# The use of triggered current limiters to reduce prospective fault currents in high voltage systems

**Mr Lee Wai Meng explains the advantages of an alternative to circuit breakers.**

## Introduction

The use of current limiting fuses to reduce prospective fault currents at low voltage (400 volts), is common as its success has been proven. However, the use of current limiting fuses in high voltage (from 3300 to 33,000 volts) systems, is not common. This is because high voltage current limiting fuses have low continuous current rating and hence are of limited use.

Figure 1 shows the range of continuous current ratings of high voltage current limiting fuses. For high continuous current, the common protection device is a circuit breaker. Circuit breakers are however not current limiting and are relatively slow interrupting devices, requiring 3 to 5 cycles. Current limiting reactors can supplement breakers, but do not improve the slow breaker clearing time. They have continuous power losses and impose a voltage drop, which can be a problem.

| Voltage / kV | Maximum Continuous Current/Ampere |
|---|---|
| 7.2 | 100, 160, 250 |
| 24.0 | 80, 100, 160 |

*Figure 1: High voltage current limiting fuses.*

Triggered current limiters, which are variants of the traditional, high voltage current limiting fuses, are an alternative to circuit breakers. They have high continuous current capability which cannot be achieved by the traditional high voltage current limiting fuses. Figure 2 shows the range of the continuous current rating of triggered current limiters.

| Voltage / kV | Continuous Current / Ampere |
|---|---|
| 2.8 | 1500, 3000, 5000 |
| 5.5 | 1500, 3000, 5000 |
| 8.3 | 1200, 3000, 5000 |
| 15.5 | 1200, 3000, 5000 |
| 27.0 | 1200, 2500 |
| 38.0 | 1200, 2500 |

*Figure 2: Triggered current limiters.*

## Triggered current limiters

Triggered current limiters for high voltage systems, consist of a high voltage current limiting fuse, in parallel with the main busbar path. These fuses are special in that they are capable of much higher energy absorption than what is achieved by a typical commercial fuse. During normal operation, the busbar path will carry the majority of the load current and a very small portion of the load current will flow through the high voltage current limiting fuse. This is due to the relatively large impedance of the fuse as compared to the impedance of the busbar path.

When a fault occurs, a current transformer will detect the fault current and will trigger the pyrotechnic charges to cut the busbar path into five segments with four gaps. The resultant arc voltage across the four gaps will cause the very fast transfer of the fault current to the high voltage current limiting fuse. The fuse will clear the fault current in 1/4 cycle for a symmetrical fault current, and in 1/2 cycle for a fully asymmetrical fault current. It is important to achieve very fast transfer of the fault current from the cut busbar path to the high voltage current limiting fuse, so as to minimise the cutoff current.

The relationship between arc voltage and limiting the fault current, can be explained by Figure 3. The source voltage is the summation of the voltage across the inductance and the arc voltage of the protection device. For current limitation to take place, the rate of change of current, or di/dt, must be negative in value. This means (Vs – Varc) must be negative, that is, the arc voltage (Varc) must be greater than the source voltage (Vs).

During the commutation phase of the busbar path, the total arc voltage across the four gaps, of about 800 volts maximum, will do little, by way of fault current reduction, because the arc voltage is far less than supply voltage. However, what this arc voltage does, is to very quickly

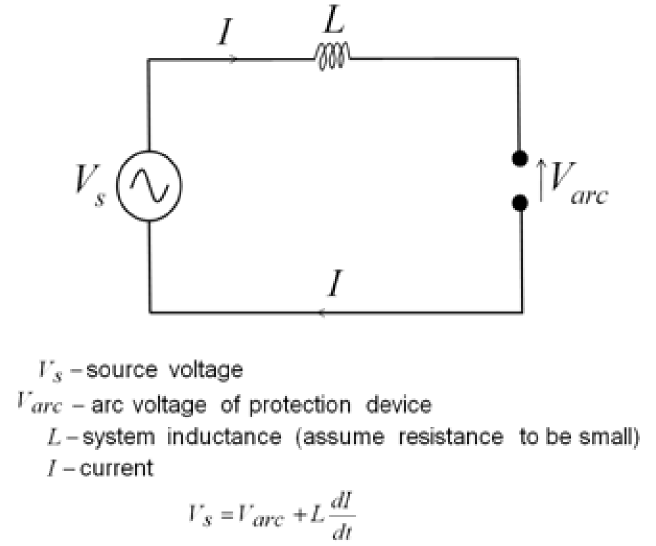
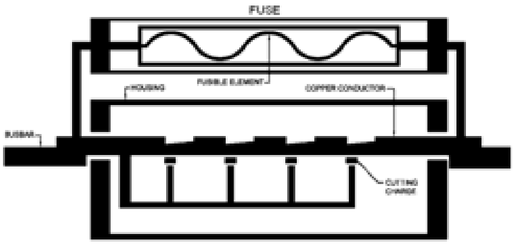


*Figure 3: Arc voltage and current limiting effect.*

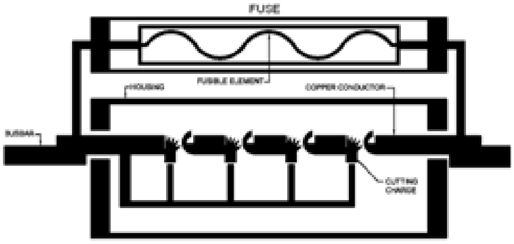
transfer or commutate the fault current to the high voltage current limiting fuse which will melt and create many small gaps during the arcing phase of the fuse, and thereby achieve arc voltages well in excess of the supply voltage. This is the reason for the current limiting behaviour of any typical current limiting fuse.

For successful arc extinction, the inductive energy of the fault circuit must be dissipated, and this is achieved by the absorption of considerable energy to melt the fine grains of sand inside the fuse. This process causes the fault circuit to change from an initially inductive circuit to a highly resistive circuit.

The fault current is forced to be more in phase with the supply voltage, and successful arc extinction is achieved at the first voltage zero. This equates to 1/4 cycle for a symmetrical fault current and 1/2 cycle for an asymmetrical fault current. Protection devices which are 'non current limiting', like circuit breakers, will rely on current zero for arc extinction. At the occurrence of the first current zero, arc extinction may not be successful and the next current zero will provide the opportunity for another attempt to extinguish the arc. Adding relay and mechanism time, this may take 3 to 5 cycles for the circuit breaker, and it explains why a circuit breaker is rated 3 to 5 cycles. The operation of a triggered current limiter is shown in Figure 4.



Normal Condition – most of load current flow through the busbar



Fault Condition – fault current diverted to the fuse

*Figure 4: Operation of Triggered Current Limiter.*

**Peak current limitation**

The peak value of a fault current will occur during the first 1/2 cycle, after the inception of the fault. This peak value will depend on the electrical angle of fault initiation with respect to the voltage wave, and on the X/R ratio at the point of fault. As most fault circuits are highly inductive, a fault initiation at voltage maximum will produce a current nearly 90° out of phase, which will result in a symmetrical fault current. For fault initiation at voltage zero, this will result in a current maximum, but because the current cannot change instantaneously, it will result in a fully asymmetrical fault current with a peak magnitude commonly approaching 2.5 times the symmetrical fault current value. The decay rate back to a symmetrical fault current is dependent on this X/R ratio.

Fortunately, circuit breakers do not need to break the peak fault current because by the time the circuit breaker opens in 3 to 5 cycles, the fault current will decay to a lower value which is dependent on the rate of AC decay and the rate of DC decay. The circuit breaker must be able to withstand the large electromechanical forces associated with the peak fault current at the first 1/2 cycle.

The peak fault current will also flow through supply transformers, and subject these transformers to large electromechanical forces. The repeated let-through of the peak fault current will decrease the life of the transformer. Triggered current limiters can reduce the peak fault current to a lower value. This capability of triggered current limiters to provide peak current limitation, is illustrated in Figure 5 which shows RMS values of the available fault current against peak values of the let-through fault current.

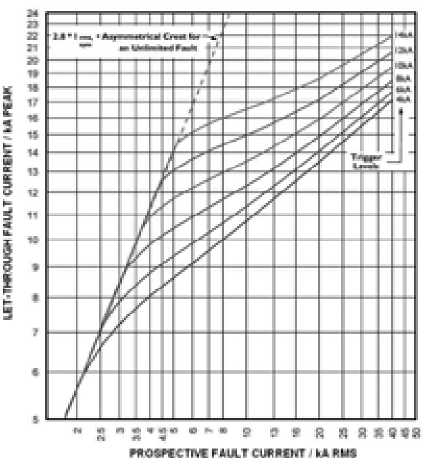


*Figure 5: Current Limiting Curve.*

**Energy limitation**

The energy developed in a fault, is approximately proportional to $I^2t$. A 5-cycle, circuit breaker, interrupting a 40 kA RMS, symmetrical fault, will let through 160 x $10^6$ $A^2S$. This is the amount of fault energy transferred through a circuit breaker to the fault, before clearing. If the circuit breaker is further time-delayed due to protection relay co-ordination, the fault energy will be more, which will equate to more damage at the point of fault. The standard triggered current limiter will typically let through 0.5 x $10^6$ $A^2S$, which is a reduction to 0.3% of that from the circuit breaker. This significant reduction of fault energy from the triggered current limiter, is due to the reduction of the peak fault current, and the fast interruption time of between 1/4 and 1/2 cycle. A lower energy release means less damage, faster repair, and improved protection for plant workers.

**Application at bus tie**

A common design involves two transformers in operation and with a normally open bus tie. To increase the reliability of supply, it is logical to have the bus tie normally closed. The fault level will be doubled and if the existing ratings of switchgears cannot handle the increased fault level, it will be very costly to discard all the switchgears and replace with higher rating switchgears. The alternative is to use triggered current limiters, so that the under-rated switchgear can handle the increased fault level. The triggered current limiter is installed at the bus tie switchgear. Figure 6 illustrates the application. For example, if the existing switchgears are rated 20 kA but the fault level is 30 kA, the triggered current limiter can be set to trigger and limit currents well below the 20 kA rating of the switchgear. During normal operation, both transformers are in continuous parallel operation via the normally closed bus tie and triggered current limiter. During the fault, the triggered current limiter will very quickly operate and eliminate the 15 kA fault contribution from transformer 2 to the fault.

The source of fault current will now be 15 kA from transformer 1, which is well within the 20 kA rating of the switchgear CB1. The fast operation of the triggered current limiter will cause almost zero voltage sag at the unfaulted bus, and dropout of equipment is not expected. The faulted bus will experience the associated voltage sag due to the fault, until operation of the switchgear CB1. Hence the triggered current limiter also provides secondary benefits to mitigate the effects of the associated voltage sag due to a fault.

As triggered current limiters are 3 x single phase units, the operation of one phase of the triggered current limiters in a single phase to earth fault, would normally create problems associated with single phasing of the source voltage. This situation is prevented by the use of a contact from the triggered current limiter which is wired to trip the series connected bus tie switchgear.

**Application at embedded generators**

Embedded generators that are synchronised to the local grid, will contribute fault currents to the grid in the event of a fault within the local grid. These fault contributions from the summation of all embedded generators of different plants, may cause the local grid switchgear to be under-rated for the increased fault level. The embedded generators will be required to limit their fault contributions to the local grid. A solution to this problem is illustrated in Figure 7. In the event of a fault within the local grid, the generator will contribute fault currents to the grid. The triggered current limiter will be set to detect this condition and very quickly operate to eliminate this fault contribution to the grid. Continuity of electrical supply to the plant is maintained from the local grid.

**Conclusions**

More plants in Singapore are investing in embedded generators that are synchronised to the local grid. This will create problems of increased fault currents to the plant and back to the local grid. In similar situations in other countries, triggered current limiters are being used to solve some of the problems.

Numerous units have been in service for more than 20 years. Typical users of triggered current limiters include utilities, power plants, substations, steel plants, oil platforms, chemical plants, pulp and paper plants etc. The installation of triggered current limiters is a proven alternative to the replacement of existing circuit breakers with higher rated ones. Triggered current limiters also minimise damage and hazard exposure for personnel.

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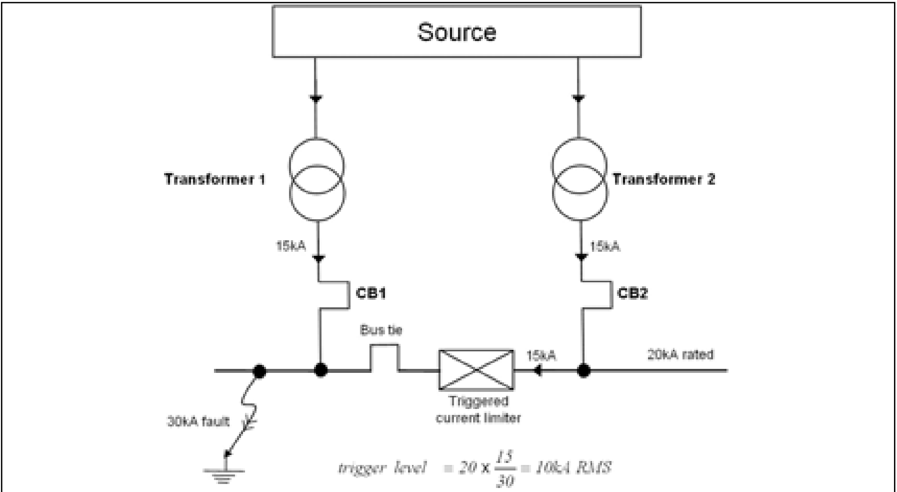

*Figure 6: Bus tie Application.*

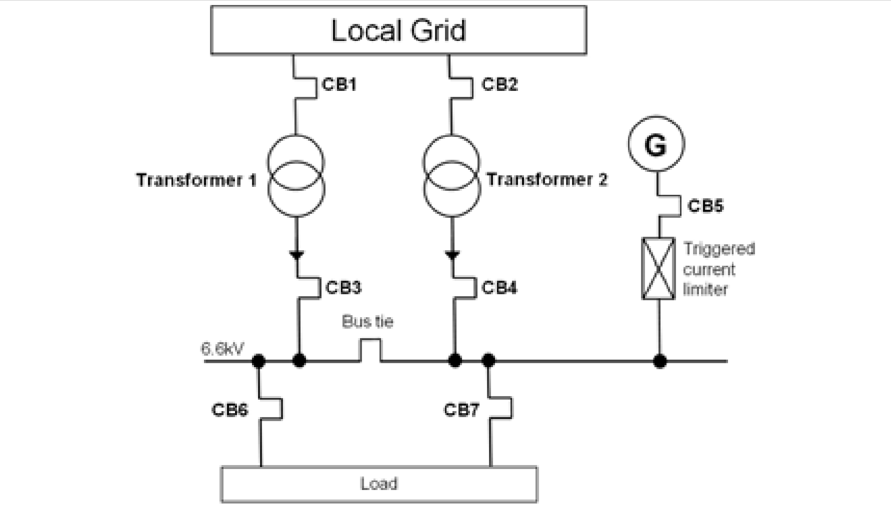

*Figure 7: Generator Application.*