Organisational Impact of Implementing IEC 61850 Standard for Communication Networks and Systems in Substations

Ramaesela P. Madiba¹, Louwrence D. Erasmus²
Department of Engineering and Technology Management, Graduate School of Technology Management, University of Pretoria, South Africa

Abstract—The lack of international standards for communication within a substation led to the development of proprietary protocols by utilities and vendors. The impact on utilities was complex and required expensive solutions, and limitations in multiple vendor solutions for substations infrastructure. Towards the end of the 20th century there was a compelling requirement in the power industry to standardise protocols for substation automation systems that would enable multiple vendor substation solutions. The requirement prompted the development of the IEC 61850 standard in 1997, a standard for Communication Networks and Systems in Substation. A case study was conducted at Eskom to establish the relationships between the substation function consolidation (enabled by technological advancement) and IEC 61850 standard, as well as organisational structure and the skills required by the power utilities. The case study findings highlighted that the skills and competency requirements were not properly defined, measured or monitored, nor was an alignment to the existing organisational structures defined. Based on the findings the authors propose a framework model to map the requirements of IEC 61850 with the capabilities of the organisation, and formulate a potential solution for the implementation of the IEC 61850 standard.

I. INTRODUCTION

The Electric Power Network Operations and Management were impacted by multiple technological advancements over the years. Without standards for substation communications, vendors developed their own propriety protocols to satisfy reliability requirements [1]. The impact of not having communication standards made communication solutions complex and expensive, increasing costs of switching vendors and limiting multiple vendor solutions for substations infrastructure.

Towards the end of the 20th century there was a compelling requirement in the power industry to standardise protocols for substation automation systems that would enable a multiple vendor substation solution. A major breakthrough was achieved with the application of the IEC61850 standard [8].

IEC61850 is a single, global and future proof standard for substation communications. Its main objectives were to improve device integration across the utility enterprise and reduce costs for engineering commission, operation, monitoring and diagnostics [1].

A. Research Problem

A preliminary investigation indicated that implementation of the IEC 61850 standard by utilities was a complex process that challenges methods of applying new standards within utilities. The standard enables consolidation of protection and control functions into a single Intelligent Electronic Devices (IED). Furthermore, the changed standard required skills and deployment strategies for substation automation within existing functional organisational structures. Therefore compliance with the IEC 61850 standard contravenes the operations of the traditional organogram based on the functions of the departments.

Power Utilities are challenged with increasing electricity consumption, coupled with regulation issues inter alia, resulting in the introduction of innovative technologies that are aimed at ensuring that utilities are operated in an efficient and effective manner[10].

In South Africa, Eskom, as a utility, decided to adopt the IEC 61850 standard into its substation while the standard itself is still maturing and the organisation is also facing the challenge of restructuring and capacity issues. The current economic status, the increase in consumer demands, negative impacts of blackouts, regulation issues, financial constraints and shortage of skills have caused undue pressure on utilities, including Eskom and South African municipalities.

These give rise to the following questions:

Does Eskom have the required skills and competencies required for the implementation of the IEC 61850 standard? What are the required skills deployment strategies for the successful rollout of the IEC 61850?

Since IEC 61850 was published, it has been shown that additional information models could be developed to increase the standard’s application. For that reason several extensions and installations are currently under way to adapt the IEC 61850 standard for wind power plants, hydro power plants, distributed energy resources, and also related to power transmission and distribution as well as power quality monitoring [9].

If IEC 61850 undergoes a major restructuring, what will the impact be on Eskom? What will be the deficiencies in the current skills deployment strategy?

B. Context of the research

Eskom is the South African Power Utility. It is the largest power utility in Africa, with the capacity of about 41194 MW. Eskom’s primary output is to generate, transmit and distribute electricity to industrial, mining, commercial, agricultural, residential customers and redistributors. It generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa (http://www.eskom.co.za/c/40/company-information/). The South African grid is shown below:
The Eskom organogram, as shown in Fig 2, is structured based on the functional output of the departments.

As some of its secondary outputs, Eskom has the accountability to effectively manage the power delivery network, including the communication system. In the Eskom organogram, as shown in Fig.2 above, this function falls under the Group Technology & Commercial.

It is the accountability of Group Technology, particularly the Secondary Plant Engineering (Protection, Telecommunication, Metering and Control) Department, to manage secondary plant technologies within the substations. This department, amongst other management of technology functions, is responsible for the management of intra-substation and master-substation communication protocol for the real-time exchange of data between the control centre and the substations.

According to [10], communication has always played a critical role in the real-time operation of the power system. Reference [10], further states that as digital communications became a viable option in the 1960s, data acquisition systems (DAS) were installed to automatically collect measurement data from the substations. Eskom also uses the data acquisition system to collected real time data from the various substations.

The current Eskom Transmission Substation Communication System as shown in Fig. 3 below:
Primary plant data is collected via hardwired interfaces from the primary plant devices through to the different protection schemes bay processors, the Intelligent Electronic Devices (IEDs). An ESKOM proprietary protocol, ESTEL, is used for communication between (IEDs) within the substation [11].

At the Station Level resides the Enhanced Remote Terminal Unit (ERTU), which is responsible for data concentration from multiple protection scheme bay processors and communications to the remote and local masters. The local HMI (Human Machine Interface) and GPS (Global Positioning System) receiver also resides at the Station Level for station wide management and time synchronisation respectively [11].

At the Bay Level reside Bay Processors and Station RTUs. The Bay Processor provides supervisory functions for dedicated protection schemes whereas the Station RTU provides supervisory functions for multiple bays (phase 1 and 2 protection schemes) and station auxiliaries via the IDF (Intermediate Distribution Frame). IEC 61870-101 is used for communication between the National Control Centre (Transmission EMS) and the Transmission substations. ESTEL protocol is used for communication between the substations and Distribution control Centre (DMS), [11].

The Distribution Substation Communication System is set up on a similar principle; the major difference being communication protocol in Distribution is the DNP3 Protocol. The implementation of IEC 61850 into Eskom substations would enable the realisation of a fully automated substation with the following architecture:
The aim of this study is to understand the requirements of the IEC 61850 standard, how it was implemented into the Eskom Network and its impact on the existing Eskom skills requirements within the functional organisational structure. This was used to establish the relationship between substation function consolidation, enabled by technological advancement and Communication Network System Standard in substations (IEC 61850), and the skills required by the utilities.

The focus of the study was limited to the Eskom power delivery business, Distribution and Transmission businesses. The Generation division only covered the Switchgear Electrical plant as this is the only plant in Generation that is currently pursuing the IEC 61850 standard.

C. Research Objectives and Research Questions

Nowadays, organisations exist within the so-called “knowledge era”. This is a technology era that is based on knowledge as a centrepiece for its source of wealth. The culture of the organisation plays a critical role in its ability to change and adapt as the technology evolves.

This relationship between technology change and organisations can be represented by the GSTM Model, adapted from class notes Technology Management University of Pretoria (2011:34), as shown below in Fig.5.

To summarize the above discussion, the aim of the study was to investigate the impact of IEC 61850 STD on:

- Technical skills and competency
- Organization structure
- Technology development

The following research questions were investigated:

- Research Question 1: Do employees understand the IEC 61850 standard and requirements for its implementation?
- Research Question 2: What are the stages to consolidate the skills requirements for the implementation of the IEC 61850?
- Research Question 3: What methodology should be used to deploy the skills to ensure effective implementation of the IEC 61850 standard?
- Research Question 4: Is the current skills base appropriate for the implementation of the IEC61850 standard?
- Research Question 5: Are the competency levels appropriate for the implementation of the IEC 61850 standard?
- Research Question 6: Is the Organisation Structure vital for the effective implementation of the IEC 61850 standard?

II. PROPOSED RESEARCH MODEL

The framework for this study was supported by the following conceptual models:

- IEC6 1850 Technology Change Impact Conceptual Model - The IEC 61850 standard implies a technology change when it is introduced to a utility. This conceptual model aims to create a framework of the impact brought in by this technology change;
- IEC 61850 Skills deployment Conceptual Model; and
- IEC 61850 Organisational Impact Conceptual Model

These models are presented below.

A. IEC6 1850 Technology Change Impact Conceptual Model

The introduction of IEC 61850 is conceptually depicted by Fig. 6. This is based on the Schumpeter waves technology change theory; the Market Pull Theory and; the Technology Push Theory. The technology adopters (described by the ‘Innovation Adoption Curve + S curve Theory) have a ‘push’ effect (described by the Technology Push Theory) or a ‘pull’ effect (described by the Market Pull Theory) on the technology. The innovators pull and late adopters are pushed.
B. Conceptual Model of the “IEC 61850” skills deployment in Eskom

The IEC 61850 standard was developed with the goal of meeting the requirements of all different functions and applications in the substation, such as protection, control, automation, measurements, monitoring and recording [2]. At the same time it should support different tasks related to the above listed substation functions, such as engineering, operations, commissioning, testing, maintenance, event analysis and security [2][3]. Traditionally, these functions operate in an independent manner, with specialised skills and capabilities confined to their areas of expertise [12].

In Eskom, these functions reside within the Protection, Telecommunication, and Measurements & Control (PTM&C) Engineering Department and the operating units. The demarcation of accountabilities is as per the core capability of the skills confined in their areas. The IEC 61850 skills requirements are depicted by Fig.7 below. What is the impact on the existing skills within the functional organisational structure and the current skills dissemination? This is modelled below. The details of the skills requirements are built up from the requirements detailed in Fig.8.

As depicted by Fig.8, the IEC 61850 standard requires an understanding of the following:

Step 1: (Green part on Fig.8)
Protection and control functions, Substation configuration Language, the communication networks (TCP/IP, Ethernet, switches, routers) and Time synchronisation via SNTP.

Step 2: Server Part
Data models, Network data analysis, Substation configuration Language, Time synchronisation via SNTP, The communication networks (TCP/IP, Ethernet, switches, routers).

Step 3:
Communications services, mapping of information models and communication services, the communication networks (TCP/IP, Ethernet, switches, routers).

The question that arises is; how will these skills requirements be captured, measured and monitored?

The study by [4] proposes a model to measure and monitor the competency level. This model adapted to the analysis framework for competency will be adapted from the model by [4].
C. Proposed Conceptual Model of the organisational impact of “IEC 61850” requirements

The above three models (Fig. 7, Fig. 8 and Fig. 9) are used to propose the conceptual model of this study. These are joined to propose the most appropriate method of skills dissemination and deployment for the successful rollout of Substation Automation solutions. The conceptual model proposed for this study is depicted as follows:
D. Hypotheses Testing

The following propositions were assessed:

Research Question 1:

a. H1 – Employees in the power utility understand the needs and implementation requirements for the IEC 61850 standard.

H1a – Employees in the power utility do not understand the needs and implementation requirements for the IEC 61850 standard.

Research Question 2:

b. H2 – The stages to consolidate the skills requirements for IEC 61850 have been defined by the power utility.

H2a – The stages to consolidate the skills requirements for IEC 61850 have not been defined by the power utility.

Research Question 3:

c. H3 – There are strategies for the deployment of skills required for the implementation of the IEC 61850 standard.

H3a – There are no strategies for the deployment of skills required for the implementation of the IEC 61850 standard.

Research Question 4:

d. H4 – The current skills within the power utility are appropriate for the implementation of IEC 61850 standard.

H4a – The current skills within the power utility are not appropriate for the implementation of IEC 61850 standard.

Research Question 5:

e. H5 – The current competency within the power utility are appropriate for the implementation of IEC 61850 standard.

H5a – The current competency within the power utility are appropriate for the implementation of IEC 61850 standard.

Research Question 6:

f. H6 – Organisational structure is vital for the effective implementation of the IEC 61850 standard.

H6a – Organisational structure is vital for the effective implementation of the IEC 61850 standard.

III. RESEARCH METHODOLOGY

The design was adopted from Buys (2011: UP lecture for Research Methodology) which is depicted by the figure below:
IV. DATA COLLECTION

A. Data Collection Strategy:
Case study strategy;
Quantitative and Qualitative method; and
Secondary data (documentation) analysis.

B. Sampling Techniques
Management: 12 + 50 Engineers + 5 Research and Development
Total research sample = 79

V. RESULTS

The six research questions were analysed using the Hypothesis Testing method, as discussed below:

A. Hypothesis testing
Test for Significance was based on the Chi-Squared goodness-of-fit test Technique. The process followed was as follows:

- Compute the Hypothesis tests to produce P-values.
- \( P \) is the probability that the null hypothesis (H0) is true.
- If \( P < 5\% \), then it is most unlikely that \( H0 \) is true and it can be rejected – this is called a significant test result.
- If \( P > 5\% \), then \( H0 \) is not unlikely and cannot be rejected – this is called a non-significant test result.

The following calculation was applied to compute the Chi-Squared goodness-of-fit test Technique:

\[
\chi^2 = \sum_{i=1}^{a} \frac{(O_i - E_i)^2}{E_i}
\]

where \( O_i \) is the observed frequency for bin \( i \) and \( E_i \) is the expected frequency for bin \( i \).

The hypotheses testing were categorised into 6 sections based on the six propositions of the study. The summary of the results is presented below:

B. Summary of the research results
- Research Question 1: Rejected the Null Hypothesis. The employees understand the requirements for IEC 61850 standard.
- Research Question 2: Rejected the Null Hypothesis. There are stages to consolidate the skills requirements for the implementation of the IEC 61850 standard has not been defined.
- Research Question 3: Accepted the Null Hypothesis. There are stages to consolidate the skills requirements for the implementation of the IEC 61850 standard has not been defined.
- Research Question 4: Accepted the Null Hypothesis. The current skills within the power utility are not appropriate for the implementation of IEC 61850 Standard.
- Research Question 5: Accepted the Null Hypothesis. The competency levels are not appropriate for the implementation of the IEC 61850 standard.
- Research Question 6: Accepted the Null Hypothesis. Organisational structure is not vital for the effective implementation of the IEC 61850 standard.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Discussion
The major hurdles for the implementation of IEC 61850 standard were as follows: Skills, Organisational Culture, Training and Competency levels.

IEC 61850 allows replacement of wire based systems with communication based operation of the substation automation system generally operating over a Local Area Network. As such, new engineering processes, specifications and tools are required, combined with new skills across the collective substation engineering community [7].

It was also found that the skills and competency requirements for IEC 61850 were not measured or monitored. The training matrix was found not to be appropriate to meet the skills requirements for the implementation of the IEC 61850 standard.

Research and Pilot was found to be a suitable strategy for the implementation of IEC 61850 standard. The data gathered also highlighted the In-house Engineering and implementation to be a suitable strategy for the implementation of IEC 61850 standard. This can only be achieved if the skills and competency level within the organisation are improved.

Organisational structure was found not to be vital for the effective implementation of the IEC 61850 standard. This is questionable since the current organisational structural design is a Functional structure, and the respondents recommended a Matrix structure as the best suitable organisational design for the implementation of IEC 61850 standard.

The research initiative undertaken by Eskom, as highlighted by [13], provided limited exposure to engineers in the organisation. Only the Eskom Distribution technology engineers, mainly in the Western grid, were aware of the project. This highlights the lack of Technology Strategy and overall Technology Plan that is effectively managed from a central location. This will promote an approach from organisational perspective, and not a silo approach. The silo approach was a result of the functional organisational structure that focused only on the deliverables of that particular division.

B. Conclusion
The following conclusions are drawn:
- The requirements for the core technical skills and competency have changed the organisational culture, training and competency levels.
- New engineering processes, specifications and tools are required.
The data gathered also highlighted the In-house Engineering and implementation to be a suitable strategy for the implementation of IEC 61850 standard. This can only be achieved if the skills and competency level within the organisation are improved.

Organisational structure was found not to be vital for the effective implementation of the IEC 61850 standard.

C. Recommendations

The researcher recommends the following:

- The proposed model be adapted to develop, measure and monitor the skills, competency and training requirements for the utility (see Fig. 10).
- The proposed model does not view organisational culture as a critical element to the study. A further study is recommended to be conducted in order to investigate the impact of organisational culture on the implementation of IEC 61850.
- The research initiatives within the power utilities should be evaluated in light of the IEC 61850 requirements to support the implementation within the utilities.

REFERENCES