nationalgrid

Date of Submission

June 2016

Network Innovation Allowance Closedown Report

Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

Project Closedown

Project Title	**Project Reference**
Assessment of Electronic (analogue and Numeric) Protection equipment end of life mechanisms	NIA_NGET0146

Project Licensee(s)	**Project Start Date**	**Project Duration**
National Grid Electricity Transmission	Apr 2014	10 Months

Nominated Project Contact(s)

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Scope

The scope of the project will establish the techniques and processes to be used on these equipment types.

These techniques and processes will be applied to a specific number of relay types to validate the process and evaluate the lives of these specific equipment types.

The specific equipment types selected will be those predominantly in service on the transmission network which current policy would require to be replaced in the next 5 years.

The establishment of a successful evaluation process for asset life would then be utilised as a research method to evaluate asset lives on other specific equipment types.

Objective(s)

The objectives are:

- To identify the critical life limiting elements within electronic protection devices
- Establish assessment and testing criteria to determine deterioration mechanisms and rates.
- Undertake testing on specific equipment types to establish current and expected deterioration.
- Evaluate results of testing to determine asset lives for the equipment types concerned
- Based on these results it will consider and recommend if the life limiting factors can be addressed by methods other than equipment replacement .

Success Criteria

- Establishment of a process to evaluate electronic protection equipment design, identify the life limiting critical elements and deterioration mechanisms leading to failure.
- Identify tests and assessment techniques to evaluate the current state deterioration, the affecting factors, expected deterioration rates and time to failure.

- Successful application of these tests and assessments on specific equipment types.
- Evaluation of the anticipated asset life for the specific equipment types tested
- Provision of options to address life limiting factors

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Overview

National Grid has approximately 1,200 circuit bays associated with its main interconnecting transmission circuits, and these bays predominantly utilise electronic (Analogue or Numeric) based equipment to provide fault detection and initiate fault clearance. The current anticipated life of this equipment and replacement policy is based on manufacturers' information and operational experience to date. Application of this policy requires a third of the equipment in these bays to be replaced in the next 8 years, with significant access and resource requirements. Due to the critical fault clearance function of protection equipment, replacement is undertaken prior to failure and the assessment of asset life is undertaken during the constant (random) failure period of the equipment lives. This means that significant statistical failure data for this specific population of equipment will not be available to confirm end of life, and investigative processes need to be established and utilised to validate or revise existing lives.

It is in the consumers' interest to avoid premature asset replacement and as we are approaching the time frame for significant replacement quantities, it is important to ensure our evaluation of asset life is robust.

The aim therefore, is to identify the critical life-limiting elements within the electronic protection devices and find, if possible, appropriate methods to address other than equipment replacement.

The project has been completed as a laboratory exercise using equipment removed from service. Three electronic protection equipment types were considered as part of this project.

A quantitative process was required to establish the aging mechanisms applicable to these specific types of electronic protection equipment. This includes determination and application of appropriate invasive examinations and tests to be applied to the equipment to determine deterioration rates and ultimately anticipated lives. This process was then applied to each specific equipment type as required to inform asset life and modify replacement plans accordingly.

Plan

The project has delivered the following:

1. The project has established an assessment and testing methodology to identify the critical life limiting elements within electronic protection devices and to evaluate the presence of deterioration mechanisms.

2. The methodology/process developed for evaluating asset life and any possible life extension included:

- Field performance evaluation – a review of performance history.
- Physical inspection – Condition evaluation – identification of components for analysis due to condition or industry-historical evidence.
- Performance Fingerprint testing – equipment performance testing in respect of fault detection with comparisons to modern equivalent and identification of degradation.

- Stress testing – Voltage and thermal stress identification/evaluation.
- In depth component evaluation – Thermal imaging, X – Ray tomography to identify component degradation.
- Failure Mode, Mechanism and Effect Analysis (FMMEA) – identification of modules/components likely to fail and analysis of effect on operation.

3. This methodology has been applied to three specific protection relay types:

- Two relays manufactured using discrete electronic and early logic/microprocessor components:
  - SHNB Micromho - a multifunctional transmission line distance protection relay.
  - THR transmission line multi-zone distance protection relay.
- One relay manufactured using Analogue - Digital convertors and microprocessors:
  - LFCB - transmission line current-differential protection relay.

4. The Summary report* (together with a presentation by the research team to National Grid Engineering specialists), and detailed investigation reports outlining the process, together with recommendations on asset life and options for consideration have been completed for the three relay types considered. These reports have been reviewed by engineering staff within National Grid to:

- Agree any change to existing asset life policies and impact on replacement plans.
- Consider establishing this process as a technique for ongoing evaluation of these specific equipment types and other similar equipment technologies.

The evaluation is now complete, and the methodology and process has been documented and included within business procedures (Technical Guides) . Users within the industry using similar products now have:

- A technique for better evaluating life expectancy of this technology type.
- A technique which can be utilised to assess life expectancy of other specific equipment types within this technology group and used in the same manner as identified above.
- A better understanding of risks associated with this type of equipment and its expected life, leading to further optimisation of replacement plans.

If the current life of these equipment types could be extended by 5 years, (and potentially beyond that) then significant savings in terms of replacement costs would be achieved.

<u>Dissemination.</u>
Research findings are limited to availability within the National Grid and the boundaries of the NIA research framework. Internal National Grid Documents will be produced; Technical Report and Policy Statement (EPS 12.08) Documentation updated accordingly.

And via the use or publication of the following papers:

1. Investigation on Ageing and Life Extension of Protective Relays, Dr. Marco Venturini-Auterei, Prof. Li Ran, Tahasin Rahman, Dr. Wen An, Dr. Dagou Zee, Prof. Peter J. Tavener, Kieran French, Durham University, Dec 2009 – Nov 2011.
2. Asset Life Extension Evaluation – SHNB, Report compiled by Quanta Technology, LLC for National Grid, B. Gwyn, February 2015.
3. Asset Life Extension Evaluation – THR, Report compiled by Quanta Technology, LLC for National Grid, B. Gwyn, February 2015.
4. Asset Life Extension Evaluation – LFCB, Report compiled by Quanta Technology, LLC for National Grid, B. Gwyn, February 2015.
5. Relay Asset Life Extension Study Process, Task 2 Report compiled by Quanta Technology, LLC for National Grid, B. Gwyn, February 2015.
6. End-of-Life Assessment for P&C Devices (Draft), Working Group I22 of Power System Relaying Committee of IEEE Power & Energy Society, January 2015.

* As this document is published on a website which has globally unrestricted access, National Grid's view is that it may not be possible to publish 'Comprehensive details' for all projects without unacceptable risk of incurring commercial harm to National Grid and/or our partners on the projects or potentially breaching other Licence Conditions, Statutory requirements or other Contractual obligations. Instead the report should draw out the main outcomes of the project in summary form and refer to supporting information that will be made available to GB licensed network operators upon request.

Required Modifications to the Planned Approach During the Course of the Project

There were no changes to the planned approach. The external work has been delivered to time and budget and the project is now complete. The project was delivered under budget by £16,000.

Lessons Learnt for Future Projects

The full completion report (available to GB network licensees upon request) for these 3 equipment types (there are significant volumes of these protection relay types on the National Electricity Transmission System, circa 500 units) provide a better understanding of the risks associated with these equipment types and their expected asset life.

The assessment process has identified that where equipment has been well designed and manufactured and utilises high quality components, well within specified design criteria; minimal degradation has been observed and operational performance remains acceptable.

A managed/staged approach to life extension is proposed with further evaluation after an initial extension period and it is these recommendations which will be used in optimisation of replacement plans.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

The project followed the described test procedure as outlined above (see Performance Compared section point 2). The results from the tests are recorded below by Relay Type.

SHNB

The SHNB Micromho is a multifunctional high-speed transmission line distance and unit protection relaying system, manufactured and supplied to National Grid between 1981 and 2001. It uses analogue integrated-circuit measurement technology with some logic and control by an earlier microprocessor type 156 units, which remain in service.

There are no in-service maloperations recorded in the National Grid Protection Performance Information (PPI) records attributable to an SHNB failure or defect. Accordingly, there is no statistical evidence of any vulnerable components or modules in SHNB relays in service today.

Operational behaviours of an SHNB 101 with 26 years of service, a SHNB 102 with 13 years of service, were tested and compared with a modern numerical relay distance function in the fingerprint testing.

Testing results under both static and dynamic tests verify that both relays are operating as designed. Both the reach accuracy and operation time are within the tolerance limits under both tests. Equipment wear/drift is not detected in the tested relays. No significant signs of degradation can be identified in terms of the operational performance, even on the relay with an in-service time longer than the expected lifetime (25 years).

THR

The type THR is a multi-zone distance relay manufactured and installed in National Grid substations between 1980 and 1990. THR is based on early-1970s discrete transistor circuit design 184 units remain in service.

There are 13 tracked THR in-service maloperations in the National Grid Protection Performance Information (PPI) records, and seven of them were attributable to a THR hardware failure or defect. Five out of seven hardware failures were caused by capacitor failures on the power supply module, so this is the most critical module for the THR life extension assessment. The other two failures were random module component failures with no emerging pattern. It is worth noting that failures of specific THR power supply capacitors cause unwanted tripping rather than inability to trip – a design characteristic of the THR. These problematic electrolytic capacitors have already been replaced with reliable types in the power supplies of all THR units in service, in accordance with the Equipment Modification Instruction (EMI) 997 replacement procedure and program. EMI 997 capacitor replacements were performed in the National Grid Light Current Repair Centre (LCRC) via module rotations, rather than replacing them in the field

The life-extension evaluation checked the operational behaviours of a heavily-used THR with an in-service time of 33 years and comparison with a modern numerical P545 distance function as part of the fingerprint testing.

The comparison of the operational performance of THR and a modern numerical distance relay verifies that the THR relay functions similar to its contemporary replacement relay in terms of basic protection function.

LFCB

LFCB is a transmission line current-differential relaying system based on microprocessor and analogue to digital converter technology, manufactured and supplied to National Grid between 1993 and 2005. 213 units remain in service.

There are eight LFCB in-service maloperations in the National Grid Protection Performance Information (PPI) records. Only two of them were attributed to relay module failures, and none have occurred recently. The cause of the remaining six maloperations is unknown but is suspected to be related to communications issues. Furthermore, National Grid Transmission Design Circular (TDC) 869 documents electronic voltage regulator integrated circuit failure vulnerability in the LFCB, which has already been addressed by replacement of all LFCB modules with the problem regulators.

Operational behaviours of an LFCB sample with 16 years of service, an LFCB with 9 years of service, were tested and compared with a modern numerical relay differential relay in the fingerprint testing.

Based on the test results, both the heavily-used and the lightly-used LFCB samples are operating as designed. The percentage bias settings for each operational phase were tested and proved to be accurate. Fast operating times of the LFCBs ensure that the relay could detect and trip the fault in a timely manner. There were no significant signs of degradation can be identified in terms of the operational performance.

Conclusion.

Each of the three relay types yielded consistent evaluation results and has demonstrated eligibility for an asset life extension. Based on condition and deterioration observed to date an initial extension of five years for each relay type is proposed. Since the tested relay types continue to perform reliably with no increase in failure rates or component degradation over many years of service, the flat failure-rate trajectory does not forecast any specific end of asset life. The proposal to extend asset life by five years comprises a service life extension of only 15% of the time for which the oldest evaluated unit has already served. The service life extension is further supported by thorough technical evaluation of any failure that occurs during the extended life interval, and re-evaluation of the policy change if any unforeseen failure pattern arises.

The process established in this project may be applied to other types of light current equipment with further investigation and development.

The Technology Readiness Level for this project started at a level 4 and completed the project on a level 6.

Planned Implementation

The same process can be applied to other products to support asset life extensions. If certain relays (or other critical equipment types) are serving reliably as they approach policy end-of life, they are candidates for study and for possible asset life extension. With experience gained in this project, it is possible to conduct these studies in the most efficient manner.

This report recommends that results for the studied relays not be broadly applied to other similar devices unless the electronic design employs the same components or hardware platform. To the extent that another product shares some of the same design, only the elements that are different (and the overall fingerprint test performance) need be evaluated. Otherwise, a full study should be carried out.

It is also possible that product study may reveal unforeseen risks by showing design weaknesses, degradation, or impending failures that could not be observed by visual inspection or by normal functional behaviour – such products may not deliver anticipated asset life. While this is not the result that an asset life extension study would hope to establish, it is valuable to know.

The project proposes that National Grid can achieve significant benefits by documenting how these procedures can be applied to other protective relay systems and mission-critical electronic control systems. Reliability is enhanced as deteriorating products are identified, while reliable ones are rated for extended service. With this information on the projected reliability of various equipment items, managers can apply capital assets and human resources where they will have the most beneficial effect.

Other Comments