

LIMITING SHORT-CIRCUIT CURRENTS IN MEDIUM-VOLTAGE APPLICATIONS

Terence Hazel
Senior Member IEEE
Schneider Electric
38050 Grenoble
France

Abstract – The power requirements for large industrial sites is increasing. Often there is also a requirement to reduce the installation volume of electrical equipment in off-shore facilities where every square meter is very expensive. One means of reducing the amount of electrical equipment is to use the generation voltage as the distribution voltage of the site. This often however, results in very high values of short-circuit current exceeding both the peak rating and breaking capacity of switchgear. Fast-acting current limiting devices can be installed in the electrical distribution system in order to reduce the short-circuit current to acceptable values.

Index Terms – electrical substations, short-circuit current, current limiters.

I. INTRODUCTION

In the past, when power requirements increased, the only solution was to increase the voltage in order to meet the limitations of nominal current and short-circuit current. This meant using transformers to step-up the generated voltage to 33kV or higher, and then to step the voltage back down with substation transformers in order to supply the loads. These step-up and step-down transformers together with the additional switchgear for their protection greatly increased the amount of space required for the installation of the electrical distribution equipment.

For grass-roots on-shore sites this design philosophy is still used since it allows the use of standard electrical equipment. For existing sites and for off-shore facilities there is often insufficient room for the transformers. Should step-up and step-down transformers not be used, it is necessary that the switchgear be able to handle the very high values of short-circuit current resulting from the use of a lower distribution voltage. Since the short-circuit current will exceed both the peak and the interrupting current ratings of standard switchgear, the only choice is to limit the value of short-circuit current that can occur.

Current limiting devices that can limit the peak current and the interrupting current are available. How these devices operate and where they can be used is the subject that will be presented in this paper. In addition to the higher values of short-circuit current, the nominal current will increase. Solutions using circuit-breakers in parallel and alternating load and source circuits in switchboards are techniques that can be used to handle this problem which is important, but not the subject of this paper.

In this paper, the term medium-voltage will be used for all voltages above 1 kV up to 36 kV. The term high-voltage will be used for voltages exceeding 36 kV.

II. POWER DISTRIBUTION IN INDUSTRIAL SITES

The type of electrical distribution system depends on many factors, one of the most important being the amount of power required. Other factors such as the availability of the power supply are equally important but not directly related to the maximum available short-circuit current. For the purpose of this paper, a radial distribution will be used since it will illustrate all the required concepts and makes the discussions easier to understand. The extrapolation of the use of current limiting devices to redundant distribution systems such as commonly used in petro-chemical facilities is easily made.

A. Distribution systems for small sites

For sites where the installed power is less than approximately 40 MW, the voltage at which the power is generated can be used directly by the loads as shown in Fig. 1. A typical voltage is 6.6 kV which is one of the most commonly used for medium-voltage motors. The only transformers required in this system are the distribution transformers for supplying low-voltage loads. This is the optimal design requiring the minimum number of transformers and distribution system circuit-breakers.

B. Distribution systems for medium-sized sites

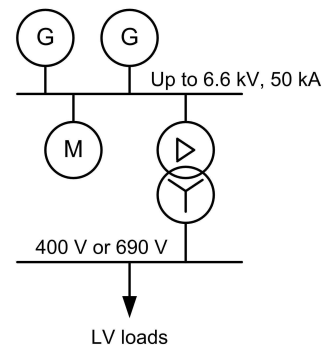


Fig. 1 Distribution for small site

When the installed power increases, it is necessary to also increase the voltage. Generator and large motors can operate at 13.8 kV which is typically the highest utilization voltage used for systems as shown in Fig. 2. The 13.8 kV is also used as the distribution voltage for supplying the unit substations located throughout the site.

Normally few motors will be supplied at 13.8 kV due to the expense of using higher voltages. Typically most medium-voltage motors will be supplied at 6.6 kV which requires

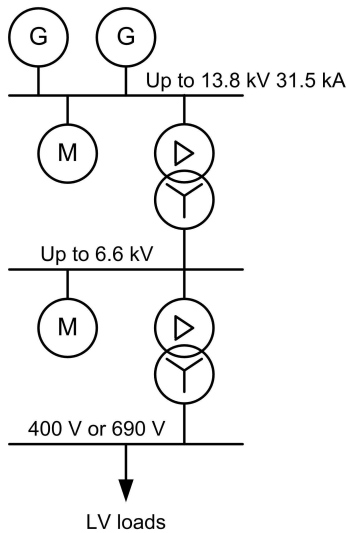


Fig. 2 Distribution for medium-sized site

additional step-down transformers in the unit substations. These transformers, together with their circuit-breakers, are the only additional equipment with respect to small sites.

C. Distribution systems for large sites

For large sites where there are no major restrictions regarding space for the electrical distribution equipment, the system as shown in Fig. 3 is typical. In order to be able to distribute the power to the different unit substations, the voltage is stepped up to 33 kV or higher. In the unit substations, the voltage is then typically stepped down to the utilization voltage such as 6.6 kV for supplying the medium-voltage motors and the distribution transformers for low-

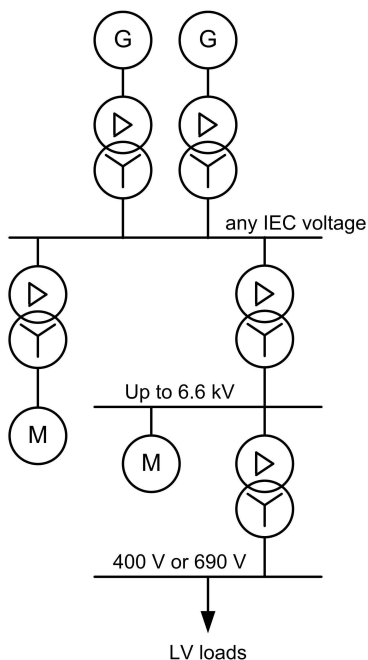


Fig. 3 Distribution for large site

voltage loads.

As can be seen when comparing the distribution system for large sites to that for small sites, there are several additional transformers which, together with their dedicated switchgear, greatly increases the amount of space required for the electrical distribution system equipment. The advantage of this system is however, the use of standard electrical equipment which facilitates its purchase and maintenance. The other advantage is the possibility of supplying very large drives directly from the distribution voltage by means of captive transformers. By connecting large loads at the highest available voltage, often starting problems can be eliminated without requiring additional equipment.

D. When space is a problem

For large sites, when space is a problem, the solution that is first looked at is to attempt to supply the power with a system similar to that shown in Fig. 2 above. This has the advantage of eliminating all step-up transformers resulting in a reasonably small footprint. The disadvantage is of course the much higher nominal currents and the very high level of short-circuit currents.

For such distribution systems, it is necessary to install additional devices in order to limit the value of the prospective short-circuit current.

III. LIMITING SHORT-CIRCUIT CURRENTS

In medium and high voltage installations, the short-circuit current is a function of the voltage and the inductive reactance of the distribution system. In order to limit the short-circuit current at the same voltage level, the only method is to increase the inductive reactance seen at the fault location. This can be done by either increasing the inductance of the circuit, or by removing parts of the circuit from the fault path. The first is done by adding reactors, the second by current limiters.

A. Use of reactors

Reactors can be installed anywhere in the distribution circuit in order to limit the fault current. Since they are essentially a linear inductive reactance, their impedance will add arithmetically to the system impedance and result in a reduction of the fault currents.

During normal operation, the power factor of the load is close to 0.9 and the voltage drops due to the current flowing through the reactors are in quadrature with the load voltage. Voltage regulation is therefore normally satisfactory. This is not the case however, during motor starting where the starting current is largely inductive. The voltage drop across the reactor is in phase with the load voltage and causes large voltage drops which can cause major problems for starting large drives.

It is therefore common not to install reactors directly in the path of the starting current of large drives. A typical example of installation is shown in Fig. 4. The reactor will limit the contribution of the generators to the short-circuit current by effectively increasing the impedance of the machines that supply the fault through the bus-tie. Since only a fraction of the motor starting current will flow through the bus-tie under normal operating conditions, the reactor will not disturb motor

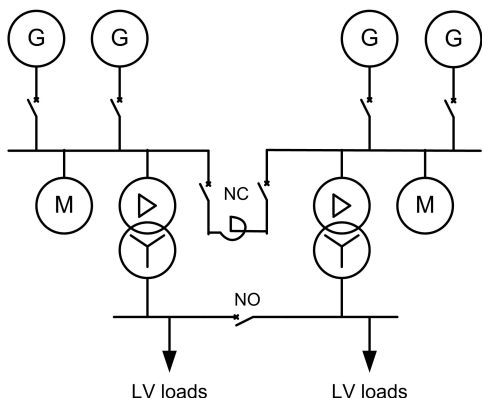


Fig. 4 Reactors for limiting short-circuit currents

starting to the same extent as if it had been installed in series with each generator.

B. Use of current limiting devices

As described in the following section, a current limiter is a non-linear device that has two states:

- conducting (with virtually zero impedance)
- limiting (high resistance)

During normal operation the current limiter acts as a conductor and therefore doesn't influence the distribution system in any manner. When limiting, it effectively inserts a high resistance in the circuit severely limiting the magnitude of the short-circuit current that flows through it. The location where current limiters are installed is similar to that of reactors as shown in Fig. 5.

IV. HOW CURRENT LIMITERS WORK

A current limiter is a parallel combination of a copper bar

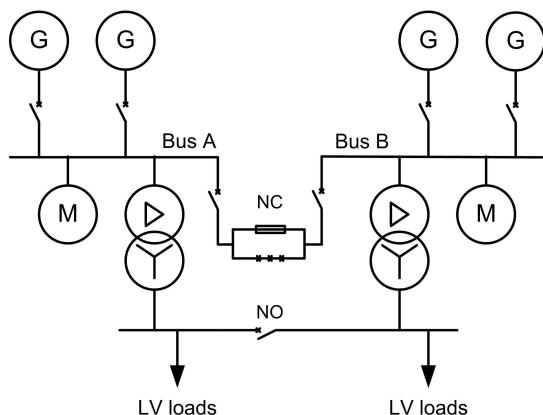


Fig. 5 Use of Current Limiters

and an current limiting fuse. During normal operation the load current flows through the copper bar which effectively shorts out the fuse. This is the reason why the current limiter has no effect on the distribution system in normal operation.

When there is a short-circuit however, it is necessary to interrupt the flow of current through the copper bar and force the current through the current-limiting fuse. This must be

done much before the peak short-circuit current value is reached if any limitation is to occur. A fast acting triggering device is therefore required. This, together with an explosive charge as shown in Fig. 6 will cause the immediate destruction of the conducting path through the copper bar. The fault current will then flow through the current limiting fuse until the first natural current zero is reached. After this current zero the fault current through the current limiter will be zero. This sequence is shown in Fig. 7.

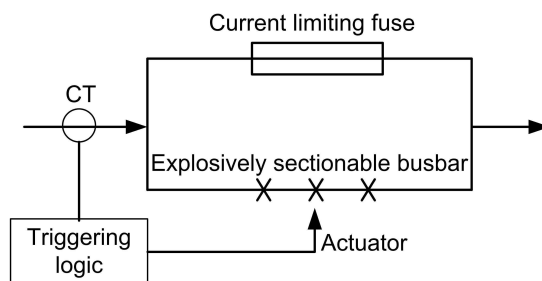


Fig. 6 Current Limiting Device

How the current limiter will reduce the short-circuit current can be seen when considering a fault on Bus A in Fig. 5. Each generator in service will contribute to the fault current and thus a large percentage will flow through the bus-tie circuit-breaker. The current limiter will greatly reduce the

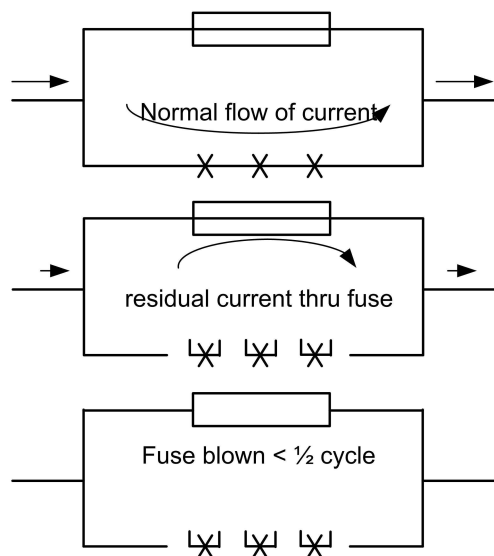


Fig. 7 Operation of a Current Limiting Device

magnitude of the fault current flowing through the bus-tie thus reducing the total current at the fault location. Fig. 8 shows the contributions to the fault current from the sources on Bus A and Bus B. For ease of understanding Fig. 8 it is assumed that the contribution from Bus B is larger. As can be seen in Fig. 8 the current through the bus-tie is limited to a value much lower than the prospective short-circuit current from the sources on Bus B. This current is limited much before the first peak of short-circuit current from Bus B occurs. The current limiter therefore reduces both the peak current and the interrupting current. After operation of the current limiter the only fault current to be interrupted by the

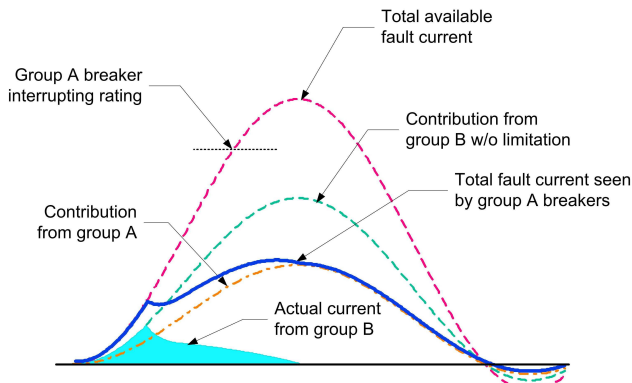


Fig. 8 Short-circuit Current for Fault on Bus A

circuit-breakers on Bus A is that generated by the power sources on Bus A.

Should a current limiter not have been installed in the bus-tie, the maximum short-circuit current would exceed the peak and interrupting capacity of the switchgear as shown in Fig. 8.

V. CURRENT LIMITER COMPONENTS

The current limiter is a three-pole device and consists of the following components in each pole as shown in Fig. 9:

- copper bar through which the load current flows in normal operation. Fig. 10 shows the explosive charge which is in the form of a wire around the copper bar. When it explodes, it cuts the copper bar into four pieces preventing any flashovers thereby forcing the current to flow through the current limiting fuse.

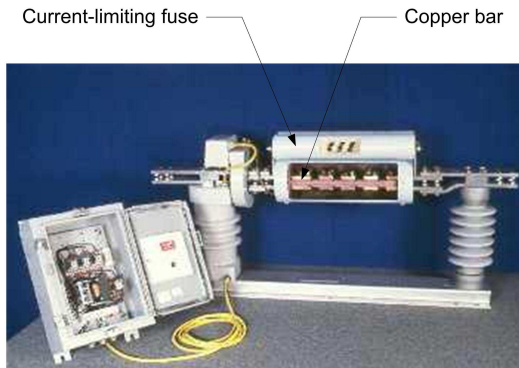


Fig. 9 One Pole of Current Limiter

- current limiting fuse in parallel with the copper bar. After triggering of the device, the fault current will flow through the fuse.
- triggering device together with its specific current transformer used to sense the current flowing through the limiter and ignite the explosive charge should the current and di/dt exceed their respective thresholds. The thresholds are determined during the detailed design based on the amount of limitation required.
- insulators for supporting the above-mentioned components. One of the insulators has a voltage transformer in it to provide the power supply to the triggering device.

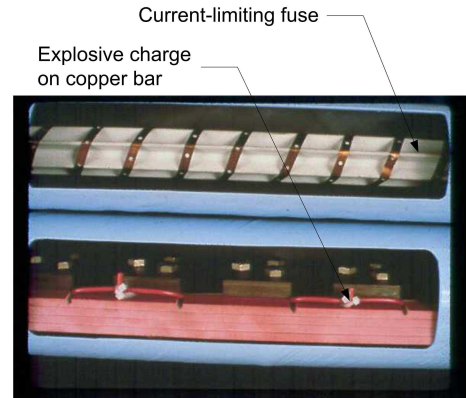


Fig. 10 Detail of Active Part of Limiter

There is also one control box per current limiter. This box have relay contacts to trip the circuit-breaker associated with the current limiter and to give the status of the device. Tripping the circuit-breaker is necessary since each pole of the current limiter operates independent of the other two poles. Very often only one pole will be triggered and it is necessary to trip the circuit-breaker in order to prevent unbalanced operation.

The three poles of the current limiters can be installed in any direction. They are often installed vertically as shown in Fig. 11 for installation within enclosures. They can also be installed outdoors without enclosures.

When the current limiter operates, the copper bar and fuse in the phases that are triggered are destroyed. They must be replaced before the current limiter can be energized again.



Fig. 11 3-pole Unit for MCSet Installation

Only the copper bar and fuse of the pole that has operated need be changed. It is not necessary to change the fuses of the poles that were not triggered since, shunted by the copper bars, no fault current will flow through them at any time.

The current limiter must be isolated in order to replace the destroyed components. In addition to the circuit-breaker, an additional isolation switch is required for this as shown in Fig. 5.

VI. INSTALLATION IN MCSET LINE-UP

As shown in Fig. 5 the bus-tie is an ideal location for the current limiter. It can be integrated within an MCSet lineup as shown in Fig. 12. The MCSet bus-tie circuit-breaker ensures three-pole operation during fault conditions, and the withdrawable truck in the bus riser allows full isolation required for changing components that have operated.

The current limiter is installed vertically within cubicles having the same dimensions as the MCSet cubicles. The busbar connections are designed to interface with MCSet cubicle busbars. The space required for integration of a current limiter in this manner is minimal. Installation of the cubicles is the same as for the other MCSet cubicles. The control box for the limiter is installed within the same cubicle

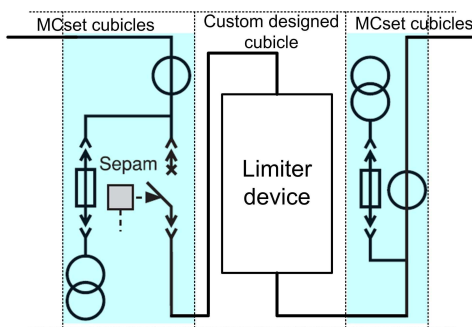


Fig. 12 Current Limiter in MCSet Bus-Tie

at the top front for easy access.

Fig. 13 shows the MCSet cubicle designed specifically for the installation of a current limiter in the bus-tie position of the lineup.

VII. SYSTEM DESIGN

Certain precautions are required in the selection and



Fig. 13 MCSet Current Limiter Cubicle

location of current limiters. The distribution system must be designed to accept the use of current limiters. This means that:

- The largest motor starting current must be much less than the prospective short-circuit current. This will allow the setting of the triggering threshold well above starting current in order to avoid any nuisance triggering.
- The current limiters are not to be installed in series with the power sources as shown in Fig.14. Installation in this manner could cause several to operate thus eliminating the power supply rather than limiting the short-circuit current.
- Plant operation must be possible during the time that is required to replace destroyed current limiter components. This means that a system such as shown in Fig. 5 shall be able to operate with the bus-tie open. Load sharing among the machines will be per busbar. If load shedding is implemented, it must also be able to operate independently on each busbar.

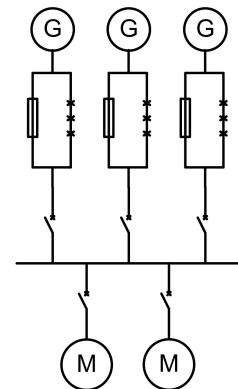


Fig. 14 What Not To Do

- Protection relays shall be set such as to allow tripping of circuit-breakers below the current limiter thresholds. Circuit-breakers will be able to clear all faults such as earth faults or cable faults. Only in case of a severe fault close to the power source will the triggering of the current limiter be required.

VIII. CONCLUSION

Current limiters are a good solution to solve the problem of unacceptably high short-circuit currents in industrial sites. Their use has been proven over the years and, in addition to clearing severe faults, they also reduce the strain on healthy equipment by limiting the peak currents and thus the mechanical stresses the downstream equipment is subjected to.

Current limiters can be easily integrated into the MCSet lineup and thus be designed and installed like a typical medium-voltage switchboard. Separate purchase orders are not required.

Severe faults in power systems are very rare and in many installations where current limiters have been installed, they have not been required to operate.

IX. REFERENCES

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X. VITA

Terence Hazel received his BSc in Electrical Engineering from the University of Manitoba Canada in 1970. After graduation he worked in Perth Australia for one year as a power coordination engineer, and in Frankfurt Germany as a

consulting engineer until he joined Merlin Gerin (now called Schneider Electric) in 1980. For 15 years he was the technical team leader for several major international projects involving process control and power distribution. Since then he has been with the tendering section of the industrial projects department and often meets with clients during the front end engineering stage to discuss and compare the various possible electrical distribution systems. He is a senior member of IEEE and has presented several papers and tutorials dealing with electrical power distribution at the PCIC and other conferences.