Enhancement of Network System Performance Monitoring through Synchronised Measurement Technology

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1. Abstract

The objective of this study is to highlight the role of technologies in improving grid operations within a Metropolitan power distribution network. This study will also discuss the deployment of a smarter grid to contribute to amongst others the network reliability, health, safety, security, infrastructure & effective energy management. The goal of Distribution System Operator is to use Synchronised Measurement Technologies SMTs to improve power supply security, monitoring and control. Transient nature of distribution network is to be monitored by SMTs. Knowing grid operation system state in real time ensures reliability and security of the electric grid. This study discusses and illustrates possibilities of having an enhanced Network System Performance within Municipal power distribution network. The synchronized data from the IEDs bring improved understanding of network performance. This allows the operator to make informed decisions on network configurations. The study will conclude by indicating possibilities of using SMTs as a key enabler of a smarter grid. It will also illustrate basic concepts of a smart network in relation with distribution grid operation in that all components of the smart grid can communicate and support all grid operation applications. The Applications include self-healing, real time monitoring and control.

2. Introduction

Increase of electric power demand has led to power systems becoming more complex. Improving existing control and monitoring system functions is needed in order to enhance overall performance of a power system. A growth in size as well as complexity of electric power system has resulted in power network being exposed to failures.

The dynamic nature of modern distribution networks can be important in optimisation of system performance such as voltage stability and control of magnitude, minimisation of technical losses and Quality of Supply (QoS). Municipal networks are relatively loaded and within budget constraintsplacing network performance at risk. Customers are also no longer only consuming energy as some users can also produce energy, being prosumers. Smart grid principles can empower municipal network operators to retain network performance. Additional system performance data is needed. Advanced Measuring devices (AMDs) allow flexibility in the type and extent of parameters to be recorded.

A high level in certainty of time-stamping similar to synchrophasor empower Distribution System Operator (DSO) with useful synchronised voltage and current phasors and aggregated data. Tracking system state conditions support reliability and security. These instruments are known as network coherent data instrument. A synchrophasor or Synchronised Measurement Technology (SMT) forms a family of network coherent data instruments. One application of such a device is to provide electrical protection functions that may be used to monitor state as well as performance of power system. In addition, it collects information and sends it to SCADA system. AMDs receive information from power equipment's sensors then it issue command to trip circuit breaker if there is rise or dip in voltage, current and frequency. This may rise due to abnormal condition that may occur in a grid.

Smart grid is about using technology to operate and control distribution network. The technology enables better monitoring, control and protection of distribution grid. The Synchronized Measurement Technologies collect data from different substations and control signals between substation devices throughout the grid. AMDs provide data as shared innovation between different components of network operation, monitoring and control.

3. Quality of Supply (QoS) Monitoring

Power quality is a term used to describe supply reliability which is an indication of adequate and secure power supply. They often compute and record industry standard NRS 048 part 2 measurement for power quality.

QoS regulations and standards are there to support a culture of continuous improvement of visibility, protection, control and stability of electric grid. As a result the customer will receive reliable quality and knowledge of network at all times. The new IEC 61000-4-30 standard will address both quality of supply (voltage) and quality of use (current). Currently, eTE use NRS 048 part 2, 4, 6 and 8 for PQ monitoring. These standards mainly cover quality of supply (voltage) and Table 1 below are the parameters covered within the NRS document:

Table 1 : Parameters Covered within NRS048 Document

Quality of the waveform (NRS 048-2)	Disturbances (NRS 048-2)	Incidents Report (NRS 048-4)	Reliability (NRS 048-6 and NRS 048-8)
Voltage Magnitude	Voltage Dips	Network Statistics	System minutes
Voltage Unbalance	Voltage Swells	Forced Interruption Statistics	
Voltage Harmonics	Voltage Transients	Site Measurement Statistics	
Voltage Flicker		Reporting to NER	

PQ monitoring depends both on utility power supply (network service provider) as well as consumer (load). The new IEC 61000-4-30 of 2015 addresses both current and voltage. Continuous PQ instruments are based on IEC 61000-4-30 and they provide real-time voltage and current phasors.

4. SCADA

Situational awareness is one of the important aspects of power system operations. A metropolitan distribution grid operator uses the Supervisory Control and Data Acquisition (SCADA) to provide situational awareness of the network. This is usually not a true reflection of distribution network grid operation especially during non-steady state conditions.. Knowing a system state in real time ensures reliability and security of the electric grid.

SCADA allows control officers to monitor and control substations remotely. Information from these substations are collected from field sensors and sent to a Remote Terminal Unit (RTU). This information is then transmitted over a communications medium such as fibre optics back to the control centre. Sophisticated hardware and software elements influence this information and present it in a user friendly manner to the control officers. Control officers use this information to make important decisions about the electrical network such as customer outages.

The SCADA system is also used to implement load shedding. All load shedding activity is safely and timeously carried out by control officers through the issuing of remote controls via the SCADA system. If this functionality did not exist, it would not have been possible to implement load shedding efficiently within the 2-hour slots.

SCADA reports steady state conditions based on relatively long aggregated measurement values. Situational awareness is one of the important aspects of power system operations. A metropolitan distribution grid operator uses the SCADA to provide situational awareness of the network [1][2][3].

SCADA is the heart beat of power system operations as any failure within SCADA may have direct impact on cost and safety.. It performs data acquisition that improve decision making of operators at the control centre.

5. Network Coherent Data Retrieval through SMTs

SMTs are power system devices that provide synchronized voltage and current phasors in real time [4]. They are a measurement and monitoring tool, which is synchronized by Global Positioning System (GPS) clock. It samples measurements of voltage, current, power angle, and Electro-Motive Force (EMF), etc.

The sampling data is synchronized by a GPS time signal so that a synchronised phase angle can be calculated from instantaneous values of voltage and current [5]. Since SMTs measure magnitude, angle of voltage and current, it is useful in wide area monitoring and controlling a power system network.

Time stamping and time synchronization measurement tools are a necessary approach by metropolitan network operators to improve network performance. Power system control and operation within the distribution grid are to be made smarter by deploying SMTs in the network. The ability to synchronize and time tag data emanating from AMDs will provide the system operator wide area network information in real time. Real time monitoring of power system security allows it to overcome contingencies. The contingencies may arise due to disturbances in an electric power system. It also provides the required input decision making process to the network management system. These inputs allow a system to perform self-configuration and self-healing tasks.

6. Role of Telecommunications in Grid Operation

Communication infrastructure allows for innovative application of digital devices to enhance network management applications. The network management system and associated applications update monitoring systems to improve awareness of the grid. This data is retrieved from substation AMDs via communication infrastructure to the control centre.

The great advantage of a smart network is the ability of having bi-directional communication between substation Advanced Measurement Devices (AMD) and Energy Management System (EMS) at the control centre. The AMDs through communication network provides collection and analysis of data in real time. This provides data as shared innovation between different components of network operation, monitoring and control. The communication network enables communication between the AMDs linked to the substation equipment. This communication network amongst others provide real time monitoring and control of the distribution grid [6].

SDH over IP support is proposed as the main protocol used in this architecture. Synchronous Digital Hierarchy (SDH) is a critical digital transport networks that allows the combination of high-speed data services..SDH is used by eThekwini Electricity as the backbone of transmission networks. It provides carrier-level reliability with short restoration time in case of path failures. With SDH each service or application is set with predefined bandwidth such that quality of service is inherent in the system. Once the circuit is established, an application can only utilize the bandwidth assigned to it.

The modern trends towards implementing communication networks for transporting power system measurements to control centre have driven motivation to improve performance of different protocols when employed in Local Area Network (LAN) and Wide Area Network (WAN) [7].

The alarms are to be brought back to the control centre using (Internet Protocol) IP based SCADA protocols. IP-based SCADA using protocols such as File Transfer Protocol (FTP), Distributed Network Protocol (DNP3), and Modbus over IP that allow for a simplified network architecture, efficient bandwidth utilization, and faster commissioning and deployment.

The data from SMT provides near real time applications on SCADA to enhance the controller's situational awareness. Furthermore, SMT data will also be used for post-mortem, PQ, system performance and EMS applications. This example illustrates a successful opportunity for technology as smart grid enablers in municipal distribution network.

7. Smart Grid Enabling Technologies for Metropolitan Distribution Networks

The architecture presented on Figure 1 represents a simple example of technology as a smart grid enabler. The legacy RTU will carry traffic for a conventional SCADA system. Whereas the SMT will carry traffic for the proposed monitoring network. Both traffic will go through the routed network via communications Wide Area Network (WAN) to the main control centre. The router at the main control centre will direct data to a relevant application server. The legacy RTU data will be sent to the SCADA system. Whereas the SMT data will go through to SCADA as well as the SMT application server. It was indicated earlier that, the SMT provide time tagged current and voltage phasors. The data from SMT provides near real time applications on SCADA to enhance the controller's situational awareness. Furthermore, SMT data will also be used for post-mortem, PQ, system performance and EMS applications [8].

This example illustrates a successful opportunity for technology as smart grid enablers in municipal distribution networks.

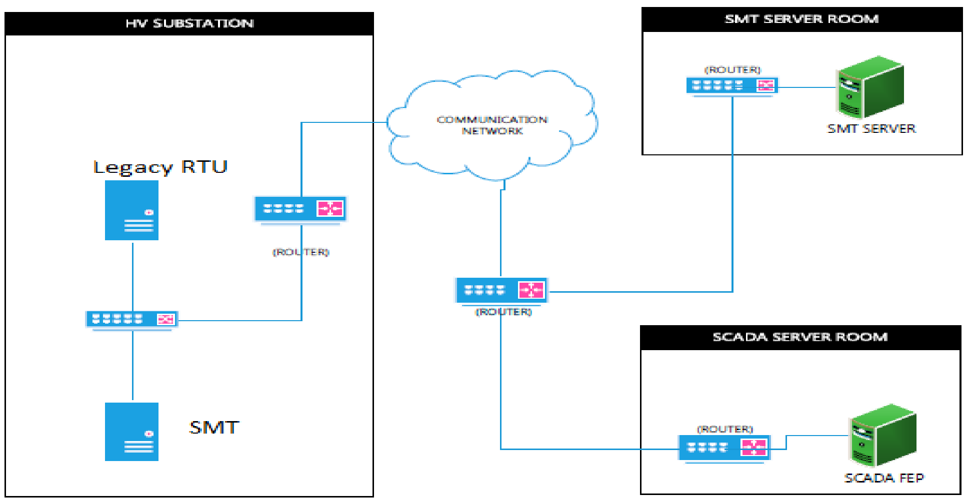

Figure 1 : Represents technology as smart grid enabler [8].

8. Distribution Network SMT Applications

The technology enables better monitoring, control and protection of distribution grid. SMT placement main goal is to give full wide area observation of a network performance in real time. Furthermore, SMT placement on each and every bus is limited by cost as well as by substation communication facilities (it must comply with IEC61850). SMTs are to be placed such that neighbouring busses also become visible [7]. To elaborate further SMT placement should be optimal such that that a total number of SMTs at the end of phasing is not more than an optimal amount of SMTs required for full observe ability. SMTs are to be placed such that if one SMT fails or there is a lack of communication, other SMTs must ensure full observability of a network [7].

8.1 Improving Network Situational Awareness

Due to high demand of electricity from the consumers, electric power system are now operating near their full capacity and that resulted in them being highly sensitive to any disturbances that may occur in a grid. Therefore wide area monitoring (WAM) was introduced to monitor and assess a state of power system as well as to reduce contingencies that may rise in a network. Wide area monitoring utilise SMTs measurement devices to understand, forecast and to control the status of power grid stability in real time [9].

Situational awareness is one of the important aspects of power system operation while assessing the operational strategy. SCADA is used to monitor situational awareness at eThekwini Electricity network. Wide Area Monitoring and Control (WAMC) using SMTs will provide operator with real time knowledge of a network or power system conditions.

With aid of SMTs an operator will have real time situational awareness of network at all times. Continuous PQ recorder will be introduced to assist SCADA during restoration of network after a disturbance or fault has occurred on network. Precise time stamping will enable operators to have improved situational awareness (transient and non-steady state behaviour) of grid at that particular instant.

8.2 Advance Power Quality Monitoring

PQ comprises of two principles namely Quality of Supply (QoS) and Quality of Use (QoU). QoS concentrates on voltage quality, the principle on which the NRS 048 is based whereas QoU concentrates on current quality. Current monitoring is needed to fully understand cause and effect on network as Power (S) comprises of voltage and current. The new IEC 61000-4-30 edition 3 addresses both current and voltage [10]. Synchronised measurement PQ instruments are based on IEC 61000-4-30 and they provide real-time voltage and current phasors.

The current eTE PQ instrument only measures voltage and doesn't cover monitoring of current. Going forward eTE will be installing PQ instruments with synchronised measurement capabilities that even comply with IEC 61000-4-30 edition 3. Table 2 compares current PQ instrument with proposed PQ instrument:

Table 2 : SMT's vs Legacy Power Quality Instruments.

Options	Option 1 (SMT)	Option 2 (Legacy PQ instrument)	Derivable
Sample Rate	1000 samples per cycle	128 samples per cycle	Synchronised instruments will improve resolution as it has a higher sampling rate. It captures more data compared to legacy instrument.
Availability of Data	SMTs will be connected directly to eTE electricity network.	It is deployed through a 3rd party network and there is latency associated with it.	SMT offers real time data streaming to network. This will help with real time wide area picture of network
Real Time Data	SMTs through use of PMUs allows real time data of current and voltage phasors	It provide non – real time voltage magnitude data.	SMTs allow you to have playbacks of events leading to fault. This can be used for root cause analysis.
Wide Area Visibility	SMTs will allow eTE network to have integrated real time readings from different substations and transmission lines.	It gives instance of fault at a certain location.	Synchronised instruments will allow us to have wide area monitoring of network which will help operator with system operation in real time.
Voltage and Current Magnitude and Phase	SMTs through use of PMUs provide real time data of current and voltage phasors	It provide non – real time voltage magnitude data.	Time data streaming will help with power factor (pf) and reactive power. This is used mainly by EMS.
Time Stamped Data	SMTs through use of PMUs provide real time, synchronized time stamped data.	It provides non-real time and it not synchronized.	Real time data streaming from Synchronised instruments will improve state estimation and assist in post-mortem. Furthermore, we do not need about latency that much as that will be time stamped.

PQ Monitoring of current and voltage provides network with full observability as well as performance of the network. Moreover, power system operator need to comply with NER by providing near real time information on the events that takes place on the network in particular actual power quality levels.

A PQ instrument that records continuously near real time or in real time will be useful for real time visualization. Accurate and reliable system models are essential for reliable and secure system operation of network. Synchronised instruments provide time stamped real-time synchronised voltage and current phasors.

8.3 Resolution of SCADA- time interval

The data received from an IED is synchronized and it carries the same time tag allowing SCADA to group them according to their tags rather than their time of arrival. The synchronized data from the IEDs bring better understanding of network performance. This allows an operator to make informed decisions on network configurations.

Real time monitoring is an online system used to monitor a systems security and stability. Operational limits of a distribution grid are dependent on voltage, current and frequency as they are used to check a systems stability and security. If any of the operational limits deviate from its normal value of a system state. The system will change from normal to emergency state. Emergency state conditions may give rise to load loss. The load loss could be as a result of voltage fluctuations or deviations of a measurable parameter. A normal state is secure if all contingencies result in a secure normal operation [29]. This is indicated in Figure 2 below.

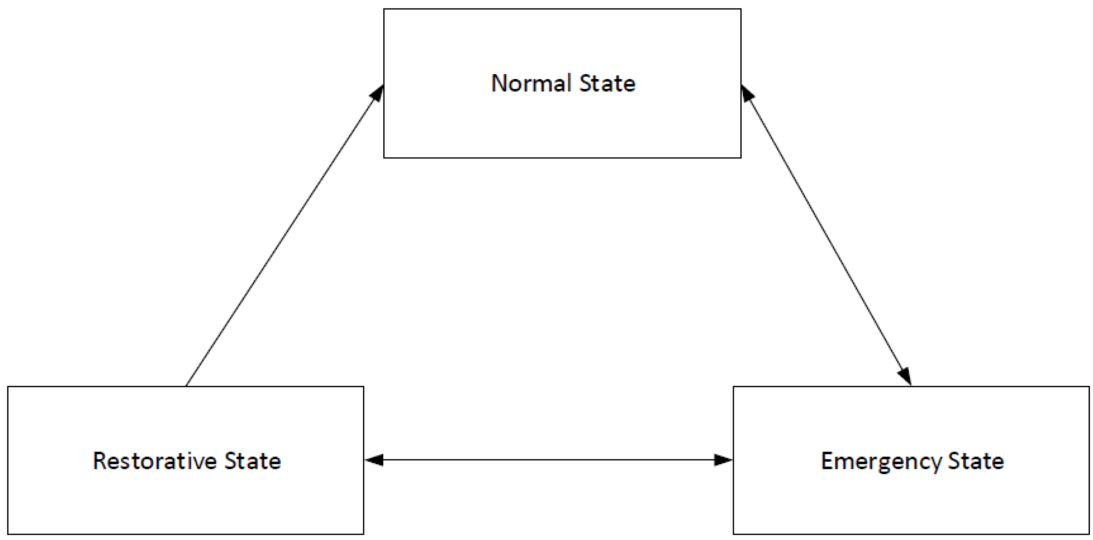

Figure 2 : SCADA three security state of operation.

Power system operation at eThekwini Electricity is based on the conventional SCADA system which receives the data from Remote Terminal Units (RTUs) located across different substations. The SCADA system normally updates the values of various quantities like real and reactive power, voltage, switch and circuit breaker positions. Limitations of SCADA include lower scan rates, asynchronous data, the provisioning of only steady state information, lack of wide area monitoring in real time and non-availability of phase angle. A continuous PQ recorder in a form of SMT along with the high speed fiber communication infrastructure from HV substations to the control centre will be used overcome the above limitation of SCADA.

Situational awareness is one of the important aspects of power system operations. A metropolitan distribution grid operator uses the SCADA to provide situational awareness of the network. A WAMC using synchronized instruments should provide an operator with real time knowledge of a network.

9. Power System Monitoring and Control

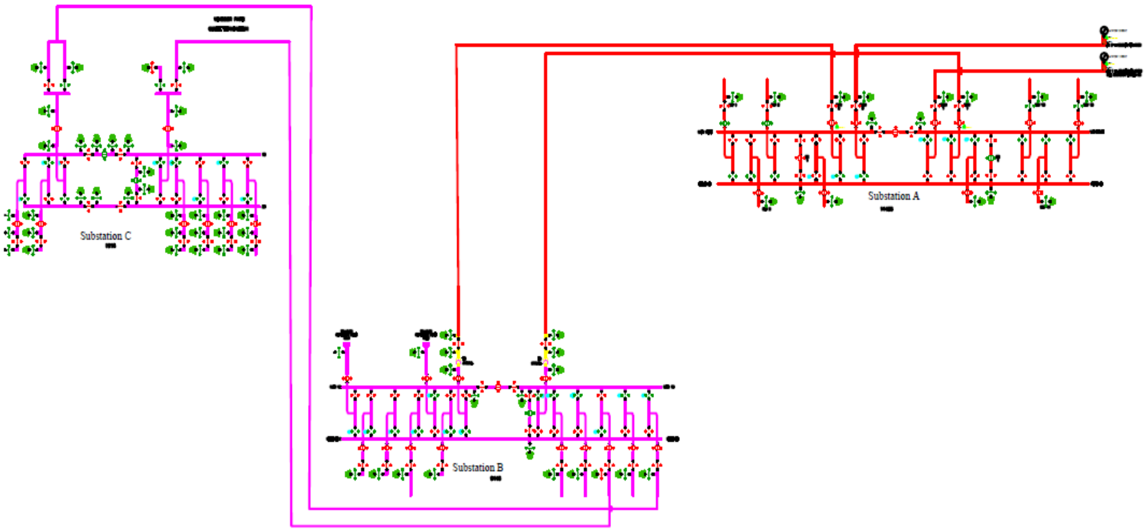

Figure 3 : Network Topology

Figure 3 above represents Substation A, Substation B and Substation C line diagrams as displayed on SCADA system. Synchronised Measurement Technologies (SMTs) embedded in IEDs can improve power supply security, monitoring and control. A role of Power Quality (PQ) in modernising Municipal Utilities through SMT will be displayed on this section. As presented on previous Section 8, SMT is used to enhance situational awareness. This section is using network coherent data to improve network performance information.

9.1 Modernising Municipal Utilities through SMT

The objective of this study is to highlight a role of technologies in improving grid operations within Metropolitan power distribution network. This study will also discuss the deployment of a smarter grid to contribute to amongst others the network reliability, health, safety, security, infrastructure & effective energy management.

The goal of Distribution System Operator (DSO) is to use Synchronised Measurement Technologies (SMTs) to improve power supply security, monitoring and control. A smart Energy Management System (EMS) is possible through the use of SMTs in municipal distribution network. Transient nature of distribution network is to be monitored by SMTs. Knowing grid operation system state in real time ensures reliability and security of the electric grid.

Situational awareness is one of the important aspects of power system operations. A metropolitan distribution grid operator uses the Supervisory Control and Data Acquisition (SCADA) to provide situational awareness of the network. This is usually not a true reflection of distribution network grid operation since it is never in a steady state. Knowing a system state in real time ensures reliability and security of the electric grid.

Table 3: Snapshot of current and voltage in real-time

Channel	Vrms (% declared)	Vrms (V)	Vangle (°)	Irms (A)	Iangle (°)
1	100.950	111.055	0.000	718.456	- 10.812
2	101.492	111.651	-120.671	711.758	-132.933
3	100.119	110.141	119.276	691.004	108.523
4	56.936m	62.634m	- 5.326	659.010u	- 5.326

Table 4 : Snapshot of S, P, Q and Pf

Power Meter	Apparent Power (VA)	Active Power (W)	Reactive Power (VAR)	Phase Angle (°)	Total PF (p.u)
P1 = V1 x I1	79.788k	78.369k	14.982k	10.823	0.982
P2 = V2 x -I3	77.151k	50.285k	- 58.513k	- 49.325	0.652
	0.000	0.000	0.000	0.000	0.000
P4 = V4 x I4	41.277u	31.229u	- 26.991u	- 40.837	0.757
Ptot = P1 + P2	135.819k	128.654k	- 43.531k	- 18.694	0.947

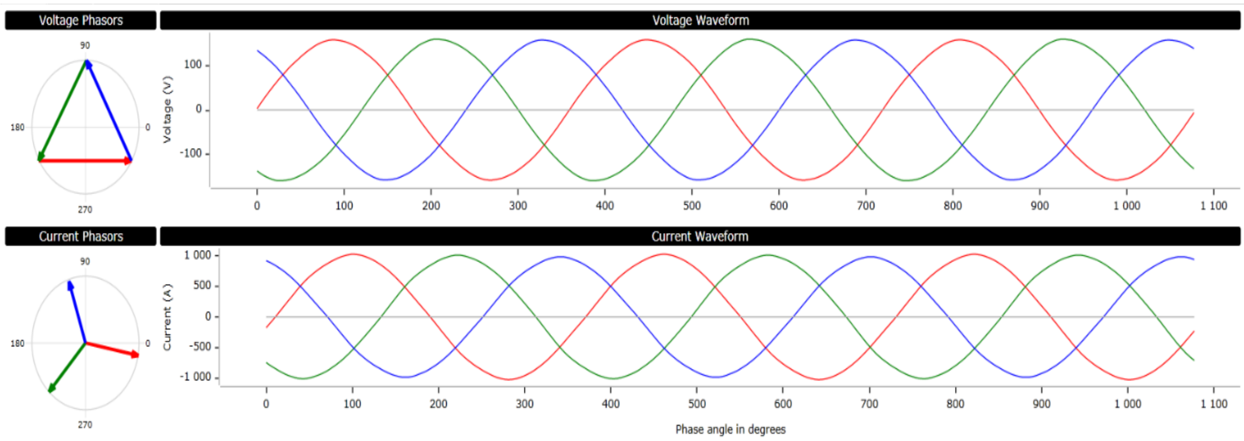

Figure 4 : Current and voltage drawn on different axis

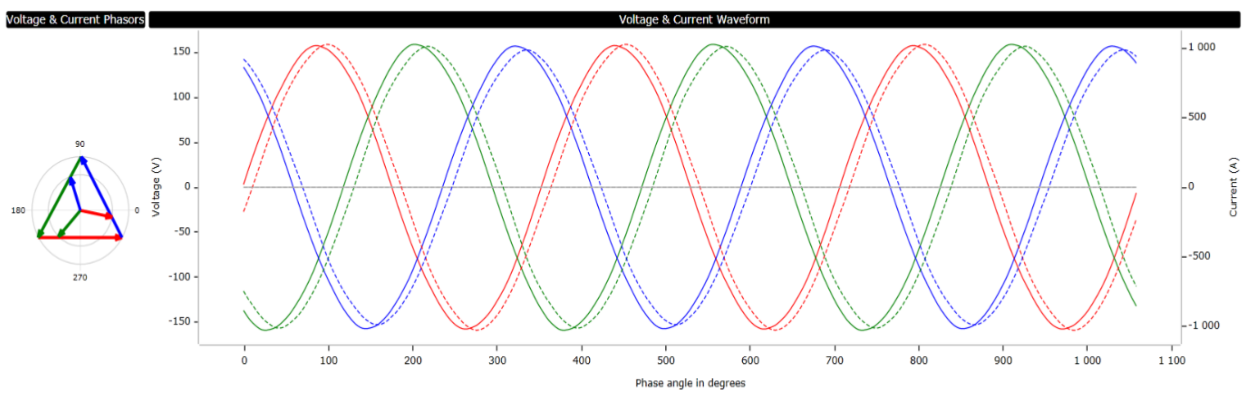

Figure 5 : Voltage and current on same axis

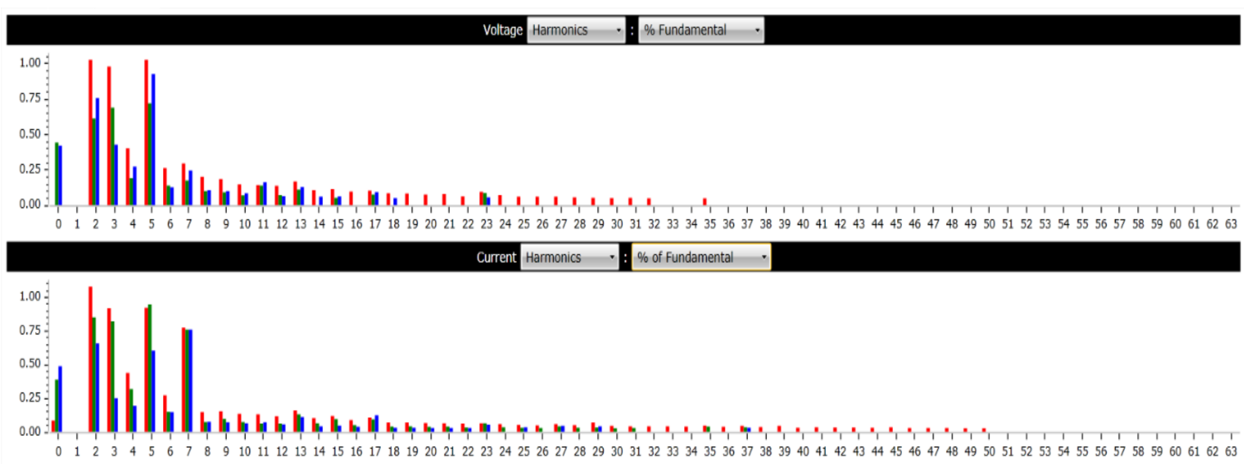

Figure 6 : Voltage and current harmonics Snapshot

Table 3, illustrates current and voltage angles at Substation A in real time, while Table 4, illustrates apparent power, real power, reactive power and power factor at Substation A in real time. Whereas, Figure 4 represents sinusoidal waveforms of current and voltage drawn on different axis, while Figure 5, represents sinusoidal waveforms of current and voltage drawn on the same axis. Finally, Figure 6 represents current and voltage harmonics up to 63rd at Substation A.

9.2 Power System Network Management and Reliability

Improving existing control and monitoring system functions is needed in order to enhance the overall performance of a power system. A growth in size as well as complexity of electric power system has resulted in the power network being exposed to failures. Furthermore, ageing infrastructure is another root cause of supply outages and network faults.

The purpose of a modernised power system is to supply highly reliable and secure supply while using an optimised economic yet sustainable approach. This also includes improving customer participation as customers are now prosumers and are technologically elite.

SCADA has historically been used to monitor electrical power systems. Introduction of SMT which provide real time stamped voltage and current phasors will improve situational awareness. These instruments embedded in IEDs can improve power supply security, monitoring and control. A smart EMS is possible through the use of SMTs in municipal distribution network, inclusive of the transient nature of distribution network. Knowing grid operation system state in real time supports reliability and security of the electric grid. Dynamic state estimation decision tool can complement control centre via SCADA. The Electric Power Utility (EPU) can now make informed decisions on network configurations.

10. Conclusion

The study concludes by indicating the effectiveness of using SMTs as a key enabler of a smarter grid. It will also illustrates, the basic concept of a smart network in relation with distribution grid operation is that all components of the smart grid can communicate and support all grid operation applications. The Applications include self-healing, real time monitoring and control and real time energy consumption.

The Electric Power Utility (EPU) need to consider deployment of SMTs for wide area monitoring and control. The benefits of using these instruments were indicated throughout this study. Thus as a cost saving mechanism, the use of a single SMT can be used for multiple applications to improve the overall distribution network business model.

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