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International standardization of power electronics for electrical systems based on CIGRÉ SC B4/IEC SC 22F/TC 115 cooperation

Current and future technical network solutions, standardization

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SUMMARY

The international standardization of power electronic equipment and systems for electrical transmission and distribution systems ensures the further technical revolution in electric power industry by the power electronics production development. The power electronics introduction into electric power systems means the thousandfold decrease of response times of control systems and operating mechanisms due to the replacement of traditional components by electronic ones. Such reduction of the response times allows to solve problems inherent to electric systems which cannot be solved (or are too expensive to solve) by traditional means - static and dynamic stability of electric power systems as well as their reliability are increased; system breakdowns are eliminated; the reliable economic and fully controlled long-distance power transmission is ensured as well as the integration of asynchronous (or operating with different frequencies) electric power systems without increasing the short-circuit current levels; a high quality of electric energy, reduction of losses, a complete control of reactive power. The application of power electronics makes any electric system practically invulnerable, reliable, economic and effective.

The international standardization of power electronics for electrical systems began in 1970 when Technical Subcommittee 22F "Convertors for high-voltage direct current (HVDC) power transmission" was established In the International Electrotechnical Commission (IEC). In 1996 SC 22F scope was expanded and its title was changed to "Power electronics for electrical transmission and distribution systems". A new scope of IEC/SC 22F reads: "Standardization of electronic power conversion and/or semiconductor switching equipment and systems including the means for their control, protection, monitoring, cooling and other auxiliary systems and their application to electrical transmission and distribution systems". In 2008 IEC/TC 115 "HVDC Transmission for DC voltages above 100 kV" was established dealing with system aspects of HVDC systems.

The cooperation between IEC/SC 22F/TC 115 and CIGRÉ/SC 14 (now B4) began in the 70s. Basic principles of cooperation between CIGRÉ and IEC Committees were formulated. Reports and Brochures produced by CIGRÉ/SC B4 were used by IEC/SC 22F/TC 115 as the scientific base for international standards and other IEC publications developed in IEC which in turn were the realization of scientific ideas created in CIGRÉ. Use of CIGRÉ materials allows to increase the productivity of work of IEC and quality of IEC publications. The report contains basic results of the liaison between CIGRÉ/SC B4 and IEC/SC 22F/TC 115.

KEYWORDS

Power Electronic Equipment - Electrical Grid – International Standard - Liaison

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1. IMPORTANCE OF INTERNATIONAL STANDARDIZATION OF POWER ELECTRONICS FOR ELECTRICAL SYSTEMS

The international standardization of power electronic equipment and systems for electrical transmission and distribution networks ensures the further progressing of the technical revolution in electric power industry by the power electronics production development. There is no doubt that the market of power electronics and in particular high-voltage direct current (HVDC) power transmission is growing fast and the ratings of power electronic systems are increasing both for the application of Line Commutated Converter (LCC) and the Voltage Source Converter (VSC) technologies. The application of power electronics makes any electric system practically invulnerable, reliable, economic and effective. Similarly the demand in power electronics is growing in other areas such as power electronic equipment for flexible a.c. power transmission (controlled series capacitors, unified power flow controllers, etc), reactive power compensation means (static VAR compensators, STATCOM, etc), power electronic equipment for smart grids and specially for distribution systems. The increase in the activities in HVDC field is due to several factors:

- Application of ultrahigh-voltage direct current UHVDC power transmission to integrate large generation resources located at very remote locations into the electrical network;
- Integration of on-shore and off-shore renewables;
- Limits imposed on the construction of new transmission lines and the need to maximize the use of the line rout transmission capabilities result in the conversion of existing AC lines to DC lines.

International Electrotechnical Commission (IEC) produces international standards and other publications in the fields of electric power engineering, electrical engineering and power electronics which are used as a base for the national standardization practically all over the world. Establishing IEC standards is one important factor for removal of trade barriers between countries. Using IEC standards helps the users and the manufacturers/suppliers to talk in the same language and the consumers to specify requirements clearly and to bring competition on a comparable basis. For industry conformity with IEC standards is a pre-condition to win a tender or to sell devices, apparatus, equipment at the world market. All over the world the brand “Matches to IEC standards” means a high quality of product. In a highly technical and fast moving area as HVDC and Power Electronic equipment, the need for IEC standards is more paramount than for other fields, mainly because of the fact that the user is not acquiring components but more of an integrated system. Therefore most countries of the world actively participate in the IEC work. High quality international standards should be based on modern scientific knowledge and they are especially important for the fast development of new progressive technologies such as the application of power electronics in electrical systems.

We are all now participating in a technical revolution in the world electric power industry. The introduction of power electronics into electrical systems means thousandfold increase in speed of control means and power units due to the replacement of traditional components by electronic ones. Microelectronics with microsecond response times replace relays with response times of several milliseconds, and converters and semiconductor switches with response times 100-200 μs replace mechanical devices with response times 10 000 μs and more.

The development and improvement of power semiconductor devices and electric energy conversion technologies resulted in the further fast-growing application of power electronics in electrical systems of many countries. Very approximate estimate gives more than 110 HVDC power transmissions and back-to-back installations with the total power surpassing 100 000 MW in operation, and by 2020 it will increase by 300 000 MW. Only in China approximately 44 HVDC power transmissions with the total power more than 200 000 MW are planned to be constructed by the end of 2020.

The application of power electronics allows to get the following positive results in electrical systems which either cannot be solved at all using traditional means or can be solved but by a very difficult or expensive way [1-6]:

- increase of the static and transient stability of electric systems, as well as the reliability of electric power supply;
- reduction of the incidents of collapses and blackouts of electric systems which number is quickly grows with the increase of capacity of electric power systems and which cause an enormous economic damage;
- reliable, economic and completely controlled long distance power transmission;
- reliable, economic and completely controlled power transmission using HVDC cables including both land and submarine cable lines and other cases where overhead power transmission lines are either impossible or irrational (e.g. power supply of big cities);
- interconnection of asynchronous electric power systems or systems operating with different frequencies (e.g. 50 and 60 Hz). Thus levels of short-circuit currents in systems do not increase, replacement of equipment (disconnectors, circuit breakers etc.) is not required as it occurs at the interconnection of electric systems by means of a.c. power transmission lines;
- high quality of electric power (elimination of voltage, current, frequency deviations, waveform distorsions, etc), power factor improvement;
- electric power supply of isolated regions, islands, off-shore wind farms, etc, not having their own electric power sources, full reactive power control.

Application of power electronics allows to transform any electric power system into practically invulnerable, reliable, economic and effective one. Besides existing practically unlimited demand for power electronics will remain in future until all electric systems in the world become absolute ones.

2. IEC IN THE POWER ELECTRONICS AND HVDC AREAS

The international standardization of power electronics for electrical systems began in 1970 when Technical Subcommittee (SC) 22F "Convertors for high-voltage direct current (HVDC) power transmission" was established in the IEC. In 1996 SC 22F scope was expanded and its title was changed to "Power electronics for electrical transmission and distribution systems". The current scope of SC 22F reads: "Standardization of electronic power conversion and/or semiconductor switching equipment and systems including the means for their control, protection, monitoring, cooling and other auxiliary systems and their application to electrical transmission and distribution systems". Typical examples are power electronic equipment for flexible a.c. power transmission (controlled series capacitors, unified power flow controllers, etc), converters and associated equipment for high-voltage direct current (HVDC) systems irrespective of d.c. voltage level, reactive power compensation means (static VAR compensators, STATCOM, etc), power electronic equipment for smart grids, connection to electrical transmission and distribution systems of renewable and distributed power generation (wind farms, solar stations, etc) including the standardization of system-related features of d.c. systems with d.c. voltages 100 kV and lower, as well as other applications where power electronics are used, e.g., phase shifters and active filters.

At that time IEC/SC 22F was the only IEC committee producing IEC publications on the equipment and system aspects of high-voltage direct current (HVDC) power transmission as the most used application of power electronics in electrical systems. By 2008 SC 22F developed 14 IEC publications and 12 of them were on HVDC power transmission systems.

In the last decade significant developments have taken place in the field of HVDC (e.g. UHVDC for d.c. voltages above 600 kV as well as introduction of Voltage-Sourced Converters). Ongoing stepwise replacement of conventional power plants and increasing use of renewable energy sources (RES) lead to a growing importance of HVDC in modern power systems. This was the motivation for IEC in 2008 to establish a new Technical Committee (TC) specifically for HVDC, TC 115 "High voltage direct current (HVDC) transmission for DC voltages above 100 kV". Focus of this Committee is on system aspects of HVDC power transmission. The decision was taken to pass all IEC publications on HVDC power transmission produced by IEC/SC 22F but not directly related to power electronics to TC 115 for the further maintenance. Furthermore, as power electronics as being the "heart" of any HVDC system there is an intensive cooperation and exchange of experts between both IEC committees.

3. CIGRÉ STUDY COMMITTEE B4

Study Committee (SC) B4 "HVDC and Power Electronics" of the International Council on Large Electric Power Systems (CIGRÉ) replaced SC 14 which also dealt with power electronic equipment for use in transmission and distribution networks. SC B4 is an active Study Committee with active participation by 27 countries. Presently SC B4 has 17 active Working Groups. SC B4 focuses on the provision of unbiased and up to date application guides for the implementation of HVDC and FACTS projects. SC B4 also provides such technical information to support the standardization required for the testing and application of new technology solutions. The cooperation between IEC and SC B4 goes back many years and was renewed recently in 2014 by establishing category A liaison between SC B4 and IEC TC 115 in September 2014. It is clear that CIGRÉ SC B4 does not issue standards, however, it can provide a guide and input to the IEC. There are historically several CIGRÉ SC B4 and formerly SC 14 publications that were exchanged between B4 and IEC, for example guide for testing thyristor valves. The cooperation between B4 and IEC is important because of the fast changes in the areas of HVDC and power electronics. Although SC B4's scope of work is not dictated by issuing standards, it can certainly help in the process. SC B4 is also reviewing old brochures to establish the need for renewal. Such review can be important for the IEC too.

4. PRINCIPLES OF COOPERATION

As a pre-condition for the successful international standardization work availability of broadly accepted knowledge and technology is mandatory. For HVDC and FACTS applications CIGRÉ has always been serving as a major contributor and has published numerous Technical Brochures covering relevant fields of applications and new trends in technology. The cooperation between IEC/SC 22F and Study Committee 14 (now B4) of CIGRÉ began in the 70s. At first this cooperation was not very active as then only post was possible for the volume communication between them. Later SC 22F secretariat organized close and fruitful cooperation (type A liaison) with CIGRÉ/SC 14 "HVDC Power Transmission". Then Mr. Marcio Szechtman was the chairman of CIGRÉ SC 14 and Prof. Willis Long was the secretary of CIGRÉ SC 14. By permission of Mr. Jean Kowal, the General Secretary of CIGRÉ at that period, Mr. Marcio Szechtman sent CIGRÉ Reports and Brochures produced by CIGRÉ/SC 14 and requested by IEC/SC 22F secretariat and they were used as the modern scientific base for international standards and other IEC publications developed by IEC/SC 22F.

IEC Directives [7] permit very wide possibilities for the interaction of A-type liaisons such as between IEC and CIGRÉ. Experts of any side can attend plenary Committee meetings, take part in the work of Working Groups, exchange information, etc. Both Committee managers can officially inform each other on all the stages of the development of any project considered by their Committees. In 2008 Mr. Jean Kowal, General Secretary of CIGRÉ, confirmed that CIGRÉ was committed to provide technical information to IEC, which IEC could then translate into International Standards as necessary. CIGRÉ would not take any part in the Standard creating process. He also noted that CIGRÉ had clearly informed IEC that CIGRÉ was not interested in CIGRÉ Technical Brochures being published by IEC as a Publicly Available Specification (PAS) or double logo document.

SC 22F never used commercial editions of CIGRÉ SC B4 Technical Reports and Brochures. All CIGRÉ materials were received by SC 22F from CIGRÉ SC B4 chairmen in WORD formats and it was agreed by the CIGRÉ management.

In 2008 concrete rules of the liaison were formulated and agreed by Mr. Bjarne Andersen, the new chairman of CIGRÉ/SC B4, and Mr. Lev Travin, secretary of IEC/SC 22F:

- IEC/SC22F (and later IEC/TC115) is invited to attend the SC B4 meetings and make a brief presentation on their current work, as has been done in the past.
- When IEC Committees identify particular technical activities that they would like B4 to pursue, then this should be communicated to the SC B4 Chairman before the Study Committee meeting. SC B4 will then consider how the request can best be accommodated within the B4 Strategic Plan and Action Plan.
- When SC 22F (and TC115) intends to start work based on a Technical Brochure prepared by B4, then the B4 Chairman should as a courtesy be informed of the scope of the proposed work.
- When the work based on a CIGRÉ Technical Brochure nears the completion of a Committee draft, the draft should be sent to the B4 Chairman for his informal comments.

Another example of excellent cooperation of CIGRÉ/SC B4 and IEC/SC 22F is the history of International Standard IEC 62501, Ed. 1: “Electrical testing of voltage sourced converter (VSC) valves for high-voltage direct voltage (HVDC) power transmission”. SC 22F just began the work on quite new technology – Voltage Sourced Converters for HVDC systems - and needed some scientific base for the subject.

A decision was taken at SC 22F meeting in Fontenay-aux-Roses, France (2004), to ask CIGRÉ/SC B4 to establish a new Working Group dealing with the testing VSC valves for HVDC systems. SC 22F proposal to establish such Working Group in CIGRÉ/SC B4 was discussed at CIGRÉ/SC B4 meeting in Bangalore, India (2005), and delegates present supported it. This proposal was approved by CIGRÉ Technical Committee and CIGRÉ Working Group B4-48 “Testing of VSC System for HVDC applications” was established at CIGRÉ SC B4 (2008). In three years CIGRÉ Technical Brochure 447 “Components Testing of VSC System for HVDC Applications” developed by CIGRÉ Working Group B4-48 was published and used by IEC SC 22F to update IEC 62501, Ed.1: “Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission - Electrical testing”.

In 2008 IEC/TC 115 “HVDC Transmission for DC voltages above 100 kV” was established dealing with system aspects of HVDC systems and after that type A liaison between CIGRÉ

SC B4 and IEC TC 115 was also agreed. A liaison officer has been formally established ensuring regular information exchange between the committees.

5. RESULTS OF COOPERATION

Cooperation between IEC/SC 22F/TC115 and CIGRÉ/ SC B4 is stable and strong at present. Reports of SC B4 Working Groups present scientific base for many IEC Standards and other IEC Publications. On the other hand IEC Publications provides the application of scientific ideas born in Working Groups of CIGRÉ/SC B4 all over the world.

In 2014-2015 the IEC/SC 22F was working on 14 Publications (including Amendments and drafts prepared for publications) and 6 of them were based on CIGRÉ SC B4 Technical Brochures prepared by SC B4 (see Table I).

Table I List of IEC Publications processed by IEC/SC 22F in 2014-2015 and based on CIGRÉ Technical Brochures produced by CIGRÉ/SC B4

##	CIGRÉ Technical Brochure	IEC Publication	Notice
1	TB 097 1995 SC 14 WG 14.12 System tests for HVDC installations	IEC 61975, Ed.1.0: High-voltage direct current (HVDC) installations - System tests	
2	TB 139 1999 SC 14 WG 14.30 Guide to the specification and design evaluation of AC filters for HVDC systems.	IEC/TR 62001-1, Ed.1.0 : High-voltage direct current (HVDC) systems - Guidebook to the specification and design evaluation of A.C. filters - Part 1: Overview - Part 4: Equipment	
3	TB 553 2013 B4-47 Special Aspects of AC Filter Design for HVDC Systems	IEC/TR 62001, Ed.1.0 : High-voltage direct current (HVDC) systems - Guidebook to the specification and design evaluation of A.C. filters - Part 2: Performance - Part 3: Equipment	
4	TB 447 2011 B4-48 Components Testing of VSC System for HVDC Applications	IEC 62501, Ed.1.0: Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission - Electrical testing Amendment 1	Published in 2014
5	TB 223 2003 SC B4 WG B4.28 Active filters in HVDC applications	IEC TR 62544, Ed.1.0: High-voltage direct current (HVDC) systems - Application of active filters Amendment 1	
6	TB 136 1999 SC 14 TF 14.01.04 Fire aspects of HVDC thyristor valves and valve halls	IEC/TR 62757, Ed.1.0: Fire Prevention Measures on HVDC, SVC and FACTS converters and their valve halls	Published in 2015

Expression “IEC Publication YY is based on CIGRÉ Technical Brochure XX” does not mean that the content of an IEC Publication exactly repeats the content of the CIGRÉ Technical Brochure. According to ISO/IEC Directives [7] the development of an IEC International Standard should take no more than three years from the moment when participating members having right to vote (P-members) of an IEC/TC/SC take such decision by voting. Main stages of the standard development are shown in Table II.

Table II Main stages of the development of an IEC International Standard

Label	Stage	Action	Notice
PWI	Preliminary Work Item	IEC TC/SC may put PWI (which is not yet ready for next stages) into its Program of Work as a possible base for future New Work Item Proposal (e.g. for emerging technologies) for three years period.	Voting in favor
NP	New Work Item Proposal	Proposal for a new standard (a draft can be attached)	
RVN	Result of Voting	Result of voting and comments on the draft are discussed at TC/SC meeting. Working Group (WG) is established	Voting in favor
WD	Working Draft	WD is prepared by WG and sent to TC/SC secretariat	
CD	Committee Draft for Comments	CD is prepared by TC/SC secretariat and circulated to IEC National Committees (NC) for comments	
CC	Compilation of Comments	NC comments are discussed at TC/SC meeting and decisions are taken	
CDV	Committee Draft for Voting	CDV based on CD, CC and decisions taken at TC/SC meeting is prepared by TC/SC secretariat and circulated to IEC National Committees for voting	
RVC	Result of Voting	Result of voting and comments on the CDV are discussed at TC/SC meeting and decisions are taken as to the next stage	Voting in favor
FDIS	Final Draft International Standard for Voting	Result of voting (comments are not permitted)	Voting in favor
PPUB	International Standard Issued		

When IEC intends to develop IEC Standard based on some CIGRÉ Technical Brochure (TB) this TB is usually attached to the NP document as it is. If the NP document is approved by voting, a newly organized Working Group is preparing a Working Draft using the content of the TB but the WG may also use other sources. The basic principle of the IEC is to get as much unanimity as possible at all stages of the standard development. Any proposal to develop a new International Standard is voted three times and comments on the draft (often quite contradictory ones) are discussed three times by National Committees – P-members of the TC/SC at TC/SC meetings. Therefore the compromises are inevitable at each stage and the resulting International Standard can considerably differ from the initial CIGRÉ TB.

In addition IEC/SC 22F sometimes used some parts from other CIGRÉ Technical Brochures [8-12] and in these cases expression “CIGRÉ Technical Brochure XX was partly used in IEC Publication YY” is more correct.

Use of CIGRÉ materials allows to increase the productivity of work of IEC and quality of IEC publications. During the last 5 years number of IEC publications produced yearly by SC 22F increased from 2-3 to 5-6. During this period no negative votes were received on CDV documents and no technical changes were adopted during the discussion of received NC comments on the CDVs. In accordance with ISO/IEC Directives, Part 1, subclause 2.6.4,b, in such cases the FDIS stage is not necessary, i.e. CDV document is published as the International Standard. The absence of negative votes (i.e. 100% voting in favour) means a high quality of CDV documents and the elimination of FDIS stage gives at least half-year reduction of the IEC Standard development time.

5. NEW TECHNOLOGIES

CIGRÉ/SC B4 Technical Brochures concerning new quickly developing technologies such as modern Electrical Energy Storage (EES) Systems, HVDC circuit breakers, HVDC grids, etc [6, 13-14], are very important for the international standardization of power electronics for electrical transmission and distribution systems as they let the IEC experts to prepare for work in these fields.

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[7] ISO/IEC Directives, Part 1, “Procedures for the technical work”, Ed.11.0, May 2014, 84 pages).

[8] Working Group TF 38.01.02 CIGRÉ.“Static var compensators” (CIGRÉ Technical Brochure number 025, 1986, 125 pages).

[9] Working Group 14-03 CIGRÉ. "AC harmonic filters and reactive compensation for HVDC with particular reference to noncharacteristic harmonics" (CIGRÉ Technical Brochure number 065, 1992, 52 pages).

[10] Working Group 14-01-02 CIGRÉ. "Voltage and current stresses on thyristor valves for static var compensators" (CIGRÉ Technical Brochure number 078, 1994, 32 pages).

[11] Working Group 14-19 CIGRÉ. "Static synchronous compensator (STATCOM)" (CIGRÉ Technical Brochure number 144, 1999, 204 pages).

[12] Working Group B4-46. "Voltage Source Converter (VSC) HVDC for Power Transmission - Economic Aspects and Comparison with other AC and DC Technologies" (CIGRÉ Technical Brochure number 492, 2012, 109 pages).

[13] Working Group B4-52 CIGRÉ. "HVDC Grid Feasibility Study" (CIGRÉ Technical Brochure number 533, April 2013, 187 pages).

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