A Supervisory Control and Data Acquisition Monitoring System for a Plant-Site Power Distribution Network*

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Abstract

Supervisory Control and Data Acquisition (SCADA) systems have taken center stage in industrial automated systems. In most processing plants, the power distribution network is not subjected to SCADA whilst a SCADA system is used in the monitoring and control of the process plant. This paper looks at monitoring of the power distribution network of a typical gold processing plant using an existing SCADA infrastructure and the possible integration of a metering system. Use was made of the Schneider electric Power Logic ION 7550 and 6200 energy meters with communication capabilities and the Wonderware™ SCADA software. Remote monitoring of the power distribution network at a mine installation was implemented by incorporating a metering system into the existing SCADA system. The resulting system promises simpler, real-time, safer and easier monitoring, functional reliability giving increased efficiency, reduction in troubleshooting time and improved energy management.

Keywords: Current Transformer, Potential Transformer, Monitoring System, Power Distribution Network

1 Introduction

At some open-pit gold mining operations, the incoming side of the power supply system to the mine is typically automated by most bulk power suppliers using Supervisory Control and Data Acquisition (SCADA) system. The power distribution side, which falls within the domain concern of an open-pit gold mining company is not SCADA automated. The substation and distribution systems are controlled and monitored using the traditional system. This basically includes the use of typical protective and monitoring devices such as electromagnetic relays, overcurrent and undercurrent relays and current transformers. The existing SCADA system monitors the high voltage (11 kV) side of the distribution system, hence, certain problems such as single-phasing, low or high voltage and current can be determined and solved. However, when the fault occurs on the low voltage side such as the 415 V phases, it cannot be detected easily.

SCADA systems have traditionally played a vital role by providing industries with valuable knowledge and capabilities such as real-time monitoring and remote control, which are key to their primary business functions. Relevance of SCADA in today's automation systems is seen by its ability to resolve most of the demerits of the old and Programmable Logic Controller (PLC) based automation systems which include lack of constant monitoring of equipment and no form of on-site remote alarm indicators. In today's industrial automation, more importance is placed on system integration, use of new communication and network technologies and access to real-time information by more users. Power systems automation, through SCADA systems directly leads to increased reliability of power supply to the consumer and results in lowering operating costs for the utility company, forecasting of accurate demand and supply management; faster restoration of power in case of a downturn and a quick alternate arrangement of power for important/emergency locations.

SCADA systems are basically Process Control Systems (PCS) specifically designed to automate systems by utilising combinations of telemetry, control and data acquisition. It focuses only on the supervisory level and involves the transfer of data from field devices such as sensors to Remote Terminal Units (RTUs) that provide an interface between the master station and the field devices. The communication system is basically a two-way traffic.

Three basic functions namely monitoring, control and user interface functions are performed by SCADA systems (Anon., 2012). The monitoring function collects data and sends the data to the central computer. The control function gathers data from monitoring sensors, processes the data and sends control signals back to the equipment according to a prescribed software program. The monitoring and control functionalities form the supervisory control part of the SCADA system and under this, other functionalities such as alarm handling and trending, access control, automation, logging, archiving and report generation come to light (Anon, 2008).

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A SCADA system element-wise, comprises hardware and software. The hardware are the physical components and include field level instrumentation and control devices; marshalling box and RTUs; communication systems; the Master Station(s); and the commercial data processing department computer system. The software component refers to the computer software used within the system and can be proprietary or open. The key features of SCADA software are user interface, graphic displays, alarms, trends, RTU (and PLC) interface, scalability, access to data, database, networking, fault tolerance and redundancy, and client/server distributed processing. The architecture of SCADA systems is of the third generation where use is made of the Wide Area Network (WAN) protocols such as the Internet Protocol (IP).

Laudable SCADA applications in electric power distribution and renewable energy systems have been reported in the literature in recent times. For the control of renewable energy sources, Camacho *et al.* (2011) considered the use of advanced data acquisition and control technologies for the control of solar and wind forms of energy generating stations to improve the reliability, security, interoperability and efficiency of the electrical grid while reducing environmental impacts and promoting economic growth. Sun tracking and temperature variations are constantly monitored by operators from remote distances in the case of solar systems whilst wind speed and wind directions are monitored and the turbines in wind turbine systems controlled accordingly. In Kim *et al.* (2011) the exploration of existing wind turbine SCADA data for development of fault detection and diagnostic techniques for wind turbines was discussed. Several measurements were taken to develop anomaly detection algorithms and investigated classification techniques using clustering algorithms and principal components analysis for capturing fault signatures. Anomalous signatures due to a reported gearbox failure are identified from a set of original measurements including rotor speeds and produced power. Madala *et al.* (2018) applied an effective SCADA system with wind and solar Distributed Generation (DG) as a management solution to monitor and control agriculture and irrigation loads in the Midwestern United States of America to achieve between 20 % and 43 % recovery in lost energy sales in two weeks. Two real-life cases were considered: one with and the other without SCADA and DG implementation.

On electric power systems, Almas *et al*. (2014), reported on the implementation of the web-browser based open source SCADA BR software in the Smart Transmission Systems Laboratory (SmartTs-Lab) at the KTH Royal Institute of Technology, Sweden with Power Monitoring Unit (PMU) integration thus enabling access to monitoring, control and automation equipment over multiple protocols. SCADA performance and features were evaluated using real-time hardware-in-loop simulations for a two-area four machine power system. Dhend and Chile (2015) gave an innovative scheme of a smart power grid distribution SCADA system. Simulation and hardware results demonstrated the effectiveness of the proposed system. Sharifian *et al.* (2015) used localised remote control switches and Very Inverse Time (VIT) automation switches to determine the level of automation in distribution networks. A case study gave improved results of six reliability indices indicators based on DIgSILENT software package simulations for SCADA with VIT as compared to SCADA only and without SCADA scenarios. Brito *et al.* (2016) implemented the Factory Internet Network Service (FINS) protocol to integrate Industrial Ethernet (IE) communication protocol via low cost electronic platforms for control and condition monitoring of electric power systems in a SCADA-deployed environment that require high level interoperability and critical time control of assets. Zhang and Diao (2018) used SCADA measurements to estimate the accurate value of network parameters for purposes of effective power system monitoring and control. Validity of their method was tested using the IEEE 118-bus system. Sangeetha *et al.* (2018) deployed SCADA as a testing platform for load balancing and reduction of human intervention in the execution of critical tasks towards the provision of fault detection, isolation and power restoration at a University campus in India.

Notably, use of Virtual Private Network (VPN) technology and SCADA for the continuous online monitoring of critical plant alarms was discussed by Kirubashankar *et al.* (2009). Reliability, response time, continuous remote real-time monitoring of plant interface under adverse environmental conditions were improved in maximising plant operational conditions. This paper basically focuses on the supervisory monitoring of the low voltage distribution system of the plant of a gold mining installation using the existing SCADA facility with an incorporated metering infrastructure.

2 Resources and Methods Used

2.1 Data Collection and Analysis

Secondary data were obtained on the electrical power distribution network of the mining company as presented in Fig. 1 and the existing SCADA topology of the same mining company presented in Fig. 2. The mine power distribution system is made up of two ringed 33 kV incomers, sixteen stepdown transformers, four substations, and two power factor correction stations positioned at various load centers and a sectionalised 8 km overland conveyor belt system meant to convey ore from the crushing plant to the processing plant. The total power demand is about 17.5 MVA. The main plant substation comprises three interconnected 10 MVA, 33/11 kV transformers taking their input from the two ringed 33 kV incomers. In the 11 kV switch room, bus bars of current rating 1250 A are used. Five Motor Control Centers (MCCs) are powered from 2 MVA 11/0.433 kV transformers and a fifth MCC has a power demand of 2.5 MVA.

In the existing SCADA topology of the process plant, all repeaters are linked to each other as well as to the SCADA master. PLCs are used for field control. The communication medium used between the PLC and the repeater is via an RS485 cable. Fiber optic cable is however used for the communication between repeaters on one hand and between the repeaters and the master SCADA. The existing SCADA architecture comprises the engineer's workstation, the Database Management Server (DMS), PLC and SCADA servers and the operator station forming the master station and the supervisory control. Field instrumentation devices are hardwired to the PLCs. PLCs communicate with the SCADA server via fibre optic cable using the Transmission Control Protocol/Internet Protocol (TCP/IP) through a repeater. The proposed system uses the same architecture as it helps to distribute the workload and the risk of communications or components failure.

2.2 Methods

The design of the proposed system is geared towards merging of the existing SCADA system with the power distribution network monitoring system. The designed system relies on the existing communication backbone, SCADA software and existing power line monitoring system. The existing power line monitoring system includes the use of remote energy meters which have no form of communication with the SCADA master. The architecture of the designed system was chosen based on certain factors such as reliability and availability. The components, however, were selected based on the parameters of the power distribution network and their ratings. The block diagram of the proposed system is given in Fig. 3, and the architecture of the proposed system is as shown in Fig. 4. Fig. 5 gives the network topology of the remote stations.

Field devices namely the Current Transformer (CT) and Potential Transformer (PT) sense current and voltage data respectively on the field and communicate it to the quality meters for data acquisition purposes. Repeaters form the intermediary between the RS 485 cables coming from the energy quality meters and the fiber optic network backbone. They facilitate switch over from the serial cable to fiber optic cable and also boost the communication signal.

2.2.1 Consideration and Selection of Components

Quality meters

Quality meters are the energy meters used for revenue-class power and energy metering, event logging, minimum and maximum logging, historical logging, expandable memory, sag and swell monitoring, harmonics measurement, waveform capture at 256 samples per cycle, set points, digital and analogue I/O, and internet-enabled multi-port communications. These form the data acquisition system of the proposed designed system. The quality meters considered are the Schneider electric power logic ION 7550 and ION 6200. The ION 7550 was positioned at the two main substations while all other substations had ION 6200 which communicates with the ION 7550. The power logic takes input from current transformers (CTs) and potential transformers (PTs) via eight standard digital and analog inputs. Meter communication is via the RS 485 network cable using the TCP/IP protocol.

The ION 7550 has a maximum voltage input of 600 V AC and 347 V DC. The overload voltage is 1500 V AC, maximum fault voltage is 1200 V and the input impedance per phase is given as 5 MΩ. For the current input the nominal current is 10 A, the maximum voltage is 600 V. The withstand voltage is 2500 V AC, 60 Hz for 1 minute. It has a burden of 0.05 VA per phase at a current of standard 5 A and impedance of 0.002 Ω per phase. The ION 6200 used has maximum input voltage rating of 400 V AC per phase and 103.5 V – 690 V line voltage. The overload rating is 1500 VAC and the dielectric withstand voltage of 3250 VAC rms at 60 Hz for 1 minute. The impedance per phase is 2 MΩ.

For current inputs the meter can afford a 10 A maximum current, an overload of 120 A for 1 second, and a dielectric withstand strength of 3000 V, for 1 minute. The starting current is 0.005 A and the burden stands at 0.05 VA at 5 A. Fig. 6 and Fig. 7 show a picture of the ION 7550 and the ION 6200 energy meters respectively.

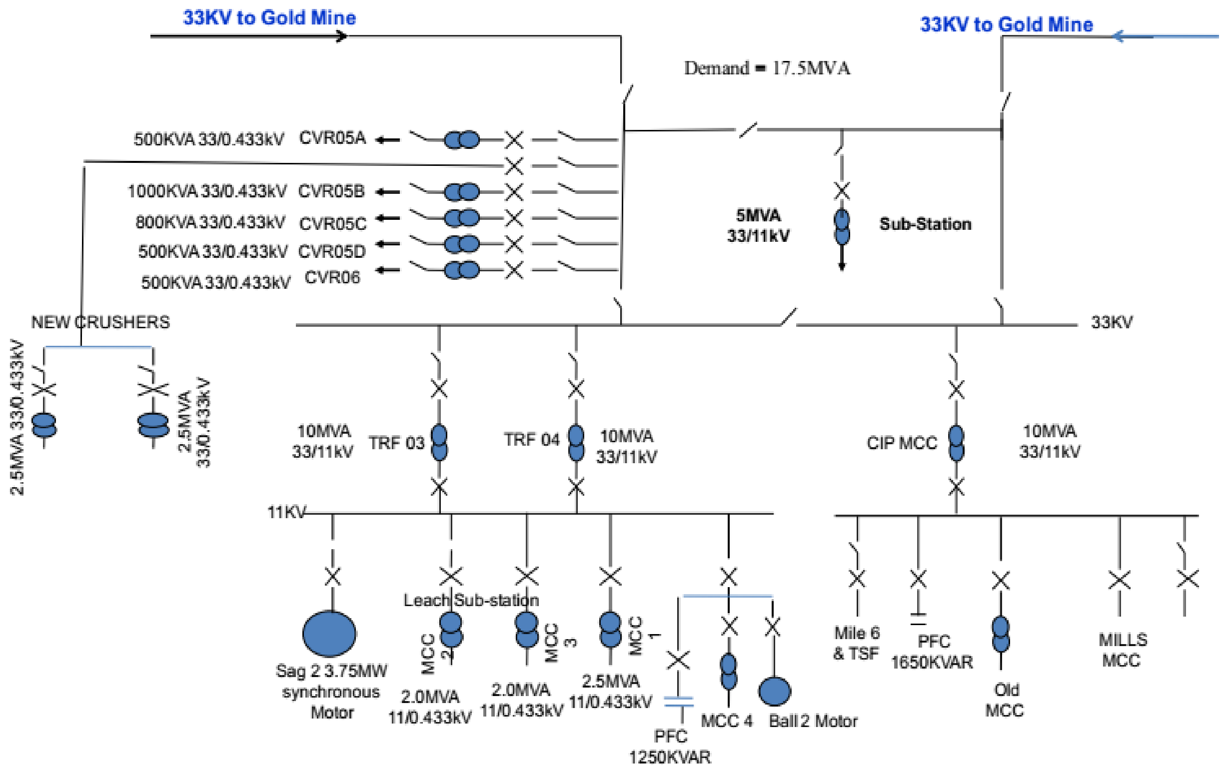

Fig. 1 Power Distribution Network of the Gold Mine

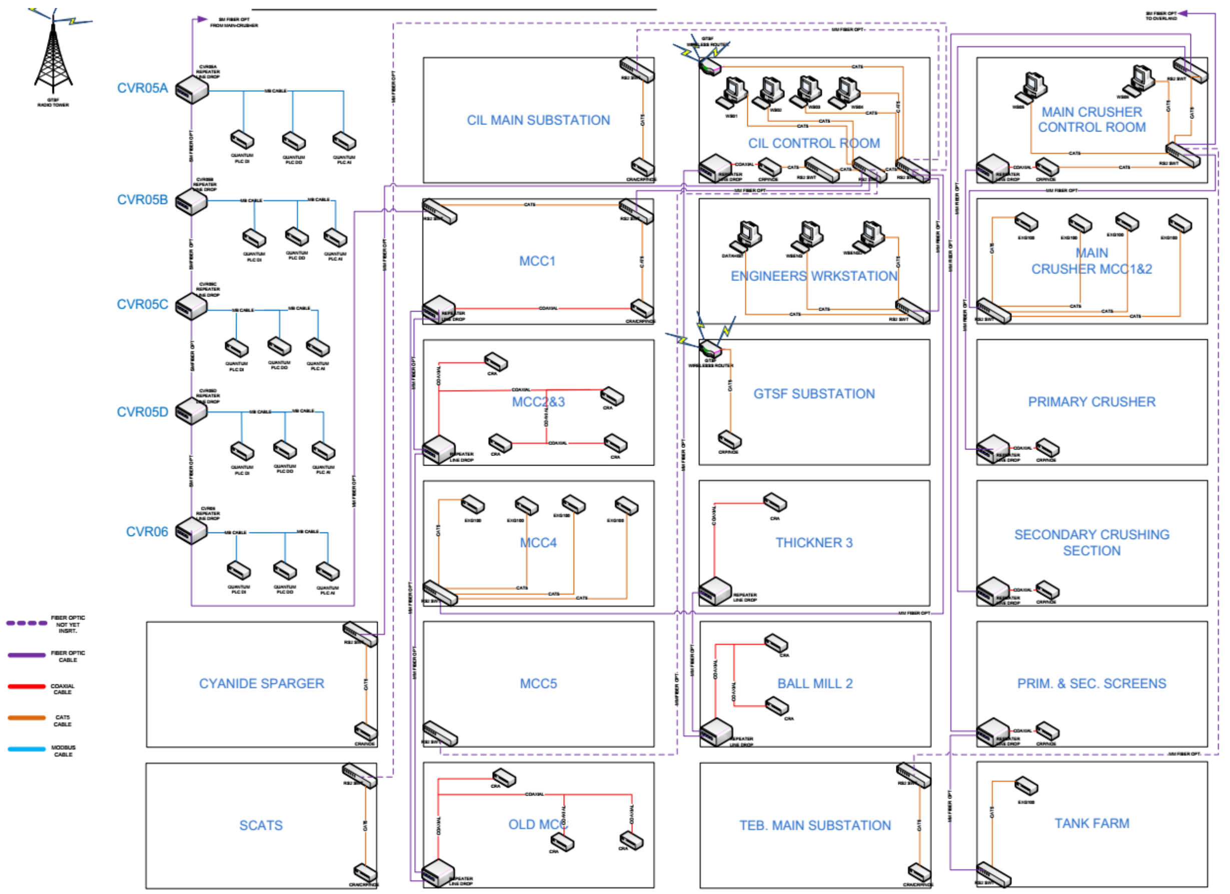

Fig. 2 A SCADA System Topology of the Gold Mine

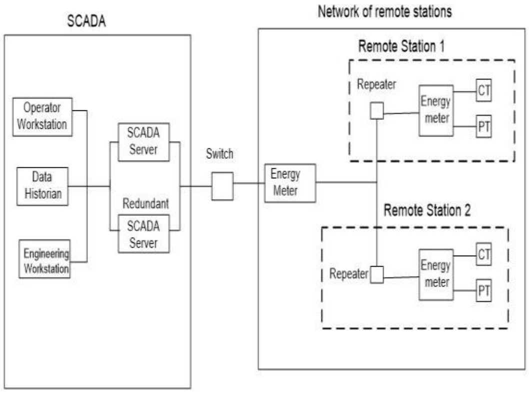

Fig. 3 A Block Diagram of the Proposed SCADA Monitoring System

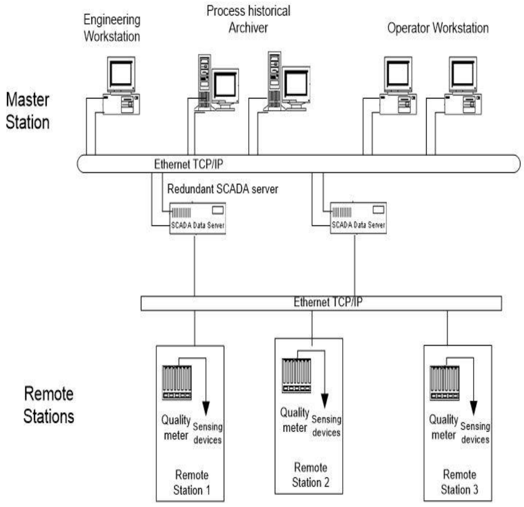

Fig. 4 Architecture of the Proposed SCADA Monitoring System

Current Transformers

The CTs used are basically for metering purposes. The choice of a particular CT was based on the rated primary current (load), rated secondary current, the CT ratio, the rated burden, the accuracy class, the accuracy limiting factor and system voltage. The insulation level and the error of the CTs were also considered in the selection process.

The nominal primary service current is computed using Equation (1) (Anon, 2019).

$$I_{ps} = \frac{S}{\sqrt{3} \times U_s} \qquad (1)$$

where, I_{ps} is primary service current in Amps, S is apparent power in VA and U_s is primary service voltage in V.

The rated thermal short circuit current I_{th} is calculated using Equation (2) (Anon, 2019).

$$I_{th} = \frac{P_{cc} \times 10^3}{U_s \times \sqrt{3}} \qquad (2)$$

Surge current coefficient, k_{si} is computed using Equation (3) (Anon, 2019).

$$K_{si} = \frac{I_{th\ per\ second}}{I_{pn}} \qquad (3)$$

The rated secondary current for use in a local situation I_{sn} = 5 A and for use in a remote situation I_{sn} = 1 A. An accuracy class of 0.5 in VA meant for the metering category was used. For the copper cable, effective power in VA that the CT must apply is computed by Equation (4) (Anon, 2019).

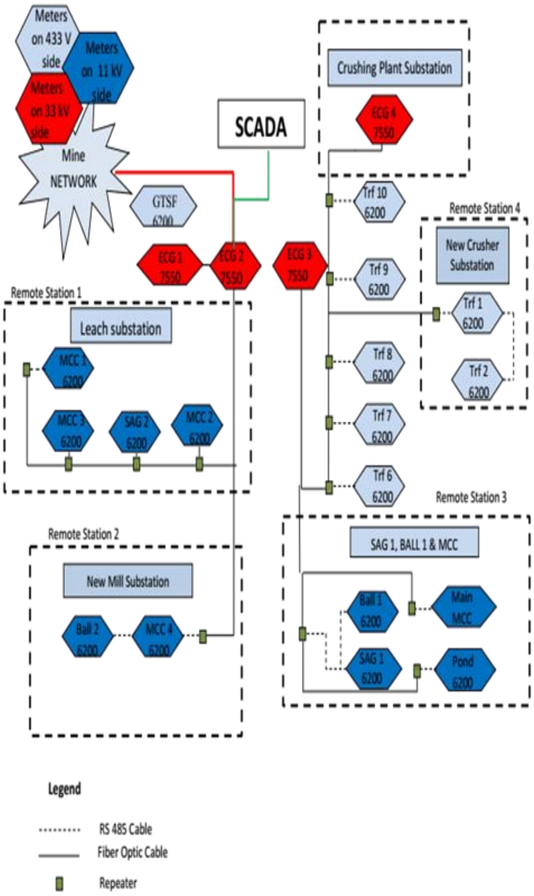

Fig. 5 The Network Topology of Remote Stations

$$VA = k \times \frac{L}{A} \qquad (4)$$

where, L is length of the connection cables (input/output loop) in meters and A is cross-section of cables in mm^2.

Rated burdens for accurate power range from 2.5 VA to 30 VA. The Safety Factor (SF) value is selected based on the short time current withstand of the receivers which lies between the values 5 and 10.

Fig. 6 A Picture of the ION 7550 Energy Meter

Fig. 7 A Picture of the ION 6200 Energy Meter

Potential Transformers

The PTs used in the remote stations are two-fold: The 2000 VA, 415/110 V types mounted in the MCCs for the powering of both equipment control circuits and energy meters; the second type being the incomer line located metering transformer meant to obtain input voltages for the energy meters. Factors considered in selecting the PTs are frequency, rated primary and secondary voltages, burden, accuracy class, insulation level voltage and the voltage ratio.

Considering the MCC 1 substation for instance, the current transformer used has a current ratio of 4000/5 A. No voltage transformer was employed as the line voltage is 415 V whilst the meter's maximum input voltage stands at 600 V. A 2 A fuse is connected in series with the energy meter on each phase.

2.2.2 SCADA System Programming

SCADA system programming involves the techniques used to achieve the desired SCADA functionalities. It includes the software considerations and configurations that aided in the actualisation of the SCADA monitoring system. In considering the software, the functionalities and the components of the software are considered. Under the software configurations the addressing system, limits settings and the HMI interface configurations are considered. The system programming was geared toward the retrieval of measured parameters from the meters in real-time.

The Wonderware™ SCADA software is used together with the Unity Pro XL™ PLC configuration software for the SCADA and the PLC applications, respectively. The software configurations included the tags development system, parameter settings and interface design. The tag names refer to a particular input. They indicate the kind of parameters and their locations. In configuring the system, certain values of the tags are set to serve as reference for the SCADA master. These form the tags dictionary of the SCADA software. The tags are linked to the Graphical User Interface (GUI) by linking each icon to a tag name.

2.2.3 Simulations

The system was simulated using the Wonderware ™ SCADA software and a real-time value generating system. Fig. 8 shows the simulated interface. The Wonderware ™ SCADA software provided SCADA functionalities based on the parameter values set and the SCADA algorithm represented in the flowchart shown in Fig. 9. The real-time value generating system refers to a programming loop created to serve as the real-time inputs received from the remote stations. This loop runs from the initial value and occasionally goes out of range to aid in the alarm generation process. The sample codes used are:

```
IF MCC_1_Vpr == 240 THEN
    MCC_1_Vpr = MCC_1_Vpr + 0.5;
    IF MCC_1_Vpr >= 240 THEN
        MCC_1_Vpr = MCC_1_Vpr - 0.008;
     ENDIF;
     ELSE
         MCC_1_Vpr =MCC_1_Vpr - 0.01;
         IF MCC_1_Vpr < 240 THEN
               MCC_1_Vpr = 240;
         ENDIF;
ENDIF;
```

3 Results and Discussion

3.1 Simulation Results

Simulation shows real-time values of power factor, current, voltage etc. of a substation are displayed. Also, parameter value deviations from safe limits and alarms are instantly displayed. Real-time phase monitoring of the substation is as indicated in the simulation results of Fig. 10. However, when the phase voltage limit was exceeded by ± 2 % (depending of owner's preference) an alarm popped up to indicate the type of fault and the location as shown in Fig. 11.

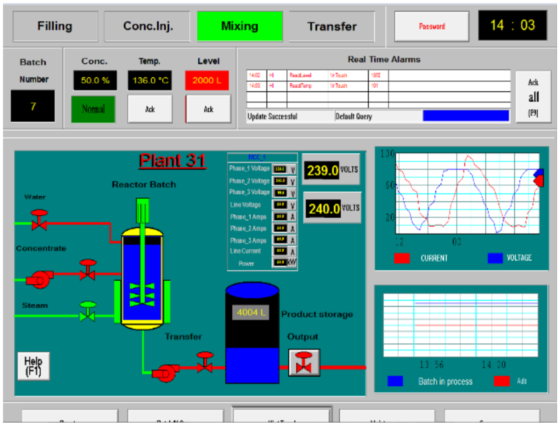

Fig. 8 The Simulated Interface

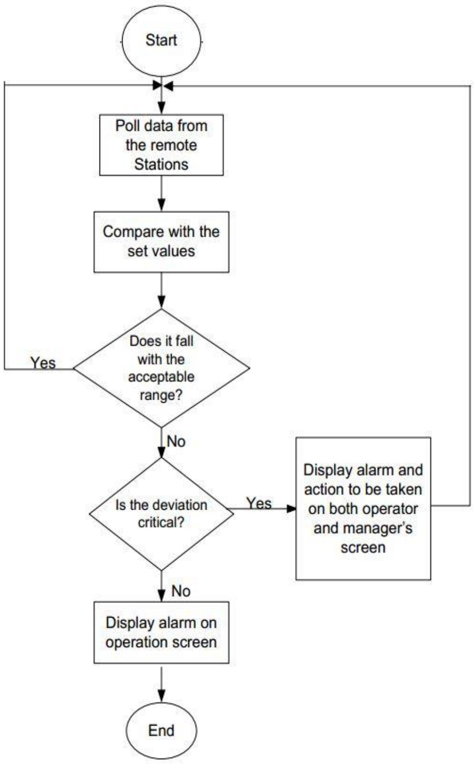

Fig. 9 The Flowchart of the Proposed System

3.2 Cost Analysis

Cost analysis considered the additional cost incurred as a result of the integrated metering system. With current and potential transformers already installed in remote stations, the summary cost is limited to the cost of energy meters and repeaters needed to enhance communication as shown in Table 1.

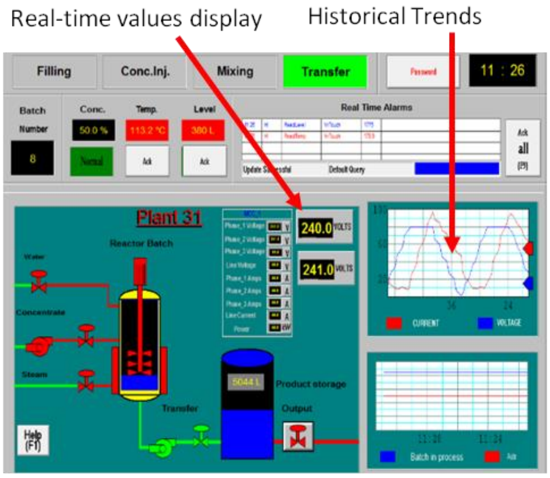

Fig. 10 The Simulation Results of the Gold Mine Monitoring System

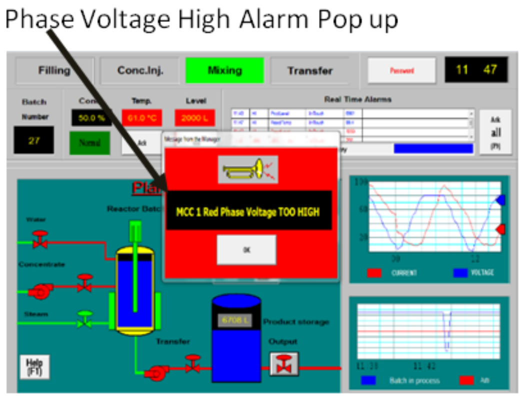

Fig. 11 A Simulation Result Showing the Fault Indication Display

Table 1 Cost of Required Components

Component	Quantity	Cost Per Unit ($)	Total Cost ($)
Energy Meters: i. ION 7550 ii. ION 6200	4 18	292.65 99.95	1 170.60 1 799.10
Repeaters	14	70	980.70
Estimated Total Cost			**$ 3 949.70**

3.3 Discussion

The results discussed are mainly focused on what the operator sees, and the historical performance obtained from the DMS. The real-time display of the various parameters enabled constant monitoring of the substation performance and hence, eased troubleshooting. Also, for a particular equipment or substation, the energy consumed could be compared with the revenue earned for the particular equipment and this may give management a more informed decision-taking base. At a cost of $3949.70, the mining company should be able to remotely monitor the power distribution network in real-time and at the same time monitor the power quality and implement a remote metering system.

4 Conclusions and Recommendation

Using the existing SCADA structures, a workable remote monitoring of the power distribution network was achieved. This system resulted from the incorporation of a metering system into the existing SCADA system. With this system enhanced, troubleshooting of power distribution related issues, better energy metering infrastructure and a more efficient power network monitoring can be implemented at reduced cost. Also, management gets access to enough decision-taking information to facilitate planning. It is worth recommending that mining and allied companies should consider a SCADA-based control of their power distribution network; and Power Distribution Services should also adopt this monitoring system for their distribution networks to aid in troubleshooting processes.

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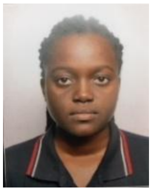

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