Power System Visualisation at Southern African Power Pool

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Abstract. Effective monitoring and control of power system elements enhance safety and reliability of power supply. Interconnection of power systems in the Southern African Power Pool (SAPP) resulted in optimisation of energy resources. However, interconnection brought complexity that threatened reliability. In 2011, SAPP installed an online visualisation tool, named the SAPP System Viewer, to aid monitoring of the interconnected power system. The project was motivated by the need to minimise accumulation of inadvertent energy, to quickly gather information about abnormal power system conditions, and to independently gather data for measurement of control performance. This paper highlights factors that motivated the project, chronicles its implementation, and discusses lessons learnt. Specifically, the SAPP System Viewer's hardware and software components, data protection, system security, and functionalities are presented. Connecting data servers using inter-Control Centre Communications Protocol is an appropriate way for extending power system visualisation and archiving power system data to multiple remote locations.

Keywords: ICCP; Interconnected Power System; SAPP; SCADA; Southern African Power Pool; Visualisation.

1 Introduction

Power system operators strive to achieve the highest standards for safety and reliability of power supply [1],[2]. The standards are normally set by energy regulators. Power supply of poor quality may damage equipment and endanger lives [3]. Power system operators invest in equipment, systems, and human resources to effectively monitor and control various elements of the power system. In the southern African region, power systems of nine countries are interconnected, forming the Southern African Power Pool (SAPP). These countries are: Botswana, Democratic Republic of Congo, Lesotho, Mozambique, Namibia, Republic of South Africa, Swaziland, Zambia, and Zimbabwe. See **Figure 1**. In 2016, the installed generation capacity and the energy consumption within SAPP were 57 917 MW and 360 471 GWh, respectively [4]. Interconnections optimise energy resources but they also increase complexity of the power system and at times threaten reliability [5].

In SAPP, the SAPP Coordination Centre, based in Harare, Zimbabwe, is responsible for monitoring the performance and coordinating the operations of the interconnection. Enhancing power system data exchange, by using such systems as the Supervisory Control and Data Acquisition (SCADA) systems, is one of the techniques for improving reliability of power systems [6]. In interconnected power system operations, apart from measured electrical element values, it is also critical to exchange such data as scheduling data, energy accounting data, and operator messages among control centres [7]. In 2011, the SAPP commissioned an online visualisation tool for monitoring of the power system. The tool was named the SAPP System Viewer. The SAPP System Viewer uses the Inter-control Centre Communication Protocol (ICCP).

The objective of this paper is to present the SAPP System Viewer. The remainder of the paper is divided into four sections. Section 2 presents factors that motivated the SAPP System Viewer project. Section 3 describes the architecture and functionalities of the SAPP System Viewer. Section 4 discusses lessons learnt. Section 5 makes conclusions and recommendations for the future.

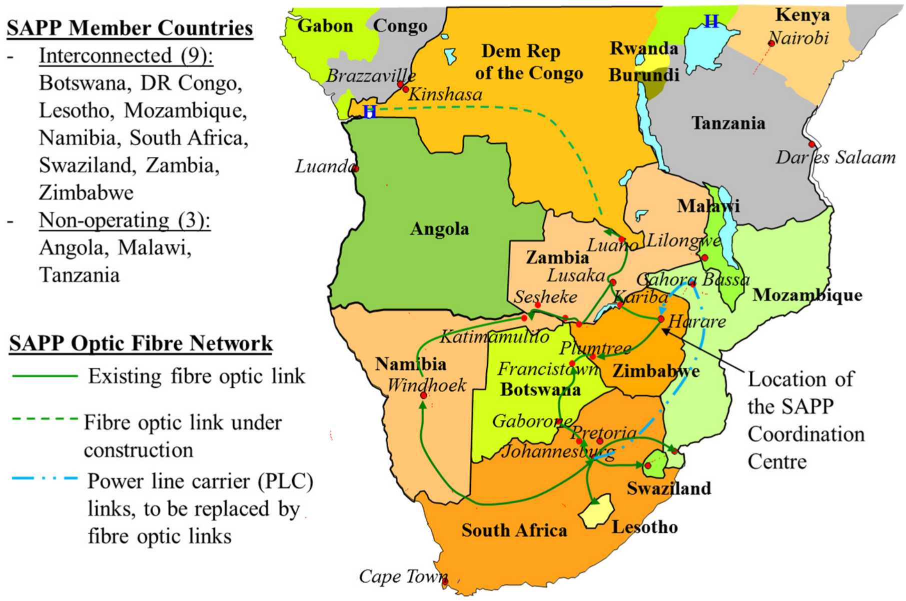

Fig. 1. Map of Southern Africa, showing telecommunications links among some of SAPP member countries (Source: SAPP, 2016).

2 Motivation for the SAPP System Viewer Project

Power transmission networks in the southern African region were not originally designed for interconnected operations. Before the formation of SAPP in 1995, there were very few energy interchange contracts. However, from 1995 to 2000 a lot of interconnectors were commissioned, linking power transmission networks of nine countries. Interconnections brought about operational challenges [5],[8]. Some of the challenges, as described below, motivated the development of the online power system monitoring tool at SAPP Coordination Centre, the SAPP System Viewer.

2.1 Accumulation of Inadvertent Energy

In a power pool, energy is interchanged among members through bilateral contracts or competitive electricity markets [8]. Energy interchange is scheduled in advance, e.g. day-ahead. Due to power system dynamics, errors in control systems, and the unpredictable nature of demand, normally there is a difference between the scheduled energy and the actual energy delivered [9]. This difference is called Inadvertent Energy in the SAPP Operating Guidelines.

In the years between 2005 and 2010, a state of power deficiency engulfed the SAPP region. This deficiency was attributed to delays in commissioning generation projects and also to the rising demand [8]. According to SAPP governing documents, Inadvertent Energy can be paid back in kind [9]. However, in the said period, almost all members were carrying out load-shedding. Opportunities to pay back Inadvertent Energy in kind were not available. As such, Inadvertent Energy kept on accumulating. This was a great risk in power utility business. In 2009, the SAPP Coordination Centre was called upon to start monitoring and intervening on daily basis in the interchange of Inadvertent Energy among member utilities. To facilitate this task, an online visualisation tool was required.

2.2 Power System Disturbances

In the USA, closer monitoring and coordination of the interconnected system was enhanced after the blackout of the northeast grid in 2003 and in Europe after the blackout of Italy in 2006 [2]. In SAPP, large system disturbances occurred in 2008. After investigation, it was found out that the interconnected power system was being operated with very limited stability margins. Any perturbation could easily trigger transient instability and lead to cascaded tripping of generators and power transmission lines [8]. In almost all cases, System Controllers had little chance to manually prevent large and nation-wide power interruptions. Their visualisation of the power system was limited to their national boundaries using SCADA systems. During those abnormal system conditions, it was not easy to source information from neighbouring control centres by telephone. It was thus noted that visualisation of a bigger part of the interconnected power system was crucial in reducing the risk of future blackouts and in system restoration [10]. Further, it was envisioned that an online system covering the entire SAPP could facilitate time-synchronisation of events reported by various SCADA systems.

2.3 Control Performance Monitoring

When power systems are connected to form a larger interconnected system, most operational problems are solved or prevented by adhering to Control Performance Standards. In 1996 the SAPP adopted Control Performance Standards from the North American Reliability Corporation (NERC). The main parameters for calculating performance in these standards are power system frequency and Area Control Error (ACE). SAPP CC sourced historic data by electronic mail from its three Control Area Operators, Eskom, ZESA and ZESCO. (Eskom, ZESA and ZESCO are national power Transmission System Operators of South Africa, Zambia, and Zimbabwe.) For credibility, it was imperative for the SAPP Coordination Centre to install an online system for obtaining the data independently and automatically.

2.4 Data for Power System Simulation

For interconnected power system operations, power system simulations are run frequently to determine power transfer limits on interconnectors and key transmission paths, to investigate power system disturbances, and to plan for equipment outages. Most power system simulation software applications are limited in their application without real-time data input [3]. The SAPP determines transfer limits based on a ‘system peak’ case file using offline data. To optimise utilisation of interconnectors for energy trading, it was desirable to start determining transfer limits for numerous cases or scenarios. It was envisioned that an online tool would facilitate acquisition of accurate data for modelling of the power system.

3 System Architecture and Functionalities

In this section, aspects of the architecture and functionalities of the SAPP System Viewer are discussed.

3.1 Hardware Selection

The hardware platform at the SAPP Coordination Centre consists of a number of mid-sized servers each with a redundant array of independent disks (RAID) configuration and sufficient memory to support the applications. The servers were installed in a virtual environment. This optimised hardware utilisation, minimised life-cycle costs and enhanced the maintainability of the servers with simple processes to backup and restore virtual machines. See **Figure 2** for a general layout of the hardware of the SAPP System Viewer and indication of the virtual machines that are hosted in each server. A number of workstations and wall-mounted monitors provide visualisation of the power system (see **Figure 3**).

3.2 Software Selection

The e-terra solution provided by Areva T&D Inc. was selected as the SAPP System Viewer software through a tender process.

3.3 Data Acquisition and Trafficking

SCADA systems have three basic layers: the “client layer” with human machine interactions, the data server layer, and the process controller layer with Remote Telemetry Units (RTUs), and transducers connected to the primary plant. The data servers are responsible for data acquisition and handling [2],[11]. The data servers of the SAPP System Viewer at SAPP Coordination Centre are connected to the SCADA data servers at National Control Centres (NCCs) of Eskom (South Africa), ZESA (Zimbabwe) and ZESCO (Zambia) via a Wide Area Network (WAN) connection. The ‘IEC 60870-6-TASE.2’ Inter Control Centre Communications Protocol (ICCP) is used for data sharing. According to [7], ICCP was developed to enable data exchange over Wide Area Networks (WAN) among utility control centres, Transmission System Operators (TSOs) and power producers. However, to initiate the sharing of control centre information, a telecommunication network must be in place to enable application protocols, such as ICCP, to intercommunicate. The SAPP was already operating a satellite-based telecommunications link (VSAT link) among the three main control centres (ZESA of Zimbabwe, ZESCO of Zambia and Eskom of South Africa) and the coordination centre in Harare. The VSAT link was replaced by a fibre optic network in the year 2016. Refer to **Figure 1** for the existing fibre optic network in SAPP.

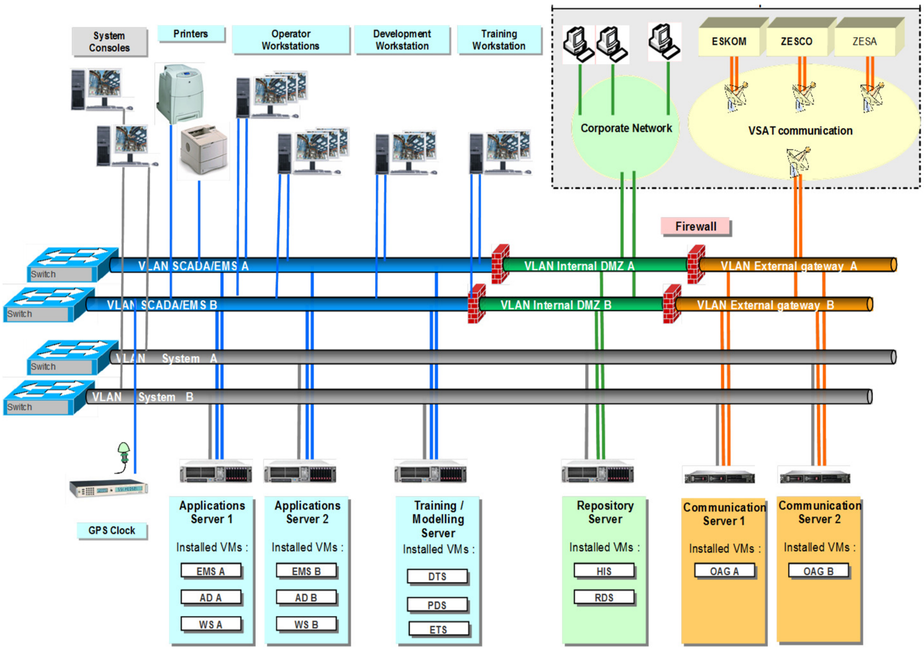

Fig. 2. General Hardware Layout of the SAPP System Viewer (Source: SAPP, 2016).

3.4 Data Protection and System Cyber Security

In typical SCADA systems, remote communication servers process data according to the system requirement and generate necessary commands for remote operation of the substation switchgear [2]. In the SAPP System Viewer, this functionality was not implemented. No remote controls were configured or allowed from either side. Data sharing between the SAPP Coordination Centre and Control Area Operators were limited to mutually agreed data values consisting of plant status and analogue indications mainly from interconnectors.

Sharing of grid information needs to be protected from manipulation and unauthorized access. Online computer systems are vulnerable to cyber-attacks. Security measures are required to block every possible intrusion point [12]. In the SAPP System Viewer, network cyber security was firstly maintained by using dedicated private network links. These links were not routed via the Internet. Secondly, firewall equipment was installed and maintained at each end-point by respective SAPP members. The installation implemented enhanced security features in ICCP as developed and specified by a technical committee of the International Electrotechnical Commission (IEC) [7]. Therefore, the SAPP ICCP network was segregated into a SCADA secure zone, a Demilitarised Zone (DMZ), and the corporate network, in accordance with the guidelines for Critical Infrastructure Protection (CIP). See **Figure 2**.

However, as observed in [7], upper layer protocol such as ICCP is subject to, and dependent on, many elements out of its control. One of these elements is the network environment that it operates within. Therefore, apart from running anti-virus software on each workstation and server, additional measures such as restricting the use of USB ports and disabling non-essential services were enforced to reduce the risk of virus infection. Unnecessary software, including office applications, were not installed on servers and operator stations. The role-based access control (RBAC) functionality was employed in assigning access permissions and passwords.

Remote support capabilities were established through Virtual Private Network (VPN) tunnelling capabilities. Confidential address-identification and port-identification features were implemented on firewalls for strict access filtering.

Fig. 3. Operator Workstation of the SAPP System Viewer (Source: SAPP, 2016).

3.5 Basic Functionalities

Typical of power system visualisation tools [3], the operator of the SAPP System Viewer can monitor bus bar voltages, power flows on transmission branches and status of circuit breakers, isolators and switches. The operator can also manually capture hourly interchange schedules on tie lines to monitor the Inadvertent Energy. The SAPP System Viewer can then alert the operator and the responsible control centre of: 1) overloads that can damage equipment, 2) change of status of circuit breakers, 3) frequency excursions, and 4) inadvertent energy outside agreed bands. Refer to **Figure 4**. above for one of the SAPP System Viewer's alarm pages, showing warnings of interconnector power flows and change of status of circuit breakers. The operator can also retrieve historic data and events.

3.6 Quality of Service

To guarantee appropriate Quality of Service (QoS) for ICCP data streams, the SAPP Coordination Centre negotiated and signed two Service Level Agreements (SLAs). The first one was with the software manufacturer and it covered maintenance of proprietary items. The second SLA was with a service provider located in the region for quick response. This covered general maintenance of software and hardware and also provision of training. These service providers were given access to the system using VPN links with appropriate security measures. SAPP member utilities also implemented various policies for QoS at their end-points.

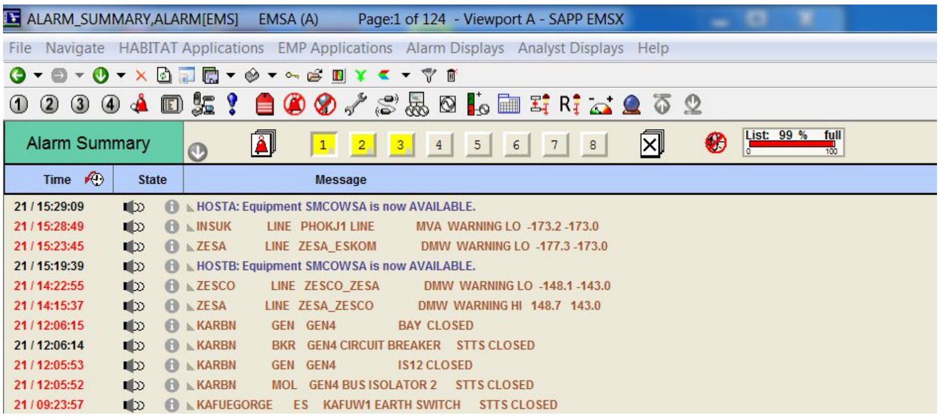

Fig. 4. One of the SAPP System Viewer's alarm pages, showing warnings of interconnector power flows and change of status of circuit breakers (Source: SAPP, 2017)

4 Discussion

Inter-control Centre Communication in SAPP was established using the available telecommunications channels. In the first 5 years, data of the SAPP System Viewer were routed through a VSAT link but often performance was affected by climatic conditions. When the SAPP commissioned an own fibre optic network in 2016, the communication channel was switched over to fibre optic. The system performance improved tremendously. SAPP members agreed in advance about the data to share via ICCP. A framework for governing data confidentiality was also put in place that was binding.

Time synchronisation of power system events from various SCADA systems as originally envisioned by users was not achieved by the SAPP System Viewer. Time stamping in SCADA systems is normally performed at controller level at the source [11]. The SAPP System Viewer received signals that had already been time-stamped at source for improved timing accuracy.

Further, constraints were experienced with the power system simulator module. Due to the scope of the network that was modelled, and the link between online data and the study environment, the simulator module did not perform well. The scope of the online data was very limited, mainly encompassing interconnectors only. The simulator module would work well if the SAPP System Viewer obtained data from almost the entire power network.

In terms of system performance, the software of the SAPP System Viewer was very stable. Availability of each server and of each process was monitored internally. Any failure or discrepancy triggered alarms. Any alarm condition was investigated and appropriate action was taken to rectify any problem. Automatic fail-over between redundant processes ensured that the system remained available under single contingencies. To sustain high system availability, a VPN link was maintained between the system and the support teams in South

Africa and France for remote trouble-shooting according to support agreements. The main down-time of the system was caused by hardware failure. At different times, hard disks of servers and electronic cards of the Uninterruptible Power Supply (UPS) unit failed due to voltage surges from utility power supply. It was learnt that a reliable and a stable power supply was very critical for such a server platform with dedicated electronic cards and disk storage. Therefore, the following additional equipment was installed: a 10 kVA DC-AC inverter, a 10 kVA 220 V voltage regulator, and a Global System for Mobile (GSM) communication module for automatically sending SMS (short message service) about power supply failure to responsible personnel. The personnel would then take action including running a stand-by power generator in the event of loss of utility power supply.

The SAPP implemented this project using funds donated by cooperating partners. It was learnt that adhering to transparent procurement processes is very important. Also, it was learnt that procurement guidelines being followed must be clearly stated to service providers.

For improved cyber security, the SAPP System Viewer must be fully secured by an intrusion detection system (IDS). Application of an IDS is one of the best security practices recommended in [7]. This system identifies the types of data and protocols that are transported on the network. An IDS host-based software utility monitors all user interactions with the host, including user permission profiles, file manipulation, and all data received and transmitted from the host. It also monitors processes within the operating systems, including process calls and memory manipulation. All profile violations are logged and can be reviewed by the system administrator [7].

Lastly, technology has already advanced beyond traditional power system monitoring and control methods using SCADA. Advanced power systems have adopted Wide Area Monitoring Systems (WAMS). According to [13], WAMS employ Phasor Monitoring Units (PMUs) to acquire global positioning system (GPS) synchronised current and voltage phasor measurements and frequency measurements of very high precision and sampling rate. These data are concentrated and routed to control centres. Wide area monitoring gives operators real-time power system visualisation and early warnings to avoid power system collapse. WAMS also facilitate detection of power oscillations, assessment of power system damping, and monitoring of increased power transfers at defined security criteria. Some SAPP member utilities, e.g. Eskom and NamPower, have already installed PMUs at critical nodes of their power systems. Other member utilities in SAPP are in the process of budgeting for WAMS. Sharing WAMS data may solve most of the problems which SAPP is facing in the operation of the interconnected power system.

5 Conclusion and Recommendations

This paper has presented various aspects of the SAPP System Viewer. Connecting data servers using ICCP in SAPP proved to be an appropriate way for extending power system visualisation and archiving valuable SCADA system data to and from a number of remote locations. The SAPP System Viewer facilitates independent monitoring and reporting of the performance of the interconnected power system by the SAPP Coordination Centre. With the increased penetration of the intermittent renewable energy sources, enhancement of visualisation of power networks is crucial in power system operations. Future development, such as sharing more information beyond cross-border lines would add more value to the

SAPP System Viewer. Lastly, when most SAPP member utilities commission WAMS, SAPP should consider upgrading the SAPP System Viewer from SCADA data to PMU phasor data.

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