Magnetically Controlled Reactors Enhance Transmission Capability & Save Energy—Especially in Compact Increased Surge-Impedance Loading Power Lines

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Benefits of Controllable Reactors

AC distribution grids usually do not require shunt reactors, but do require capacitor banks (i.e. capacitive shunt compensation). These capacitor banks need to be controlled because of changing load conditions. Yet the manual or thyristor switching operations typically used for capacitor bank control are not really efficient and wear out both switching equipment and power transformers. And they do not actually meet reactive power load and voltage control requirements very well, since the step control they provide does not really fit the load smoothly.

Intrinsic line capacitance in long AC grids of 400 kV or higher must be compensated to decrease reactive load losses, which can quickly become unacceptably large, since they are proportional to the square of line voltage. Compensation must also ease the Ferranti effect, when load conditions are changing. Usually this is accomplished with shunt reactors, and some of these need to be controlled as well.

Studies conducted during last decade by Prof. George A. Evdokunin and his colleagues in Russia, Kazakhstan, Brazil, India, and China show that in 500 kV grids the optimum number of controllable shunt reactors for a system is about one in three, in order to damp all significant voltage surges and to improve power stability limits. With compensation at this level, higher voltage can be transmitted even through extended power lines. This also saves energy. In extreme cases, power transmission losses can be decreased by about 30% in this way. In US grids where power transmission loss is about 4% (G.J. Molteni, 2001), power transmission savings would be 1 to 2 percent.

Flexible control of reactive power and voltage in both lower and higher voltage grids is usually realized by static var compensators (SVCs) or more sophisticated static synchronous compensators (STATCOMs) or by controllable reactors as separate units.

In SVCs, controllable reactors are used with capacitor banks to control reactive power load, to dampen voltage surges and to decrease power transmission loss by decreasing reactive current circulation.

Nowadays the most common controllable shunt reactors are thyristor controlled reactors (TCRs).

However, utilities in Russia and the other CIS countries often use extremely highly saturated magnetically controlled shunt reactors (MCRs).

MCR control is based on low-power magnetic biasing, and does not use a high-rated thyristor system which, as is well known, is the main cause of the unreliability of TCRs. MCRs also do not need step-down transformers to decrease grid voltage to rated thyristor voltage, which must be less than 35 kV.

Advantages of Magnetic Control

- MCRs are as reliable and simple to operate and maintain as ordinary transformers.
- In more than 20 years' field operation of what is now 40 installations, no MCR has had to be replaced.
- MCRs can sustain 50% overload for 20 minutes and 100% overload for 20 seconds.
- MCRs' overvoltage limitation is 2.3 times rated voltage.
- MCRs' current-distortion coefficient, without filters, is less than 3%. Thus, fewer filters are required.
- MCRs require no additional operation and maintenance substation personnel.

- MCRs require about 10 sq.ft / Mvar of the substation open space.
- MCRs have low external magnetic field, requiring no shielding.
- MCRs experience about half the internal power loss of TCRs: 0.05% kW per kvar of rated reactive power (rkvar) in standby no-load mode, and 0.5% kW per rkvar in rated reactive power load mode.
- MCRs can be designed to respond like TCRs, in as little as 0.02 second. But unlike TCRs, the price of an MCR is related to response time. MCRs of the shortest response time would cost about the same as equivalent TCRs— approximately $20/kvar— but for more typical grid requirements of 1 second, they cost only *half as much* as TCRs, or about $10-11/kvar (ex works price).
- MCRs cost half as much as TCRs to install, operate, and maintain.
- More important than this cost differential, though, is the sheer *reliability* of this new technology.

Economy, reliability, and maintenance simplicity are the features that utilities most desire from power equipment.

Field Experience with MCRs

In Russia at Permenergo's 80 MVA Kudymkar substation, which was equipped with capacitor banks, power fluctuations required over 800 *manual* switching events per year, with corresponding serious capital outlay for labor and rapid depreciation of attached switching and transformer equipment. An MCR was installed in 1999, and the system *immediately* stabilized, with only *twelve* manual switching events per year since then. The substation saved 7.3 GW-hours over the first year of usage, and construction of a planned new power line has become unnecessary for at least 10 more years— saving the utility well in excess of $25M. And already the utility has all but recovered the cost of installing the MCR.

ISIL increases transmission distance and saves construction costs

One important application of MCRs is in combination with compact increased surge-impedance loading (ISIL) power lines [A.M.Bryantsev et al, Power Quality 2000].

Transmission capability in AC overhead lines is limited by their inductive impedance. Series capacitors are used to compensate inductive impedance, but such compensation is costly and creates difficulties for system operation.

Transfer distance and/or capacity of them could be increased in the following ways:

1. Increase the effective conductor diameter, employing several subconductors in each line phase: The greater the transmitted power or line length, the greater the number of subconductors required.
2. Optimize the spacing of subconductors in split phases so as to provide maximum permissible field strength in each subconductor.
3. In order to obviate undesirable increase of phase dimensions due to the increased number of subconductors:
    - modify the tower structure to exclude the tower's grounded elements from the interphase space;
    - find the optimum phase spacing;
    - allow larger interphase overvoltage limitations to decrease interphase air gaps; and
    - use interphase insulation spacers to decrease wind-induced interphase distance changes.

There are currently 5 compact ISIL lines in operation and 2 lines are projected, specifically:

- ✓ 220 kV line of about 30 km with 4 subconductors per phase in China;
- ✓ 220 kV line of about 150 km with 2 subconductors per phase in Russia;
- ✓ 330 kV line of about 150 km with 4 subconductors per phase in Russia;
- ✓ 500 kV line of about 750 km with 4 subconductors per phase in Brazil;
- ✓ 500 kV line of about 83 km with 6 subconductors per phase in China;
- ✓ 500 kV line of about 500 km with 6 subconductors per phase in Russia (projected);
- ✓ 500 kV line of about 500 km with 6 subconductors per phase in Kazakhstan (projected).

For 220 kV, a 60Hz line with three subconductors per phase inductive impedance of 0.28 to 0.33 Ohm/mi was achieved, as compared to 0.77 Ohm/mi for a standard 60 Hz line. For a 500 kV line with 6 or 7 subconductors, inductive impedance can be lowered by half, in comparison with lines of the usual design.

Lowering the inductive impedance of long distance transmission lines decreases the power angle between the line terminals and improves steady-state stability limits without series capacitive compensation. Series capacitive compensation is usually about 1/3 of the cost of line construction— and eliminating this requirement would result in significant savings.

Also, along with the interphase dimensions, for guyed power transmission line support, both the tower mass and the width of line right-of-way decrease as well, saving on construction and land costs.

When the power load becomes lower than the surge impedance loading of the line, long-line reactive power and voltage can most efficiently be managed by means of controllable electric shunt reactors. For ISIL applications the most cost effective and energy saving type of controllable reactors is magnetically controlled reactors (MCRs).

Results might differ somewhat in different economic and technical environments, but for example in a 330 kV line located in Russia, which had four subconductors per phase, placing more subconductors in the ISIL line phases translated into a 5% increase in line construction costs per each three additional subconductors. But since ISIL lines do not require series capacitive compensation, there was a 35% decrease in line construction costs. Because the ISIL structure generally decreases linear inductive impedance while increasing linear capacitive impedance, it was desirable to install MCRs for compensation of the latter, and this added 5% to construction costs. But the net result of these several modifications was a savings of 15% over ordinary transmission line construction.

What’s the bottom line?

Decade of experience in Russia, China and Brasil, have shown the extreme reliability and considerable cost and energy savings with both MCRs and ISIL lines.

We believe that today’s energy and energy policy climate positively demand MCR-ISIL technology. A pilot installation of an MCR and compact ISIL line in the US would show us the most simple, efficient, and reliable path to significant savings in both power and cost.

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