SEISMIC PROTECTIVE MEASURES FOR ELECTRIC UTILITIES IN SWITZERLAND – IMPLEMENTATION OF THE ESTI GUIDELINE 248

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ABSTRACT

According to vulnerability studies the electric power distribution in Switzerland, as one of the most crucial infrastructure, presents typical weak points, which can potentially cause important disruptions in case of an earthquake. In the field of the federal earthquake risk mitigation program of the Swiss Confederation, the enforcement of a new guideline for the seismic safety of the electrical power distribution (ESTI 2015) defines specific requirements and the documents to be submitted in the planning approval procedure of the Swiss Federal Inspectorate for Heavy Current Installation (ESTI). The practical guideline is widely supported and focusses on the reduction of the highest risks, thus on aerial substations in the high-voltage power grid, especially on the anchoring of power transformers, high-voltage equipment – especially of fragile materials (e.g. ceramic) and further relevant components. Since enforcement of the ESTI guideline 248, different substation projects were planed and are realised. The paper presents the context in Switzerland as well as the development, the scope of application and the requirements of the guideline. The implementation of seismic protective measures for electric utilities is shown by different examples. To resolve in a practical way the conflict between the conservative requirements for the slack of connection cables between components and the requirements for the short-circuit loads investigations are ongoing.

Keywords: earthquake; power supply; seismic protective measures; Switzerland; guideline

1. INTRODUCTION

Electric power distribution has a crucial importance in our modern societies. According to vulnerability studies, the electric power distribution system in Switzerland presents typical weak points, which can potentially cause important disruptions of electrical power supply in case of an earthquake. The enforcement of a guideline (ESTI 2015) for the seismic safety of the electrical power distribution since 2012 should reduce the vulnerability of key components of the electrical power distribution infrastructure. The involvement of the relevant stakeholders, like the Swiss Federal Inspectorate for Heavy Current Installation (ESTI) or companies like Swissgrid has led to a widely supported and very practical guideline that focuses on the reduction of the highest risks through the implementation of targeted protective measures. Since then a number of projects in substations have implemented these measures. Beside a brief introduction of the guideline (ESTI 2015) that consider also the state of the art (e.g. ASCE 1999, IEEE 2005 and 2006), this paper presents some projects where protective measures were implemented.

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2. CONTEXT IN SWITZERLAND

2.1 Mitigation program of the Swiss Confederation

The Swiss Confederation has started a federal earthquake risk mitigation program in the year 2000 (see www.bafu.admin.ch/erdbeben). This program (FOEN 2017) is updated every four years under the lead of the Coordination Centre for Earthquake risk mitigation of the Federal Office for the Environment. One of the measures of this program is to improve the seismic safety of infrastructures in the domain of competence of the Confederation, which encompasses the national roads, the surveillance of nuclear installations, dams and chemical installations as well as the authorisation of infrastructure projects in the domain of electric power production and distribution, pipelines, railroads and air transport infrastructure.

2.2 The electrical power distribution system in Switzerland

The Swiss electricity market has been partially liberalised since 2009 and is strongly fragmented with over 800 network operators. In 2013, the extra high-voltage power grid (6700 km) was transferred to the newly created national operator Swissgrid, which owns the grid and is responsible for its operation, maintenance and development. The reorganisation of the Swiss electricity market resulted in the separation of electricity production, trading/distribution and transportation of electrical power through the extra high-voltage national grid of Swissgrid. The national grid has a voltage of 380 kV or 220 kV and a frequency of 50 Hz. In addition, there is an electric power supply network for the railway system that transports electricity at a voltage of 132 kV and with a frequency of 16.7 Hz.

The Federal Inspectorate for Heavy Current Installations (ESTI) is competent to issue authorisations for construction or modification projects on the 50 Hz network. It also conducts inspections of the installations under its surveillance. The Federal Office of Transport (FOT) is the surveillance authority for public transport and is competent to issue authorisations for construction or modification projects on the 16.7 Hz network of the railway system.

3. MITIGATION MEASURES FOR THE ELECTRICAL POWER DISTRIBUTION SYSTEM

The study of the vulnerability of the electric power distribution system, the publication of the ESTI guideline 248 through the Swiss Federal Inspectorate for Heavy Current Installation, as well as the control of projects according to this guideline are part of the federal seismic mitigation program.

3.1 Vulnerability studies

According to the findings of the vulnerability studies (Koller 2009 and Koller 2011), that also considered the experiences from real earthquakes worldwide, the biggest damage potential for the

Figure 1. Extra high-voltage power grid in Switzerland (50 Hz), Swissgrid
electrical power distribution system in Switzerland in case of earthquakes is at the level of substations. The higher the voltage level, the higher the vulnerability. More specifically, damage is expected on power transformers, as well as on high-voltage equipment. Mainly because of their lack of anchoring for uplift and sliding. It was also observed that cable connections are often too tight. The lack of slack in connections can result in high interaction forces between components that cannot oscillate independently and produce damage to the equipment. Secondary systems, such as emergency power batteries or control units, also present important weak points so that they can fail even in the case of moderate earthquakes. The studies also showed that most of these issues can be addressed with technical measures that are relatively simple and cost effective. The voltage level of the railway power supply is lower and therefore less vulnerable. Because of the lower redundancy of the railway net and its importance for the society regulations have also been defined in the guideline, but are not presented furthermore in this paper.

3.2 Technical Guideline ESTI 248

3.2.1 Development

Despite the fact that the building codes contain seismic safety requirements, it was necessary to define more specific requirements for projects in the domain of electrical power distribution. The requirements in the ESTI guideline 248 (ESTI 2015) are based on the vulnerability studies, on the current Swiss building codes, on international standards of the electricity sector (especially IEEE 2005 and IEEE 2006) as well as on the ASCE Guide to Improved Earthquake Performance of Electric Power Systems (ASCE 1999). Representatives of the Swiss Federal Inspectorate for Heavy Current Installation (ESTI), of the national company Swissgrid and of other private companies participated very actively in the preparation of the guideline which was published in 2012. The guideline is very concise and is focused on the reduction of the highest risks through the implementation of protective measures in substations. To facilitate its application, the guideline contains design tables, calculation procedures and clear requirements on the documents to be submitted in the planning approval procedure by ESTI.

3.2.2 Scope of application

The requirements in the guideline are function of the seismic zones and the voltage level. In order to guarantee a broad acceptance of the guideline and to avoid disproportionate measures, the requirements are limited to new facilities and new electrical components. For existing facilities, the requirements have the status of recommendations. The following table defines the scope of application in function of the voltage-level (Table 1).

<table>
<thead>
<tr>
<th>Seismic safety of</th>
<th>Voltage-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformers</td>
<td>All voltage-levels</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>Voltage-level 220 kV and higher</td>
</tr>
<tr>
<td>Power distribution equipment in racks</td>
<td>All voltage-levels</td>
</tr>
<tr>
<td>Connection cables (slack)</td>
<td>Voltage-level 220 kV and higher</td>
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<tr>
<td>Secondary systems and other subcomponents</td>
<td>All voltage-levels</td>
</tr>
<tr>
<td>Buildings containing secondary components</td>
<td>All voltage-levels</td>
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<tr>
<td>Aerial transmission lines</td>
<td>Voltage-level 220 kV and higher</td>
</tr>
<tr>
<td>Cable lines</td>
<td>All voltage-levels</td>
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</table>
3.2.3 Requirements

The requirements of the guideline for substations focus on the following aspects:

- **Transformers**
  A seismic certification (according to IEC) as well as a verification of the anchoring are requested in function of the seismic zone and the slenderness ratio of the transformer.

- **High-voltage equipment**
  A seismic certification (according to IEC) of the equipment as well as a verification of the anchoring are requested in function of the seismic zone.

- **Connection cables**
  Required slack lengths are given in function of the resonance frequencies of the two connected components, the seismic zone and the soil class.

- **Buildings**
  For all voltage-levels new buildings must be designed according to the building codes. For existing buildings, the seismic safety verification has to be made according to the current seismic building code for existing structures (see also SIA 2017).

- **Secondary systems**, equipment in racks and other subcomponents
  For all voltage-levels and all seismic zones, it is required to secure components like control racks, backup power batteries, elevated floors, partition walls, etc.

For existing substations, situations are defined for which a seismic verification and an eventual retrofit should be done on a voluntary basis by the owner. This concerns mainly secondary systems and subcomponents in the framework of maintenance works as well as important substations for which no substantial renovation is planned for the next 20 years.

3.3 Implementation of the guideline

The Swiss Federal Inspectorate for Heavy Current Installation (ESTI) is responsible for the technical supervision and inspection of electrical installations throughout Switzerland. One of its tasks is the approval of high-voltage systems. The evaluation of the projects files regarding seismic safety is done by the Coordination Centre for Earthquake risk mitigation of the Federal Office for the Environment (FOEN). For the planning approval procedure, the documents to be submitted are defined in ESTI guideline 248. They vary according to the importance of the installation. Following documents can be required before construction:

- Documentation of the exploitation and protection objectives for the installation.
- Written confirmation that the ESTI guideline 248 is observed.
- Description of the seismic conceptional and constructive measures.
- Calculation sheets for anchorage forces and need of slack.
- Execution plans of the anchorages or the cable connection with relevant details.

3.4 Application

Since enforcement of the ESTI guideline 248, different substation projects between the transport system (extra high-voltage grid) and the distribution system (high-voltage grid) were planed and are realised. Further substation projects in the distribution system were also realised according to the new seismic requirements on the initiative of the operators. In all cases it was necessary to design the necessary protective measures very early in the planning phase in order to coordinate the design of the equipment to be delivered, the anchoring elements and the foundations (figure 2).
3.4.1 Transformers

A seismic certification (according to IEC) from the manufacturer as well as a verification and conceptual design of the anchoring are requested in function of the seismic zone and the slenderness ratio of the transformer (figure 3). The verification of the anchoring must be provided for uplift and shear forces or only for shear forces (low seismic zone). The following examples show different approaches for the anchoring of transformers with bolted and welded solutions.

For a new 380 kV to 220 kV substation in Romanel a building with a gas insulated switchgear and four cells for new transformers were constructed. The transformers (3 phases plus 1 reserve) have together an output of 800 MVA and weight each about 350 tons. For the design spectral acceleration of $S_e = 3.5 \, [m/s^2]$ and the slenderness ratio of $s = 2.2$ no uplifting is expected. As shown in figure 4 an anchoring with steel inserts and welded plates was built to avoid horizontal displacements of the transformers under earthquake loading.
Figures 4, 5, and 6 present other examples of anchoring systems. Even lower voltage levels transformers are secured by constructive measures to assure their stability like in Tramelan with a 25 MVA Transformer from 50 kV to 16 kV (see figure 7).

Figure 4. Transformer anchoring (380/220 kV, 800 MVA) without wheels, welded directly on steel inserts embedded in the concrete foundation, Swissgrid (pictures: Jürg Hegner)

Figure 5. Transformer anchoring (220/110 kV, 70 MVA) without wheels, with steel plates fixed with anchors into the concrete foundations, axpo (ESTI 2015, picture B.1, page 26)
3.4.2 High-voltage equipment and cable connections

For high-voltage equipment, certificates according to seismic IEC standards are requested. Without detailed calculations or measurements of the natural frequency of the connected equipments, the guideline gives the required slack for typical components in function of the expected frequency, the seismic zone and the soil class. In the following example from the substation Rüthi, the connection (see plan in figure 8, left) between the circuit breaker (2 Hz) and the measuring group (2 Hz) needs a slack of 125 mm while the connection between the measuring group (2 Hz) and the loop isolator (4 Hz) needs a slack of 95 mm (figure 8, right). Connection configurations with a vertical offset present generally a better seismic behaviour.
3.4.3 Secondary systems, equipment in racks and other subcomponents

It is usual to see existing substations with many secondary systems, equipment in racks or other relevant subcomponents that are not secured against horizontal accelerations. The measures required to solve this issue are often very easy to realise and should be taken into account not only for new substations but also for the periodic maintenance of existing substations. The measures concern control racks, backup power batteries and units as well as elevated floors, partition walls, etc. Some examples are shown in the figures 9 to 11.

Figure 9. Fixations of equipments in racks – left: to the wall and on the steel frame (Arnold AG, Valentin Gaudry), centre: to the wall (axpo, Ingo Schulz), right: to the ceiling (Swissgrid)

Figure 10. Fixation of an auxiliary power transformer (16/0.4 kV, 250 kVA), BKW (pictures: Lukas Eggimann)
3.5 Main issues

Within the projects, it was observed that the conservative requirements for the slack for the higher seismic hazard zones and for large distances between the components can be in conflict with the requirements for the short-circuit loads. Investigations are ongoing to resolve this issue. For the time being, if the conservative slack requirements according to ESTI guideline 248 cannot be met, a more detailed analysis to compute the required slack or a change of the system configuration are necessary.

4. KEY LESSONS

The implementation of a new guideline needs a broad acceptance from all stakeholders. It is therefore important to involve all the relevant persons from the beginning of the development of such a product. The involvement of specialists on the side of the utilities has proven very productive as some measures require to change habits and to rethink some typical modes of operation. For a country with a low to moderate seismicity it is central to consider the proportionality of the measures that must be implemented. The different documented projects show that the relative costs of seismic safety measures according to the ESTI guideline 248 are very low in comparison with the global investment for such projects.

5. CONCLUSIONS

The broad acceptance of the new ESTI guideline 248 (ESTI 2015) for the seismic safety of the electrical power distribution in Switzerland is based on the involvement of all relevant stakeholders and on the strategy to reduce the highest risks, through the reduction of the vulnerability of key components of the distribution network. The availability of design tables, calculation procedures and clear requirements on the documents to be submitted in the planning approval procedure helps greatly the implementation in practice.
6. ACKNOWLEDGMENTS

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7. REFERENCES


