THREE PHASE MAGNEX: AN ALTERNATIVE TO CONVENTIONAL DISTRIBUTION TRANSFORMER PROTECTION

Eugene KNABE
Cooper Power Systems - U.S.A.
Gknabe@cooperpower.com

Antonio M. VÁZQUEZ VILLOT
Union Fenosa – Spain
Avazquez@uef.es

Nick VASSILIOU
Cooper Power Systems – Greece
Nvassiliou@cooperpower.com

INTRODUCTION

The MagneX® Interrupter is a three-phase primary side interrupter device that provides unique protection capabilities not previously available in MV transformer protection. The MagneX offers the ability to design self-protected Medium Voltage pad-mounted transformer that reduce overall operating costs. Reduced costs come from smaller footprint transformer designs and reduced equipment needed to protect the transformer from overloads. Union Fenosa has been a pioneer in MagneX protected transformer designs and has developed unique MV/LV Center designs for both urban and rural applications.

THE MAGNEX® INTERRUPTER

The MagneX Interrupter is a high-voltage side transformer protector. It was originally designed to protect single-phase pole-mounted transformers in a similar manner as secondary breakers. However, the MagneX has significant advantages over a secondary breaker, making it an ideal protective device for areas of high environmental contamination and power pilferage.

Figure 1. Single-Phase MagneX

The three-phase version of the MagneX Interrupter extends the advantages in the single-phase version of the MagneX to three-phase transformer applications. This new method of three-phase protection, in conjunction with a three-position sectionalizing switch, allows for optimized compact substation designs, while providing similar performance of existing MV/LV Substation designs.

A primary advantage of the MagneX over secondary breakers is its ability to sense faults contained within the windings of the transformer. Since it is applied on the high-voltage side of a distribution transformer, it will react to primary and secondary winding faults that are detectable. Since the MagneX does not rely on high rated-current (HRC) fuses to clear low-current faults, the MagneX protects the transformer from single-phasing conditions.

Another advantage of the MagneX is its ability to protect line personnel against internal transformer faults upon being connected to the distribution network. Unlike secondary breakers, when the MagneX is connected to the line with contacts in an open position, the coil assembly is not immediately connected to the network. This allows line personnel to switch the transformer on from a safe distance, using an insulated fiberglass hookstick for operation. In addition, internal lightning arresters can be protected by connecting them on the line-side of the MagneX, providing utilities the capability of completely self-contained transformer installations.

When compared to a fuse link in a fused cutout, the MagneX provides superior protection through the thermal sensing capabilities of the curie element sensor. The MagneX uses an electro-mechanical latch that reacts to disconnect the transformer when temperatures exceed limits that may damage insulating materials.
The MagneX sensor is made from a special curie element that switches from a ferro-magnetic to a para-magnetic state as the temperature of the metal rises. The combination of the I^2R heating from the current flow through the sensor, combined with elevated transformer oil temperature, causes the sensor to lose its magnetic attraction. When the attractive magnetic force becomes less than the spring tension of the latching mechanism, the MagneX trips, opening all three-phases simultaneously.

Under high fault current conditions, the I^2R heating of the sensor dominates the effects on the MagneX sensor, thus causing the MagneX to operate similar to a fused device. In fact, the TCC characteristic of the MagneX under fault current is similar to that of a fuse link. Thus, the current rating system employed in fuse link products has been adopted in the MagneX sensor sizing system. Ten discrete sensor sizes are presently available (E01, E03, E06, E10, E12, E18, E20, E30, E40 and E50).

Unlike fuse links, however, under periods of overload, the MagneX Curie element reacts to high oil temperature. In the instance where the protected transformer experiences long period of high overload current, the core and coil assembly will release heat into the oil, as the transformer tries to cool itself. If properly selected, the MagneX sensor will react to the elevated winding temperatures and open at a point just prior to the oil reaching potentially damaging temperatures.

**Thermal Reaction of the MagneX**

In order to evaluate the ability of the MagneX to sense overload conditions, overload testing was conducted to verify the ability of the MagneX sensor to react to elevated transformer temperatures. First, simulations were conducted to estimate the thermal reaction of the MagneX to rising oil temperature. Following simulation, actual lab testing was conducted to validate the estimates.

Figure 3 shows the temperature rise profile of the transformer under overload conditions. Transformer oil temperature was monitored along with transformer loading. Table 1 shows the estimated trip temperature as compared with actual results from testing. As can be seen in the table, the selected MagneX sensor reacted to the sustained transformer overload by tripping at approximately 120 degrees C. This value is slightly above the point at which damaging temperatures can begin to affect transformer life.

<table>
<thead>
<tr>
<th>Ambient Temperature</th>
<th>Noload Preload</th>
<th>Transformer Overload</th>
<th>Top Oil at MagneX Trip</th>
<th>Time to MagneX Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simmulation</td>
<td>25 °C</td>
<td>6.25 A</td>
<td>11.8 A</td>
<td>115.1 °C</td>
</tr>
<tr>
<td>Actual</td>
<td>28 °C</td>
<td>6.25 A</td>
<td>11.8 A</td>
<td>120.1 °C</td>
</tr>
<tr>
<td>Percent Dev.</td>
<td></td>
<td></td>
<td></td>
<td>4.16%</td>
</tr>
</tbody>
</table>

Table 1. Overload Protection of MagneX Interrupter

With proper sensor size selection, the MagneX protected transformer will allow maximum overload capability and optimum transformer life. Ten discrete sensor sizes allow the transformer protection level to be customized to meet utility-specific protection requirements.

**Obtaining Fault Differentiation with MagneX**

When troubleshooting problems with the distribution system, any additional information that can be provided to line personnel as to the origin of the problem becomes immensely useful. Additional information can reduce diagnostic time and add to line personnel safety.

Most utilities that have distribution systems that can deliver significant fault current duty to a failed transformer acknowledge the usefulness of HRC fuses in preventing violent failures. When used in series with the MagneX Interrupter, HRC fuses and the MagneX provide complete full-range fault clearing capability.

When coordinated properly, the MagneX/HRC fusing system can also provide fault differentiation that cannot be obtained through conventional protection practices.

Since the maximum fault current, due to a secondary fault, that is seen on the primary side of a transformer is limited by...
the impedance of the transformer windings, proper selection of the HRC fuses can limit their operation to fault currents consistent with high-current primary faults. Thus, the MagneX will operate for detectable secondary faults and overloads.

Furthermore, since the minimum let-through $I^2t$ of the HRC fuses will cause operation of the MagneX on high-current primary faults, no striker mechanism is required to trip the MagneX in the case of a primary phase-to-phase fault. Thus, single-phasing is prevented, regardless of the magnitude of the fault.

Proper coordination between the MagneX and HRC fuse protection will signal to line personnel that if the HRC fuses have operated, the transformer has likely experienced a primary transformer fault. In this case, the transformer will need to be replaced. If line personnel close back into the faulted transformer with the MagneX, the operated HRC fuses will prevent closing into the fault, protecting line personnel from potential violent transformer failure.

The simplicity of the protection scheme results in maximum overcurrent protection with minimal transformer tank size.

**CASE 1 : THE PAD MOUNTED TRANSFORMER VS CONVENTIONAL UNDERGROUND DISTRIBUTION MV/LV CENTERS INCLUDING RING MAIN UNIT**

**Conventional Transformer Protection Scheme of MV/LV Centers.**

The most widely applied transformer design in a typical European MV/LV Center (as part of a cable distribution system) includes a full range fusing system that is designed to protect against high current primary faults as well as transformer overloads.

The fusing system is typically incorporated in the MV panel of the distribution center with the Ring Main Unit (RMU). A typical scheme like this is indicated in Figure 5.

![Figure 5. Typical MV/LV Underground Distribution Center](image)

In recent years, there has been a constant demand for footprint reduction of the MV/LV Center. As they become more compact, several alternatives have emerged; with the most recent tendency being to incorporate the HRC fuses inside the transformer tank (ref. 1).

**Pad Mounted Transformer : An alternative to conventional MV/LV Centers.**

Although widely used in North America, the Pad Mounted Transformer is only recently introduced in Europe. A typical design of this transformer is indicated in Figure 6.
The basic components involved in this design are as follows:

- Two – three-phase / three position sectionalizing load break switches to perform source transfer
- One – three-phase/ two position sectionalizing load break switch to perform transformer disconnection and ground high-voltage cables.
- One – three phase MagneX resettable breaker.
- Three – single phase under-oil current limiting, partial range fuse type ELSP
- Three – under –oil MOV surge arresters (optional, not shown in Figure 2)

Advantages of the Pad Mounted Transformer Over Conventional MV/LV Underground Distribution Centers

The Pad Mounted Transformer is typically much more compact and has smaller footprint than the conventional MV/LV center.

Its overcurrent protection is based on a dual element concept: the resettable MagneX breaker, that protects against low amplitude faults – having their source in the secondary, and the under-oil current limiting fuse that only operates in the event of a major internal transformer fault.

It is more economical than the conventional MV/LV Center, and is more economical for small rated KVA transformers, in contrast to the conventional MV/LV center, where the cost of the Ring Main Switchgear must always be accounted for in the package.

Unlike conventional transformers, the pad mounted transformer has unique overload capabilities, which are also a function of its protection scheme involving the MagneX. The same level of functionality is maintained, as in the case of the Ring Main Unit (source transfer, tee-off, grounding the cable from one side, disconnecting the transformer)

CASE 2: POLE TYPE TRANSFORMER WITH MAGNEX VS. CONVENTIONAL OVERHEAD DISTRIBUTION MV/LV CENTERS

The Conventional Overhead Distribution MV/LV Center

The typical overhead distribution MV/LV Station consists of a pole mounted three-phase transformer, its primary protection against over-current and over-voltage and the LV Distribution Panel.

The primary protection basically consists of three single-phase expulsion fuses in the form of fused cut outs, typically installed on an additional cross arm above the transformer.
life since the transformer dielectric system will not be stressed as a result of excessive oil temperature.

The MagneX is the ideal protection to prevent transformer damage due to temporary overloads. Sometimes overloads are very difficult to predict or estimate, due to variations from regular loading patterns, or, in some cases, even power theft.

The MagneX allows for temporary transformer overload, whereas the fuse does not. For this reason, the maximum overload capability of the transformer can be used safely and without compromise. This actually represents an advantage that can reflect to initial power rating of the transformer, since there is no need to over-specify the transformer to cover temporary overloads.

As a temperature-sensitive device, the MagneX needs no future adjustment after installation. Its rating is selected based upon the transformer kVA rating.

The MagneX is an under-oil breaker and is unaffected by external contamination. In contrast, the fuse cutout is susceptible to pollution and external flashovers. The MagneX–protected transformer requires no time to re-fuse in case of operation, and thus, the time to restore service is reduced.

Elimination of the fuse cutout also eliminates the risk of erratic fuse operation due to lightning. The lightning protection of the transformer can be more effective, since it is possible to install the surge arresters on or inside the transformer tank. It has been common practice to install the surge arresters in front of the fused cutout in order to protect the fuse against lightning damage. It is also possible to install under-oil surge arresters that further improve the surge protection and simplify the installation.

The use of the fused cutout is sometimes prohibited or impractical in fire-hazardous environments such as urban or forest areas.

Elimination of the fuse also decreases the risk of replacing the fuse link with the wrong rating. Therefore, it is less likely to compromise the protection scheme. The MagneX eliminates the need for the LV master breaker and simplifies the protection on the LV side.

The MagneX–protected transformer offers improved aesthetics and improved anti-vandalism protection. It is also more environmentally friendly, and can be offered with complete wildlife protection.

The initial installation time of the MagneX-protected transformer is significantly reduced because there are no fuses to connect and no need to install additional cross-arms. It is also possible to have the transformer connected via an insulated dropper lead with live line connectors, thus avoiding power interruptions for transformer replacements.

The incorporation of all protection devices in the transformer itself will represent a large benefit to the electrical utility in terms of inventory and replacement convenience.

**ACTUAL CASE STUDY: TRANSFORMER OPTIONS INVOLVING THE MAGNEX WITH UNION FENOSA, SPAIN**

Union Fenosa, one of Spain’s largest electrical utilities, is currently investigating specific options for their Spanish and Latin American transformer applications. The MagneX is their preferred protection scheme for a number of applications, as presented below. While some of the applications are experimental, others (like pole top transformers for their Latin American properties) involve the MagneX as the specified protection scheme.

**CASE 1.1. Urban Pad Mounted Transformer**

The scheme is identical to the one shown in Figure 6. This transformer is designed primarily for indoor installation. The electrical parameters of this application are as follows:

- Rated Power: 250, 400 or 630 KVA
- Rated System Voltages: 15 or 20 kV
- Switching is done via two–three position selector blade switches and one–two position selector blade switches, as in Figure 6. The short circuit rating of these switches is 16 KA.
- The primary protection consists of a three-phase MagneX in series with a partial range current limiting fuse, type ELSP.
- The insulation medium is Cooper Power Systems R-Temp – less flammable transformer fluid.

Union Fenosa has been using Cooper Power Systems’ Pad Mounted Transformer for many years. The difference now lies with the three-phase MagneX, which has been substituted for the three single-phase MagneX units.
CASE 1.2. Rural Pad Mounted Transformer

Union Fenosa has an ongoing project employing underground cable in new expansions of their rural distribution networks, 15 and 20 KV. One part of this project is replacement of the conventional overhead MV/LV station with the Pad-Mounted Transformer. Union Fenosa’s specification “Centro de Transformacion 1x 250 KVA Pie de Poste” refers to this specific design.

As an alternative to this specification, Union Fenosa is considering use of a Pad-Mounted Transformer protected with the MagneX in series with an under-oil partial range current limiting fuse (ELSP). The design also involves a two-position selector blade switch, rated 16 KA, and is filled with mineral oil. The specified ratings are 100, 160 and 250 KVA, 15 or 20 KV.

Figure 10. Rural Pad Mounted Transformer