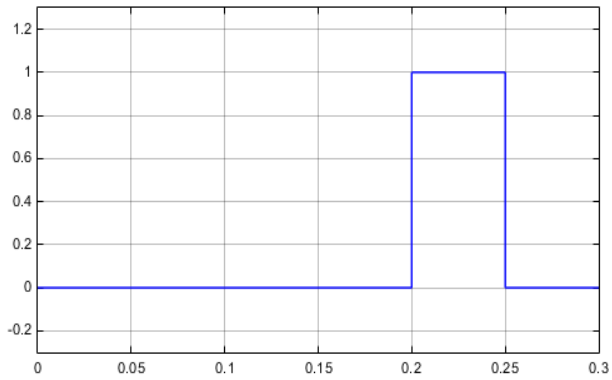

Fig 6. The fault pulse duration though 0.2 to 0.25 seconds

The voltage and current diagram of each of three phases in different points of the system are given below. We assume at first that there is no limiting factor in the circuit. Then we simulate and compare the graphs with the limiter. THD analysis is one of the important elements in the analysis of this case. Figures 7 and 8 show the voltage of the busbar 5 with and without the limiter. Figures 9 and 10 also show the fault circuit with and without using a current limiter. It's also worth noting that all values are prionited in terms of their base in the network.

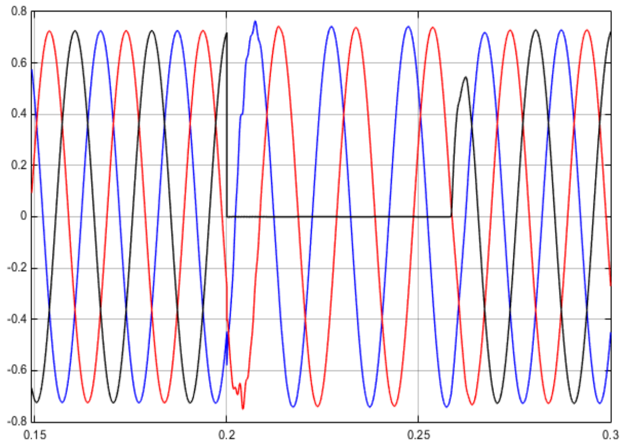

Fig 7. The busbar voltage (No.5) in the state of fault without using the limiter of the current

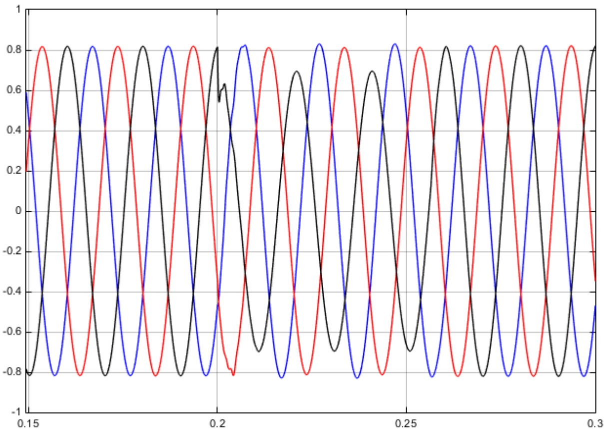

Fig 8. The busbar voltage (No.5) in the state of fault with using the limiter of the current

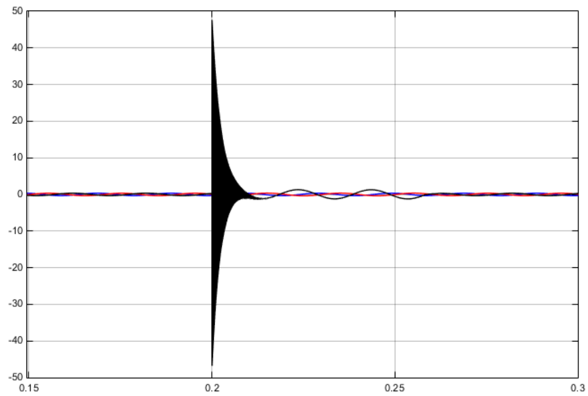

Fig 9. The busbar circuit (No.5) in the state of fault without using the limiter of the circuit

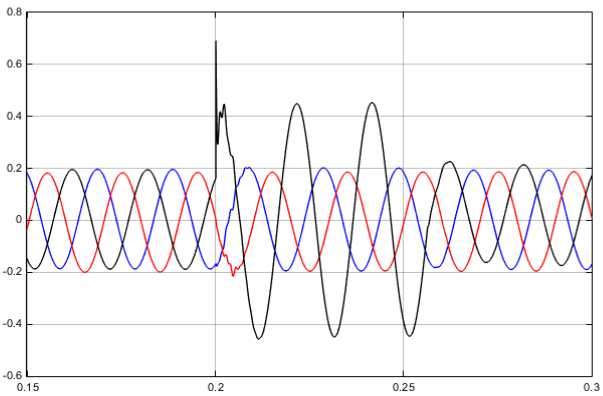

Fig 10. The busbar circuit (No.5) in the state of fault with using the limiter of the circuit

In Figures 7 and 8, it is clear that in the time of the presence of a limiting factor in the busbar 5, the voltage variations fluctuate regularly, and vice versa, and without limiting, there is no additional fluctuation.
Also, the fluctuations of the circuit in the busbar 5 do not reach the maximum value using the limiter. In other words, the short circuit current decreases. In Figure 9, the current is increased to 50 amps, but in Figure 10, due to the current limitation, it increases to about 1 amp.

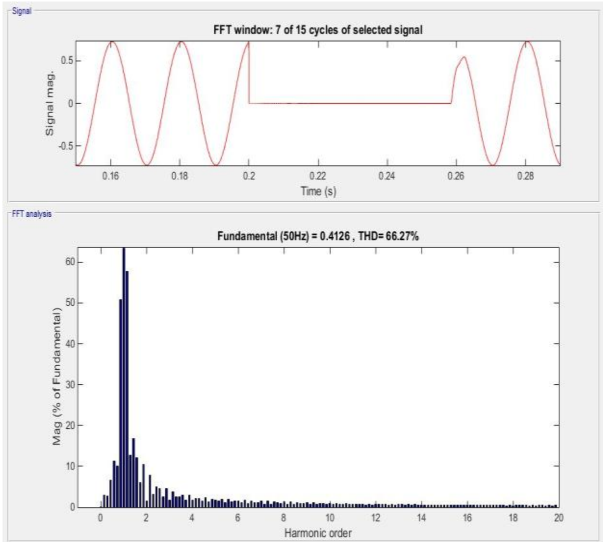

Fig 11. Fourier series analysis and THD for the voltage of phase A without using limiter

It is observed that during the fault, the voltage is completely zero. This theme dramatically increases the THD. It also causes the nonlinearity of the circuit and the formation of incorrect multiples of the harmonics. In this case, the main harmonic value of the voltage is equal to 0.41 psi and the THD is equal to 66.27%. Figure 12 illustrates this analysis for the use of the limiter.

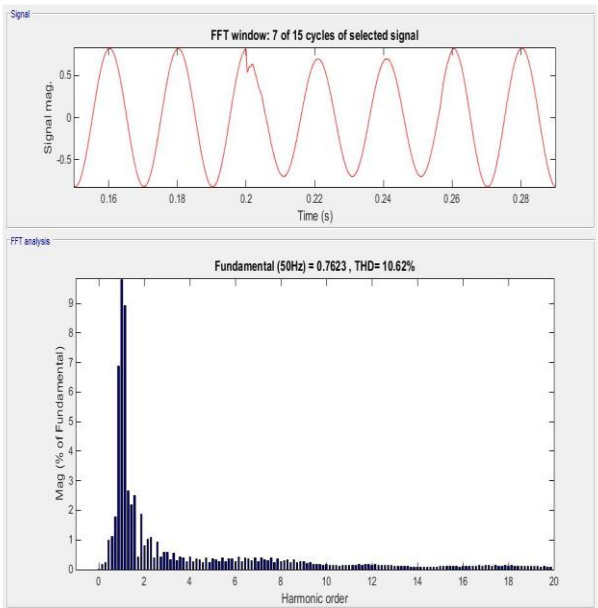

Fig 12. Fourier series analysis and THD for the voltage *of phase A with using limiter*

As shown in figure 12, THD value is much better and the voltage status has reached to a satisfactory level. In this case, the main harmonic voltage level is 0.76 psi and THD equals to 10.62%.

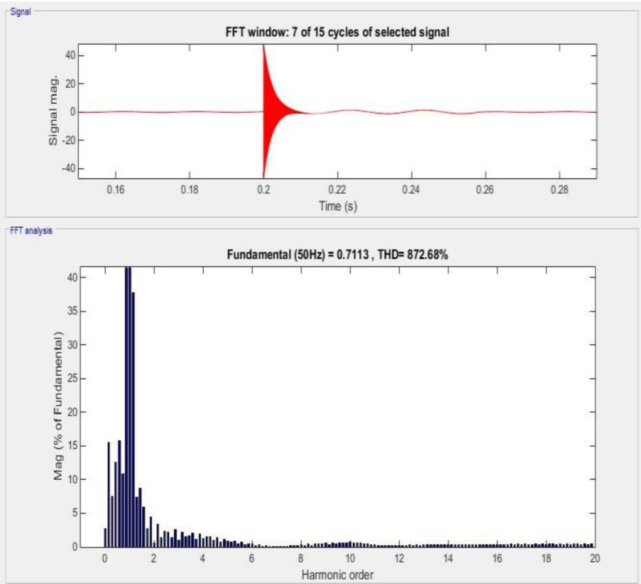

Figure 13. *Fourier series analysis and THD for the current of phase A without using limiter*

At the same time, the same analyzes can be used for a limiting condition in the circuit. Figure 14 shows the graph of this analysis. In fact, it now appears that the THD has reached 54.28%, which is lowered compared to the above status. Note that this harmonic disturbance is still not within the standard range and only reduces the effects of the short circuit mode.

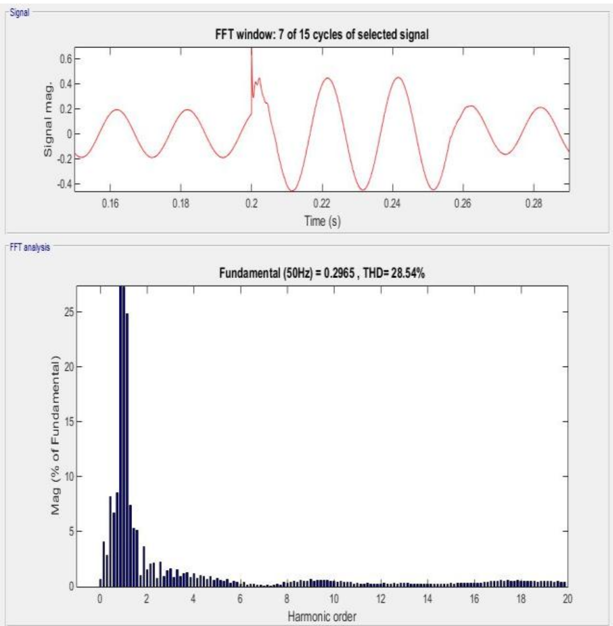

Fig 14. Fourier series analysis and THD for the current of phase A with using limiter

5. CONCLUSION

Due to the possibility of excessive faults and exhaustion of the system's protective equipment such as relay protection, bracket, fuse, etc., in the distribution system, the power quality and its improvement are considered essential. Nowadays, due to the use of voltage-sensitive equipment in modern industry, power quality issue has become more noticeable in electricity companies. Due to the network connection to each other and the entry of new equipment, in which power quality is very important, power quality issues have become very important. Among the factors that affect the quality of power, it can be mentioned lightning or switching, voltage drop, voltage regulation, fault current, network connection, harmonics, repair and maintenance, etc. In this article, it is intended to improve the quality of the power due to the fault current.

To improve the quality of power, there are solutions such as compensators, their configuration through algorithms, and so on, but the fault current limitation is the best solution to deal with the fault current on the system. Fault limiting factors increase the reliability and stability of the distribution system beyond the limitation of the fault current, as well as the stability of the system and its protection is also very effective. Fault current limiters in serial circuits cause fault current to supply through the impedance (resistance or inductor) to the capacity of the breakers.

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