Switching Shunt Reactors

Beginning with
A brief review of shunt reactor application
And switching technology

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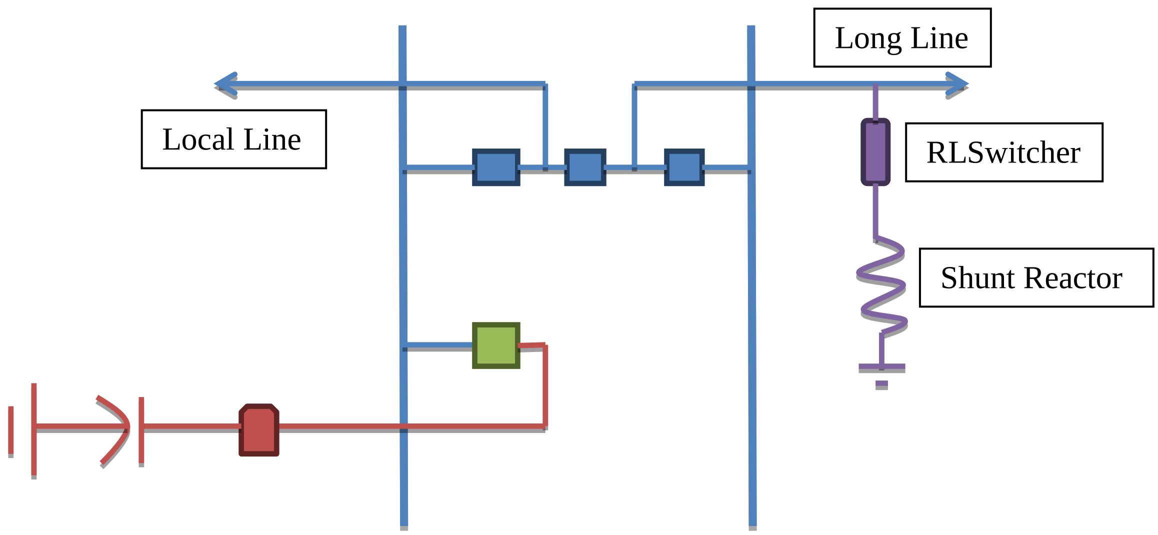
Typical 362kV Substation with Shunt Reactive Compensation



Shunt Reactors

The need for large shunt reactors appeared when long power transmission lines for system voltage 220 kV & higher were built. Long cables for system voltages of 100 KV or more may also need shunt reactors. The same goes for large urban networks to prevent excessive voltage rise when a high load suddenly falls out due to a failure. Shunt reactors are applied to regulate the reactive power balance of a system by compensating for the surplus reactive power generation of transmission lines or cables. Reactors are normally switched off for times of heavy load and are switched on to the lines at periods of low load.

The other effect of shunt reactors is to control excessive voltage rise. This voltage rise is caused on lines by Ferranti rise[1] and capacitive rise[2] when they are lightly loaded[3]. For this reason, shunt reactors are normally connected to the line (not the bus).

1. Ferranti rise is an effect where a lightly loaded transmission line has a higher voltage at the distant end than the source end. It can be explained as the line charging current creating a voltage rise through the line self inductance. It becomes a concern on lines longer than 150 miles.
2. Capacitive rise is the voltage rise which comes from drawing charging current of a line, cable, or capacitor through the source inductance.
3. Light loading would be less than 70% of **S**urge **I**mpedance **L**oading (SIL). For a system operating at 345kV, and having lines with a surge impedance of 350 ohms, the SIL is about 340MW.

Why does the reactor need to be switched?

If the load on the line increases, consequently decreasing the voltage, then the reactor will be switched off since it is no longer needed. If the load lessens and the voltage starts to rise again the reactor will be switched on. Note that the reactor is being used not just to correct the power factor, but also to keep the voltages at a safe level for all of the other equipment on the line, and in the substation.

If there is a fault in the shunt reactor circuit beyond the switching device, the line should be tripped with the shunt reactor connected to avoid excessive line end voltage after fault clearing. The excessive voltage that the reactor is controlling, especially at the end of the line, is dangerous to the connected equipment. Specifically, it is very likely that the higher voltages would exceed the ratings of the line circuit breakers, jeopardizing the line protection and even the ability to simply switch the line off using the breakers. Therefore it is not advisable and in fact dangerous, to have a circuit breaker to interrupt faults in the reactor circuit, disconnecting it from the line, when it needs to be there to keep the voltage at safe levels.

Legacy Shunt Reactor Switching

The device chosen for switching shunt reactors depends on the details of the application.

Fixed Reactors

For some long EHV lines that will always be loaded well below SIL (Surge Impedance Loading) the shunt reactor is always in service. The reactors are "fixed" and not routinely switched off for high loads because there are no high loads. Usually there is an isolation switch (disconnect switch) that can only be opened when the reactor-line combination is deenergized. In such applications, there may be multiple shunt reactors for redundancy, to allow the line to function properly with one reactor out of service. Fixed shunt reactors may also be employed on long underground cable circuits to counteract the very high capacitive charging current of long underground cables.

Infrequently Switched Reactors (switched <10 times/year)

In some applications the shunt reactor is either on most of the time or off most of the time, and is switched only for certain contingencies. Modified circuit breakers have been used for these applications. Some have special nozzles installed with a longer throat section and a long leakage path over the outside of the nozzle. Controlled opening (synchronous opening) is also used to force as long an arcing time as possible. Both of these modifications are an attempt to reduce the number of high energy reignitions produced during the opening process.

Frequently Switched Reactors (switched > 100 times/year)

Since Wind, Solar Thermal, and Photovoltaic generators have a large daily output swing, most shunt reactors employed in connecting these to the power grid would be switched at least daily. Thus they fall into the frequently switched category.

Most circuit breakers are designed for a 2000 operation mechanical life. Even modified circuit breakers will have a shorter operational life switching shunt reactors than for other switching duties. The nozzle may wear out, or puncture long before the mechanical parts wear-out. Circuit breakers tend to create significant stress on the shunt reactor when opening. They limit the number of times the reactor can be deenergized without failure. Circuit switchers may be a better choice than circuit breakers for frequent shunt reactor switching. A special purpose shunt reactor switch is a superior solution.

Interrupting Small Inductive Currents

Shunt reactors carry small currents, typically 300 A or less. It is relatively easy to interrupt small currents at first. When the current extinguishes, the shunt reactor voltage oscillates toward zero at the reactor natural frequency, typically 1 to 5 kHz. The supply side varies at 60 Hz power frequency. The difference between the reactor and supply side voltages is called the Transient Recovery Voltage (TRV). Both sides of the switch start at the crest voltage of the power system, but due to the high frequency of the Shunt reactor, its voltage rapidly departs from the system voltage creating a steep and high magnitude TRV. This high/fast TRV causes the interrupter to reignite until there is sufficient contact gap to sustain complete interruption. For additional information on TRV please see: http://www.ewh.ieee.org/soc/pes/switchgear/TRVTutorial/TutorialTRVAlexander-Dufournet.pdf

Choice of Switching Devices for Shunt Reactor Switching

Disconnect Switch

A normal disconnect switch cannot be used to switch off a shunt reactor. It will continue to arc over in the fully open position. Closing may work but the pre-arcing could damage a standard air disconnect switch. A disconnect switch severely limits operating flexibility. One needs to de-energize the line, then open or close the disconnect switch, and then reenergize the line.

General Purpose Circuit Breaker

For routine switching of shunt reactors, general purpose circuit breakers are not very well suited. It is like using a pile driver to drive a tack. Not only is it “overkill” in the usual sense, but most circuit breakers produce many high energy reignitions when attempting to open shunt reactor circuits. These can be stressful to the shunt reactor and cause internal turn to turn overvoltages. These stresses cannot be controlled with terminal connected surge arresters. Excessive turn to turn stresses can lead to premature failure of the shunt reactor.

Modified Circuit Breaker

A modified circuit breaker (described above under infrequently switched reactors) is a slightly better choice, but the number of switching operations will be limited, and the shunt reactor may be overstressed by high energy reignitions.

Circuit Switcher

A circuit switcher is a somewhat better choice than a circuit breaker because it is designed for more switching operations and has a smaller interrupting effort, and will likely produce fewer high energy reignitions. One might expect a circuit switcher performance to be similar to a modified circuit breaker in terms of reignitions, but it would likely have a better switching endurance than a breaker.

RLSwitcher

A special purpose switching device such as the Southern States RLSwitcher is well suited for the onerous switching duty of reactor switching. The Southern States RLSwitcher interrupter is unique in that it is designed to delay the first interruption until the contact gap is large enough to avoid high energy reignitions. The delay is accomplished with a special internal design that will not allow the interrupter to sustain an interruption until the contacts have developed sufficient gap. In the 245 kV Test Report it was seen that there are low energy reignitions on about 20% of the 662 A interruptions and nearly all of the 100 A interruptions. By studying the data, it is clear that these reignitions are for a very short duration with very little energy. This is by design. These low energy reignitions are part of the normal interruption process and cause no harm to any circuit components. In four reactor switching test programs, the RLSwitcher had very few high energy reignitions. This is less than 1/5 of what a conventional breaker would do in switching off a shunt reactor.

The way the RL interrupter works is that for the first couple of current zeros the interrupter deliberately does not interrupt, followed by a transition region where it will try to interrupt but experience a low energy reignition, and finally, when the contacts are sufficiently opened, the interrupter completely clears delivering a “clean” interruption with no high energy reignitions. Statistically, on a regular SF_6 interrupter there is around a 50% probability of having a significant, high energy, reactor reignition on each opening operation. With the RLSwitcher the probability of a significant reactor reignition is less than 10%.

The sample test Oscillogram below shows a 245kV RLS switching off a 101A reactor.

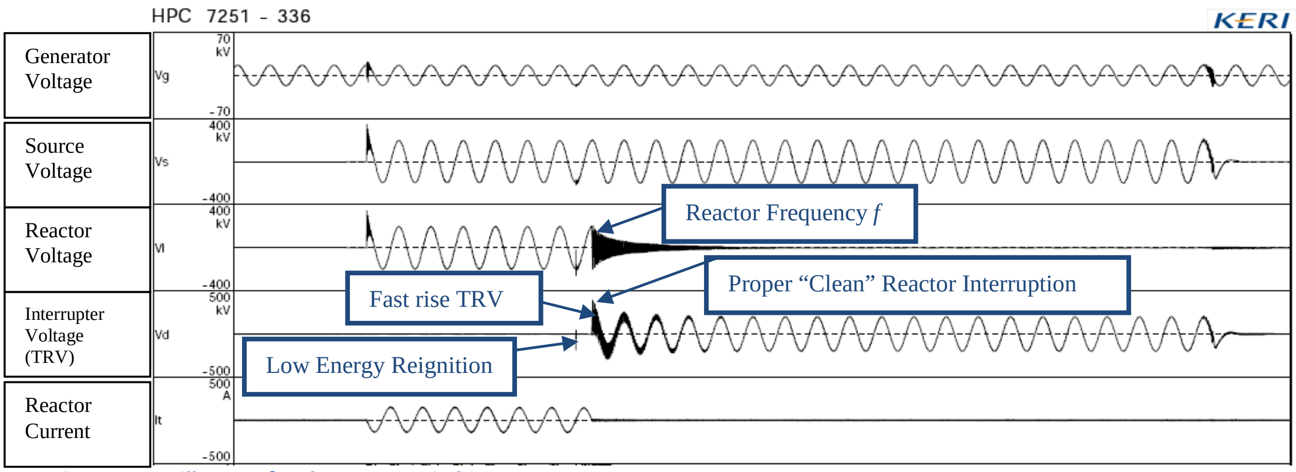


Figure 1: Oscillogram for the 101A, Switching Test

The RLSwitcher does not provide fault protection. Because of the way a shunt reactor is used on a power system, it is not necessary for a shunt reactor switch to have fault interrupting capability, since that fault interrupting capability can never be used.

Conclusions

When special purpose switching devices are available for harsh switching duties, such as shunt reactor switching, they will often be a better fit to the application than general purpose devices. Over the years, circuit breakers and circuit switchers have been adapted for routine shunt reactor switching. It is unreasonable to expect them to perform as well as a device like the Southern States RLSwitcher that has been designed, from the ground up, just to tackle the onerous shunt reactor switching duty.

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27 January 2011