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CENTRALISED MONITORING AND CONTROL DISPATCH CENTRE FOR THE GEOTHERMAL WELLHEAD POWER PLANTS IN KENYA

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ABSTRACT

Wellhead geothermal power plants in Kenya's Eburru and Olkaria geothermal fields are mostly located in remote and inconvenient places. These plants are located far apart from each other making operation and maintenance expensive and a challenge. Remote monitoring and control of these units will enhance the power plants availability, reduce maintenance, operational, and other related costs. Supervisory control and data acquisition (SCADA) systems are used to monitor and control geographically dispersed plants. A good SCADA technology with a good communication infrastructure will enable the collection of real time data from all these scattered wellhead power plants to one control room. The real time monitoring and control of KenGen's wellhead power plants in a centralised control centre will assist with rapid detection of faults, diagnosis and repair so that downtime of the units due to faults can be reduced, thereby increasing availability and efficiency. Design of a centralised SCADA system and communication network for the wellhead units and economic and financial analysis of this project is discussed in this paper. Optimisation of operation and maintenance costs without compromising safety and technical performance of a power plants is also discussed.

1. INTRODUCTION

Kenya Electricity Generating Company, Ltd. – KenGen produces 80% of the electricity consumed in the country. The company utilizes various sources to generate electricity ranging from hydro, geothermal, thermal and wind. The east African rift passes through Kenya and this is the main reason why the country is vastly endowed with geothermal resources. Commercial generation of geothermal electricity in Olkaria started in 1981. Today (late 2016), the installed capacity of geothermal power plants in the area is about 673 MWe. The rapid economic growth and industrialization in the country accelerated the need for drilling more geothermal wells, as well as avoiding dependence on hydro power plants. Long droughts resulted in reduced power production from the hydro power plants and leading to high reliance on expensive diesel engines. In 2010, KenGen embarked on execution of developing geothermal wellhead plants under a *Research and Development Programme* culminating in the successful implementation of a pioneer plant in early 2012. Now, the total installed capacity amounts to about 84 MW. Wellhead power plants are small modular plants installed next to a wellhead. The plants have a shorter construction time, are modular and can be relocated to newly drilled wells.

Following reservoir productivity by monitoring over time during operation helps to gather data to access the potential of the resource. The units are used to generate power to the grid during resource development of a large project and for utilization of wells that have small-scale application potential.

2. OVERVIEW OF OLKARIA GEOTHERMAL WELLHEAD POWER PLANTS

2.1 Description of the location of Olkaria geothermal wellhead power plants

The first geothermal wellhead plant was located in the Eburru geothermal field, located in Kenya’s rift valley approximately 140 km from Nairobi, 11 km northwest of Lake Naivasha. The field is located to the north of Olkaria at the foot of the Mau escarpment. The Eburru and Olkaria geothermal fields are about 40 km apart. Surface exploration studies at Eburru were done in the early 1980’s, with four wells drilled by KenGen between 1988 and 1994. For the pilot plant, well EW-01 was selected to serve as the production well (GDA, 2011). Geothermal Development Associates (GDA) from Reno, Nevada, USA commissioned the Eburru wellhead station in 2012. The modular power plant has an installed capacity of 2.44 MW.

Olkaria geothermal field, which is estimated to be approximately 80 km², is divided into seven sectors: Olkaria East, Olkaria Northeast, Olkaria Central, Olkaria Southwest, Olkaria Northwest, Olkaria Southeast and Olkaria Domes (Ouma, 2007). Wellhead power plants have been installed in the Olkaria Domes, Olkaria East and Olkaria Northeast fields (Figure 1).

The Olkaria OW37 wellhead power plant, which has a design generation capacity of 5.5 MWe, was commissioned in January 2012 (Table 1). It was the first plant installed by Green Energy Geothermal,

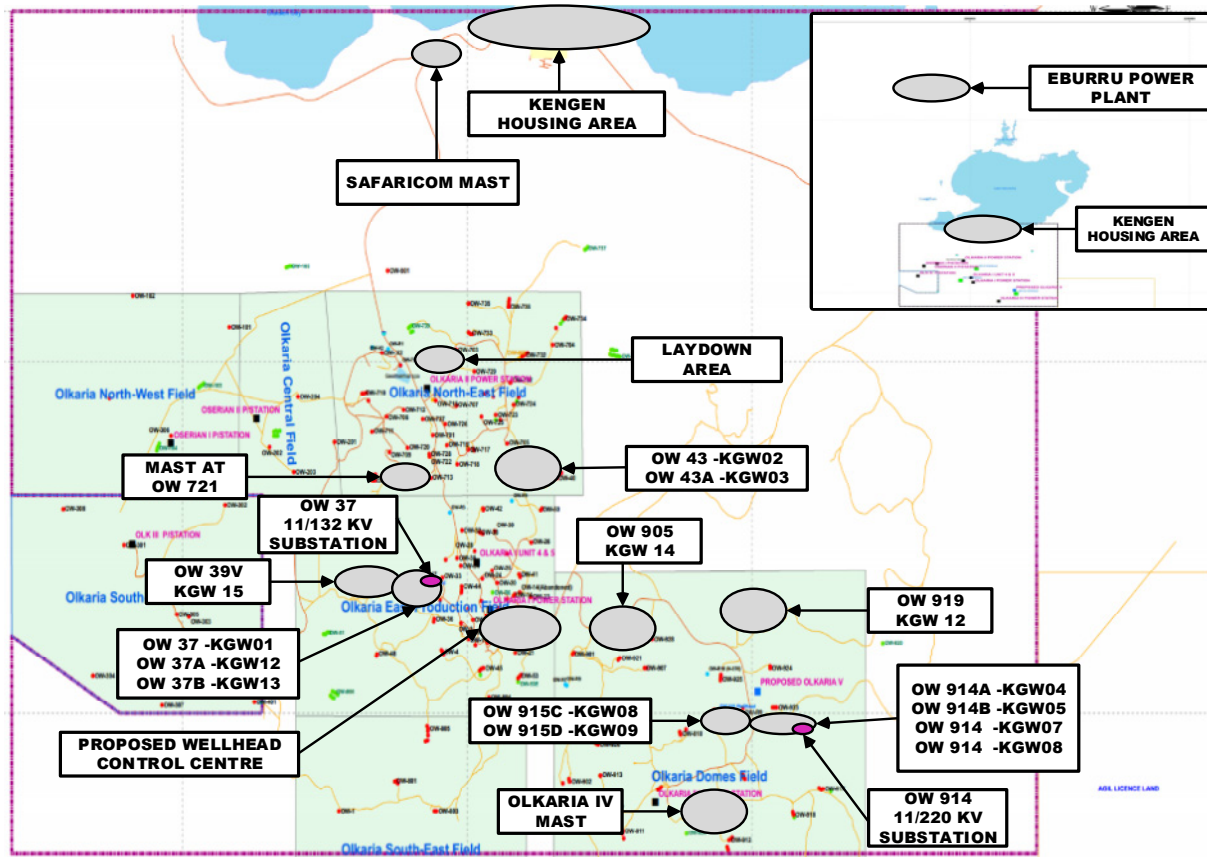


FIGURE 1: Map showing location of wellhead power plants, and associated stations

TABLE 1: Wellhead power plants key information

| Field | Well | Wellhead no. | Plant model | Installed power [kW] | Year installed |
|--------------------|---------|--------------|----------------------|----------------------|----------------|
| Eburru | EW-01 | EBURRU | Elliott Model DYRPE8 | 2440 | 2012 |
| Olkaria east | OW-37 | KGW01 | C64 | 5500 | 2012 |
| Olkaria North East | OW-43 | KGW02 | C64 | 6400 | 2013 |
| Olkaria North East | OW-43A | KGW03 | C64 | 6400 | 2013 |
| Olkaria domes | OW-914A | KGW04 | C64 | 6400 | 2013 |
| Olkaria domes | OW-914B | KGW05 | C64 | 6400 | 2014 |
| Olkaria domes | OW-914 | KGW06 | C50 | 5000 | 2014 |
| Olkaria domes | OW-914 | KGW07 | C50 | 5000 | 2015 |
| Olkaria domes | OW-914C | KGW08 | C50 | 5000 | 2015 |
| Olkaria domes | OW-915C | KGW09 | C50 | 5000 | 2015 |
| Olkaria domes | OW-915D | KGW10 | C50 | 5000 | 2015 |
| Olkaria domes | OW-919A | KGW11 | C50 | 5000 | 2016 |
| Olkaria east | OW-37A | KGW12 | C50 | 5000 | 2016 |
| Olkaria east | OW-37B | KGW13 | C50 | 5000 | 2016 |
| Olkaria domes | OW-905 | KGW14 | C50 | 5000 | 2016 |
| Olkaria east | OW-39 | KGW15 | C50 | 5000 | 2016 |

Iceland. Since then, a total of 16 wellhead plants have been installed for KenGen, and a total of 21 turbines (Figure 2). The total installed capacity is 83.54 MW.

2.2 Wellhead power plant models

Eburru power plant has an 8-stage, axial flow turbine Model DYRPE8 manufactured by the Elliot company, Jeanette, PA. It is a single-flash geothermal power plant. The gas extraction system has only a single-stage gas extraction using a liquid ring vacuum pump due to the relatively low non-condensable content (Mendive and Green, 2012). Green Energy Geothermal (GEG)

has two types of wellhead power plants installed in the Olkaria geothermal field: C50 and C64 wellhead units. The C50 single turbine setup is a modular type geothermal wellhead power plant, which consists of a single turbine generator unit (1×5 MW) that operates on one single steam and condensing system. The C64 plant consists of two identical turbine and generator (TG) units (2×3.2 MW) that operate on one single steam system and two separate condensing systems. The two types of plants consist of four main systems:

- Steam system;
- Condensing system;
- Turbine Generator set;
- Electrical & Control system.

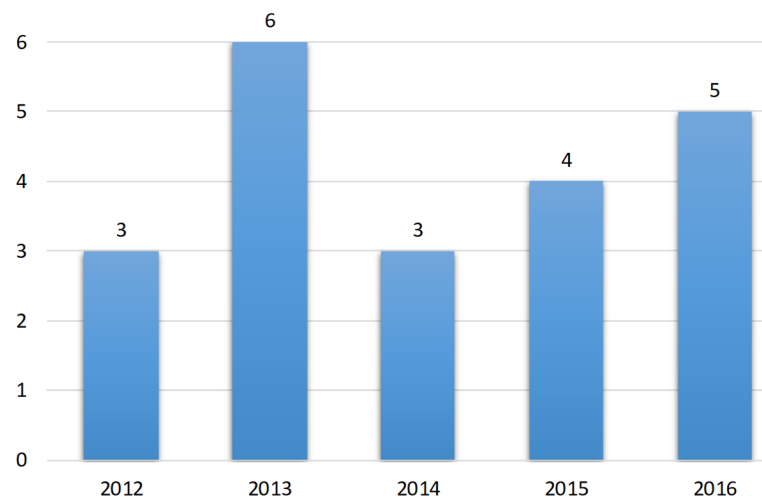


FIGURE 2: Installed wellhead power plants – historical development

Steam is discharged from the well and supplied into the steam separators. The separators remove any liquid, droplets or mist from the steam before it enters the turbine. The steam is then expanded through the turbine. In the condenser, the steam is mixed with cooling water, which condenses the steam creating the desired back-pressure vacuum. The condenser further cools down non-condensable gases that are extracted with a two-stage steam ejection system. The condensed steam/cooling water mixture is then pumped in to the cooling towers where it is cooled down and re-used as coolant.

3. CONTROL AND PROTECTION HARDWARE ARCHITECTURE

The protection relays and control equipment used in the wellhead power plants come from different manufacturers and are designed with a complete line of protection and control (Table 2).

TABLE 2: Wellhead units' control and protection equipment

| | Plant PLC | Generator protection relay | Digital excitation control system | Steam turbine control (Governor) | 11 kV transformer protection relay | Feeder protection |
|--------|--|--|-----------------------------------|----------------------------------|------------------------------------|---|
| Eburru | Productivity 3000 programmable automation controller (PAC) | Basler electric BE1-11G | Basler electric DECS-200 | WOODWARD 2301D-ST | Basler electric BEI-CDS220 | SEPAM S80 |
| OW37 | Siemens Simatic S7 300 | Unit 1: WOODWARD MFR32 Unit 2: Siemens SIPROTEC 7UM62 | Basler electric DECS-200 | WOODWARD 505 | Electro-mechanical relays | 11 kV circuit breaker: WOODWARD MRA4 33 kV circuit breaker: WOODWARD MRDT4 |
| C64 | Siemens Simatic S7 300 | Siemens SIPROTEC 7UM62 | Basler electric DECS-200 | WOODWARD 505 | SEL 787 | SEL 751A |
| C50 | Siemens Simatic S7 1500 | SEL 700G | Basler electric DECS-250 | WOODWARD 505 | SEL 787 | SEL 751A |

3.1 Wellhead power plant protection scheme

The main function of a protection system in a power plant is to detect and isolate faults occurring in a power system. Generators and transformers can be subjected to internal or external faults or both. Faults occurring in the power system should be cleared as soon as possible to avoid expensive equipment damage and failure while maintaining system performance and increasing availability of the plants. The main equipment protected are the generators, transformers and feeders.

3.2 Excitation control system

The excitation control system of a generator is used to control the generator's terminal voltage as well as the generator's reactive power (MVAR) output. The level of DC excitation current supplied to the field winding determines the generator's terminal voltage and reactive power output. The digital excitation system has been interfaced with the plant's control system via digital input/output cards. The Basler Digital Excitation system (DECS 200 and DECS 250) installed in the Olkaria and Eburru geothermal wellhead units have four control modes:

- Automatic voltage regulations;
- Manual or field current regulation (FCR);
- Power factor regulation (PF);
- Reactive power regulation (RP);

3.3 Turbine governor

The WOODWARD governor system drives the steam turbine valves to control turbine parameters. The main controlled parameter is speed (or load). The WOODWARD communicates directly to the plant control system and the Human Machine Interface (HMI) through Modbus communication ports.

3.4 Turbine supervisory instrument – TSI

Information provided by the TSI units is very critical and ensures that the turbine generator is operating within the safety limits. The parameters monitored by the TSI are: turbine generator bearing vibrations, rotor eccentricity, high-pressure turbine casing expansion, high-pressure and low-pressure turbine axial differential expansions, shaft axial position, assorted turbine generator temperatures, turbine speed (over speed and zero speed) and steam valve position. Vibration monitoring is very critical. The aim is to detect defects early by analysing changes in the vibration condition of the equipment during operation (Karani, 2008). The information is trended over time and analysed to detect defects or anomalies.

3.5 Olkaria geothermal wellhead power plant Distributed Control System (DCS)

3.5.1 Eburru power plant control system

Eburru plant control and monitoring system is networked on an Ethernet backbone (Figure 3). The network allows connected devices to communicate using several Transmission Control Protocol (TCP) protocols including Modbus TCP and Transmission Control Protocol/Internet Protocol (TCP/IP) (GDA, 2011). The Programmable Logic Controller (PLC) monitor and control plant systems, issue alarms and trips, and provide real-time data to the Human Machine Interface (HMI) and historical data server. Remote Input/output (I/O) Systems are used to minimize field wiring. They collect data between the plant instrumentation and the PLC. These remote I/O systems are located remotely near the field instrumentations. Energy meters via current transformers and voltage transformers provide accurate and real-time power information to the PLC and the operators via the HMI. The intelligent motor starters and controllers are used to start and stop motors and display motor status information to the PLC. Generator Management Relay (GMR), which is a generator protection relay, monitors the generator status, alarms and trips isolating the generator when there is a fault in the system. GMR functions independently from the PLC, but sends its status to the PLC for monitoring.

3.5.2 Green Energy Geothermal C64 wellhead power plants control system

The plant is run by a Siemens SIMATIC S7 300 PLC controller (GEG, 2015a). The PLC controller handles supervisory control and data acquisition for all signals and devices from the plant's systems. Signals to this PLC are read from the Ethernet communication bus from devices through MOXA MGATE 41101-MB-PBS gateway, which provides a communication portal between Profibus PLCs (Siemens S7-300) and Modbus devices (Figure 4). The rest of the signals are transmitted via a redundant Ethernet link to and from the PLC. A 19" SIMATIC human machine interface touch screen is installed at the panel door.

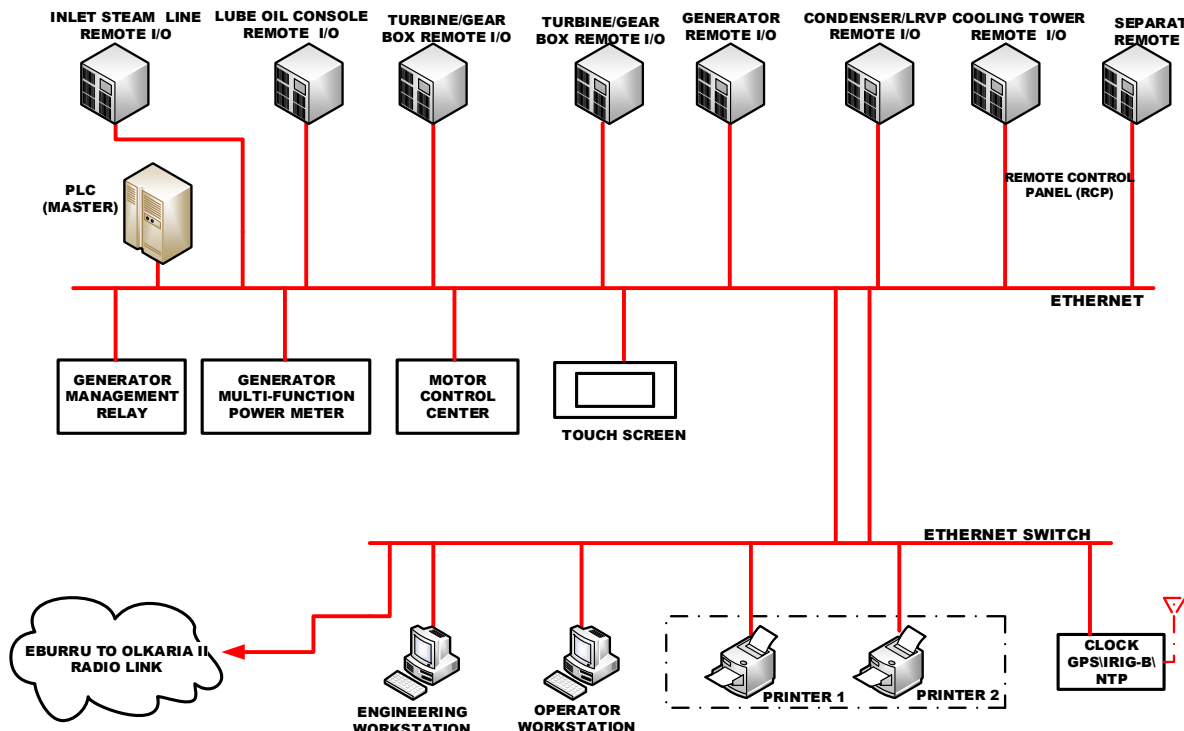


FIGURE 3: Eburru control system architecture

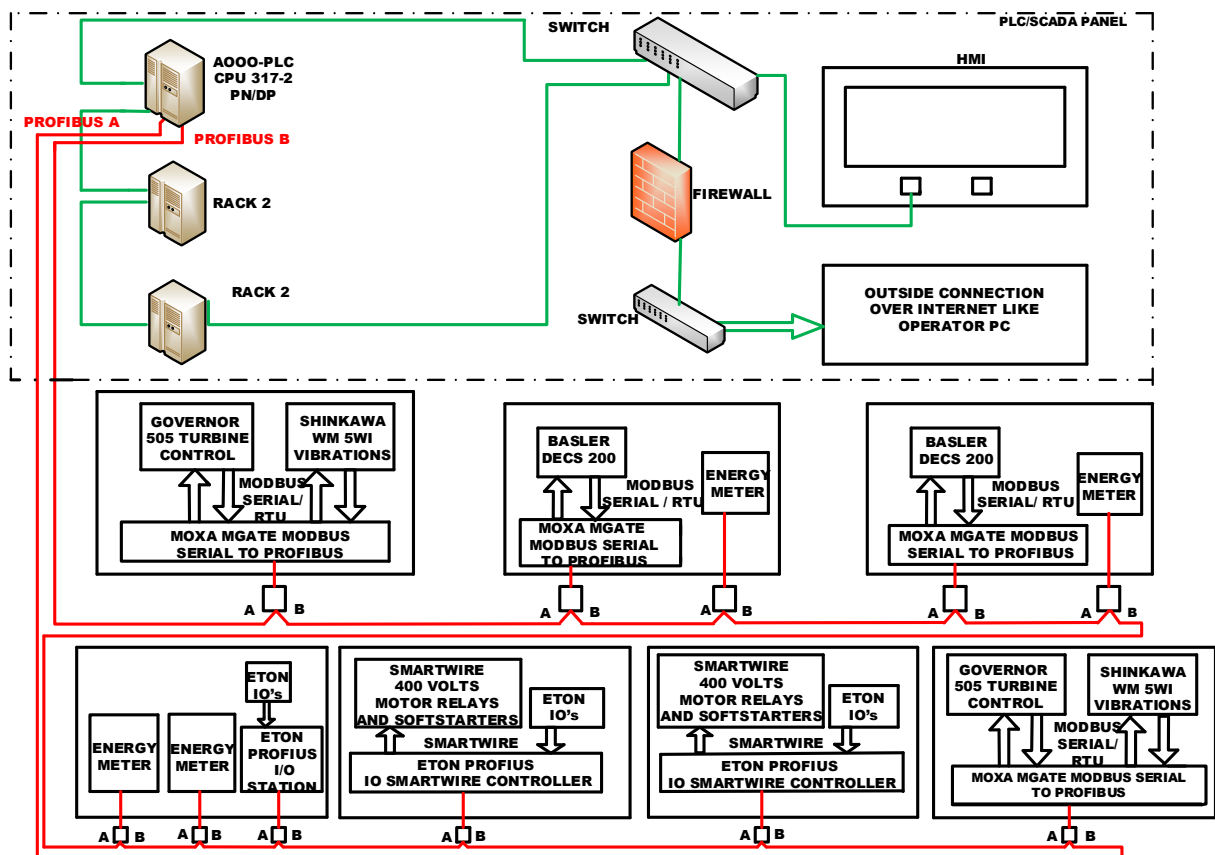


FIGURE 4: C64 wellhead unit control system

3.5.3 Green Energy Geothermal C50 well head power plant control system

The plant is run by a Siemens SIMATIC S7 1500 PLC controller. The C50 wellhead units' plant control elements are connected together through communication buses (Modbus TCP/IP) to form a distributed control system (Figure 5). The common PLC controller handles supervisory control and data acquisition for all signals and devices from the plant's common systems. Signals from instruments used for protection purposes of the steam supply system are hardwired to the electronic control unit where electrical marshalling cubicle are located, while the rest are connected to a remote-IO and transmitted via a redundant Ethernet link to and from the PLC (GEG, 2015a). Other signals to this PLC are either connected to IO cards located in the PLC rack or read from the Ethernet communication bus from other devices: DC distribution panel, AC distribution panel (PLC) or feeder Protection relay. A 19" SIMATIC human machine interface touch screen is installed at the panel door. The unit control system PLC controller handles all unit systems signals and devices. Signals from the cold end are routed through a terminal box and signals from instruments are connected to a remote-IO and transmitted via a redundant Ethernet link to and from the PLC. Turbine signals are routed through a turbine terminal box, protection signals from various instruments are hardwired to the ECU, while the other signals are connected to a remote-IO and transmitted via a redundant Ethernet link to and from the PLC (GEG, 2015a). Other signals that originated from the ECU itself to this PLC are either connected to IO cards located in the PLC rack or read from the Ethernet communication bus from vibration monitoring system, excitation control and generator protection relay.

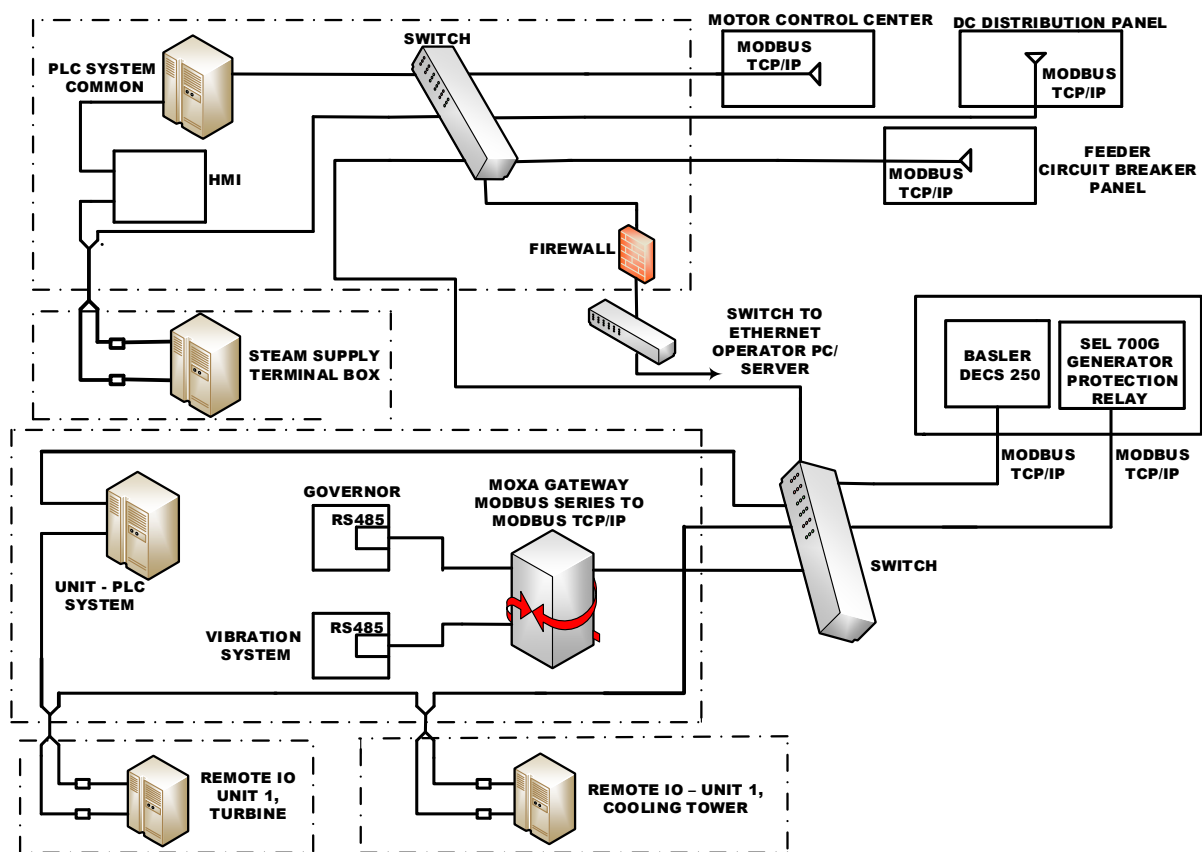


FIGURE 5: C50 wellhead unit control system

3.6 OW914 substation automation

A SEL-3530 Time Automation Controller (RTAC) is used as a protocol gateway and a Remote Terminal Unit (RTU) in OW914 to collect downstream data from all the relays connected to OW914

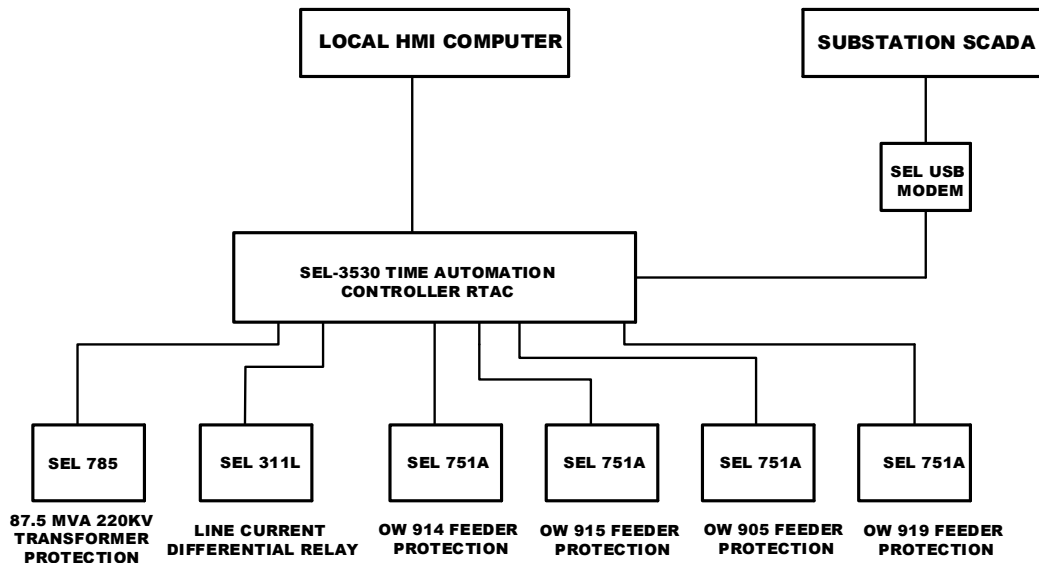


FIGURE 6: Substation automation

substation (Figure 6). These relays, which are used to protect the feeders and transformers are:

- SEL 311L line differential relay at OW914;
- SEL 311L line differential relay at Olkaria IV substation;
- SEL 787 transformer protection relay at OW914;
- OW915 feeder protection relay SEL 751A at OW914;
- OW919 feeder protection relay SEL 751A at OW914;
- OW905 feeder protection relay SEL 751A at OW914;
- SEL energy meters.

The RTAC uses IEC61850 GOOSE protocol to collect data from these relays. The messages are then converted to Distributed Network Protocol (DNP3) for connection to the SCADA. RTAC has been used as the substation SCADA data concentrator, logic processor and to collect station-wide sequential events records, events report and metering updates. This enhances system reliability providing more and better information to the operator.

3.7 Existing wellhead communication network architecture

3.7.1 Eburru radio link network

A 30 km point to point radio link over water from Eburru power plant to KenGen housing site has been implemented. A Safaricom radio tower is located near the housing unit. Two Nano station M5 radio transceivers have been installed at both Eburru power plant and on top of the Safaricom radio tower. Additionally, two rocket dishes 5G-30 are installed on top of the tower and the geothermal housing site. There, an existing fibre Ethernet cable is connected to Olkaria II power plant. At Olkaria II power plant, the fibre Ethernet cable is converted to a copper Ethernet cable connected to an operator station. Time synchronization between the two network levels has been coordinated. Time synchronization is essential to ensure all alarms and events are recorded in a sequential manner to help in emergency response and fault finding activities.

3.7.2 C64 and C50 wellhead units' communication network

Radio is used as the media of communication. Radio links exist from OW914, OW905, OW919 and OW915 to the Olkaria IV radio mast, and from OW43, OW37, OW39 to a radio mast at OW721 (Figure

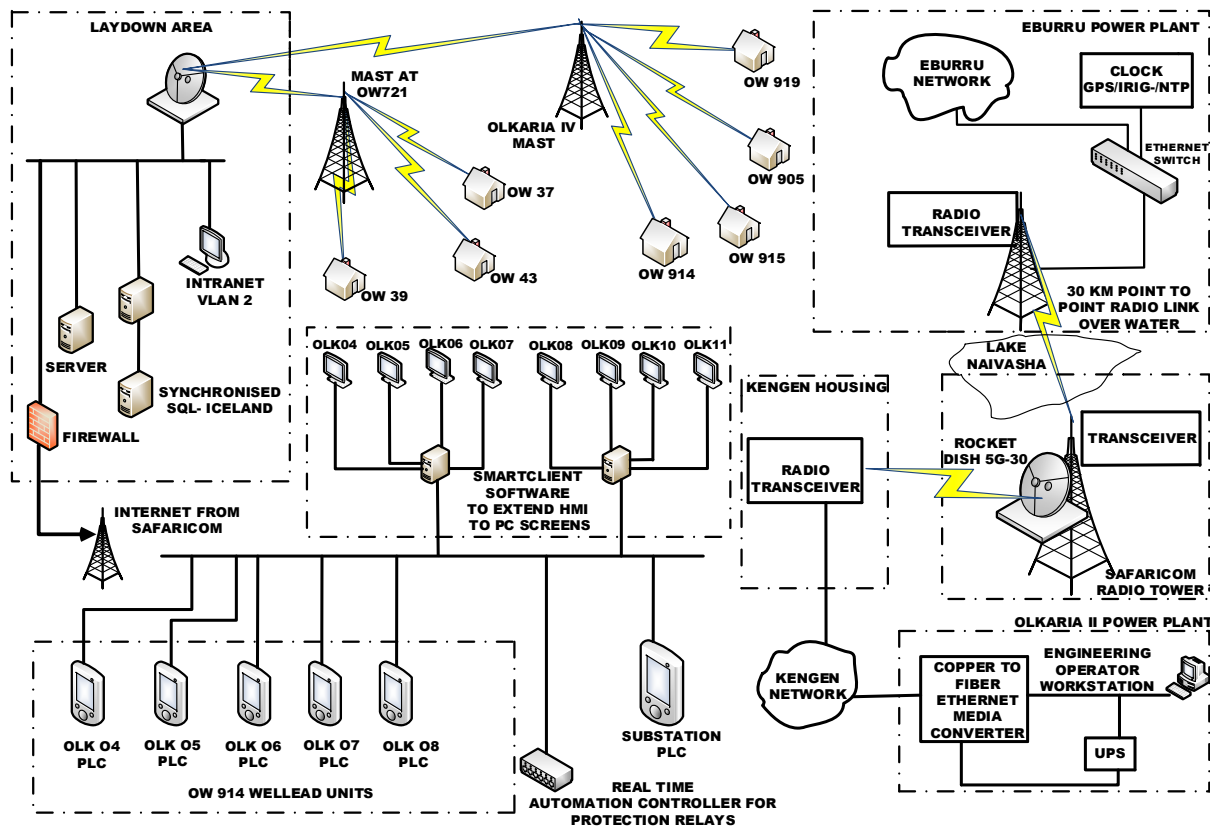


FIGURE 7: Wellhead units' telecommunication network architecture

7). There is another radio link from OW72 to the laydown station. At OW37 well pad, wellhead OW37A, 37B, OW39, OW37 are all connected to the same Virtual Local Area Network (VLAN). These plants are able to be remotely accessed from OW37 as a Siemens remote viewer is connected to an individual local HMI in each plant. At OW914, monitoring of OW915, OW905 and OW919 is also possible through remote desktop. Currently there is no GPS clock for the C64 and C50, making fault finding difficult and even impossible as time is not synchronised. GEG owns the current communication network and KenGen needs to negotiate the take-over of the network.

3.8 Olkaria geothermal power evacuation

The typical design of the wellhead power plants is such that the station auxiliary transformers are connected to the system side of the synchronizing circuit breakers. The separation point between KenGen and Kenya Power who are the grid operators is the high voltage bushing of the generator step-up transformers. Bulk energy meters capable of capturing both export and import energy are located at the separation points. At Eburru, power is generated at 11 kV and stepped to 33 kV through a 3000 kVA transformer before evacuation. The station has a 300 kVA Auxiliary transformer connected to the associated 415 V auxiliary supply board through a 415 V circuit breaker. For wellhead power plants located at Olkaria East production field: OW37, OW37A, OW37B and OW39 generation is at 11 kV channelled to the 11kV bus bar at the OW37 substation. The 11 kV is then stepped up to 132 kV via a 45 MVA 11 kV/132 kV transformer and evacuated to Olkaria I substation. Power from the OW43 units is evacuated to a 33 kV network. There is a proposed plan to step down the 33 kV to OW37 substation after which it is stepped up to 132 kV to Olkaria I substation. At the wellhead power plants located at Olkaria Domes field: OW914, OW905, OW915 and OW919 11 kV generated power is evacuated from OW914 substation 11 kV bus bar via an 87.5 MVA 11/220kV step-up transformer to Olkaria 4 substation. Figure 8 shows the Olkaria geothermal wellhead units' power evacuation scheme. Proposed future wellhead projects are also shown.

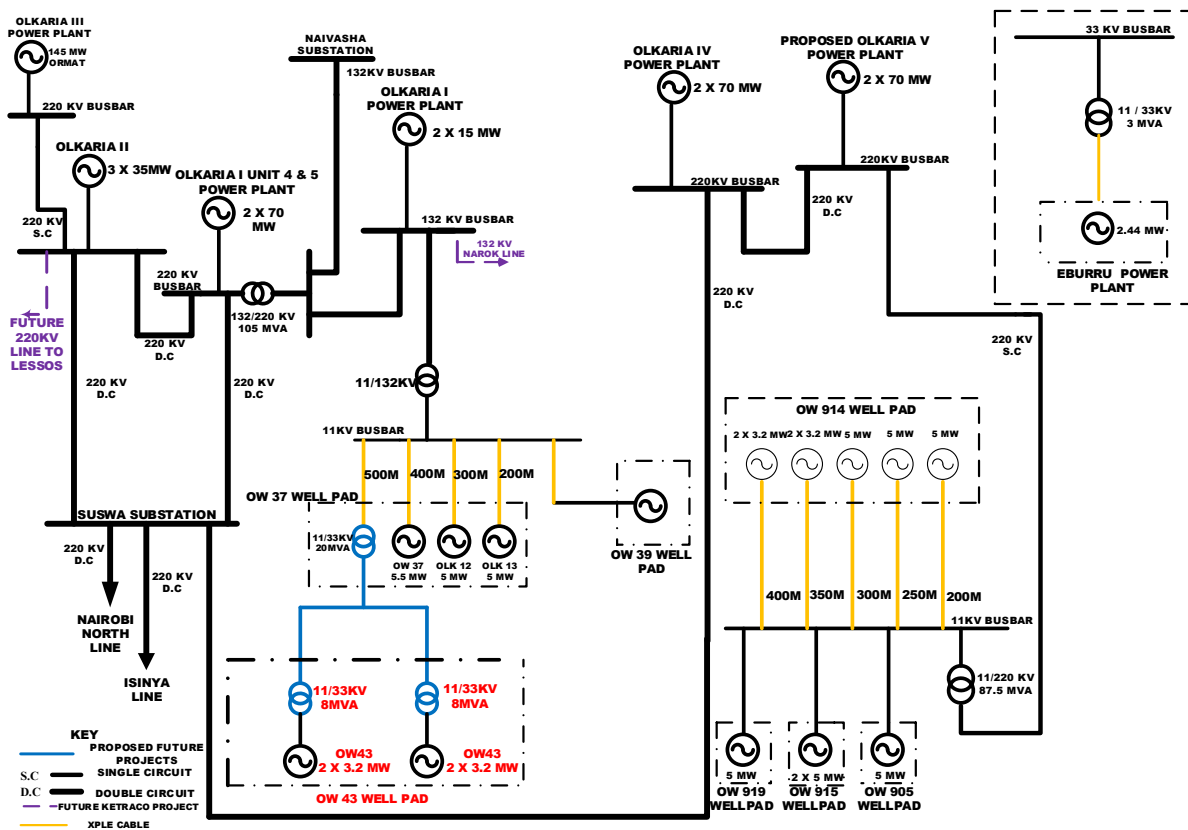


FIGURE 8: Olkaria geothermal wellhead units’ power evacuation scheme

4. NEED OF SCADA MONITORING AND CONTROL CENTRE FOR THE WELLHEAD UNITS

4.1 Improved plant availability and reduced process operating and maintenance costs

The geothermal wellhead units are located in remote and inconvenient places. Therefore, it is important to install remote control and monitoring system in a centralised control centre. Also Closed Circuit TV (CCTV) is becoming popular for remote monitoring of geothermal power plants. (Magnússon, 2003). The wellhead centralized monitoring and control centre will streamline the geothermal area operations and optimise staff utilization. This will reduce the cost of operation and maintenance and prepare for ongoing market shifts and changes in Power Purchase Agreement (PPA) requirements. Different power plants control systems are connected via communication links to a SCADA in a conveniently located control centre. The real time monitoring of the wellhead unit’s entire operation will assist with rapid detection of faults so that outage times due to faults can be reduced thereby increasing the availability and efficiency of the power plants. Careful consideration of all factors affecting plant availability is needed when planning for remote control (Magnússon, 2003). Operation of a geothermal power plant includes:

- Overall control and monitoring of the whole power plant;
- Adjust controls to regulate the power flow from the plant and coordinate with the grid operator;
- Cold and hot start-up of a power plant;
- Emergency shutdown of the plant in case there is a problem with any of the systems;
- Safe shutdown of the plant;
- Read and maintains logs, i.e. charts, energy meters and gauges to monitor voltage and electricity flow;
- Take hourly and shift checks of running equipment to ensure proper running of various systems.

The operators are responsible for maintaining power plant components to ensure the safety of both the plant and the personnel and to optimize the plant output and availability. They usually work on rotating shifts of 12 hours. The wellhead units have totally 84 staff members, 64 of which are operators (Figure 9). A separate centralized team of electrical, instrumentation and control engineers gives support during breakdowns and planned outages. Having one remote centre will reduce the number of operators to minimize the cost to an absolute minimum. Figure 9 shows the organizational structure.

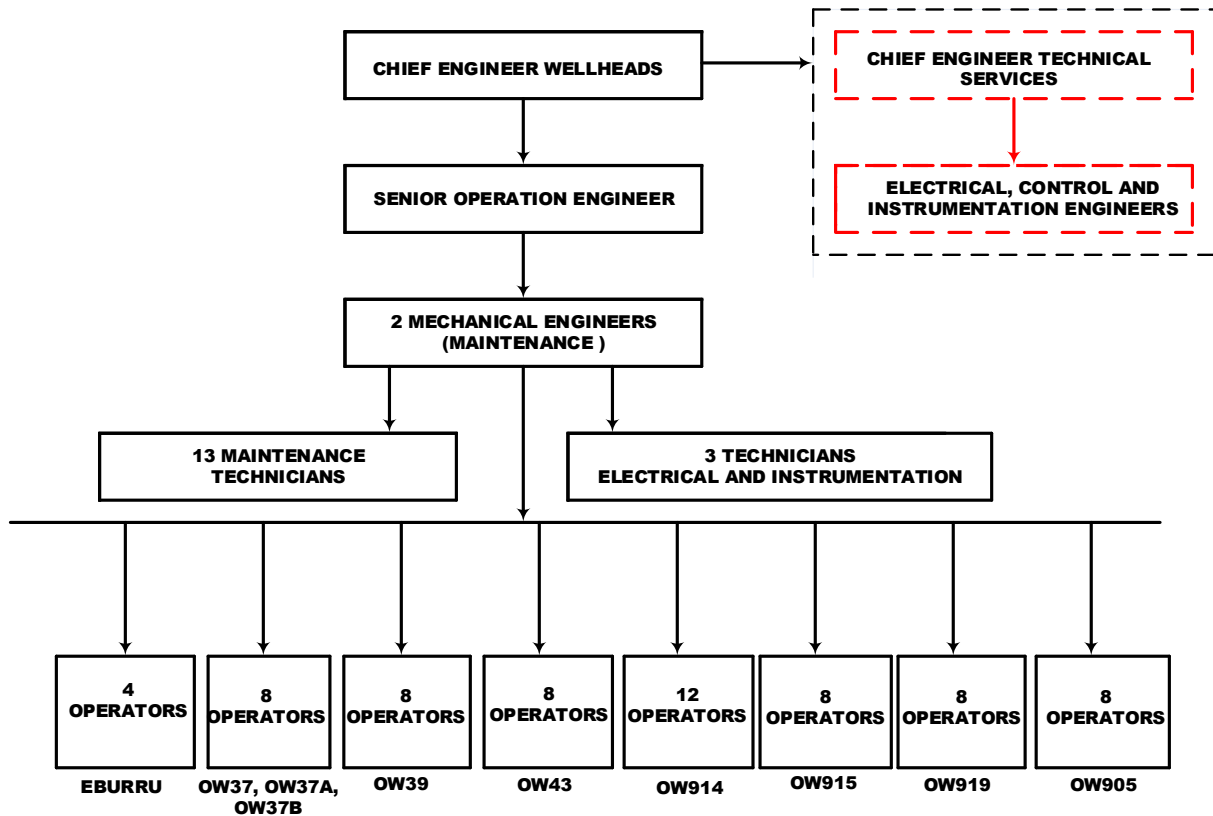


FIGURE 9: Wellhead organizational structure

It is quite common for plants, which have been operated locally for some time without remote monitoring and control that some actions require manual operator intervention since some equipment or automation functions are not working properly anymore. Some of these malfunctions can sometimes lead to outages or delays during the starting of a unit. When remote monitoring and control is installed and commissioned, these malfunctions need to be remedied which then in many cases reduces outages and speeds up starting of a unit. This is an indirect benefit of installing a central SCADA.

4.2 Comparison between plants controlled centrally with a common SCADA system and plants without a central SCADA

Troubleshooting and repair has three key areas: situation analysis, problem solving and decision making (Tomal and Agarajanian, 2014). Situation analysis, which is more of an analysis of the problem, involves discussing the defect with the operator and the overall condition of the problem. A well-trained operator should be able give a detailed background of the device and previous trips caused by it (Table 3). Decision making involves selecting the optimal option to solve the problem. The existence of a SCADA system effects the troubleshooting and repair work as explained in Table 3.

TABLE 3: Comparison between systems with SCADA and without SCADA

| | Without a centralised SCADA system | With a new centralised SCADA system |
|--------------------------------------|--|---|
| Trip – initial response | The respective wellhead operator notifies the engineer-in-charge. The operator as per the alarm list reports, gives details of the trip or fault. The engineer-in-charge appoints a team to investigate the incident and carry out the necessary repairs to restore operations. This involves getting a standby vehicle and mobilising the team, which can take up to one hour to get to site. | The control room operator notifies the engineer-in-charge who appoints a team to investigate the incident. This can in many cases or to a large extent be done remotely through the Central SCADA in addition to remote desktop or remotely connected engineering system, reducing the need for traveling to wellhead site. |
| Situation analysis or fault analysis | Trouble shooting starts on site If the operators fails to analyse the trip correctly and maintenance team is not able to relate or understand the issue, trips to the office and back to the plant to pick proper tools or equipment will increase the downtime of the plant. Not always the correct maintenance team is sent to site due to lacking information. | Alarm list and detailed information from engineering system can be investigated from the central control room or in the office or at home using remote desktop. Complete analysis of the problem is done at the centralised control room or office through remote desktop. This enables the team to carry required tools, manuals, equipment and spare parts to site. The correct maintenance team is sent to site after proper central analysis. |
| Decision making | Problem is fixed. During start up, the plant might encounter normal start up issues, which may trigger a need to call for more people that further increases downtime. | Problem is fixed. In case of any start-up problems, these can be solved through remote desktop or remotely connected engineering system, eliminating the need for specialists to travel to site. |

Maintenance engineers using SCADA and/or remote desktop and/or remote connected engineering system reduce the downtime of the machine and improve the availability of the power plants. The operators at the wellhead control room should be well trained in order to be able to interpret alarms and faults. The operators must understand the full operation of the power plant and all its auxiliaries. Operating a centralised SCADA centre reduces the downtime of the plant, overtime paid for off-shift callouts and capital and maintenance costs of vehicles. SCADA is also a tool used in Condition-Based Maintenance, CBM. CBM improves system reliability, availability and security and reduces direct maintenance costs by predicting equipment failures through changes in certain performance parameters (Bore, 2008). Remote engineering from manufacturers and other specialists is an additional advantage as it will enable them to find quick solutions to problems encountered while operating the plants. Today advanced CCTV with automatic person and vehicle detection are available. Such a system is in operation in at least one large geothermal power plant in Iceland. The system promptly issues an alarm if unexpected traffic is detected. With this kind of a system a large area can be efficiently monitored with few staff.

4.3 Proposed new operation structure for wellhead power plants

The size of the operating staff depends on the system size, complexity and its operating philosophy as it is the largest non-maintenance costs (Boyer, 2004). Table 4 sums up the need for operators for the two different options discussed below.

TABLE 4: Number of operators

| Existing scheme | Option 1 | Option 2 |
|-----------------|----------|----------|
| 64 | 52 | 36 |

4.3.1 Option 1

This operating structure allows highly qualified operators to monitor and control all the wellhead power plants at the wellhead central control centre. A few operators are stationed at each wellhead plant to man the plants and manually operate them when needed (Figure 10). This significantly lowers the number of operators stationed at each wellhead unit per shift and reduces the risk of accidents since it decreases the staff's exposure to high voltage equipment.

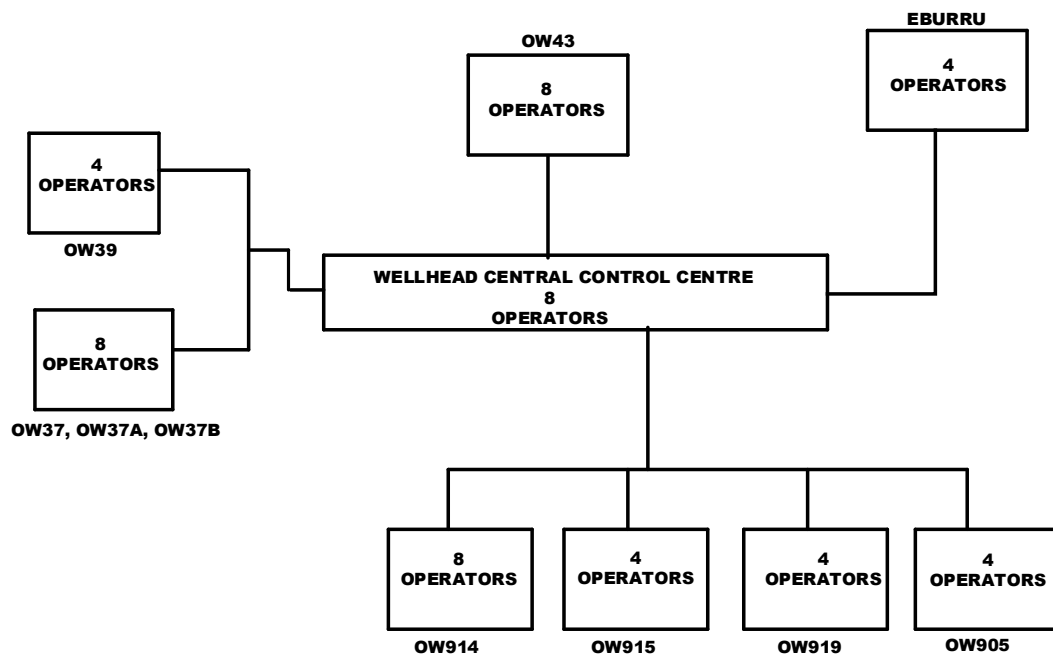


FIGURE 10: Option 1- wellhead operations structure

4.3.2 Option 2

Well trained operators are stationed at the central control centre to monitor and control all the units. Two operators per shift are stationed to monitor and operate OW37, OW37A, OW37B and OW39 at OW37 via SCADA and remote desktops and two operators per shift to monitor and operate OW914, OW915, OW905 and OW919 at OW914 via SCADA and remote desktops (Figure 11). This scheme can only work if the control system is made redundant, this means having standby/backup pumps starting up automatically in case of failure. The disadvantage of leaving the plants unmanned can negatively affect the availability of the plants as it takes time to respond to faults.

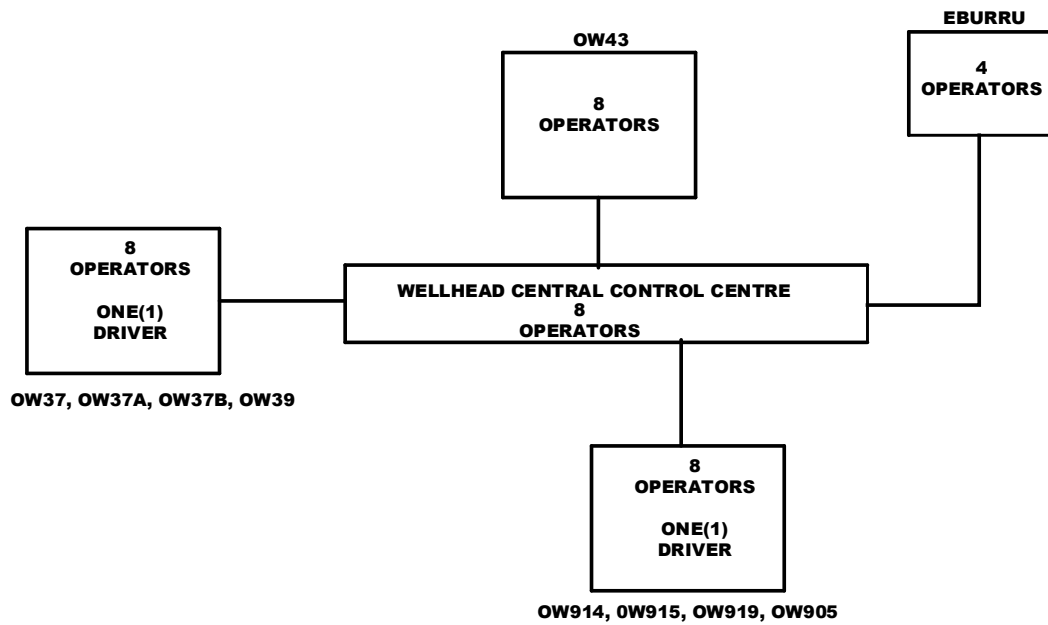


FIGURE 11: Option 2 - wellhead operations structure

5. TELECOMMUNICATION ARCHITECTURE FOR THE WELLHEAD POWER PLANTS.

5.1 General overview of SCADA communication

A comprehensive telecommunication infrastructure needs to be installed to provide the communication links between the wellhead power plants and the centralised control centre. All supervisory control and data acquisition aspects of the SCADA entirely depends on the communication system for an organised flow of data between wellhead units and the SCADA master. The communication at the wellhead units is either handled by specialized communication cards in the PLCs, by specialized remote terminal units (RTUs) or via connection with operator computers. Speech, video and data signals can be transmitted over a telecommunication network via:

- Fibre optic links
- Microwave radio links
- Power Line Carrier (PLC) links
- Metallic cables
- Leased circuits

5.1.1 Fibre optic

Fibre optic is the most powerful and versatile communication medium due to its high bandwidth capability and immunity to electromagnetic interference. The use of optical fibre as digital communication medium has therefore become common in most power utilities as the benefits of implementing fibre optic communication systems and decreasing costs have become more apparent. The advantages of using fibre optic cable links are: long distance transmission without repeater, unaffected by the topology of the terrain of the area, no interference from other communications system, not affected by electromagnetic induction, large potential bandwidth and approval from regulatory authority is not required. The disadvantages of using fibre optic links are: high investment costs, it requires right of way and investment costs are proportional to the length of the transmission link.

5.1.2 Microwave radio

Microwave radio links are used to provide communication services for both speech and data. They operate with radio frequencies ranging from 1.5 GHz up to 50 GHz. The selection of frequency depends on various parameters: the distance, transmission capacities, environmental conditions and restriction on available frequencies. The system design must include a path study between the transmitter and receiver (Boyer, 2004). It is easy to use radio system as they require no physical connection, needs little time to install and low capital costs compared to the fibre optical if large numbers of very tall radio antenna supporting structures are not involved. However, there are problems involved in the initial planning of these systems:

- Radio frequency licences from the regulatory authority is needed and a fee has to be paid annually for these licenses.
- Electromagnetic interference levels and atmospheric conditions are likely to be encountered because radio signals propagate through space as electromagnetic waves and are hard to distinguish from other electromagnetic waves of the same frequency (Boyer, 2004).
- Interference from neighbouring frequency assignments.
- Path loss and possible fading effects.
- Limited to 'line-of-sight', so repeater stations, antenna towers or mast structures for transmission over hilly terrain need to be installed.

5.1.3 Leased circuits

Dedicated leased circuits from local telecommunication service providers can be used as a communication media with minimal investment cost and high flexibility when routing signals. Full dependence on the telecommunication service provider regarding permanent availability, reliability and repair times is an issue when it comes to using leased circuits.

5.1.4 Power line carrier

A power line carrier (PLC) is used by electrical power utilities as communications media, they are the conductors in overhead power lines. PLC links operate in a frequency range between 40 and 500 kHz. The performance of these PLCs depends on the sound/noise ratio and attenuation characteristics of the lines. PLC performance is unaffected by the topology of the terrain and setup cost is independent of transmission length. However, there are disadvantages in using PLC. These include limited bandwidth, the system suffers from electromagnetic interference and adjacent channel interference.

5.2 Communication network design philosophy

The main function of the wellhead telecommunication system is to provide reliable speech, video and data channels between the wellhead power plants and the wellhead centralised control centre. The Open Systems Interconnection model (OSI model) allows the system or network to exchange signals, message packets or addresses. The first layer which is the physical layer defines the relationship between a device and a physical transmission media. A duplex type of communication will allow information to be transmitted and received at the same time. The proposed telecommunication network backbone should use fibre optic and a microwave radio system as communication medium. For security needed for SCADA operations the telecommunication network should be designed in such a way that the SCADA data network is separate from the corporate data network. Equipment shelters and power supply systems are required at the wellhead power plants and the housing site for powering up the radio equipment. Properly rated battery chargers and battery systems provide emergency power to the communication equipment in case of a main power supply failure. Power supplies for electronic equipment, especially in remote locations, are the foundation stones on which a reliable communication system is built (Bailey, 2003). A good communication network should be reliable and have a high availability.

5.3 Communication network architecture

Installation of fibre optic lines from OW915, OW905 and OW919 to OW914, and similarly from OW37A, OW37B and OW39 to OW37 is shown schematically in Figure 12. Optic fibre can be installed in the ground wire of the Overhead Power Transmission Line (OPGW) to OW914 11/220 kV substation and OW37 11/132 kV substation. A microwave radio links OW914 and OW37 to the new centralised wellhead control centre. A 30 km point to point radio link over water from Eburru power plant to KenGen housing site also exists. A Safaricom radio tower is located near the housing unit. A radio links the mast at the housing site and the wellhead control centre.

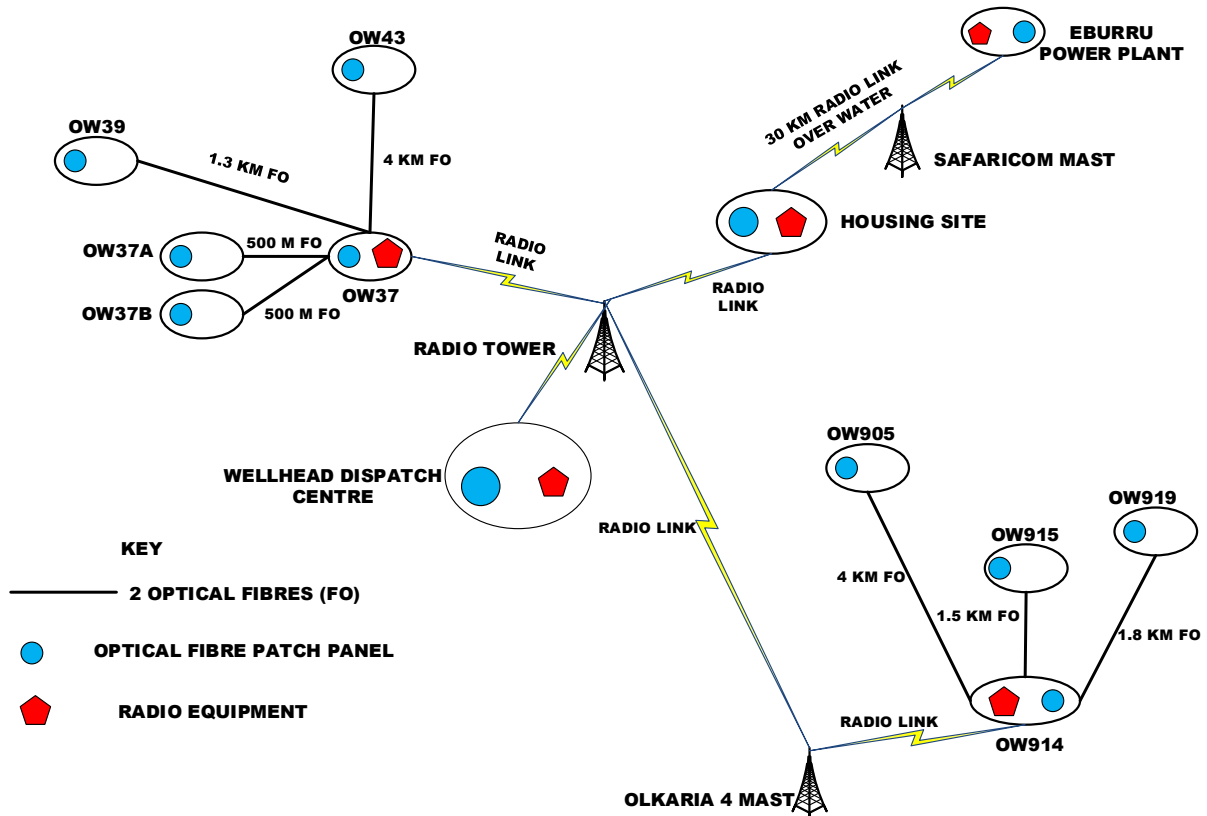


FIGURE 12: Telecommunication network based on fibre and radio links

5.4 Telecommunication network architecture for the geothermal area

The proposed telecommunication network backbone for the convectional plants and the wellhead central control centre should use Synchronous Digital Hierarchy (SDH) fibre communication medium (Figure 13) (Parsons Brinckerhoff, 2013). SDH technology offers transmission capacity ranging from synchronous transport modules STM-1 (155 megabits per second) to STM-16 (2.5 Gb/s or higher). The new fibre optic communication system and existing communication system should employ SDH technology capable for providing STM-1 (155 Mb/s) transmission level. All the SDH nodes on the fibre optic cable will be monitored and supervised by a telecommunication Network Management System (NMS) at the proposed Geothermal Remote Control Centre – GRCC at Olkaria I Additional Units power plant (Olkaria I AU). All the geothermal convectional power plants and the wellhead units will be monitored at Olkaria I AU (Parsons Brinckerhoff, 2013).

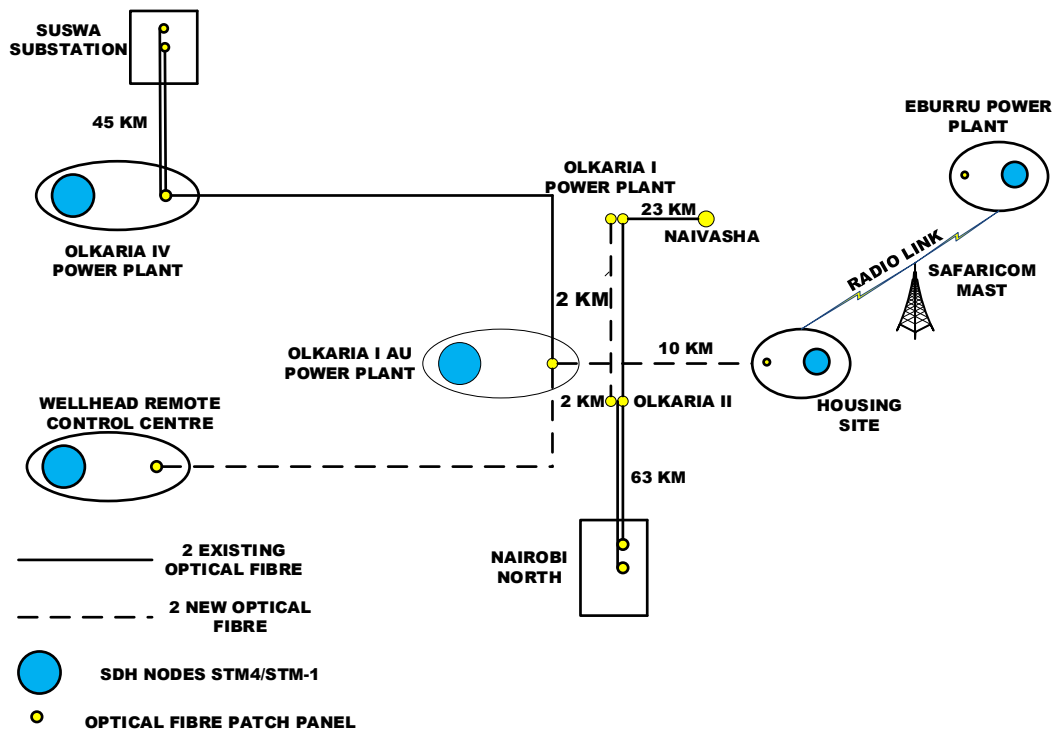


FIGURE 13: Olkaria remote control centre network communication for all the plants (Parsons Brinckerhoff, 2013)

6. OPTIMISED WELLHEAD CONTROL CENTRE SUPERVISORY CONTROL AND DATA ACQUISITION SCADA SYSTEM

6.1 SCADA system functions

6.1.1 Dispatching of generation

One of the primary functions of the new SCADA system will be the provision of facilities for the centralized dispatch centre to receive dispatch requests from the grid operator, and to accurately and efficiently implement those instructions in accordance with the requirements of the power purchase agreements. Proper coordination with the grid operator for energy management will enhance improvement of system stability and quality of energy.

6.1.2 Operational control

Real time information on the status of the plant will be made available to the wellhead control centre operators to enable them to effectively manage the plants remotely and to take any necessary remedial action when alarms are raised. Alarms are retained in lists to which the operators can refer to be reminded of outstanding fault conditions that are pending action.

6.1.3 Rapid fault detection and accurate fault analysis

The real time monitoring of the entire area operation will assist with rapid detection of faults and dispatch of the right maintenance staff to the site. This will reduce outages, thereby increasing the availability and efficiency of the wellhead units. The SCADA system can assist the operators and the maintenance team to quickly identify the root causing the faults in order to reduce downtime. The system

can be configured to transmit critical messages by email and/or SMS to a mobile phone, for the person in charge to respond in the shortest time possible (Karani, 2008).

6.1.4 Plant condition monitoring

Many plant parameters such as temperatures, pressures, vibration levels and hours of running time can be collected or derived by the SCADA system. SCADA can be used to determine the condition of the wellhead power plants and identify operating limits and maintenance requirements. Using predictive techniques, condition monitoring and observation can be used to predict a possible time of failure and enhance the ability of the plant to plan in the best way possible (Mulugeta, 2009). Condition based maintenance allows the lowest cost and the most effective type of maintenance. The main objective of condition based maintenance is to enhance system reliability, increase the plant availability and to limit maintenance costs to an absolute minimum.

6.1.5 Analysis of historical recorded data

The historical information system will store and ultimately archive all incoming and outgoing data and internally generated values, alarms and events arising from operator actions, software applications and diagnostic routines. The main advantage is the analysis of the plant performance including faults, which aids in troubleshooting and optimization of operation.

6.1.6 Revenue collection

Data from the power plants revenue energy meters at each site are presently collected manually every half hour by staff at each site and entered into a spreadsheet. The proposed design should be able to fully automate this process by retrieving the data directly from the meters then transmitting it via the SCADA system to the centralized dispatch centre.

6.2 The location of the centralized wellhead control centre

The proposed location of the wellhead dispatch centre is at the Olkaria East field near Olkaria I power plant. The area is located centrally to all the wellhead units. Movement from the proposed dispatch centre location to the wellhead power plants is more flexible. The proposed site is about 2 km from Olkaria II power plant where all the maintenance teams are located. The road from Olkaria II to the area is tarmacked.

6.3 Monitoring and control of existing wellhead units

6.3.1 Option A – minimum monitoring

Minimum monitoring of the wellhead units includes unit active power and a few key alarms connected to the central SCADA. This limited remote monitoring will require limited modification of the existing control system. This will benefit the area as the plants do not have to be manned all the time. Key alarms and faults are identified quickly and a maintenance team is dispatched immediately and this will reduce the downtime of the plant.

6.3.2 Option B – minimum monitoring and control

This system will allow minimal control of the plant. This will allow control of active and reactive power and a few controls like tripping the plants by opening the generator circuit breakers.

6.3.3 Option C – full monitoring and control of the power plants

This type of system will allow full control and monitoring of new wellhead power plants. All the plants key information is connected to the control centre and most of the commands from the wellhead unit control system are made available from the control centre, including automatic starting and synchronization of the unit.

6.4 Retrieving data from the existing wellhead control system

The major difficulty in this project is to find an economically viable means of retrieving the desired data from each site. Once retrieved locally at each site, the technical issues of transferring that data to the wellhead control centre and processing, displaying and storing is done by the SCADA and the telecommunication network. Transducers and sensors provide the interface between the equipment and the SCADA system by converting physical phenomena into electrical signals that the signal conditioning and/or data acquisition hardware can accept (Park and Mackay, 2003):

- 4 – 20mA field analogue signals from transducers for voltages, currents, active and reactive power and frequency or from measuring probes for level, flow, pressure and temperature;
- Auxiliary switches that provide information in digital form about the status of an item of plant, i.e. 0 or 24 V equipment status signals or 0 or 24 V alarm switch signals;
- Pulse train meter signal;
- Serial input from field equipment.

6.4.1 Option 1: RTU – hardwired

Signals from and to the field are hardwired to a new SCADA Remote Terminal Unit (RTU) at each site and then the new RTUs are linked to the wellhead centralised control centre via a reliable communication network. This may be the best option for existing wellhead power plants in the case that a bus connection to a RTU is not feasible for some reason. This hardwired approach can be very expensive because the PLC design requires extensive I/O wiring. Few signals are usually hardwired to the new RTU since this option is expensive (Appendix I). The sensors, actuators and the wiring that SCADA uses to interface with the processes that are monitored and controlled form the biggest part of the total project cost (Boyer, 2004).

6.4.2 Option 2: RTU with bus connection to PLC

If there is easy access to a programmer with knowledge of the wellhead PLC programs, then probably a bus connection from the PLC to a bus connected RTU (often called gateway) might be the best solution for retrieving data from control system (Appendix II) (GEG, 2015b). For any control to be possible, the control system must be able to implement control commands received from the remote system. The existing wellhead control system should be able to allow the remote system to interrogate the data stored in its database. The wellhead control centre and SCADA systems both need to support a common communications protocol for the transfer of data and control commands between the two systems. This approach requires additional protocol modules and can be difficult or impossible to implement because of the needed configuration expertise to modify the existing programme to suit the new scheme. The wellhead control system and RTU could communicate using several TCP protocols including Modbus TCP and other TCP/IP based protocol or popular SCADA-RTU protocols such as for example DNP3.

6.5 Central SCADA design philosophy

The most important things to consider when designing a SCADA system are redundancy for a more reliable system, a routable protocol, reliable communication network, time stamping and an

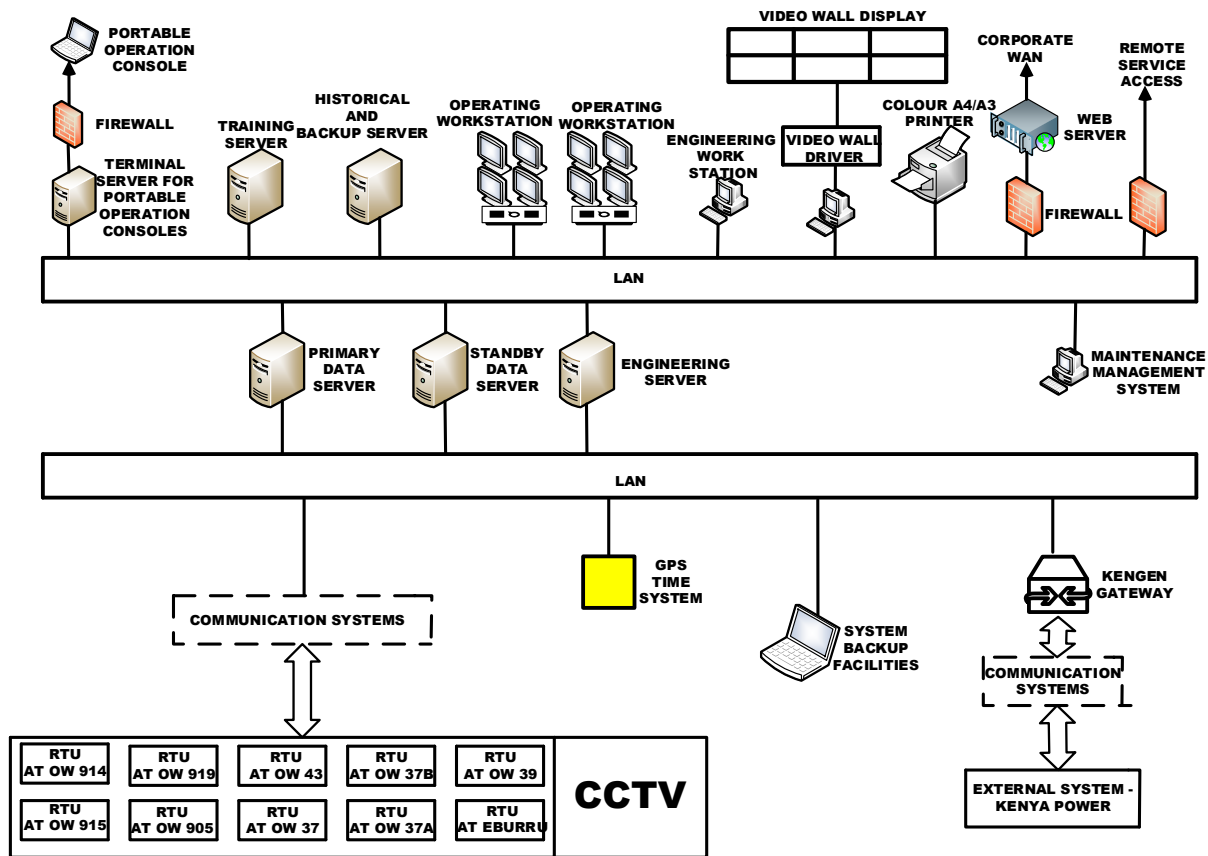


FIGURE 14: SCADA architecture for the wellhead power plants

uninterruptable power supply. Key features of a SCADA system are the user interface, graphics displays, alarms, trends, RTU/PLC interface, access to data, database, networking, fault tolerance and client/server distributed processing (Figure 14) (Bailey and Wright, 2003).

6.5.1 Data servers

Redundant server-client based SCADA architecture with distributed resources along a TCP/IP wide area network (WAN) ensures high availability and guards the system against loss of any critical functionality due to single failures. The systems must have the capacity to retrieve large quantities of real time data from multiple communication channels. The data servers communicate with field devices through process RTUs. Data servers are connected to each other and to client operating stations and engineering stations via an Ethernet LAN. Servers are responsible for data acquisition and handling of the data from the wellhead units and the two 11/132 kV and 11/220 kV substations. Under normal operating conditions both servers should run and are connected to each other. The primary server (Primary Data Server) has the active role and backup server (Standby Data Server) has the standby role. The standby data server does not communicate directly with devices to have access to all data (current and historical) and alarms/events are acquired from the data server. Instead, the primary data server will constantly communicate with the secondary server updating its status and the appropriate databases. If the primary data server fails, the standby data server will take over as the primary server and transfer information to the clients on the network.

6.5.2 Operating work stations

Workstations present process data to an operator through which the human operator controls the process. Operating and engineering work stations are linked to the SCADA system’s databases and software programs and help visualize and control all processes. The video display is capable of presenting both

computer display graphics and real-time moving image video from other sources and zoom in on the problem, after being identified.

The SCADA system will maintain an overview display of the real time data coming from the grid operator (Kenya Power Company) and other external customers via dual redundant communications utilising the Inter Control Centre Protocol (ICCP - IEC 60870-6 TASE.2).

6.5.3 Historical data servers

The historical information system is based on a dual redundant server architecture with secure mass storage facilities, reliable database management system and a reporting package for extracting (via SQL like queries) and presenting the data in the acceptable formats.

6.5.4 Training servers

A training platform for the operators for plant and network simulation should also be considered to improve the skills and competency of the operators. Training simulators give valuable insight into the main factors affecting the operation of a modern geothermal plant and have proved to be the most effective and economical method in engineering teaching and training (Magnússon, 2003).

6.5.5 Web servers

A web server in a SCADA system allows using a normal web browser to access the SCADA web data server pages. The function of a webserver is to store, process and deliver web pages to clients via HyperText Transfer Protocol (HTTP) network protocol (Wikipedia, 2016). This allows managers and engineers to monitor the plant through a standard web browser from any desktop. The web server allows access according to IP address and selected webpages. Network firewall has to be incorporated to filter any traffic from the corporate network.

6.5.6 Printers

A A3/A4 printer for printing reports is installed. Printing should be minimal because all required information is available on the screen.

6.5.7 Time synchronisation

The global positioning system (GPS) clock system is an accurate representation of time using Network Time Protocol (NTP) in order to synchronize the computers, process data sub-systems and a networked NTP server. The GPS receiver located at the wellhead control centre via DNP3 protocol synchronises the RTUs and the RTAC with the SCADA.

6.5.8 Protection against hydrogen sulphide (H₂S)

Electrical equipment associated with control, instrumentation and protection is vulnerable to corrosion and failure due to hydrogen sulphide. H₂S is a very corrosive gas and it is advisable to minimize the adverse effects by making a careful selection of materials and maintain appropriate environmental conditions (Rivera, 2007).

6.5.9 Cyber security

The performance of the system depends entirely on the network credibility. Threats and attacks are dangerous to the plant network. Some of these threats include unauthorised access by outsiders and access by authorised users to unauthorised database. Controlling accesses to the network is done by means of authentication, routers, firewalls, intrusion detection system and encryption. Authentication is

done only by allowing authorised persons to access network through passwords. Firewalls monitor both outgoing and incoming traffic to protect the system from the outside network. To ensure the network is secured a firewall network security system and protection through authentication are integrated to the SCADA system.

6.6 Control system users

Remote desktop is remote control of computers by using other devices via the internet or other networks. Because of security concerns it is not advisable to actually run a plant remotely via the internet, but internet can be used as a remote access facility to view real-time data on site (Bailey and Wright, 2003). Remote desktop enables an engineer to access power plant information from a different location (Figure 15). An engineer can be able to monitor the plants or even assist and support the team on site with ideas and solutions from a remote area during a breakdown. Engineering specialists may have full control of the plants and are able to provide technical assistance from anywhere in the world.

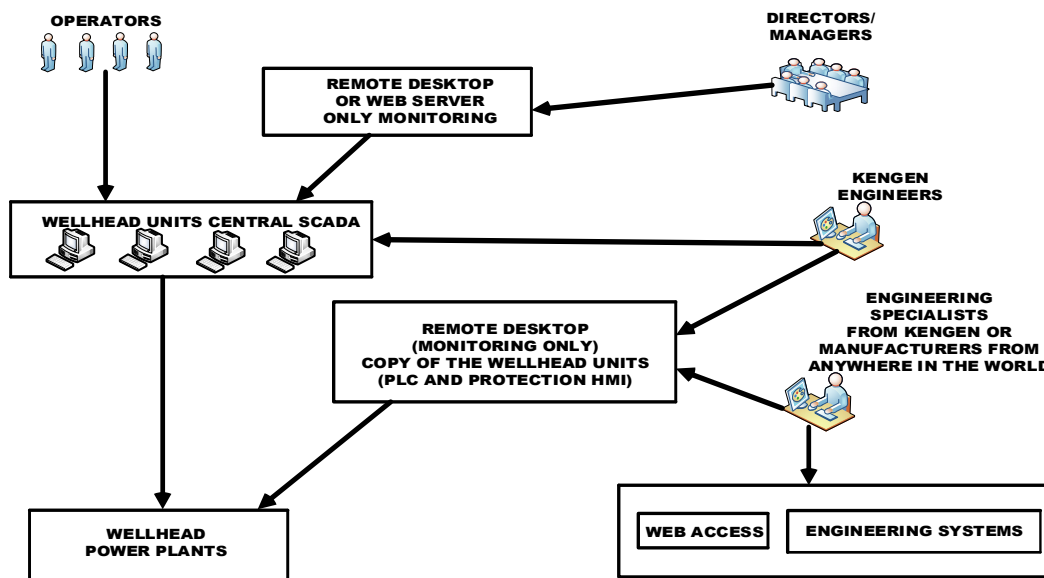


FIGURE 15: Control system users

6.7 Comparison between SCADA workstations and remote desktop

The use of SCADA workstations and remote desktop is widely used and both have advantages and disadvantages (Table 5).

6.8 Operation and maintenance of the power plants and the SCADA system

It is very important to come up with a good maintenance strategy that caters for the entire system, which includes the wellhead control centre, communications infrastructure, plant interface equipment at power plant and substation and maintenance of all the major and auxiliary system of the power plants. The staff should understand the four main maintenance strategies:

- *Corrective or breakdown maintenance* where an anomaly is detected and the aim is to restore the plants or equipment normal operation. This is usually unplanned, but with better knowledge and skills the downtime of a plant can be reduced.

TABLE 5: Comparison between SCADA and remote desktop

| Remote desktop | Scada |
|--|--|
| <p>Pros Green Energy Geothermal are already using remote desktops at OW37 and OW914. Show same information as the local plant Human Machine Interface (HMI).</p> | <p>Pros All information in one database. Overview display of all the wellhead units. Easy comparison of data logging. Centralised alarm system. Centralised HMI display. Easy to learn.</p> |
| <p>Cons Not all equipment is connected (protection relays are sometimes connected). One computer per wellhead is needed for continuous monitoring. HMI not standardized between wellheads. No overview displays of all the wellhead units. Data logging is not in one data server. No good centralised alarm system.</p> | <p>Cons Costly. Connection to existing equipment such as PLCs is uncertain as programming/modification of the PLC programme is expensive.</p> |

- *Preventive maintenance* is a time based type of maintenance which is intended to prevent failure by following routine or overhaul maintenance procedures allowing the team to predict, budget and plan maintenance.
- *Condition based maintenance* where an early detection of an equipment failure is noted through monitoring of parameters and periodic testing.
- *Root cause finding*.

A maintenance management system should be used to record maintenance history and control maintenance costs. This system controls all the work orders, routine inspections, man power, tools and spare parts. The maintenance management system should be located at the wellhead control centre. Proper maintenance planning focuses on reduction of maintenance costs, improvement of the plant availability and reducing failures to an absolute minimum.

6.9 Training strategy of the wellhead power plants operation and maintenance staff

Training is key to power plant maintenance and operation, as it encourages knowledge and improves performance of the staff. Training improves skills, knowledge, abilities and the overall availability and performance of the plants. A good strategic plan starts with identification of the training needs of the staff and understanding the equipment and systems to be operated and maintained in a safe, professional and reliable manner. The most common methods used are classroom training, on job training and self-study. Use of simulators, which illustrate general concepts and display all the process in a power plant, enhances better understanding of all the physical process, basic operation and overall operation of the plant. There is need to identify specific roles and corresponding job description and establish the starting baseline in terms of existing capability and the requirement for training. Emphasis should be on proper understanding of all the main and auxiliary components of the power plant, communication and SCADA system. The testing and commissioning of a new plant is a most important opportunity for thorough training. It is therefore very important that the staff, who will become operators and maintenance personnel of the plant, participate as much as possible in the testing and commissioning activities.

6.10 Management of spare parts

Since plant data will be interfaced with the existing enterprise resource planning system that is implemented on SAP software the control of plants spare parts is manageable. With a properly designed maintenance strategy all assets are recorded in the maintenance system and spare parts are connected to the assets. This helps the team to have spare parts available for maintenance during both planned and forced outages. The team is also able to plan and procure spare parts in advance. The timely availability of the power plant, communication and SCADA spare parts, materials and services is a key element of a strong and effective maintenance program (Mulugeta, 2009).

6.11 Transport

In order for the maintenance team based in one or two locations to maintain the dispersed wellhead power plant a more reliable transport system will be required to support the maintenance effort without wasting time, thus reducing the downtime of the plants.

7. IMPROVING PLANT AVAILABILITY - SUMMARY

No chain is stronger than its weakest link and such is the case with availability improvements that typically rest on several factors or links. The following chapter summarizes some of the key factors mentioned in previous chapters for improving plant availability.

7.1 Commitment

Significant improvements in availability require strong commitment and backup from the plant owners and management to ensure allocation of sufficient resources for the availability improvements.

7.2 The pillars of availability

Any significant improvement in plant availability rests on several pillars, a central SCADA system is only one of the necessary ingredients. Some examples of the key issues here are:

- *Staff skills* through natural talents, proper education, plant specific training, on site operational experience and resourcefulness and initiative. Staff motivation is also important in this context. A SCADA system with built in training simulator can also help here.
- *Organization*. An effective organization chart is evidently important for a cost effective and efficient plant operation. Related to this is the proper location of the staff, availability of vehicles etc. A modern central SCADA system facilitates flexible location of staff and reduces need for staff travel through easy access to online plant information almost anywhere.
- *Spare parts*. The availability of spare parts that can be rapidly brought on site is evidently important for availability. The lack of critical spare parts can potentially keep the plant shut-down for a long time. A SCADA system that keeps track of failure statistic for different types of equipment, counts operations and operating hours can be of help in the planning of preventive maintenance work and in the planning of spare parts procurement.
- *Proper tools for plant maintenance*. It is not enough to have spare parts on site, it is also necessary to have the right tools for prompt repair work available on site. The staff must have the right training in applying the tools for repair work. This also applies to each plant control and protection system (i.e. engineering system) and the central SCADA.

- *Weed out unreliable equipment.* In plants of new design or with new equipment, low availability is often experienced during the first few years of operation. Through methodical analysis of the root causes of failures and other unavailability causes, unreliable equipment will gradually be weeded out and improved or replaced by more suitable equipment. A central SCADA with its accurate event logging, trend analysis etc. is essential in this work. It should also be noted here, that when a plant has been operated for a long time without the use of remote monitoring and control, then some equipment may not work well enough for remote operation due to lacking maintenance. The equipment may only work when operated manually by an operator. In this case the equipment in questions must be repaired or replaced by better functioning equipment in preparation for remote operation.
- *Design improvements such as redundancy of critical and/or failure prone equipment.* In some instances, it may be difficult to achieve sufficient availability through simple weeding out of unreliable equipment. In this case, an acceptable improvement in availability may be reached through design changes based on redundancy of equipment. For example, if a single pump does not provide the sought after plant availability, then redundant pumps may be the solution, i.e. adding a backup pump. Triple redundant measurements are an example of another availability improvement solution.
- *Accelerate troubleshooting of failures.* In some cases, it can be time consuming to find the root cause of a trip or other failure. As an example, the root cause cannot be found due to lack of information or lacking staff skills. The plant may then be re-started without fixing the root cause first, and may possibly trip again soon. A central SCADA together with other tools such as remotely connected engineering systems can greatly facilitate the search for the root cause of a failure.
- *Accelerate repair and re-starting.* KenGen experts and/or experts from the manufacturer or appropriate consultants can easily assist here, through a central SCADA and other tools such as remotely connected engineering systems. This expert advice can be made immediately available on site and thus helps in fixing the problem and assistance with re-starting can also be provided.

8. COST, ECONOMICS AND FINANCIAL ANALYSIS

8.1 Capital costs

Capital costs are costs used to acquire or upgrade fixed assets with a useful life extending beyond the taxable year. Basic project costs are estimated and economic and financial analysis of the project is made based on these costs. This includes cost related to the SCADA hardware including spare parts and software devices, telecommunication devices, engineering and management works at the plants and the control centre, technical services offered by specialists, training, warehousing and transport. Assuming existing communication masts and radio communication system will be used and the lifetime of the SCADA and telecommunication systems for the purpose of calculating overall lifetime cost is 15 years, SCADA capital cost estimate can be divided into three sections:

- Works required at the power wellhead control centre;
- Works required at OW37 and OW914 substation automation using RTAC;
- Works required at the wellhead power plants.

8.1.1 Items required at the power wellhead control centre

Table 6 shows items required at main wellhead control centre.

TABLE 6: Wellhead control centre works – bill of quantities

| No. | Description | Quantity |
|-----|--|--|
| 1 | GPS reference time signal receiver | 1 |
| 2 | Gateway to grid company dispatch centre (Kenya Power) Gateway (redundant pair) Software (implementation of all signals and communication signal table) | 1 1 |
| 3 | <i>HMI hardware - wellhead dispatch centre</i> Control Cubicles (computer equipment cabinets (for servers, gateways, DC/DC converters, switches etc.) Hardware, operator stations and associated equipment Operator station computers - DCS clients + maintenance management computer Portable operator consoles Terminal server for remote access DCS servers including database servers (virtual server) redundant Monitors for operator consoles and servers (24") LCD, including a monitor stand with each OS Video wall display CCTV (in all the wellhead power plants) Colour laser printer for the SCADA system | 2 5 4 1 1 12 1 LOT 2 |
| 4 | <i>SCADA dispatch centre software (operating system and basic software)</i> Operating system and other server software, all included (backup software, graphical user interface, real-time clock, power failure restart etc.) including engineering, historian, and database programming tools Client software for operator stations Software for portable operator consoles Engineering software Maintenance management software (for years) | 1 1 1 1 1 |
| 5 | <i>The station and PAC networks</i> Station LAN main network switches - layer 3 External connections - firewalls (redundant pair) Other PAC LAN main network switches - layer 2 Firewall for service access to the station and PAC LANs | 1 2 2 1 |

8.1.2 Items required at OW37 and OW914 substation

Table 7 shows items required at the OW37 and OW 914 substation. This includes acquiring existing data from the two RTAC at OW37 and OW914 to an RTU and interfacing it with the new SCADA.

TABLE 7: OW37 and OW914 RTAC – bill of quantities

| | |
|---|---------------|
| <i>RTU - bus connection to RTAC</i> RTU software, including installation and configuration: Software I/O, DCS programming and display design for RTU signals | 2 |
| <i>Basic objects</i> Digital Analog Process displays | 25 25 2 |

8.1.3 Items required at the wellhead power plants

Option 1: RTU with hardwired connection to the PLC

Table 8 shows the items needed for the hardwired connection to PLC.

TABLE 8: Hardwired connection to PLC – bill of quantities – RTU

| | |
|--|----------|
| <i>Control cubicles (remote I/O - wellhead): Remote I/O</i> | 1 |
| <i>Equipment in remote I/O control cubicles:</i> | |
| CPU and communication card (DNP 3 or similar) including installation and configuration | 1 |
| 110 V/24 V DC converters (redundant pair) | 1 |
| Digital output units (16 DO) | 1 |
| Digital input units (16 DI) | 4 |
| Analogue output units (8 AO) | 1 |
| Analogue input units (8 AI) | 4 |
| Bus connection to RTU (redundant pair) | 1 |
| Optical converters for connecting remote I/O to fibre optic cable (pairs) | 1 |
| Isolating 4-20 mA / 4-20 mA amplifiers for analogue signals | 32 |
| Wiring per signal (wellhead marshalling cubicle to RTU) | 87 |
| <i>Software I/O, DCS programming and display design</i> | |
| Digital monitoring | 55 |
| Analogue with alarming | 32 |
| Control valve | 3 |
| Process displays | 2 |

Option 2: RTU with bus connection to the PLC

Table 9 shows the items needed for the bus connection to PLC.

TABLE 9: RTU-bus connection to PLC – bill of quantities

| | |
|---|----------|
| <i>RTU, including installation and configuration</i> | 1 |
| Software I/O,DCS programming and display design for RTU signals | |
| <i>Basic objects</i> | |
| Digital | 106 |
| Analog | 83 |
| Process displays | 4 |

8.2 Total capital cost

Table 10 presents the total capital cost estimates to implement the wellhead central SCADA control system. This includes installation, testing, project management costs, training and cost of spares parts – i.e., overall cost estimates to implement the SCADA

8.3 Economic and financial benefits of the SCADA project

Economic benefits from the new dispatch centre are based on evaluating the potential savings in operating costs and energy saved due to reduction in outages for unscheduled and scheduled maintenance, hence higher availability for dispatch.

8.3.1 Pre-feasibility study of investment in improved operation and increased availability

The first step in deciding whether to invest in improved operation and increased availability should be a pre-feasibility study of the potential improvements. This should be done in the light of the current operation and obvious availability and operation issues today. It is possible for example that this will reveal that most trips or other operation disturbances and problems can be traced to external grid problems or are due to fundamental design or material selection problems in the turbine rotor for example. The conclusion could then possibly be that it is more economical to operate the unit with the

TABLE 10: Overall project costs to implement the SCADA system

| | Unit price (USD) | Number of wellhead units | Option 1 - Only hardwired RTUs (USD) | Option 2- Only bus connected RTUs (USD) |
|---|------------------|--------------------------|--------------------------------------|---|
| <i>RTU – Hardwired</i> | 54,000 | 16 | 864,000 | |
| RTU – hardwired, cubicle and wiring cubicle design and prototype construction and testing | | | 67,200 | |
| <i>RTU with bus connection to PLC</i> | 27,000 | 16 | | 432,000 |
| RTU with bus connection to PLC. Program design and prototype construction and testing | | | | 224,000 |
| RTU with bus connection to RTAC (OW37 and OW914) | | | 18,000 | 18,000 |
| RTU with bus connection to RTAC- planning of configuration and testing | | | 22,400 | 22,400 |
| GPS clock | | | 3,400 | 3,400 |
| Gateway to grid company dispatch centre | | | 14,600 | 14,600 |
| HMI hardware - wellhead dispatch centre | | | 90,000 | 90,000 |
| SCADA software - wellhead dispatch centre | | | 64,400 | 64,400 |
| The station and PAC networks | | | 8200 | 8200 |
| Installation, configuration and testing, 15% of above | | | 172,830 | 131,550 |
| Training and documentation, 7% of above | | | 92,800 | 70,600 |
| Specified spare parts, 4% of above | | | 56,700 | 43,200 |
| Project management costs, 20% of above | | | 294,900 | 224,500 |
| Miscellaneous cost, 15% of above | | | 265,400 | 202,000 |
| Total project cost | | | 2,034,800 | 1,548,800 |
| VAT 16% | | | 325,568 | 247,808 |
| Overall project cost | | | 2,360,368 | 1,796,608 |

current problems rather than invest in expensive remedies with questionable return on investment. As a result, a shortened lifetime of the wellhead unit may then have to be accepted. In the light of such a situation an investment in availability improvements, including central SCADA may not be financially justifiable. In other words, if a wellhead unit has very difficult operational problems, caused by for example a problem prone turbine rotor, then investment in the connection of the unit to a central SCADA will hardly be economically feasible.

8.3.2 Reduced operation and maintenance costs

The output of the wellhead units for 363 days per year is:

$$83,540kW \times 363 \text{ days} \times 24 \text{ hours} = 727,800,480 \text{ kWh}$$

The income with an energy price of 0.085 USD/kWh, as per the power purchase agreement (PPA), is:

$$727,800,480 \times 0.085 = \text{USD } 61,863,040$$

The KenGen operating and maintenance staff costs of the power plant is assumed to be 2.3% of the income or USD 1.4 million. It is estimated that this cost can be reduced by at least 20% through SCADA and a new staff organisation. The economic benefit due to this is USD 280,000 annually.

8.3.3 Economic benefits of increased availability

Here it is assumed that the yearly income from electricity sales from the Olkaria wellhead units today is around USD 60 million and the average yearly availability is estimated 90%. Official availability figures are not available, so this is an estimate based on available information, with the availability probably having been somewhat lower in recent years.

The availability of exemplary geothermal power plants around the world can be 95% or even higher. A target availability improvement of 2%, i.e. to estimated 92% can be considered realistic if the plants do not have serious problems that are not economical to fix, and provided sufficient strong commitment and backup from the plants owners and management to ensure allocation of sufficient resources can be secured.

It should however be emphasized here that a precondition for this assumption is that a pre-feasibility study of potential availability improvements (see Section 8.3.1 – assessment of investment in improved operation and increased availability), has shown that problems in the operation of the unit are of such a nature that investment in operation and availability improvements are economically feasible.

If the result of the mentioned pre-feasibility study is positive, then it should be possible to increase the availability of the power plants by 2% through a central SCADA, better education and training, new staff organisation, better maintenance and spares management, access to service backup from equipment manufacturers, gradual improvement of reliability by root cause analysis and subsequent wellhead improvement. Then the economic benefit or income due to increasing the availability of the plants is USD 1.20 million annually. See also section on improving plant availability above.

8.3.4 Total economic benefits of increased availability and reduced operating costs

The yearly economic benefit (income) from reduced operating costs and increased availability is USD 1.48 million based on previous assumptions. However, this benefit might take time to be realised. For the first 3 years, it could look like this: an example USD 0.5 million in the first year, 1 million in the second year, 1.48 million in the third year etc. In this case, the calculated Net Present Value (NPV) will be lower. This economic viability analysis, based on a calculated NPV of the forecast economic benefit (income) associated with implementation of the selected SCADA options and other improvements. Furthermore it assumes an operational life of 15 years with an annual discount rate of 8% in accordance with the assumptions for the Least Cost Development Plan for Kenya (ERC, 2011), and indicates a total amount of 11,3 million USD.

With an approximate investment cost of 2 million USD for SCADA Option 1 and approximately 2.4 million USD for the Option 2 and assuming a 15% yearly cost for SCADA maintenance, retraining etc. subtracted, the benefits minus costs for the NPV is reduced to 7.5 million and 6.7 million USD, respectively. Simply said, it could be stated that this is the amount available for other investments needed before the project shows loss.

In this paper, only the cost of a central SCADA equipment has been calculated with some accuracy. An investment in increased availability and reduced operating costs will involve many other investments that are outside the scope of this paper. Housing for central SCADA is one example. A more comprehensive feasibility study, involving many more items than the central SCADA will have to be completed before the final decision can be made regarding investments in increased availability and reduced operating costs.

9. DISCUSSION AND RECOMMENDATIONS

The centralised control and monitoring SCADA scheme for the KenGen wellhead power plants is potentially viable when considering the impact it has on the economy of the wellhead plants and Kenya. Having a reliable and improved availability will result in additional electricity to consumers. The project is potentially financially viable to KenGen and will save both operations and maintenance costs. Efforts have to be made at the plant project design stage to factor in and ensure full remote monitoring and control of future plants. For the existing wellhead units, minimum remote monitoring and control is feasible with only key information from the wellhead control system connected to the central dispatch centre. For more reliable power plants, the following key improvements are recommended for even greater reliability:

1. The wellhead power plants have limited redundancy. It is possible to reduce the impact of equipment failures by introducing a more reliable equipment design, such as 2×50% instead of 1×100% which has control equipment that starts automatically in order to keep the power plant running at least on partial load in case of failure of one piece of equipment such as a pump or control valve. Related to this is the weeding out of unreliable equipment.
2. Wellhead plants need to be connected to a more stable grid to minimize the frequent trips due to line faults.
3. From the beginning of operation, critical spare parts should be purchased and stored at site to increase reliability. Purchase of appropriate tools and software for maintenance work should also be included.
4. Proper and regular equipment inspections, maintenance and routine tests should be carried out.
5. Training of all operations for maintenance staff and organisation improvements should be done regularly.

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REFERENCES

- Bailey, D., 2003: *Practical radio engineering and telemetry for industry*. Newness – Elsevier, Oxford, 320 pp.
- Bailey, D., and Wright, E., 2003: *Practical SCADA for industry*. Elsevier, Amsterdam, 304 pp.
- Bore, C.K., 2008: *Analysis of management methods and application to maintenance of geothermal power plants*. University of Iceland, MSc thesis, UNU-GTP, Iceland, report 5, 60 pp.
- Boyer, S., 2004: *SCADA, supervisory control and data acquisition* (3rd ed.). ISA – Instrumentation System and Automation Society, USA, 240 pp.
- ERC, 2011: *Updated least cost power development plan for Kenya - study period 2011-2013*. Energy Regulatory Commission, Kenya, 203 pp.
- GDA, 2011: *Preliminary control system function specification*. Geothermal Development Associates, report, 29 pp.
- GEG, 2015a: *Geothermal power plants operational manual*. Green Energy Geothermal, document number: C50-00-0401-MAN-001_1.0, 97 pp.
- GEG, 2015b: *C50 operation and maintenance manual*. Green Energy Geothermal, Electrical as-built drawings, drawing number: C50-4-E0033-DW, 189 pp.
- Karani., T.W., 2008: Improved operations and reliability by upgrading Olkaria I control system and installing remote monitoring and control system for Olkaria I and II geothermal power plants in Kenya. Report 21 in: *Geothermal training in Iceland 2008*. UNU-GTP, Iceland, 331-364.
- Magnússon, J.Th., 2003: Operational simulators and automatic control systems. In: Fridleifsson, I.B., and Gunnarsson, M.V. (eds.), *Lectures on sustainable use and operating policy for geothermal resources*. UNU-GTP, Iceland, publication 1, 185-194.
- Mendive, D.L., and Green, L.H., 2012: Wellhead geothermal power plant at Eburru, Kenya. *Geothermal Resources Council, Transactions*, 36, 4 pp.
- Mulugeta, A.A., 2009: *Evaluation of maintenance management through benchmarking in geothermal power plants*. University of Iceland, MSc thesis, UNU-GTP, Iceland, report 3, 52 pp.
- Ouma, P.A., 2007: Geothermal exploration and development of the Olkaria geothermal field. *Paper presented at Short Course II on Surface Exploration for Geothermal Resources, organized by UNU-GTP and KenGen, at Lake Naivasha, Kenya*, 17 pp.
- Park, J., and Mackay, S., 2003: *Practical data acquisition for instrumentation and control system*. Elsevier – Newness, Amsterdam, 425 pp.
- Parsons Brinckerhoff., 2013: *SCADA phase II and central dispatch centre inception report*. Parsons Brinckerhoff, report for Kenya Electricity Generating Company - KenGen, 147 pp.
- Rivera, M.A., 2007: Design considerations for reliable electrical, control and instrumentation systems in geothermal power plants with emphasis on hydrogen sulphide related problems. Report 20 in: *Geothermal Training in Iceland 2007*. UNU-GTP, Iceland, 461-490.
- Tomal, D.R., and Agajanian, A.S., 2014: *Electronic troubleshooting* (4th ed.). McGraw-Hill Education, NY, USA, 448 pp.
- Wikipedia, 2016: *Web server*. Wikipedia, website: en.m.wikipedia.org/wiki/Web_server.

APPENDIX I: Option 1, RTU – Hardwired**DIGITAL INPUT**

- | | |
|--|--|
| 1. Turbine exhaust pressure HIGH HIGH | 29. Auxiliary transformer 11 KV Earth Switch CLOSED |
| 2. Lube oil system trip oil pressure low | 30. Auxiliary transformer 415 V AC TRIP |
| 3. Turbine vibration system trip | 31. Auxiliary transformer 415 V AC TRIP |
| 4. Turbine control turbine governor TRIP | 32. Back generator 415 V CB TRIP |
| 5. Turbine control turbine governor FAULT | 33. Compressed air compressor fault TRIP |
| 6. Excitation control TRIP | 34. Cooling tower 1 fan motors FAULT TRIP |
| 7. Turbine control speed sensor 1 FAULT | 35. Cooling tower 2 fan motors FAULT TRIP |
| 8. Turbine control speed sensor 2 FAULT | 36. Cooling tower 3 fan motors FAULT TRIP |
| 9. Turbine governor actuator # 1 | 37. Cooling tower 4 fan motors FAULT TRIP |
| 10. Turbine governor actuator # 2 | 38. Cooling tower 1 fan vibration TRIP |
| 11. Turbine governor over speed | 39. Cooling tower 2 fan vibration TRIP |
| 12. Turbine governor emergency trip | 40. Cooling tower 3 fan vibration TRIP |
| 13. Turbine governor Manual External trip | 41. Cooling tower 4 fan vibration TRIP |
| 14. Generator circuit breaker CLOSED | 42. Cooling auxiliary H ₂ O pump FAULT TRIP |
| 15. Generator circuit breaker earth switch OPEN | 43. Fire alarm system annunciation 1 st stage ALARM |
| 16. Generator circuit breaker earth switch CLOSED | 44. Fire alarm system annunciation 2 nd stage ALARM |
| 17. Generator circuit breaker protection relay TRIP | 45. Fire alarm system annunciation FAULT |
| 18. 11 KV feeder circuit breaker OPEN | 46. Fire alarm system annunciation ALARM |
| 19. 11 KV feeder circuit breaker CLOSED | 47. PLC/SCADA system main DC supply alarm |
| 20. 11 KV feeder earth switch CLOSED | 48. PLC/SCADA system back up DC supply alarm |
| 21. 11 KV feeder circuit breaker protection relay TRIP | 49. PLC/SCADA system power supply ALARM |
| 22. Auxiliary transformer 11 KV circuit breaker CLOSED | 50. DC distribution 110V DC rectifier fault |
| 23. Auxiliary transformer 11KV circuit breaker OPEN | 51. DC distribution DC/DC converter FAULT |
| 24. Steam separator brine level HIGH HIGH | 52. DC distribution unit 1 110V DC CBD FAULT |
| 25. Condenser water level HIGH HIGH (TRIP) | |
| 26. Turbine drain drum water level HIGH HIGH | |
| 27. Lube oil system oil level in tank LOW | |
| 28. Auxiliary transformer 415 V AC CLOSED | |

ANALOG INPUT

- | | |
|---|---|
| 1. Well head outlet pressure value | 8. Turbine steam inlet 1 temperature value |
| 2. Two phase distribution supply pressure value | 9. Turbine control valve 1 position |
| 3. Steam separator brine level value | 10. Turbine emergency shutoff valve 1 |
| 4. Steam outlet to silencer pressure control valve position | 11. Turbine control valve 2 position |
| 5. Turbine inlet 1 pressure value | 12. Turbine emergency shutoff valve 2 |
| 6. Turbine steam inlet 2 pressure value | 13. Cooling circuit water to cooling tower pressure value |
| 7. Lube oil system pressure value | 14. Condenser water level value |

- | | |
|--|--|
| 15. Cooling circuit water to cooling tower temperature value | 24. Turbine bearing rotor rear journal temperature value |
| 16. Turbine HP radial X vibration | 25. Transmission gear pinion front journal temperature value |
| 17. Generator voltage | 26. Transmission gear pinion rear journal temperature value |
| 18. Generator current | 27. Transmission gear pinion wheel front journal temperature value |
| 19. Frequency | 28. Transmission gear pinion wheel rear journal temperature value |
| 20. Generator active power | 29. Turbine steam inlet 2 temperature value |
| 21. Generator reactive power | |
| 22. Turbine bearing rotor front thrust temperature bearing | |
| 23. Turbine bearing front journal temperature bearing value | |

DIGITAL OUTPUT

- | | |
|--|--|
| 1. Vacuum breaker valve CLOSE COMMAND | 3. Turbine control turbine governor trip turbine |
| 2. Governor Circuit Breaker Relay Trip command | |

ANALOG OUTPUT

- | | |
|---|---|
| 1. Turbine control valve 1 control | 5. Turbine emergency shut off valve 2 control |
| 2. Turbine control valve 2 control | 6. Turbine control active power feedback output value |
| 3. Turbine pressure inlet steam output value | |
| 4. Turbine emergency shut off valve 1 control | |

APPENDIX II: Option 2, RTU with bus connection to PLC

DIGITAL INPUT

- | | |
|---|---|
| 1. Turbine exhaust pressure HIGH HIGH | 15. Turbine control and protection PLC power supply ALARM |
| 2. Lube oil system trip oil pressure low | 16. Turbine control and protection IE Switch ALARM |
| 3. Turbine vibration system trip | 17. Generator circuit breaker OPEN |
| 4. Turbine control turbine governor ALARM | 18. Generator circuit breaker CLOSED |
| 5. Turbine control turbine governor TRIP | 19. Generator circuit breaker spring charged |
| 6. Excitation control Fault | 20. Generator circuit breaker Earth switch OPEN |
| 7. Excitation control TRIP | 21. Generator circuit breaker Earth switch CLOSED |
| 8. Lube oil system emergency oil pump Running | 22. Generator circuit breaker protection relay ALARM |
| 9. Lube oil system emergency oil pump FAULT | 23. Generator circuit breaker protection relay TRIP |
| 10. Turbine control and protection 110V supply FAULT | 24. 11 KV feeder circuit breaker OPEN |
| 11. Turbine control and protection main DC supply ALARM | 25. 11 KV feeder circuit breaker CLOSED |
| 12. Turbine control and protection backup DC supply ALARM | 26. 11 KV feeder circuit breaker spring charged |
| 13. Turbine terminal box 24 V DC FAULT | 27. 11 KV feeder earth switch CLOSED |
| 14. Cooling circuit terminal box fault | |

28. 11 KV feeder circuit breaker protection relay ALARM
29. 11 KV feeder circuit breaker protection relay TRIP
30. Auxiliary transformer 11KV circuit breaker OPEN
31. Auxiliary transformer 11KV circuit breaker CLOSED
32. Auxiliary transformer 11KV circuit breaker FAULT
33. Auxiliary transformer 11KV Earth Switch CLOSED
34. Auxiliary transformer temperature protection ALARM
35. Auxiliary transformer temperature protection FAULT
36. Steam separator brine level LOW
37. Steam separator brine level HIGH
38. Steam separator brine level HIGH HIGH
39. DC distribution 110V DC rectifier fault
40. DC distribution unit 0 110V DC CBD FAULT
41. Condenser water level LOW
42. Condenser water level HIGH HIGH
43. Turbine drain drum water level HIGH HIGH
44. DC distribution DC/DC converter FAULT
45. Lube oil system oil level in tank LOW
46. Lube oil system oil level in tank LOW
47. Lube oil system oil differential pressure AOP/MOP LOW
48. Ejector system motive steam 1st stage valve CLOSED
49. Ejector system motive steam 2st stage valve CLOSED
50. Ejector system inter-condenser inlet valve CLOSED
51. Cooling circuit vacuum breaker valve CLOSED
52. Auxiliary transformer 415 V AC CLOSED.
53. Auxiliary transformer 415 V AC TRIP.
54. Back generator 415 V CB CLOSED.
55. Back generator 415 V CB TRIP
56. Compressed air compressor READY
57. Compressed air compressor fault TRIP
58. Compressed air compressor RUNNING
59. Air conditioning system cooling unit 1 RUNNIG
60. Air conditioning system cooling unit 2 RUNNIG
61. Ventilation system 1 H₂S filter fan running
62. Ventilation system 2 H₂S filter fan running
63. Fire alarm system AC power supply ON
64. Cooling tower 1 fan motors READY
65. Cooling tower 2 fan motors READY
66. Cooling tower 3 fan motors READY
67. Cooling tower 4 fan motors READY
68. Cooling tower 1 fan motors OVERHEAT
69. Cooling tower 2 fan motors OVERHEAT
70. Cooling tower 3 fan motors OVERHEAT
71. Cooling tower 4 fan motors OVERHEAT
72. Cooling tower 1 fan motors FAULT TRIP
73. Cooling tower 2 fan motors FAULT TRIP
74. Cooling tower 3 fan motors FAULT TRIP
75. Cooling tower 4 fan motors FAULT TRIP
76. Cooling tower 1 fan vibration TRIP
77. Cooling tower 2 fan vibration TRIP
78. Cooling tower 3 fan vibration TRIP
79. Cooling tower 4 fan vibration TRIP
80. Cooling auxiliary H₂O pump READY
81. Cooling auxiliary H₂O pump FAULT TRIP
82. Cooling tower1 switch disconnecter CLOSED
83. Cooling tower 2 switch disconnecter CLOSED
84. Cooling tower3 switch disconnecter CLOSED
85. Cooling tower 4 switch disconnecter CLOSED
86. Cooling tower1 switch disconnecter CLOSED
87. Cooling tower 2 switch disconnecter CLOSED
88. Cooling tower3 switch disconnecter CLOSED
89. Cooling tower 4 switch disconnecter CLOSED
90. Fire alarm system annunciation 1st stage ALARM
91. Fire alarm system annunciation 2nd stage ALARM
92. Fire alarm system annunciation FAULT
93. Fire alarm system annunciation ALARM

- | | |
|--|---|
| <ul style="list-style-type: none"> 94. PLC/SCADA system main DC supply alarm 95. PLC/SCADA system back up DC supply alarm 96. Steam supply terminal box 24 V DC FAULT | <ul style="list-style-type: none"> 97. PLC/SCADA system main alarm buzzer off COMMAND 98. PLC/SCADA system power supply ALARM |
|--|---|

ANALOG INPUT

- | | |
|--|---|
| <ul style="list-style-type: none"> 1. Well head outlet pressure value 2. Two phase distribution supply pressure value 3. Steam separator brine level value 4. Steam outlet to silencer pressure control valve position 5. Steam outlet to silencer pressure value 6. Brine outlet to silencer level control valve 7. Wellhead outlet temperature value 8. Two phase distribution supply temperature 9. Turbine inlet 1 pressure value 10. Turbine steam inlet 2 pressure value 11. Turbine nozzle box pressure turbine exhaust pressure value 12. Lube oil system MOP discharge pressure value 13. Lube oil system AOP discharge pressure value 14. Lube oil system EOP discharge pressure value 15. Lube oil system pressure value 16. Gland steam system pressure value 17. Lube oil system trip oil pressure 18. Turbine steam inlet 1 temperature value 19. Turbine steam inlet 2 temperature value 20. Turbine exhaust temperature value 21. Steam supply steam value 22. Turbine bearing rotor front thrust temperature bearing 23. Turbine bearing front journal temperature bearing value 24. Turbine bearing rotor rear journal temperature value 25. Transmission gear pinion front journal temperature value 26. Transmission gear pinion rear journal temperature value 27. Transmission gear pinion wheel front journal temperature value 28. Transmission gear pinion wheel rear journal temperature value 29. Lube oil system oil cooler inlet temperature value | <ul style="list-style-type: none"> 30. Lube oil system oil cooler outlet temperature value 31. Gland system steam temperature value 32. Generator Bearing #3 Radial X vibration 33. Generator Bearing #4 Radial X vibration 34. Generator Bearing #3 Radial Y vibration 35. Generator Bearing #4 Radial Y vibration 36. Generator voltage 37. Generator current 38. Frequency 39. Generator Active Power 40. Generator Reactive Power 41. Turbine control valve 1 position 42. Turbine emergency shutoff valve 43. Turbine control valve 2 position 44. Turbine emergency shutoff valve 2 45. Turbine control turbine governor actuator output 1 46. Turbine control turbine governor actuator output 2 47. Cooling circuit condenser inlet valve position 48. Cooling circuit condenser level valve position 49. Cooling circuit condenser bypass valve position 50. Cooling circuit hot well pressure value 51. Cooling circuit water to cooling tower pressure value 52. Cooling circuit sump water level value 53. Cooling circuit inlet pressure value 54. Ejector system inter condenser pressure value 55. Condenser water level value 56. Condenser pressure value 57. Cooling circuit hot well outlet temperature value 58. Cooling circuit water to cooling tower temperature value 59. Oil cooling circuit inlet temperature value 60. Oil cooling circuit turbine outlet temperature value 61. Oil temperature generator outlet temperature value |
|--|---|

- | | |
|---|---|
| 62. Ejector system condenser outlet gas temperature value | 67. Electrical control unit air temperature 2 value (RTD INPUT) |
| 63. Ejector system inter-condenser temperature value | 68. Electrical control unit air temperature 2 value (RTD INPUT) |
| 64. Ejector system inter condenser gas temperature value | 69. Electrical control unit outside temperature value (RTD INPUT) |
| 65. Electrical control unit air temperature 1 value (RTD INPUT) | 70. Electrical control unit outside temperature value (RTD INPUT) |
| 66. Electrical control unit air temperature 1 value (RTD INPUT) | 71. Air compression system air pressure |

DIGITAL OUTPUT

- | | |
|---|--|
| 1. Ejector system motive steam 1 steam 1 st stage valve OPEN COMMAND | 5. Turbine control turbine governor trip turbine |
| 2. Ejector system motive steam 1 steam 2 nd stage valve OPEN COMMAND | 6. Turbine control turbine governor enable CAS |
| 3. Ejector system inter condenser inlet valve OPEN COMMAND | 7. Governor circuit breaker relay trip command |
| 4. Vacuum breaker valve CLOSE COMMAND | 8. Lube oil system emergency oil pump stop COMMAND |

ANALOG OUTPUT

- | | |
|--|--|
| 1. Steam outlet to silencer pressure control valve control | 7. Gland steam system pressure control valve 2 control |
| 2. Brine outlet to silencer level control valve control | 8. Turbine control valve 1 control |
| 3. Cooling circuit condenser inlet valve control | 9. Turbine control valve 2 control |
| 4. Cooling circuit condenser level valve control | 10. Turbine emergency shut off valve 1 control |
| 5. Cooling circuit condenser bypass valve control | 11. Turbine emergency shut off valve 2 control |
| 6. Gland steam system pressure control valve 1 control | 12. Turbine pressure inlet steam output value |
| | 13. Turbine control active power feedback output value |