Power System, Substation, Automation and the Smart Grid, how should universities react?

An internationally benchmarked review of electrical engineering curricula in selected African countries against the backgroung of increasing computer network and communication technology in power systems.

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***Abstract*—The rapid introduction of computer and network technology in the area of power systems generally and substations in particular is being embraced by many utilities, especially in the most developed countries. The technology itself is not new. It is vigor, the aggressive marketing, the pace accompanying the technology, however that requires all level minded persons to pause to examine the wider implications of these developments. The most far-reaching of impact of this technology will be on those utilities and countries with limited capabilities in the information communications and technology sector (ICT). Since this surge towards automation is considered irreversible, it is incumbent upon educational institutions to undertake an urgent review is paper describes what substation and smart-grid achieve and examines the attendant opportunities and threats. given in this document.**

Index Terms—*Substation Automation, Engineering Education, Curriculum Review.*

I.BRIEF HISTORY OF AUTOMATION

Automation is “the application of machines to tasks once performed by human beings, or increasingly, to tasks that would otherwise be impossible”, Encyclopedia Britannica [1]. The term automation itself was coined in the 1940s at the Ford Motor Company. The idea of automating processes and systems started many years earlier than this as part of the agricultural and industrial revolutions of the late 18th and early 19th centuries. There is little disputing that England was a major contributor to the Industrial Revolution and indeed was the birth place of some prominent inventors, for example. in the area of textiles:

- James Hargreaves: Spinning Jenny
- Sir Richard Arkwright: Mechanical Spinning Machine
- Edmund Cartwright: Power Loom

Cartwright’s power loom was powered by a steam engine. At these early stages we see the symbiotic relationships between automation, energy and power. The early forms of automation can only largely be described as mechanization, but the emergence of electrical power systems in the late 19th century and the entry of electronic valves in the early 20th century heralded the humble beginnings of modern automation. With electronic valves came computers. One of the earliest computers was the ENIAC (Electronic Numerical Integrator and Automatic Computer) built over two years between 1943 and 1946. It occupied an area of 1000 square feet (about 93 square meters), had 18000 valves and consumed 230 kW [2].

Before the deployment of computers in industrial automation, relays and RELAY LOGIC, the wiring of circuits with relays to achieve automation tasks, was in common use. Today, however, relay logic is far less used than computer-based, PROGRAMMABLE LOGIC, which has followed the invention of the transistor, integrated circuits and microprocessors.

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II. AUTOMATION OF POWER SYSTEMS AND ORGANISATIONAL ROLES

A. Traditional Power Systems and their control hardware

The early power plants had a modest number of sensor and action variables, of the order of several hundreds. Modern large power stations have in excess of hundreds of thousands, even tens of million variables [3]. It is therefore easy to see that automation took root in power and generating stations earlier than in transmission and distribution. One of the useful applications of automation is in the railway industry where remote control of power is often vital. This manifests itself in systems to control and manage power supplies to electric locomotives. The deprivation of power to any locomotives in a section could seriously disrupt schedules, inconvenience customers and in the end have serious adverse financial implications. Remote control of power as well indication of statuses and transmission and recording of abnormal events (alarms) are now standard features of power systems in the generation, transmission and distribution of electricity. Over time the systems are now well understood. The requirement for computer technicians with networking skills have been modest and it has usually been possible to revert to traditional manual control (e.g. sending technicians out to attend to a problem when for example when communication links or other hardware has failed). Figure 1 shows the general arrangement of a power network of a type that has been operating for many years. Figure 2 shows the equipment yard of modern substation in Namibia, one of the first of its type in the region to utilize the IEC 61850 substation automation protocol.

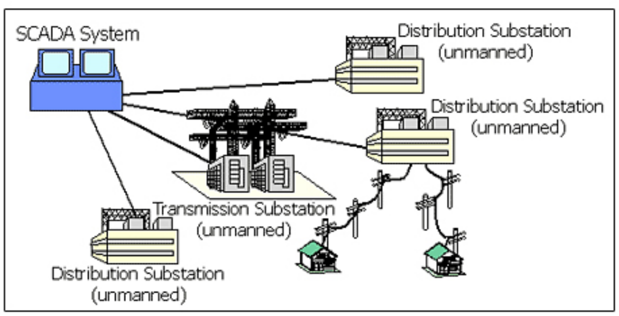

Figure 1. SCADA controlled Network (Tepco, Japan)

Figure 2. A Modern HVDC substtation utilising the IEC 61850 Standard

B. Organizational structures in traditional large utilities

Traditional and most utilities in developing countries have hierarchical structures and technical disciplines regimented. Sadly this regimentation had also influenced our educational institutions. In a Railway organization the divisions of Civil, Electrical, Mechanical and Civil Engineering have been in vogue for many years. In Electrical Utilities, segmentation is often function based, i.e. Generation, Transmission Distribution with some specialized centralized, e.g. Planning, Protection, ICT and Asset Management. By analogy we find that many reputable universities have followed the old, "British" model in which students must choose one discipline out of say, Civil, Electrical or Mechanical Engineering. In addition, in particular with Universities of Technology in South Africa, the students must choose, for example, electronics, power or computer networks. Unfortunately the technology in modern power system infrastructures, such as the emerging modern substations is not segmented in according to study disciplines. Before the entry of substation automation, the situation was problematic enough. With the new entry of computers and networking systems inside our substations and with in some cases copper conductors being replaced by software, a shake up of the entire industry is inevitable.

III. AN EXAMINATION OF ELECTRICAL ENGINEERING CURRICULA OF AFRICAN UNIVERSITIES

In this section we shall explore the structure and types of degree programmes offered in selected African Universities. The selection is based on the availability of information to an appropriate depth.

A. University of Pretoria

The University of Pretoria (UP) is one South Africa's top universities. The QS rankings, one of three most respected ranking organizations, ranks the world's top 700 Universities places UP at number 345 in the world and number 4 in South Africa. Another respected academic ranking organization, academic ranking of world universities (ARWU) does not show UP 2008-210, but places it in 4th place among South African Universities. Analysts believe that the ARWU gives more weight to the science area.

1) UP Electrical Engineering Programmes

From the Department's website we learn that it offers degrees in Electrical, Electronics and Computer Engineering. An inspection of the latest curriculum indicates that there is an emphasis on electrical principles, power systems and power electronics, machines and drive systems. Digital systems and microprocessors are taught in early years. Figure 2 shows the topics covered in the 4th and final year (first and second semester).

TABLE I.

Electrical Engineering Final Year Semester 1 Topics		
Module Name	***Credits***	***Prerequisites***
BPE45* Prof. Ethics for Engineers	8	
EPR400 Project	16	Finalists only, EED32*
E8T410 Automation	16	E88320gs
EAD410 Electrical Drives	16	ELX311. EDF320
E''410 Advanced Power Electronics	16	EX"320
	72	

TABLE II.

Electrical Engineering Final Year Semester 2 Topics		
Module Name	***Credits***	***Prerequisites***
COM420 Environmental Management	8	
EPR400 Project	48	Finalists only, EED32
EES42" Specialisation	16	
	72	
	144	

On examining Table 1 we see that there is indeed a module with the name "Automation", but the content does not cover the more acute issues involved in power system and substation automation. The content we read from UP's Faculty Handbook is as follows:

"Plant automation issues. The steps taken to establish controllers for industrial processes. Static and dynamic properties of sensors and actuators. Obtaining models from process data. Plant automation platforms. Model-bases PID and internal model control. Turning and troubleshoot control loops. Unconstrained single-input-single-output model predictive control. Economic evaluation of automation systems."

On examining other programmes we note that, Automation is also offered for the Electronics programme. Computer Networks, a topic with the most relevance to power system and substation automation, is covered in the 3rd year of the Computer Engineering Programme.

B. *University of Cape Town*

The University of Cape Town (UP) is one South Africa's top universities. The QS rankings, one of three most respected ranking organizations, ranks the world's top 700 Universities places UP at number 156 in the world and number 1 in South Africa. Another respected academic ranking organization, academic ranking of world universities (ARWU) also places it in 1 place among South African Universities.

From the Department's website we learn that it offers degrees in Electrical, Mechatronics and a new programme Electrical and Computer Engineering. An inspection of the latest curriculum indicates that the department has a good balance of what has been called "light current" in the same programme, for example, in the BSc Electrical Engineering Program, EEE3084W, Communication System & Network Design is mandatory. Such a course is very relevant in power and substation automation. The programme in addition is very flexible in the final year, allowing students to choose from a menu of power systems, electronics, communications and computer related subject areas. Table III presents some possible combinations in the first semester of a UCT BSc Electrical Engineering Degree.

TABLE III.

Electrical Engineering Final Year Semester 1 Topics		
Module Name	***Credits***	***Prerequisites***
BPE45* Prof. Ethics for Engineers	8	Finalists only, EED32*
EPR400 Project	16	

C. *University of Stellenbosch*

The University of Stellenbosch is one South Africa's top universities. The QS rankings, one of three most respected ranking organizations, ranks the world's top 700 Universities places UP within the 401-450 range in the world and number 3 in South Africa. It is not ranked in the latest rankings. From the Department's website we learn that it offers degrees in Electrical and Electronic Engineering, Mechatronic Engineering and a programme in Electrical Engineering and Computer Science which is now being phased out and being replaced by a new programme with Informatics specialization. There is a Computer Systems 414 a 15 credit module which includes embedded systems and computer networks.

D. *University of KwazuluNatal*

The University of KwaZuluNatal (UKZN) is one South Africa's top universities. The QS rankings, one of three most respected ranking organizations, ranks the world's top 700 Universities places UKZN in the 401-500 range in the world and number 5 in South Africa. (ARWU) places UKZN in the 401-500 range in the world and number 3 among South African Universities. The programme is largely similar to that of UP but it may be noted that a 4th year Data Communications module is offered for Computer and Electronic Engineering Students. Those following the Electrical Engineering Curriculum cannot take this offering.

E. *A summary of other African University Electrical Engineering Programmes.*

1) University of Zimbabwe and National University of Scince and Technology (NUST, Zimbabwe)

The University of Zimbabwe, Electrical Engineering programme is very much similar to that of the University of

Cape Town. In the final year 8 topics approximately divided equally are offered, 4 in Semester 1 and 4 in Semester 2. Students may choose all 8, but only the best 4 are considered for the purpose of determining the degree aggregate. Those students who believe that doing so will enhance their career choices will take all 8 but the workload will usually be excessive since in the same year the students must also do their final year project which has a weight 4 times any of the 8 topics. Data communications is one of the 8 topics. An interesting addition is the opportunity of all students to undertake the major part of the CISCO CCNA curriculum at no extra cost.

NUST the University of Science and Technology in Zimbabwe has BEng. Degree in Electronic Engineering. It is a 5 year program in which the 4th year is spent in industry. Its electronics designation

2) Michael Okpara University of Agriculture (MOUA)

The Electrical Engineering Programme as published on its website has many options, especially in the final year. Relevant to power system and substation automation is the level 5, EEE514 and the EEE528 Power System Communication and Control.

F. International benchmarks

According to the on-line dictionary Wikipedia Rose-Hulman Institute of Technology (RHIT) (USA) is a small private college specializing in teaching engineering, mathematics and science. RHIT is highly regarded for its undergraduate engineering program, which US News and World Reports ranked in 2013 as No. 1 in the United States of engineering schools where a doctorate degree is not offered, a position it has held since 2000. An examination of its Electrical and Computer Engineering programme shows the extent to which it goes to fulfill the requirements of the multi-disciplinary industry. In the first two years the content is similar giving grounding in mathematics, physics, and electronics.

In the wording of the department:

Electrical Engineering encompasses a broad array of areas including signal processing, communication systems, electronics, integrated circuits, digital systems, controls, power engineering, and electromagnetics. An electrical engineer may design a system as large as a power plant for an entire city or as small as an integrated circuit. An electrical engineering degree may provide the opportunity to design the analog or digital processing or the wireless communication for tomorrow's electronic products.

According to the departmental website, the following attributes are to be demonstrated by the student, at the time of graduation:

- *an ability to apply knowledge of mathematics, science, and engineering*
- *an ability to design and conduct experiments, as well as to analyze and interpret data*
- *an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.*
- *an ability to function on multidisciplinary teams*
- *an ability to identify, formulate, and solve engineering problems*
- *an understanding of professional and ethical responsibility*
- *an ability to communicate effectively*
- *the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context*
- *a recognition of the need for, and an ability to engage in life-long learning*
- *a knowledge of contemporary issues*
- *an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice*

The above are quite similar the outcomes of the Engineering Council of South Africa (ECSA).

IV. OBSERVATIONS, COMMENT AND ANALYSIS OF THE VARIOUS PROGRAMMES.

When we analyse the above programmes, we see that the programmes differ widely sometimes in name and at other times in content. Among the Universities that offer a wider curriculum and subject choices are the University of Cape Town, the University of Zimbabwe, Michael Okpara University of Agriculture and Rose Hulman Institute of Technology. Some of the attractive features offered by some of the institutions include:

- Emphasis on projects and teams (Rose Hulman Institute of Technology)
- CISCO Network integration (University of Zimbabwe)
- Wider Subject Choices, UCT, University of Zimbabwe, University of Stellenbosch

V. NEAR AND LONG TERM APPROACHES

The automation of substations, currently embodied in the IEC 61850 protocol, will unfortunately not be an end in itself and technology will continue to evolve. This means that some of the prescriptions of today will bear no relevance tomorrow.

A. Immediate to near term prescription

The near term objective will be to expand the learning horizon of our engineers, to introduce multidisciplinary teams, and to address present gaps by introducing short courses.

Team working though very commendable may not be practical for smaller organizations.

B. Long-term prescription: Cambridge University Example

In the long term however, we need to have engineers with a different kind of training. In 2011 the University of Cambridge achieved number 1 QS ranking and number 5 in the ARWU rankings. There is no split in the programmes between Electrical, Electronic or Computer Engineer *per se*. In terms of its philosophy, Engineering is treated broadly:

> *Engineering is about designing processes and making products to solve real-world problems. Our course enables you to develop your engineering knowledge, skills, imagination and experience to the highest levels in readiness for your future career.*

Cambridge's standard degree is a BA for arts, science engineering. In line with the UK Engineering Council and European recommendation, the MEng degree is now a requirement for professional registration. At Cambridge this is done in 4 years. An inspection of the first three years of the degree reveals its multidiscipline and broad nature covering, mechanical and electrical (including advanced electronics, data communications, relevant to power system automation). The 4th and final year is split into several thematic areas or groups, enabling some specialization. It is known that Cambridge is highly selective so to prescribe a Cambridge model which includes so many disciplines may not be possible.

Figure 3. Technicians working inside the control room of a highly automated substation (Namibia)

VI. CONCLUSIONS

In this investigation we have sought to investigate electrical engineering of mostly African Universities and tried to establish the extent to they are able to train the electrical engineer of the future. We have found that some universities have remained on the old traditional paths while encouragingly others have come up with flexible curricula. In our opinions it is this later group of Universities that bear the most promise. Also in our own opinion, the technological advances are quite rapid and it is not difficult to imagine that in only a few years, even these technologies that we call revolutionary, will also become obsolete. For this reason, it will be those programmes that emphasize on more basic sciences, (e.g. physics, mathematics) that will ride the wave. In this paper we have presented the courses offered by some universities here in Africa and abroad. Perhaps however it will be instructive to read the following summary about the attributes of a good engineer:

Boeing list of "Desired Attributes of an Engineer"

- A good understanding of engineering science fundamentals, Mathematics (including statistics), Physical and life sciences
- Information technology (far more than "computer literacy"
- A good understanding of design and manufacturing processes (i.e. understands engineering)
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
- Economics (including business practice)
- History, the environment, customer and societal needs
- Good communication skills, Written, Oral, Graphic, Listening, High ethical standards
- An ability to think both critically and creatively - independently and cooperatively
- Flexibility. The ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork

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