Leveraging open source technologies in the municipal landscape: A remote monitoring solution case study

Author and presenter: R Singh, Pr. Eng, BSc. Eng, BEng (Hons), MEng – Chief Engineer, eThekwini Electricity
Co-author: G Nkomo, BTech Eng, Senior Technician, eThekwini Electricity

1. Introduction

The 18th-century seafarers who conquered the oceans and invaded the lands to seek gold in a region that was once pivotal in trade route economics were met with a humble force that saw the end of more than a century-old colonial empire.

Unbeknown to many, the threat of colonisation beckons yet again but this time through a different guise. Under the nuances of Industry 4.0, Africa is fast losing its technical sovereignty.

In a technology article by the Business Report [1], a case about foreign backed companies recolonising Africa through technology prompts fears. The technology influence of foreign companies is beginning to surface through disruptions in transportation and monetary systems. Whilst digitisation makes for a good argument in 21st century economics, it requires thought leadership to strike a balance between modernisation and the prosperity of the nation. One solution to this conundrum is through better technology participation.

Specifically, within the Electrical and Electronics manufacturing sector in South Africa, the import-export ratio using GDP figures (in USD) for 2018 was 8.6:1.8 [2]. This figure raises questions about the structural changes for innovation that are needed if technology participation in the global market is a priority; given SA's unemployment rate standing at 26.6%.

One entry point to innovation is through open source technologies. Apart from fast-tracking product development, it offers significant cost efficiencies. Bank Zero, the new app-based South African bank start-up, has stressed the role that open source technology can play in spurring innovation within incubating start-ups [3].

Inspired by Enel's innovative and successful Open Meter project initiated in 2001, a team of engineers at eThekwini Electricity set out to develop an open-source monitoring unit that meets the requirements of the control room operator whilst conforming to industry best practice.

2. Monitoring opportunities and business case

Utilities are generally able to deploy remote monitoring equipment to tier 1 (High Voltage (HV)) and subsets of their tier 2 (Medium Voltage (MV)) networks. As one begins to deploy monitoring equipment deeper into the grid, the costs begin to grow exponentially because of the sheer volume of infrastructure.

Several monitoring opportunities for both operational and asset management purposes exist. In order for operators to control the network, they require visibility regarding the state of critical elements on the network. Asset management practitioners are required to understand the operating characteristics of an asset in order to develop maintenance strategies throughout its asset lifecycle. At the very minimum, the following information about the MV grid is relevant to both operators and asset management practitioners:

a. **Circuit Breaker (CB) status**: these assist operators in quickly identifying a fault on the network. Asset management practitioners use the CB open/close count to drive breaker maintenance practices; whether these have tripped on load, under fault conditions, etc.

b. **Isolator status**: similar to the CB status, these assist operators in understanding the real-time network topology. Asset management practitioners use isolator open/close counts to drive condition based asset maintenance practices.
c. **Earth Fault Indication (EFI)**: these assist operators with the quick identification and isolation of a faulted circuit.
d. **Load at strategic points**: these assist operators with load transfer strategies. It also assists planning engineers in understanding network growth and designing for future network capacity. Asset practitioners correlate load profiles and other independent variables such as temperature to better understand the operating performance of an asset.

The above information also serves as an input into a state estimation engine within a Distribution Management System (DMS) at the control centre. More data collected from the filed improves the overall observability of the network. Apart from an operational and asset management perspective, information regarding the physical security of the asset can also be acquired viz., access to a cubicle through a door contact, tamper detection, etc.

Table 1 depicts eThekwini's distribution assets that are considered for remote monitoring within its distribution automation strategy.

Table 1 eThekwini Electricity distribution assets

Asset	Description	Count	Monitoring opportunities	Average cost to monitor	Total cost
DSSs	Incomers from major substations and feeders to local transformers and other DSSs.	731	Per Bay Digitals (6): Breaker status; breaker position; cable earth; overcurrent; earth fault; relay fail Analogue (1): Phase current Control (2): Open and close General substation: a.c. fail; d.c. fail; charger fail. Typically 6 feeders Digitals: 36 (6 bays) + 3 (station) = 39 Analogues: (6) Control: (12)	~ R 50 000 (2014 figures)	~ R 36 550 000
MSSs	Typically residential 11kV to 400V transformers.	5849	1 x EFI 3 x LV fuse fail (per circuit) x (1-6) circuits 1 x door open 3 x CTs (LV busbar)	~ R 28 000 (2015 figures)	~ R 163 772 000
Kiosks	Industrial, commercial and residential 11kV to 400V transformer with switchpillar and LV panel.	2835	1 x EFI 3 x LV fuse fail (per circuit) x (1-6) circuits 1 x door open 3 x CTs (LV busbar)	~ R 28 000 (2015 figures)	~ R 79 380 000
Pole top transformers	Residential (typically rural). Similar concept to MSSs.	6090	3 x 11kV drop-off fuse 3 x LV fail (per circuit) x (1-3) circuits 3 x CTs (LV)	~ R 28 000 (2015 figures)	~ R 170 520 000

The figures indicate that as one moves deeper into the grid the cost of monitoring acts as an inhibitor to increasing grid visibility. This is because of the sheer volume of assets that exist on MV networks. It is therefore reasonable to investigate alternative options.

Options to reduce such costs include:

a. the deployment of monitoring equipment only at strategic points on the network and thereafter to use state estimation techniques to resolve at un-telemetered junctions;
b. changing the traditional concentrator type Remote Terminal Unit (RTU) infrastructure to one that deploys lightweight sensors similar to those offered by Internet of Things (IoT) devices over Low Power Wide Area Networks (LPWAN) technologies. This strategy becomes cheaper with volume as base station costs spread over the amount of sensors that are deployed; and,
c. the use of open source technologies.

This paper focusses on option c above. The objectives of this paper are therefore to investigate the following:

a. Can open source technology offer a technically viable remote monitoring solution for the smart grid?

b. What are the non-technical challenges that exist with open source technologies and how to overcome these?
c. What are the cost advantages associated with the Open Source Remote Terminal Unit OS RTU when implemented within the municipal landscape?

This paper is structured as follows: Section 3 describes the technical requirements of an open source monitoring unit. Section 4 examines the open source literature. Section 5 discusses the community development hardware platforms available on the market. Section 6 conducts an investigation of the objectives of this research based on the open source monitoring unit proposal. Section 7 discusses the findings. Section 8 presents opportunities for future research. Section 9 concludes this paper.

3. Technical requirements

As a case study, this paper investigates the use of open-source technologies at an indoor mini substation viz., Crestmore SS 3532. This substation supplies a block of flats in the Durban central area. Figure 1 depicts the details of the station.

Figure 1 Crestmore Substation

The station was wired for remote telemetry by in-house electricians. A signal list was developed based on the control room requirements and the wiring effort required. Table 2 depicts the signal list.

Table 2 Signal list

Name	Characteristic	Type
EFI	normally open	digital
Door	normally closed	digital
Red phase fuse fail	normally closed	digital
White phase fuse fail	normally closed	digital
Blue phase fuse fail	normally closed	digital
Red phase LV busbar current	0-400V	analogue
White phase LV busbar current	0-400V	analogue
Blue phase LV busbar current	0-400V	analogue
Red phase LV busbar current	0-800A	analogue
White phase LV busbar current	0-800A	analogue
Blue phase LV busbar current	0-800A	analogue
Ambient temperature	ºC	analogue
Relative Humidity	0-100%	analogue
Transformer kVA	max. 500kVA	analogue

There is currently no private communications from the Municipal Control Centre to Crestmore substation. The use of General Packet Radio Service (GPRS) technologies was therefore provisioned. Some of the key requirements of a modern-day RTU extracted from eThekwini's specifications are detailed in the Table 3.

Table 3 Technical requirements for open source RTU

Characteristic	Requirement
1. Provisioning of digital inputs	minimum 8 expandable
2. Provisioning of digital outputs	minimum 2 expandable
3. Provisioning of analogue inputs	minimum 4 expandable
4. Standard communications protocol over ethernet	DNP3 (slave), Modbus (master)
5. Provisioning of Human Machine Interface	Web browser
6. Should be easily configurable through a web interface	Web browser
7. Compliance with temperature and EMI regulations	IEC61850-3 CX3; IEC 61000
8. Compliance with cyber security requirements	IEC62351
9. Compliance to availability/uptime requirements	Five nines principle

eThekwini Electricity is aligned to the IEC suite of protocols as are most other distribution Utilities in South Africa. These requirements were used as a guide in the development of an Open Source Remote Terminal Unit (OS RTU) proposal.

4. Open source technologies

4.1. Open source: What is it?

Open source refers to a concept that is owned and modified by the public; a community of users that serve a common purpose. It allows for collaborative participation, rapid prototyping and transparency for open exchange of products and ideas [5].

4.2. Open source software vs proprietary software

The source code for open source software is available for anyone to inspect, modify and enhance [5]. This differs from proprietary software wherein the team or organisation that developed the software has full or exclusive control over it.

The Open Source Definition describes the ten tenets of open source software [6]. These include:

1. No fee for distribution
2. Un-compiled and compiled source code must be made available
3. Must allow for modifications of source code
4. Can allow for integrity of author's code through the distribution of path files
5. No discrimination against groups or people
6. No discrimination against fields for endeavour
7. The license must be technology neutral
8. The license must not restrict other software
9. The license shall not be specific to a product
10. The license must automatically apply to all to whom the software is distributed

4.3. Licensing

Open source licensing allows developers and users to use, modify and share licensed software for any purpose, subject to the conditions that preserve the openness of the software itself [7]. The main two types of open source licenses in the market are discussed below.

Copyleft licenses: Developers are allowed to utilise the software under this license for commercial purposes and to modify the code provided that they disclose the source, state the changes that were made and preserve the copyright and license notices. The modification must however be under the original license and the developer shall make the complete source code available. An example of this license is GNU General Public License (GPL).

Non-copyleft licenses (Permissive): Very similar to copyleft license but much less demands are made on the user or modifier of the source code. Developers can modify the source code and declare their work as proprietary. Examples of such licenses include Apache and Berkley Software Distribution (BSD).

Both licenses have limitations on liability and warranty.

5. Community based hardware development platforms

Several hardware development platforms exist in the market that compete on specifications such as power consumption, temperature performance, memory and storage capacity. For remote monitoring purposes, the key requirements are: a) temperature performance; b) provision of on-board digital inputs; c) provisioning of on-board digital outputs; d) provisioning of analogue inputs with at least a 16 bit ADC; e) provisioning of a real-time clock; and f) on-board storage. Some of the more popular development boards include the Arduino, Beaglebone and Raspberry Pi (RPI) and a comparison of these are shown in Table 4. Each board has its own merits depending on the functionality that is intended to be deployed on them.

Table 4 Development board comparison

Board	Arduino Uno	RPI	BeagleBone	Requirement
Model	R3	Model 3B	Black	Open Source eco-system
Flash	32KB	SD Card	4Gb Onboard	External/on-board
GPIO	14	40	69	At least 8 and expandable
Analog Input	6	External	7	At least 4 and expandable
IDE	OS - Arduino	OS - Linux	OS - Linux	Open Source (OS)
Ethernet	None	Yes	Yes	Yes
Real-Time Clock	External	External	Onboard	External/on-board
Temperature performance	85ºC (1)	85ºC (2)	85ºC	70ºC
Project	Arduino LLC	RPi Foundation	BeagleBone.org	-
Cost	USD 30	USD 35	USD 55	-

(1) ATMEGA chip
(2) Broadcom Application processor runs the hottest and can withstand temperatures of up to 85ºC. RPI foundation is unable to qualify the exact operating temperature. COMPULAB offers RPI unit with maximum operating temperature of 80ºC.

Based on the technical requirements discussed above, the BeagleBone Black and RPI fit the requirements well. Since the RPI is ubiquitous in the market; having been named the third best-selling general purpose personal computer after Apple and Windows PC [4], it was decided to be utilised in this open source project. It should be noted that since both the RPI and Beaglebone Black have Linux Integrated Development Environments (IDEs), the option to utilise the BeagleBone Black as the hardware platform can be achieved with similar effort. Both the RPI and BeagleBone Black boards operate on the open source software ecosystem.

6. Analysis

This section conducts an analysis of the objectives set forth in Section 2.

6.1. Objective 1: Can Open Source technologies provide a technically feasible remote monitoring solution for the smart grid?

This question is answered by investigating the Open Source technology market and whether such can match the technical requirements listed in Table 3. To investigate the technical performance of the proposed solution, three key performance metrics are suggested and explored viz., temperature performance, availability performance, and processor and memory usage. The potential failure modes of the proposed solution is also investigated as a means to understand the performance over the operating lifecycle of the asset.

Open Source Remote Terminal Unit proposal

OS RTU is an Open Source Remote Terminal Unit (RTU) based on the RPI hardware platform. An option for utilising the BeagleBone black industrial platform is also available.

To meet the technical requirements listed in section 3, a proposed hardware architecture is presented in Figure 2.

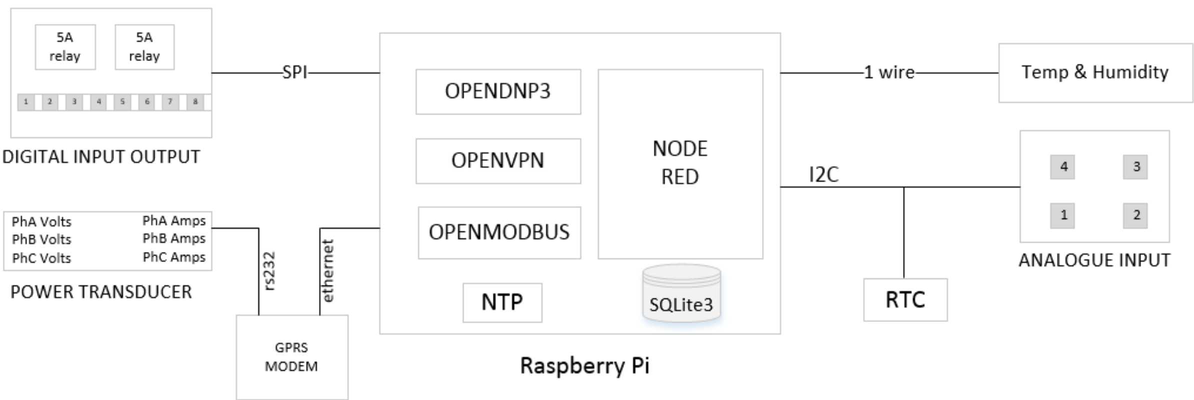

Figure 2 OS RTU Hardware architecture

The proposed architecture makes use of the RPI as the main hardware platform.

It utilises the one-wire protocol to communicate with a DH-22 temperature and humidity sensor. The Serial Peripheral Interface is utilised to communicate with an expandable Input/Output board viz., PiFace Digital. The PiFace digital is equipped with eight digital inputs and two 5A switchable relays. These inputs are expandable as required. 5000Vrms isolation is achieved on the inputs through an opto-coupler circuit. As analogue inputs are not available as a default option on the RPI platform, the board communicates with an ADS1115 ADC chip using the I^2C communications interface. The ADS1115 chip is equipped with four 16 bit ADC channels. For the specific implementation at Crestmore substation, the ADC chip is not utilised as the analogue values are interfaced through a power transducer.

In order to maintain time when the network goes down, a real-time clock (RTC) is integrated into the system. A DS3131 RTC is integrated into the platform using I^2C communications.

Communication Protocols

DNP3

DNP3 is the de-facto communications protocol used for information exchange between a remote telemetry site and the control centre within Electric Utilities. DNP3 is often a preferred protocol as it supports buffered and unsolicited event reporting.

OPENDNP3 is an open source implementation of the DNP3 protocol as defined by IEEE 1815. This stack offers both master and outstation implementations of the DNP3 library as C++ code. This code is published under the GNU General Public License (GPL) implying, amongst other conditions, that there must be full disclosure of the source code within derived implementations.

MODBUS

Modus is an industry standard protocol used for digital communications between master and slave devices. For this application, the Modbus protocol is used for communications between the RTU and transducer devices.

The Pymodbus protocol is an open source implementation of the Modbus protocol as managed and maintained by The Modbus Organisation. This code is published under the BSD license implying a more permissive utilisation of the source code.

Security

IEC62351-3 specifies Transport Layer Security (TLS) as a requirement for Machine to Machine communication for Virtual Private Network (VPN) connections.

OPENVPN is an open source application that implements VPN techniques using TLS security for point-to-point connections. VPN technologies allow for encryption of data thus ensuring the integrity of information traversing a third party network. It also allows for the authentication of remote devices thus ensuring that the master station is not communicating with a potential rogue device.

The OPENVPN client stack can be readily deployed on the hardware development platforms mentioned earlier. This code is published under GNU GPL, with similar restrictions imposed as with OPENDNP3.

Configuration

Node red is a flow based visual programming tool for the Internet of Things. It is browser based and open source with a large database of templates and libraries. Node-red has a strong social development interest in place. It is licensed under the Apache software agreement, i.e. a more permissive type license.

Database

There are a plethora of database types available in the market. SQLite was chosen as the preferred database as it is lightweight, scalable, efficient and intuitive to use. It is a popular database that is built for embedded devices. SQLite source code is in the public domain. However, the general public is not able to openly contribute to the SQLite software itself. A team of developers regularly update the code based on community requirements.

An investigation into the performance of the OS RTU using the 4 key metrics viz. temperature, processor and memory usage and availability statistics follows below.

Temperature performance

In order to investigate the OS RTU for thermal runaways, approximately 300 temperature samples were taken over a three day period. It should be noted that the core processor operates at a higher temperature than the ambient. The maximum operating temperature of the processor is 85ºC after which the processor will begin throttling activity. Figure 3 presents the temperature performance of the OS RTU. A linear basic fit is applied to the results. The small and negative gradient indicates temperature stability of the unit thus confirming no thermal throttling or runaways. The average temperature of the processor is also well below its thermal operating limit.

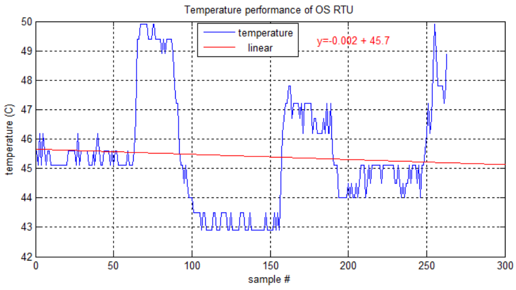

Figure 3 OS RTU temperature performance

Processor and memory performance

In order to determine the stability of the code implemented on the RPI, processor and memory usage were monitored over a week. The results are presented in Figure 4 and Figure 5 respectively. A basic fit linear equation is superimposed onto the results. In the case of CPU usage, the small and negative gradient (-0.000096) confirms that the processor is well matched for its application. Regarding the memory availability on the RPI, whilst low, the small and positive gradient (0.008) confirms system stability. The illustrations indicate that there no runaways in processor and memory usage thus pointing to stability in the code and architecture of the system.

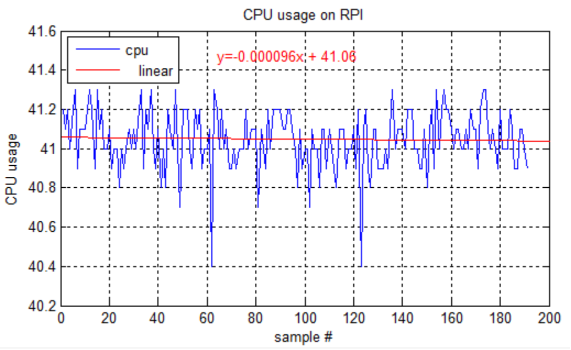

Figure 4 RPI CPU usage

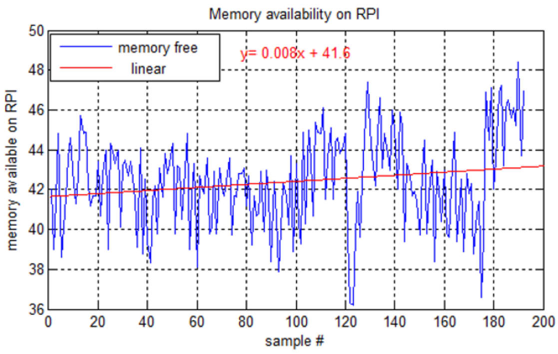

Figure 5 RPI memory usage

Availability Performance

Prior to installing the OS RTU at Crestmore substation, a unit was installed at a high voltage substation to monitor critical battery charger alarms. The unit was installed in April 2017. The system uptime and the uptime of the key DNP3 process was investigated. The results are shown in Figure 6.

```
Last login: Mon Apr 10 22:27:49 2017 from 10.12.210.90
pi@raspberrypi:~ $ ps -ef | grep outs
www-data  1734     1 99  2017 ?        47721-20:24:18 ./outstation-demo
pi        7077  7066  0 13:48 pts/1    00:00:00 grep --color=auto outs
pi@raspberrypi:~ $ uptime
 13:53:13 up 499 days, 22:52,  2 users,  load average: 1.49, 1.45, 1.40
pi@raspberrypi:~ $ ps -o etime= -p 1734
499-22:52:32
pi@raspberrypi:~ $
```

Figure 6 Uptime of open source RTU

The results reveal that the hardware was online for 499 days. The OS DNP3 application was also online for 499 days confirming that the application did not fail since being commissioned. The stability of the hardware platform and OS DNP3 application therefore provide technically compelling results. The availability performance also validate the CPU, memory and temperature performance statistics discussed above.

Electromagnetic interference (EMI)

Electromagnetic interference occurs when an external source affects an electrical circuit through electromagnetic induction or electrostatic discharge. Electromagnetic compatibility ensures that all electronic devices function reliably within their intended environments [8]. There is significant radiated electromagnetic disturbances within the power system environment and any electronic system installed within such an environment should be hardened such that it is immune from such disturbances. Whilst immunity to EMI disturbances are important, designers of hardware should also ensure that their products do not emit unintentional radiation that could possibly interfere with other electronic systems in the near vicinity. Devices should therefore be subjected to both emissions and susceptibility compliance tests.

Electronic devices that have no radio equipment are classed as unintentional emitters as they may contain a high speed clock which may introduce unwanted interference to local devices. The RPI 3B+ specifically has a Bluetooth and WiFi interface and is therefore considered an intentional radio transmitter. In South Africa, the RPI 3B+ has been approved by ICASA under Type Approval number: TA-2018/1426. This however, only ensures that the device does emit interference onto other devices within its immediate vicinity. In order to determine the impact of EMI on the device itself, certain immunity tests against electrostatic discharge, electromagnetic fields, fast transients, etc. within industrial environments as called for in the IEC 61000 standard is required. Research on EMC susceptibility of the RPI 2 platform was carried out in an IEEE paper by Mach et al [9] with findings revealing compatibility in industrial type field strengths of 10V/m across a wide frequency range. Consideration of EMC requirements when designing enclosures for the unit itself can assist with conformity requirements within such environments. Enclosure shielding through concepts like the Faraday cage effect can be taken into account. Stringent EMI susceptibility tests on the current implementation is further warranted.

Failure modes

As with any electronic device, there are many failure modes at play that could result in complete failure or reduced performance of the device. The main failure modes associated with the OS RTU is presented in the Fishbone diagram of Figure 7. Each failure mode is discussed categorically.

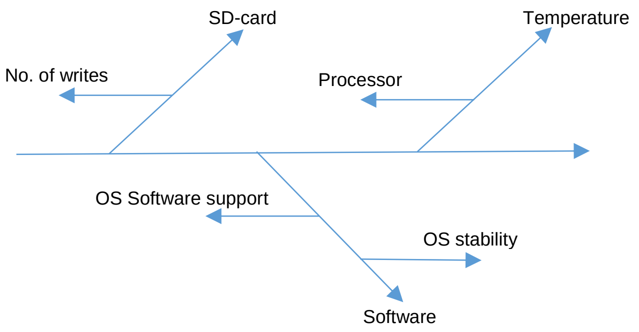

Figure 7 Fishbone diagram – OS RTU

Secure Digital (SD) card

Flash memory has a limited amount of write cycles which is normally in the region of 100 000 cycles. This figure improves with the quality of SD card that is utilised. Some higher quality SD cards employ wear levelling techniques that prevent cards from pre-mature failure. In the manner in which this unit is designed, a wear levelling SD card is recommended. It is also not a difficult technical process to keep a backup image of the SD card. This SD card can be replaced every 10 years at a minimum cost.

Temperature range

Whilst there is no official operating temperature of the RPI, thermal imaging of the device under heavily loaded conditions reveals that the broadcom chip (processor) runs the hottest on the board [10]. Temperatures above 80ºC have shown significant performance degradations and the system is known to throttle performance at temperatures above 82ºC. Heat sinks are available that can be attached to the broadcom processor chip. An industrial grade RPI is available from COMPULAB [11]. This supports industrial grade operating temperatures of up to 80ºC.

Software

i. Raspbian Operating System

There are no known issues regarding the stability of the Operating System. The operating system development community is very active in enhancing the performance of the system. There have been many iterations of the Raspbian operating system with each iteration providing performance enhancements. The fewer hardware devices attached to the system improves the overall stability figures.

ii. OS Software applications

According to a 2015 Open Source survey, 78% of companies already run open source technologies [12]. Standard implementations of the open source applications will improve the overall reliability of the system. Custom implementations run the risk of the changed code not being vetted by third party independent sources. Open source applications that have strong community participation offer a high level of quality assurance as there are many independent code reviews from global and random participants.

Municipal engineers are encouraged to subscribe, participate and contribute towards the OPENDNP3 software application and other relevant open source technologies related to their specialist fields.

6.2. Objective 2: What are the non-technical challenges associated with OS technologies and how to overcome these?

Several non-technical challenges exist which include the resource constraints to assemble such units, the availability of spares and ongoing support. These are discussed below.

Human resource constraints

Apart from the technical issues there are also human resource constraints that need to be considered. Assembling a physical device requires effort and time. A business case and project plan will need to be thoughtfully constructed. This however, remains outside the scope of this paper. The system should be designed for ease of maintenance. As the intelligence of the OS RTU resides on the SD-card, a simple clone of the card should be kept as a spare.

Spares availability

Depending on the community development board that is chosen, the availability of spares will vary. In the case of the RPI and BeagleBone Black, the unit is available from many suppliers locally. Moreover, the BeagleBone hardware is built from open electronics. This means that the design is publicly available for modification and further development. Building of the hardware from the ground-up using readily available common of the shelf components, standard processes and open infrastructure is therefore possible. If a strong development community is built around the concept of the OS RTU, there will be no reason to be dependent on any specific supplier for spares.

Support

Support is necessary throughout the operational lifecycle of the asset. Support for community based hardware platforms and open source software cuts across several industries and therefore far surpasses the cohort of support groups available from individual suppliers of proprietary products. However, whilst the breadth of knowledge is high, the depth of support may not be as detailed as those received from supplier product centric focus groups. Again, if a strong development community is formed around the concept of the OS RTU, support will grow commensurately. Using a forum member statistic as an indication of the breadth of support available, the RPI hardware platform has a forum with approximately active 270 000 users [13].

6.3. Objective 3: What are the cost advantages associated with the OS RTU when implemented within the municipal landscape?

A costing comparison was conducted for remote monitoring at Crestmore substation.

The costing for the OS RTU is based on present market value prices. The approximate costs illustrated for a vendor specific unit is drawn from recent public tender opening prices in 2015. This specific vendor product was the cheapest and most technically compliant. Table 5 below depicts the cost comparison.

Table 5 Cost Comparison

Item	RPI	Vendor specific
Microprocessor with DNP3 license	R 550	R 22 000
IO board (8 inputs)	R 650	R 2 000
Real Time Clock	R 50	Incl
Analogue board (3 inputs)	R 100	R 4 000
Case	R 150	Incl
Temperature and humidity sensor (additional)	R 50	R 200
Cabinet and accessories	R 1 500	Incl
Total (15 000 units)	R 3 050 (45 750 000)	R 28 200 (423 000 000)

From a cost point of view, it is clear that for small stations with a low signal count, the OS RTU is very cost effective. In the case of eThekwini Electricity who maintains approximately 15 000 MV assets, the sheer capital cost savings based on volume immediately warrants further consideration.

From an operational cost point of view, there is no financial commitment to a specific vendor regarding support. Support is available within a virtual online ecosystem from a global user-space.

7. Discussion

The objective of this research was to investigate whether open source technologies can offer a technically appealing and cost effective remote monitoring solution for the smart grid. It also goes on to investigate the non-technical challenges in implementing such technology within a municipal landscape.

The research indicates that open source hardware and software technologies exist in the public domain that can meet the remote monitoring requirements of distribution utilities. The OS RTU proposal put forward in this paper offers a compelling option. The technical metrics investigated indicate stability of the open source code and overall system architecture. However, it is recommended that stringent immunity tests against the IEC 61000 standard is conducted as a design imperative.

The non-technical challenges associated with implementing OS technologies within the municipal landscape can be reduced through the formation of a strong open source community consisting of like-minded engineering practitioners. It is recommended that Utility Engineers collaborate on open source projects in order to share knowledge and where possible, contribute positively to code that ultimately resides in the public domain. Such collaboration spurs interest in research and development and reduces the financial commitments that larger equipment manufacturers place on customers with regard to support.

A cost analysis reveals that there are significant upfront cost benefits in utilising open source technologies for grid monitoring when compared to proprietary options. In some cases, the cost of proprietary systems act as an inhibitor to increasing grid visibility. The recommendation is that it is better to implement some level of monitoring through cost optimised methods than to omit any attempt to extend grid visibility because of funding complexities. There is also reduced operating costs associated with OS technologies as users have access to a large development community within a virtual ecosystem that is free-of-charge. Furthermore, there is no vendor lock-in and code is generally hardware agnostic.

8. Future Research

The current implementation of the OS RTU is within an indoor mini-substation. A future implementation and subsequent evaluation will be on a pole-top transformer. OS technologies within the smart metering environment has already gained traction, viz. YOMO, the open source and open hardware metering board [14].

9. Conclusion

An investigation into the use of open source technologies within the smart grid for remote monitoring has shown that the open source market is mature enough to spur product innovation. It is recommended that utility specialists contribute, even at a functional level, to the open source knowledge base.

The OS RTU proposal put forward in this paper offers a compelling low cost remote monitoring solution for municipalities. The source code is available for other municipalities to adopt and implement where needed.

The use of open source technology removes vendor lock-in thus bringing flexibility and technology agility to the organisation. The collective power of crowd-sourcing from global communities introduce new ideas and concepts more effectively than rigid teams working on proprietary alternatives. Open source stands to democratise new technology and with the recent uptick in open source usage by global industry, South African utilities need to position themselves well to also harness the full benefits that open source has to offer.

10.Acknowledgements

The authors of this paper would like to thank eThekwini Electricity MV/LV Electricians and Management teams for their support in the design, testing and implementation of the OS RTU project. Special thanks to Dhannir Singh, Ronnie Pandaram and Ivan Laban for their guidance along this journey.

11.References

[1] Business Report, South Africa, accessed 27 August 2019, https://www.iol.co.za/business-report/technology/opinion-is-africa-being-recolonised-through-tech-29083464
[2] World's Top Exports, accessed 27 August 2019, http://www.worldstopexports.com/
[3] Businesstech, accessed 27 august 2019, https://businesstech.co.za/news/general/48791/michael-jordaans-new-investment-firm-montegray-capital/
[4] The MagPi magazine, accessed 27 August 2019, https://www.raspberrypi.org/magpi/raspberry-pi-sales/
[5] Opensource, accessed 27 August 2019, https://opensource.com/resources/what-open-source
[6] Opensource, accessed 27 August 2019, https://opensource.org/osd
[7] Choosealicense, accessed 27 August 2019, https://choosealicense.com/licenses/
[8] NIST Programs, Electromagnetic Compatibility of Smart Grid Devices and Systems, accessed 27 August 2019, https://www.nist.gov/programs-projects/electromagnetic-compatibility-smart-grid-devices-and-systems
[9] Electromagnetic compatibility of RPI development platform in near and far-field
2017 Progress in Electromagnetics Research Symposium, IEEE, 2017, DOI: 10.1109
[10] Makezine, accessed 27 August 2019, https://makezine.com/2016/03/02/raspberry-pi-3-not-halt-catch-fire/
[11] Compulab, accessed 27 August 2019, https://www.compulab.com/2017/11/26/compulab-introduces-a-raspberry-pi-based-iot-computer-with-3glte-modem-dual-ethernet-and-wide-temperature-range/
[12] Vlad, V, (2015), Why Open Source is good for business, accessed 27 August 2019, https://rubygarage.org/blog/why-open-source-is-good-for-business
[13] RPI Forum, accessed 27 August 2019, https://www.raspberrypi.org/forums/
[14] Klemenjak, C, (2014, YOMO – The Arduino based Smart metering Board, Energy Informatics, Zurich, Switzerland.