German – Ukrainian Collaboration in the Assessment of Digital I&C Systems for Safety Applications in NPPs

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Abstract: German – Ukrainian collaboration in safety assessment of digital Instrumentation and Control (I&C) systems began to be in progress since 1995 as part of the established collaboration in the field of Ukrainian NPP safety declared by the German Ministry BMU and Ukrainian Ministry of Environmental Protection and Nuclear Safety and aimed at the support of the Ukrainian Regulatory Body in supervision and licensing of NPPs. The collaboration in I&C was triggered by the contract between Rovno NPP (Ukraine) and Siemens (Germany) on procurement of digital emergency protection system for Unit 4. The collaboration has been realized between regulatory authorities and supporting organizations of both countries: GRS/ISTec - Germany and Nuclear Regulatory Authority and State Scientific Technical Center of Nuclear and Radiation Safety (SSTC NRS) – Ukraine. From the beginning the collaboration was intended to cover not only the single specific system, but also a great number of tasks concerned with safety assessment of digital I&C systems. As a result the existing Ukrainian standards on I&C assessment have been re-evaluated and supplemented by requirements concerning software-based digital I&C safety systems.

1. INTRODUCTION

Digital I&C systems are more and more widely adopted from year to year by all world under modernization of operating NPP as well as under construction of new NPP instead of analog systems used earlier (see [1,2]):

The reasons of wide spreading of digital I&C are as the following (see [1,2]):
- high reliability;
- high efficiency (high progressing rate, high data transmission rate, high accuracy of signal processing and thus higher performance quality of control- and surveillance functions);
- high system variability (capable of processing analog and digital signals, extendable, enabling communication with other systems and processing of complex tasks);
- manufacture at relative low cost for fault tolerant operation;
- compared to analog hardwired systems, significantly lower demand on space and wiring;
- using of optical fiber wires;
- extended self-test functions, which can be established online; extended maintenance and diagnostic opportunities;

– possibilities for introducing modern – man – machine – interface to support the operator (high productive workstations, displays with high resolutions, possibility of control by display keys, etc).

Both Germany and Ukraine follow this tendency. Thus, in Germany during last years, digital reactor control and limitation system (Unterweser NPP), limitation, reactor control and rod control systems (Neckarwestheim NPP), protection system of new Munich research reactor FRM-2, etc., were implemented.

In Ukraine during last years, digital systems for all units of VVER-1000 and both units of VVER-440 (e.g. computer information systems, digital regulators, control rod systems, safety parameter display systems) were implemented. Even at Unit 3 of Chernobyl NPP closed in December 2000, some modernization with use of digital systems was carried out two years before the closing.
Some difference between situations in Germany and Ukraine consists in the use at NPPs: In Germany systems and hardware designed and produced as a rule by German companies are applied. Systems designed not only (and not so much) by Ukrainian manufacturers, but also by manufacturers from other countries (USA, France, Czech Republic, Russia, Germany) are and will be used at Ukrainian NPPs. Let us note, that Ukrainian companies have a great experience in design and manufacture of digital I&C systems for military purpose, especially for missiles. Now, during the conversion process, some of these companies began to design I&C systems for NPP.

Wide use of digital systems for NPP safety applications resulted in necessity of their safety evaluation under licensing process.

2. STAGES OF THE COLLABORATION

In 1994, the administration of Rovno NPP concluded a contract with Siemens-KWU on design, erection, procurement and setting up of emerging and warning protection systems and neutron flux monitoring system for Unit 4 of VVER-1000. The construction of Unit 4 of Rovno NPP was suspended earlier in consequence of moratorium on commissioning of new units of NPP adopted by Ukrainian Parliament.
After a disaffirmation of the moratorium, the Administration of Rovno NPP adopted a decision about putting digital systems on the basis of the new specifically for safety application developed product family “Teleperm-XS” into Unit 4 instead of analog system provided before in the project, using hardware UKTS and neutron flux monitoring system of type AKNP-3 (these systems are implemented at the other operating Ukrainian units of VVER-1000).

At that time, it was supposed that this system for Rovno NPP would be the first use of “Teleperm-XS” in NPP safety system: neither Germany nor other countries used “Teleperm-XS” in safety system (in particular in protection systems). Ukrainian Nuclear Regulation Authority (UNRA) began in advance to prepare for work on the safety assessment of the digital systems.

It is necessary to note, that UNRA was created in 1992 simultaneously with the creation of Ukraine as an independent state. At the same time, the State Scientific Technical Center on Nuclear and Radiation

Safety was created as a supporting organization for UNRA. In 1993, I&C Department was created in the scope of the SSTC NRS. Its basis consists of specialists with experience of design of I&C systems (especially, computer information systems “Complex-Titan” for VVER-1000 units in Russia, Ukraine, Bulgaria), and reliability analysis of I&C, but these specialists did not have experience in both licensing activity and safety assessment.

An imperfection of the standards base used for the licensing of digital I&C systems was one of the main problems:

- The standards for NPP I&C system, which existed in the Ukraine were built on different principles and had many contradictions (from the definitions of the main terms to qualitative and quantitative requirements to NPP control systems characteristics).
- Existing standards did not take into account the modern principles of I&C systems creation, in particular not the presence of software.
- Many requirements of these documents did not take into account requirements of international standards (for example, acting standards do not have requirements for equipment qualification, to software verification and validation).

In the same time, the specialists of GRS/ISTec which have been involved in digital I&C safety research and in international standardizing committees over many years have had a great experience both on safety assessment of different NPP I&C systems and on the specific features of the Teleperm-XS system. On behalf of the Bavarian State Licensing Authority the experts of ISTec (subsidiary and competence center of GRS in computer applications and safety assessment) has been assessing the design and development process continuously from the safety point of view. In 1992 the “Expert review on conception of Siemens-KWU digital safety control system” [3] was issued where ISTec analyzed the conformity of this system with KTA standards and internationally agreed requirements such as discussed as consensus in IEC working groups (International Electrotechnical Commission). Later on ISTec proposed to extend type-testing also to software components of the Teleperm XS system, performed the testing, and documented the results in certificates.

Taking into consideration the already existing contacts between BMU/GRS and UNRA, it was expedient to begin the collaboration between GRS / ISTec and UNRA / SSTS NRS with the purpose of rendering assistance to Ukraine for safety assessment of digital system for Unit 4 of Rovno NPP. It is necessary to note that terms planned earlier concerning design and procurement of digital systems was changed essentially. The financing of the system procurement became dependent on commissioning of Unit 4 of Rovno NPP. In turn, it was dependent on the closing of Unit 3 of Chernobyl NPP and the resolution of the financial organization of Europe as per credit granting to Ukraine for commissioning of two new units – Unit 4 at Rovno NPP and Unit 2 at Khmelnitsky NPP.

A delay with the financing resulted in the fact that during this time Siemens designed and implemented digital systems for units VVER-440 in Paks (Hungary) and in Bohunice (Slovakia). ISTec was included in the licensing procedure as a consultant of the Hungarian Licensing Authority and as a consultant of the Slovak Technical Expert Organization VUJE required by the Slovak Authority. The delay of implementation of systems at Rovno NPP had a positive aspect – the collaboration could be extended and has spread from the safety assessment of one particular system (really, the most important from the point of view of safety) for a specific NPP to general problems of safety assessment of digital systems. Now the financing of works for Unit 4 of Rovno NPP was started. In addition, it is proposed to

Table 1. Main stages of collaboration between GRS / ISTec (Germany) and UNRA / SSTC NRS (Ukraine)

Years	Contents of stage
1995	Definition of basic aims and principles of collaboration organization (within the frames of annual meeting of GRS-IPSN)
1996	Training of SSTC NRS specialists in ISTec (type tests of HW)
1997	Training of SSTC NRS specialists in ISTec (type tests of SW)
1998	Giving a more precise definition to the further stages of collaboration (within the frames of annual meeting of GRS-IPSN)
1996-2000	Working meeting of ISTec – STC NRS as per problems: – analysis of ISTec experience as per elaboration of requirements and criteria of digital systems assessment; – analysis of experience as per safety assessment of hardware and software of Teleperm-XS; – analysis of experience as per fulfilled expertise of NPP I&C safety system; – comparison of German and Ukrainian standards on NPP I&C systems required for carried out of expertises and acceptance of certificates; – discussion over normative document of Ukraine elaborated by SSTC NRS and containing regulative requirements to I&C systems [4]; – getting acquainted with experience of ISTec as per licensing of commissioning of digital I&C on the basis of Teleperm-XS at NPP Paks and Bohunice; – getting acquainted with principles of expertise of system tests.

install the digital system at Unit 2 of Khmelnitsky NPP. In connection with that, it is proposed the further development of the collaboration GRS / ISTec and UNRA / SSTC NRS with respect to safety assessment of digital I&C.

The collaboration was carried out on the basis of “Declaration as per Collaboration in the Sphere of Safety of Ukrainian NPP” signed by officials of GRS and UNRA. The collaboration was carried out as per “Plan for Fulfillment of Works for Support of Ukrainian Regulative Body under Assessment and Licensing of Digital System of Reactor Protection at Rovno NPP”. The main stages of collaboration are given in Table 1.

3. PRINCIPLES OF SAFETY ASSESSMENT OF DIGITAL I&C SYSTEMS

One of the basic difficulties under implementation of digital systems at NPP is both a complexity of safety assessment and evidence of possibility of these systems use. Safety assessment consists in the following:

- identification (certain definition) of regulatory requirements to the system and its components;
- establishment of compliance between the system with its components and each of regulatory requirements imposed to them.

The main principles of digital system safety assessment used both in Germany and Ukraine are as the following:

1) Safety assessment has to include both software and hardware analysis along with analysis of system as whole.
2) Safety assessment has to begin at the earliest stage of I&C creation and to cover the basic stages of systems life extension:
   - system specification (Terms of Reference);
   - planning;
   - system design;
   - verification and validation;
   - factory acceptance and plant-specific system tests;
   - on-site installation and tests;
   - safety analysis report;
   - operation.
3) Safety assessment has to include the analysis of the interface between both I&C modernized and unchanged parts of systems (in the case of modernization only of system central part).
4) Safety assessment has to include the analysis of the following:
   - defense -in-depth;
   - reliability;
   - meeting the single failure criterion;
   - meeting the independence criterion;
   - meeting the diversity criterion (for protection systems);
   - meeting the criterion on protection against common mode failure;
   - meeting the man-machine interface criterion;
   - meeting the criterion on protection against non-authorized access;
   - meeting the criterion on resistance against action of external factors;
   - meeting the criterion on resistance against power supply parameters variations, etc.
5) Using the results of the of plant-independent generic qualification (type testing of hardware and software components and test of a representative system configuration).
6) Establishing of independent V&V teams (for example, ISTec – together with representatives of Slovak NRA for V&V of Bohunice system; SSTC – together with representatives of Ukrainian Science Academy, NPP and Czech specialists for V&V of digital control rod system for South-Ukrainian NPP).

4. BENEFITS OF UKRAINE OWING TO COLLABORATION

It is possible to assort the results of the collaboration into the following groups:

- assistance as per study and further use of GRS/ISTec experience on safety assessment;
- assistance as per safety assessment of Teleperm-XS.

The assistance as per study and use of GRS/ISTec experience on safety assessment consists in getting acquainted both with regulative requirements of Germany used for digital I&C systems and with general methods on safety assessment adopted by ISTec; reliability assessment of software, principles of tools use for safety assessment including the tools RETRANS and REVEAL developed by ISTec.
The practice of Teleperm-XS assessment carried out by ISTec permit to decrease the scope of works of SSTC NRS under expertise. It concerned the type tests of HW and SW, type tests of representative systems. Licensing plan for protection system of Rovno NPP elaborated by SSTC NRS was discussed with ISTec. These results have influenced the creation of the Ukrainian standard base used for regulation (see below), as to practice of expert review of different digital I&C systems.

5. UKRAINIAN STANDARD BASE FOR REGULATION IN NPP I&C AREA

Ukrainian standard base for regulatory activity in the area of NPP I&C systems which was elaborated by UNRA and SSTC NRS now includes – to a large degree as a result of the collaboration of SSTC NRS and ISTec - three documents:

- "Requirements on Nuclear and Radiation Safety to I&C Systems Important to Safety on NPP" [4]
- "Methodic of Assessment of Compliance of NPP I&C Systems to Safety Requirements" [7]
- "Requirements to Order and Contents of Life Extension of Instruments which are included into Safety Important Systems" [8]

ISTec representatives had read the document [4] and sent their remarks to SSTC NRS helping along improvement of this document.

The main peculiarities of this document are the following:

- The requirements are valid for the following:
  - new/modernized systems;
  - systems qualified as safety-important ones;
  - both systems as a whole and its components (hardware and software).
- In the document the following is taken into account:
  - the majority of modern I&C systems are digital ones and use microprocessors with software;
  - the requirements lacking in Ukrainian standards but exist in the international standards (V&V, EMC, etc).
- The requirements are harmonized with international standards, codes and rules (IAEA, IEC, etc) as well as with standards of the main authoritative national technical societies (IEEE, etc).
- We tried to take into account perspective documents – Draft of IAEA Safety Standard "Instrumentation and Control Systems Important to Safety in Nuclear Power Plants" which will supersede IAEA 50-SG-D3 and 50-SG-D8.

Standards [4] and [7] have been used for safety assessment of digital I&C systems implemented at Ukrainian NPP (table 2, 3). These standards will be used for different I&C systems of new units: Unit 4 of Rovno NPP and Unit 2 of Khmelnitsky NPP.

Table 2. Digital I&C systems which have been assessed by SSTC NRS and were implemented in Ukraine for 1997-2001

System	Designer		NPP
	Name	Country	
Group and Individual Control Rod System	Scoda-Control	Czech Republic	KhNPP 1 SUNPP 1,2
Computer Information System	SYSECA	France	RNPP 1,2
Computer Information System	Westinghouse	USA	SUNPP 1
Safety Parameters Display System	Westinghouse Burns&Roe	USA	ZNPP 1,2, 3, 4, 5,6
	NPP Support Operation Institute	Ukraine	RNPP 3 KhNPP 1
	Westron	Ukraine-USA	SUNPP 1, 2, 3
Safety Parameters Display System	Westinghouse	USA	ChNPP3
	NIKIET	Russia	
	Westron	Ukraine-USA	
Refueling Machine Control System	Odessa Polytechnic University	Ukraine	ZNPP 1
Computer System from machine room control (at the base of ASUT-1000M)	Shevchenko Plant	Ukraine	ZNPP 1
	LvivORGRES	Ukraine	
Steam Generator Level and Feedwater Control System	WESE	Belgium	SUNPP 2
	LvivORGRES	Ukraine	
	Westron	Ukraine-USA	

Table 3. Digital I&C systems which are being assessed by SSTC NRS now and will be implemented in Ukraine for 2002-2004

System	Designer		NPP
	Name	Country	
Protection System, Neutron Flux Monitoring System	Siemens	Germany	RNPP 4 KhNPP 2
In-Core Reactor Monitoring System	Impuls	Ukraine	ZNPP 3
Automatic Power Regulator	SNIIP	Russia	SUNPP 1
Automatic Power Regulator	Khartron	Ukraine	RNPP 1, 2
Computer regulators of 1-st circuit (at the base of ASUT-1000R)	Shevchenko Plant	Ukraine	SUNPP 1, 2
Refueling Machine Control System	Hanz	Hungary	SUNPP 1, 2
Refueling Machine Control System	Odessa Polytechnic University	Ukraine	RNPP 3
Steam Generator Level and Feedwater Control System	WESE	Belgium	SUNPP 1
	LvivORGRES	Ukraine	
	Westron	Ukraine-USA	
Group and Individual Control Rod System	Khartron	Ukraine	ZNPP 3
Neutron Flux Monitoring System	SNIIP	Russia	ZNPP 2
	Impuls	Ukraine	SUNPP 2

The direct collaboration between the specialists of ISTec and SSTC NRS is supplemented with their interaction within the bounds of IAEA. Two of the authors of this article are official representatives of their countries in IAEA International Working Group of Instrumentation and Control (new name of this group since 2000 – Technical Working Group on Nuclear Power Plant Control and Instrumentation). The same persons are as co-authors of a new IAEA document on I&C modernization [10] and continue their joint operation on a new project of IAEA "Scientific Basis and Engineering Solutions for Cost-Effective Assessments of Software-based I&C Systems".

CONCLUSION

Modernization of I&C systems in a NPP including systems important to safety up to the highest safety category opens a high potential to increase the overall safety of the plant. In East-European NPPs hard-wired analogue technology of the original design needs to be replaced more and more often due to increasing failure rates. Problems with the procurement of spare parts, but also in particular the technological change that has taken place in the meantime - i.e. away from analogue towards digital (computerized) technology - have led to the fact that Eastern nuclear power plants are upgraded by digital safety I&C at a growing rate. In this context, the authorities are facing new problems in connection with the licensing of software-based systems technology.
ISTec has been asked to support the Ukrainian regulatory body and its technical/scientific advisors with its long-term experience and broad knowledge in the field of digital I&C safety assessment and, in particular, with its detailed and deep knowledge in the Teleperm XS technology which is foreseen to be used for modernization in some Ukrainian NPPs. The collaboration between the experts of the involved organizations has been very successful: Knowledge transfer enlightening the Western methodologies and the specific German approach when using Teleperm XS (type-tested, generic qualified, independent V&V of plant-specific system configuration) took place in an open manner. The existing Ukrainian standards on I&C assessment have been re-evaluated and supplemented by requirements concerning software-based digital I&C safety systems.

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REFERENCES

1. G. Schnürer, D. Wach, F. Seidel, L. Weil. Upgrades of Digital I&C in German Nuclear Power Plants. Regulatory Aspects and Qualification Requirements. In IAEA Specialists' Meeting on "Modernization of Instrumentation and Control Systems in Nuclear power Plants", 1995, Garching

2. M. Yastrebenetsky, V. Vasilchenko. VVER Control Systems Upgrades (Safety Aspects). In Proceeding on ICONE-8. 2000, Baltimore.

3. W. Bastl, J. Brummer, E. Hoffmann, D. Wach. Expert Review on Conception of Siemens-KWU Digital Safety Control system. GRS-A-1921, 1992.

4. NP306.5.02/3.035-2000. Requirements of Nuclear and Radiation Safety to NPP I&C Systems Important to Safety on NPP. Nuclear Regulatory Administration of Ukraine, Kiev, 2000.

5. A. Lindner, D. Wach. Experience gained from independent assessment in licensing of advanced I&C systems in NPPs. Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC & HMIT 2000). American Nuclear Society, 2000, Washington, DC.
6. M. Yastrebenetsky. Safety Assessment of NPP Instrumentation and Control Systems. Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC & HMIT 2000). American Nuclear Society, 2000, Washington, DC.

7. NP 306.7.02/2.041-2000. Methodic of Assessment of Compliance of I&C Systems to Safety Requirements. Nuclear Regulatory Administration of Ukraine, Kiev, 2000.

8. ND 306.711-96. Life Extension of Hardware included into Safety Important I&C Systems. Ukrainian Ministry of Environment Protection. Kiev, 1996.

9. D. Wach. Upgrading East-European Nuclear Power Plants with Digital Safety Instrumentation and Control Systems, Chapt. 11.1, GRS Annual Report, 1999.

10. IAEA TECDOC 1016. Modernization of Instrumentation and Control in Nuclear Power Plants. Vienna, 1998.