Electric Power Component Design

G. Engdahl[a],

[a]Department of Electromagnetic Engineering, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden

Abstract

Electric power component design is a vast area of knowledge, experience, and expertise. In the beginning, however, the discovery of electricity mainly was regarded as something that one could experience as joyful phenomena presented in live performances. Today electric power component design has established as an own discipline and plays an important role regarding the efforts to improve the functional properties and the efficiency of electric components such that fewer resources are needed i.e. that the cost benefit ratio can be reduced. The from the beginning main challenges electrical, magnetic, mechanical, and thermal considerationsstill are the same irrespectively of what component is regarded. Over the years design tools as dynamic simulation and finite simulation software has emerged as a design aid when optimizing existing components developing components with new functional features. The importance of these is increasing because they make it possible to make more efficient and functional designs of components comprising functional and nonlinear materials that cannot be done with traditional analytical approaches based on knowledge and experience. This is especially relevant regarding design of components based on new advances in the semiconductor, photovoltaic and electrochemical technologies. However, still there is potential in improving the capability of existing design tools also for old components as e.g. transformers and switchgears that comprise magnetic materials showing hysteresis phenomena and electric arcs respectively.

Introduction

Electric power component design is a vast area of knowledge, experience, and expertise. In the beginning, however, the discovery of electricity mainly was regarded as something that one could experience as joyful phenomena presented in live performances. Electrical components then were designed by the discoverer or the electricity phenomenon or an inventor with own experience of electricity or magnetism. The area of electric power component began to emerge when one was able to get benefit of electricity for illumination. It was first with the inventions of the electrical machine and the transformer that design of electric power componentswas established asan own discipline. The driving force in the development of this was and still is to improve the functional properties and the efficiency of the components such that fewer resources are neededi.e. that the cost benefit ratio can be reduced.

Electric Power Components

Electric power componentstraditionally cover the electric energy handling components that are used for generation, transmission, distribution, and use of electric power there the energy content of the transmitted power is essential. This means that apparatus and devices for generation, transmission, distribution, processing, and use of electric energy there the information content is essential are excluded. This distinction, however, now has begun to erode since the introduction of smart electrical power system or in so-called *smart grids*. Nevertheless the main basic electric power component remain to be generators, transformer, motors, overhead power lines, power cables, disconnectors, electric breakers, and fuses. The discovery of semiconductors has opened up for power semiconductors as thyristors, power transistors as IGBTs that constitutes the technology basis for e.g. electric power converters/inverters for electrical machines and HVDC terminal stations. The semiconductor technology also has resulted in photovoltaicswhich constitutes a base for the solar panels technology. Electric power components today also include fuel cell technology and batteries and that is one example of the emerging technology *electric energy storage*.

Design Challenges

Irrespective of what power component is regarded there are 4 critical issues that have to be addressed. 1. Electrical considerations 2. Magnetic considerations 3. Mechanical considerations 4. Thermal considerations. The relative importance between these issues varies depending on which component is regarded.

Electrical considerations: This is traditionally the most obvious consideration, because electricity is extremely dangerous for humans – both with respect to voltage and current. Only 10 mA through the heart may kill a person. Electric design is normally related to how to design the component such that it will be harmless for humans and render protection of the device itself and its surrounding. This task comprises electric field calculations with choice and dimensioning of appropriate insulation materials.

Electrical design also includes considerations such that the damages externally and internally in the component will be delimited in cause of a failure i.e. if a short-circuit or a current interruption occur.

This task then includes short-circuit calculations both internally in the component in the surrounding electrical network.

Magnetic considerations: All electric components that carry electric current are surrounded by magnetic flux. One task then is to dimension the device such that the flux density for all frequencies that exposes humans are under the limit what legally is allowed. In addition the emitted electromagnetic radiation also should be low enough such the actual devise not interfere with other electric components in its vicinity. In electric components that are based on magnetic phenomena a dimensioning of its magnetic circuits also has to be done such that the required flux for an appropriate function of them are obtained. This includes magnetic field calculations with choice and dimensioning of appropriate magnetic flux path materials.

Mechanical considerations: Electric power components are usually made to handle high electric power. This means that either the rated current is considerable or the voltage is considerable and in many cases both are considerable. This means large conductor areas and/or long insulation distances. This implies that the size of an electric component normally is big. For that reason it is essential to mechanically dimension an electric power component with enough margin such that it can withstand its own weight and actual climate and weather conditions as it normally is placed outdoor. Devices that carries huge currents normally or under a fault condition also must be dimensioned such it can manage occurring current forces.

Thermal conditions: All electric power components show an electrical efficiency less than 100 % i.e. they also dissipate heat during operation. This means they must be designed such that there is a heat removal process that can carry away the generated heat. If this fails, a more or less infinite rise of the temperature will occur that will result in a thermal failure of the devise.

Design Tools

The fulfillmentof an appropriate design of an electric power component comprises a trade-off between all mentioned challenges. This means that all of them need to be addressed simultaneously. A common way is to use an iterative technique such one begins to dimension with respect to the most important and severe demand. After that one looks at the next severe demand and one sees if this is fulfilled – if not one has to go back and modify the design fulfilling the first demanduntil both of the first two demands can be met. After that one continues with the two remaining challenges in a similar way until all challenges are met. The tools that can be used are 1. Analytical methods 2. Circuit analyses by dynamic simulation 3. Field calculation by use of a finite element FE software.

Analytical methods: First one should use some analytical approach that can be described as making a rough calculus based on own experience, handbooks, and basic physics and math. This will give a hint on how to rank the challenges with respect to severity.

Circuit analyses by dynamic simulation: All devises can be modelled with a lumped element approach(1).This means that the devise in principle can be described as an electrical, magnetic, mechanical circuit, and/or thermal circuits that show more or less coupling to each other.Using this approach gives more detailed information as an aid in the design work. This, however, requires some knowledge in lumped element modelling and access to appropriate software as PSPICE, DYMOLA (2), SABER (3) or skill in MATLAB programming.

Field calculation by use of a FE software: The most comprehensive support in the design work is got by using a finite element software. On drawback of this approach is that it is rather demanding with respect to computational power. A lot of information not necessary for the design also is got. The interpretation of the obtained numerical result then is more demanding. One quite popular FE software is COMSOL Multiphysics.

Design Example

An electric power transformer is one example of a component, where all mentioned design challenges must be treated. A rough dimensioning of the design data as number of winding turns, wire and core cross sectional areas can be done by use of the so-called analytical method (4). For studying and adapting its electrical behaviour in a power network one need to perform some circuit analyses with dynamic simulation. For the interior designof the transformer one also needs to consider the electric field for appropriate choice and dimensioning of insulation materials and the magnetic flux to avoid magnetic saturation, to attain the wanted short circuit impedance, and to assess occurring current forces during short circuit conditions. Besides one need to estimate the temperature rise caused by occurring lossmechanisms. This can be done by use of a finite element software that can treat electric, magnetic, mechanical,and thermalfields. Because these fields are coupled the software needs to manage this coupling. An advantage is if thesoftware also can treat the magnetic core materials that show nonlinearity. Even better is if the software also can manage magnetic hysteresis appropriately. Promising results has been attained in research scale (5). Some time, however, is left before these can be offered commercially.

Future tasks and challenges

The electric power systems tends to be based on electric power components that comprises more materials showing nonlinear and/or hysteresis features as semiconductors, photovoltaics, electric arc discharges and functional materials. This means that there is need for a development of appropriate design tools that can handle those. This is important, because the world now needs more appropriate use of its resources for generation, transmission, distribution and of electric power to reduce the harmfuleffects of the environment

Conclusion

As a final remark it can be mentioned that the ability to design appropriate electric components for the future electric power systems will contribute to more a healthy and wealthy world. One conclusion then is that the development of new design tools for electrical power systems must be encouraged, especially in these parts of the world that suffer from bad environmental and climate conditions.

References

1. J. Voldman, Lecture 8 notes; Lumped-element Modeling with Equivalent Circuits, Massachusetts Institute of Technology, spring 2007

2. Saber, www.synoptics.com/saber

3.Mathworks, http://se.mathworks.com

4.S. Kulkarni, S Kharpade, Transformer Engineering – design and practice. CRC Press Inc., 2004

5. S. A. Mousavi, Electromagnetic Modelling of Power Transformers for Study and Mitigation of Effects of GICs.Doctoralthesis at Kungliga Tekniska Högskolan, TRITA-EE 2015:003, ISSN1653-5146, ISBN 978-91-7595-411-0, 2015