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I&C accelerated ageing and I&C re-engineering

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ABSTRACT

Many Nuclear Power Plants in the world are operating beyond their original designed life-time a.k.a Long Term Operation (LTO). LTO operation typically means for the I&C components that a considerable amount of I&C must be replaced or renewed due to ageing. Since a power plant has typically got tens of thousands of I&C components installed and running, it is important to have proper I&C ageing management means in place so that appropriate action plans (e.g. repair, replace or renewing tasks) can be started on time. Lead times in safety related nuclear I&C are typically very long and replacing a whole I&C system typically takes many years. Thus, it is important to know the condition and spare part status for each installed I&C component at the plant. This paper discusses two topics: 1) I&C accelerated ageing and 2) I&C re-engineering. With the former topic, the conditions of the I&C components are also tried to be estimated for the coming years when as the latter topic is a one possible action plan for renewing ageing I&C components. I&C re-engineering has been used much more widely in US than in Finland due to regulation and legislation differences. In US re-engineered I&C component is often seen as a replacing spare part when as in Finland re-engineered I&C components are always considered as new I&C components which means heavier qualification). Both am. topics (I&C accelerated ageing and I&C re-engineering) are first introduced in chapter 1 of this document briefly. In chapter 2, the lately performed accelerated ageing tests inside Fortum are discussed more. In chapter 3, the I&C re-engineering is discussed more. Chapter 4 aims to give conclusions among with the benefits and draw-backs for both topics (I&C accelerated ageing and I&C re-engineering).

1 INTRODUCTION

The idea of I&C accelerated ageing is to accelerate the ageing of electronics and other materials in I&C so that within months the aged I&C component would resemble as much as possible the same component in used operation environment after normal traditional ageing without acceleration. Acceleration ageing of I&C components is normally done in product development phase, in component type testing or for already aged components to gain a better view of the components' remaining life-time. Fortum has performed accelerated I&C ageing for 4 different I&C systems in Loviisa. Results and conclusions are shown in chapter 4 of this document.

I&C re-engineering is normally used only after other options to secure the I&C lifetime have been analysed not to be feasible. These other options can e.g. be 1) Repairing/refurbishment of existing I&C components (for life-time extension of the original components), 2) Replacements of original components (e.g. via new spares procured or commercial grace dedication [1] which has originally been developed as an alternative path for accepting items from suppliers outside nuclear industry).

Energiforsk of Sweden has also researched different I&C re-engineering strategies [2-4]. After it has been analysed that often easier and cheaper options than re-engineering are not feasible for the case, re-engineering jumps into picture. There are different ways to perform re-engineering depending on existing documentation and OEM's (Original Equipment Manufacturer) position on topic. Here are some examples:

- Re-manufacturing - together with OEM or with a permit from OEM manufacturing of the product with the original design specifications.
- Re-engineering - re-engineering company manufactures new components with original documentation (and partially with investigative work where original documentation does not exist)
- Reverse engineering - re-engineering company needs to investigate specimen and take it apart to understand how it works and what the requirements for the new component should be in case where original document does not exist or is very scarce.

2 ACCELERATED AGEING

Fortum performed accelerated ageing tests for 4 different legacy Siemens I&C systems recently (Teleperm-C, Simatic-P, Simatic-N, Transidyn). Test setup consisted of 3 racks and 32 I&C boards (see table 1 below) in the racks. Racks and boards were inserted in a heat chamber during testing. Thermocouple measurements were used to measure temperatures of the boards during testing.

Table 1. Board types tested.

Board type	Pcs
Siemens Teleperm-C M74004-A111	7
Siemens Simatic-P Z24	6
Siemens Simatic-P B22B	6
Siemens Simatic-N 71458-A527-A1	6
Siemens Transidyn TS721-V32828	7

Tested board types were selected so that they represent the most used board types at the plant. Tested boards also contain components that are used in many other boards as well. It is important to have enough of each board types in the test so that random faults that occur during testing resemble reality as much as possible.

Arrhenius' equation (Eq. (1)) is commonly used for the reliability analyses in electronics. It is used for defining the temperature dependent fault frequency of certain components. Equation can be defined as follows :

$$AF = \frac{t_1}{t_2} = e^{\left(\frac{E_a}{k}\right)\left[\frac{1}{T_1} - \frac{1}{T_2}\right]} \quad (1)$$

t_1 = lifetime expected in temperature T_1 [h]
t_2 = test time in temperature T_2 [h]
E_a = activation energy for ageing [eV]
k = Boltzmann's constant 8,617385 x 10^{-5} eV/K
T_1 = normal environment temperature [K]
T_2 = ageing temperature [K]

For the testing, worst case temperatures in the I&C cabinets were recorded and used in testing that defined the length for testing. Expected lifetime was selected to be 30 years (262800 h). Ageing temperature 80 °C was used and activation energy 0.7 eV. Used activation energy for the ageing of electronics depends on the materials. There is more discussion of the accelerated ageing theory e.g. in an IEC condition monitoring standard [5].

Interim measurements were performed many times during the testing in order to know whether boards still functioned properly. Racks and boards had electricity switched on during testing but there was no PLC logic etc. programmed to change the states of inputs and outputs.

Visual results also showed valuable results from the tests. Especially wiring between boards and racks aged much faster than the boards itself. Also many polymeric parts got more fragile during testing and got broken more easily when bent.

I&C board faults during testing were compared to actual faults at the plant. All faults encountered in testing were of similar types than the actual faults occurred in the plant's history. There were example transformer faults, transistor faults, relay faults and opto-isolator faults in testing. First faults occurred already in the beginning of testing and the next faults after couple of years in ageing. However, boards were fixed and returned in testing and there were no faults that would prevent the further usage of boards after repair. In general, the usage of tested boards until end of current remaining lifetime of Loviisa 2027 (LO1) and 2030 (LO2) was seen possible based on test results and existing amount of spare parts for repairing the boards.

3 I&C RE-ENGINEERING

There are many possible strategies for the strategy of I&C re-engineering. One possibility is to re-engineer just the most critical components as spare parts. It is also possible to re-engineer whole racks or I&C cabinets at once. Intellectual Property rights need also to be checked from the OEM before the re-engineering process can be started.

A design basis must be gathered for the I&C components selected to be re-engineered. Existing specimen, OEM documentation and user manuals, system drawings, schematics, plant operation and maintenance procedures, existing and requested environmental conditions (needed especially for the qualification) and other possible documentation helps with the requirements for the re-engineering. Re-engineering can also be started from scratch meaning that there is no documentation available for the component to be re-engineered but only the existing specimen (reverse engineering or black box engineering).

I&C re-engineering company needs to have a Quality Assurance Program that is approved by the regulator in order to supply safety classified components. V&V activities need also to be designed in the re-engineering project. As much as original testing procedures exist, the better. If little or none OEM documentation exists, then detailed circuit analysis is needed for determining each input and output and tolerances for those. This is of course more time consuming than in situations where the original OEM documentation exists and OEM documentation can be treated as acceptance criteria. Main point here is that any acceptance criteria's origin needs to be justified (i.e. OEM documentation, circuit analysis etc.).

A manufacturing tester machine can also be designed and built together in the re-engineering project so that manufacturing testing can be made on a factory level also for bigger batches for the products. After the re-engineering project, this new tester can also be procured for the plant's own I&C maintenance department for the repair work carried on by license holder itself.

I&C re-engineering process for one item from the requirements to manufacturing first batch takes typically from 6-12 months. First article to be manufactured includes inspection, testing and measuring of specimenmechanical design, electrical design, test procedure development and part ordering.. After first article is manufactured, qualification work tasks such as type testing and third party type approvals take place ending in suitability analysis in Finnish nuclear industry. After first article has been finished and approved (by license holder and regulator), a re-designed I&C component batch can be manufactured according to agreed quality management programs and shipped to a customer.

4 CONCLUSIONS

With accelerated ageing, it is easier to anticipate the behaviour of tested I&C components in the coming years so that correct amount of spare parts, re-engineering or digital I&C renewal projects can be started on time before I&C components are deteriorated. Accelerated ageing has also got its drawbacks as the results are not always reliable. It can for example be hard to define correct activation energies if there are many different materials on I&C components or the materials are not well known.

I&C re-engineering is usually the last option after other possibilities such as repairing or replacing the I&C components have been checked. The more I&C component types there are to be re-engineered makes it a worse solution economically. Based on interviews with the companies in re-engineering business, whole digital I&C system upgrade can start to be more feasible economically when amount of boards to be re-engineered exceeds 20-50 different board types.

On the other hand, benefits for the I&C re-engineering are that obsolescence issues can be dealt with individually without the need to upgrade whole I&C system (e.g. when there still are enough spare parts for the other components).

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