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Commissioning the 280MW Geothermal Power Plants in Kenya

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ABSTRACT

Commissioning geothermal power plants is considered a crucial step in the geothermal energy development cycle. It is the last stage prior to commercial operation and it aims at ensuring that all guaranteed system conditions are met. In the year 2015, Kenya Electricity Generating Company (KenGen) PLC, injected 280MW of power into the national grid from geothermal sources after commissioning two power plants namely Olkaria 1 Additional Units (AU) and Olkaria IV. This was considered to be the single largest geothermal power project in the world and in the same year, there was a 65% drop in the cost of electricity fuel component which is the single largest portion in the electricity bills in Kenya. Apart from power stations, the project also entailed other systems in steam gathering, substations and transmission. Due to the complex nature and uniqueness of geothermal projects, various challenges were experienced thus affecting project commissioning timelines. These challenges are failure of glass reinforced plastic pipes, pressure let down station silencers and scrubber internals. Additionally, there was excessive pressure drop through the main steam strainers and turbine first stage nozzles which meant that the turbine efficiencies or steam rates did not meet contract requirements. This led to modification of the first stage nozzles and steam strainers. This paper purposes to discuss in detail, commissioning of main plant systems, challenges faced and lessons learned during project commissioning.

1. INTRODUCTION

Energy is a major driver of development in Kenya and is well captured in the country's Vision 2030. This Vision identifies energy and electricity as key elements of Kenya's sustained economic growth and transformation (Kenya Vision, 2030). Electricity is produced by different sources of power namely: hydro power, diesel generators, wind power, solar, biogas, gas and geothermal. In the recent past, geothermal energy development has been championed by the National Government in helping displace equivalent amount of thermal electricity generation that use costly fossil fuel as resource for power generation. Kenya is currently ranked 9th globally with an installed geothermal generation capacity of 676MW from Kenya Electricity Generating Company (KenGen) PLC and Orpower 4 Inc. Both power producers operate from the Olkaria geothermal field as shown in Figure 1 below.

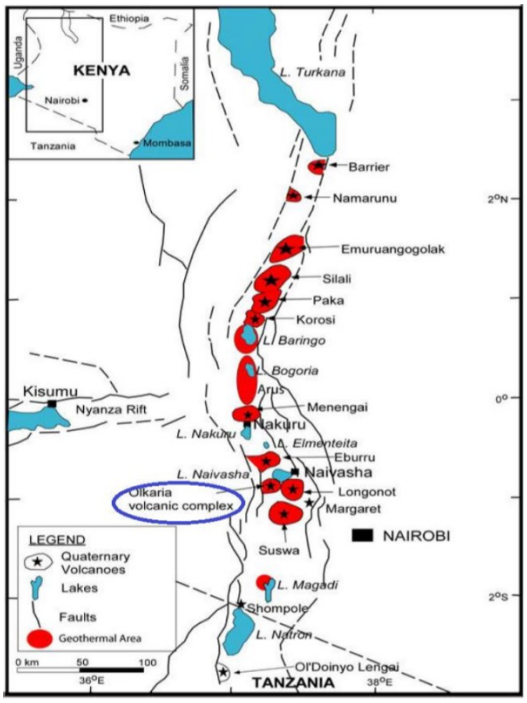


Figure 1: Location of Olkaria 1AU and Olkaria IV

KenGen PLC is the largest electricity producer in Kenya and contributes to approximately 78% of the country's electric power. It owns and operates four conventional geothermal power plants and fifteen wellhead units with a total installed capacity of 533.8 MW. In the year 2015, KenGen PLC injected 280MW of power into the national grid from geothermal sources after commissioning two power plants namely Olkaria 1 Additional Units (AU) and Olkaria IV.

2. 280MW POWER PLANTS PROJECT

The 280MW geothermal power project was implemented in Olkaria, the picturesque volcanic masterpiece in the heart of Kenya's Great Rift Valley. It consists of systems in steam gathering, power plants, substations and transmission. This project is a combination of two power plants namely Olkaria IV and Olkaria 1 Additional Units (AU). Olkaria IV was co-financed by the Government of Kenya (GoK) through KenGen and by a series of development partners, including World Bank (IDA), Japan International Cooperation Agency (JICA), European Investment Bank (EIB), Development Bank (KfW) and Agence Francaise de Development (AFD). This power station has two Units with a design rating of 74.9MW but contracted capacity of 70MW each.



Figure 2: Aerial view of Olkaria IV

Olkaria 1AU was fully funded by Japan International Cooperation Agency (JICA). The design rating for the two Units in this power plant is 75.2MW each but with a contracted capacity of 70MW each.



Figure 3: Aerial view of Olkaria 1 Additional Units

The project was implemented in phases divided into five contracts namely Lot 0, Lot A, Lot B1, Lot B2 and Lot C (Judkins, 2016). Lot 0 covered consultancy services. Lot A involved installation of steam pipelines, separators and steam field control systems and was done by Sinopec International Petroleum Service Corporation from China. Lot B1 and B2 represents construction of Olkaria 1AU and IV power stations respectively and this was implemented by a consortium of Japanese firm Toyota Tsusho Corporation and Hyundai Engineering and Construction from South Korea. Lot C involved construction of transmission lines and sub stations by KEC International of India.

Civil and construction works were sublet to local subcontractors. The site work for power station started in January 2012 while Steam field site works started in July 2012 (Judkins, 2016) as indicated in Table 1. The overall project management was overseen by Jacobs Sinclair Mertz of New Zealand (Lot 0).

Task Name	Olkaria 1AU		Olkaria IV	
	Start Date	**End Date**	**Start Date**	**End Date**
Contract Signing	7th November 2011		7th November 2011	
Performance Certificate	11th January 2015		2nd September 2014	
Steam field				
Construction and commissioning	July 2012	September 2014	July 2012	April 2014
Power Stations				
Construction	May 2012		January 2012	
Plant Commissioning	January 2015		September 2014	

Table 1: Project commissioning schedule

This project has attained various accolades such as Outstanding Clean Power Project of 2014/15 (KenGen, 2019) and Innovative Energy Project of 2016. The project has also enabled KenGen to be recognized with Continental Award for Africa's Best Energy Company and Excellence in Power Generation in 2016.

3. PLANT SYSTEMS AND CHARACTERISTICS

The power stations consist of the following systems: Steam and condensate, steam turbine and generator, circulating and service water, non- condensable gas extraction (NCG), compressed air, digital electro hydraulic control, heating ventilation and air conditioning (HVAC), chemical dosing, waste water treatment and firefighting. However, some are considered as main systems and therefore form the basis of this section. These include steam and condensate, steam turbine and generator, non-condensable gas extraction and circulating water.

3.1 Steam field

The steam field consists of wells, steam and brine pipelines, separators, pressure let down valves, vent valves, rock mufflers and their associated control systems. Geothermal fluid is piped from production wells and separated at 10 barg. After separation brine is piped to hot reinjection wells. Steam then flows through a pressure let down station which contains pressure control valves that perform adiabatic expansion of the saturated steam while maintaining an upstream steam field pressure of 10 bar and the desired downstream pressures for both plants. Excess steam is vented to the atmosphere via rock mufflers.

Table 2 below shows some project steam field characteristics.

Item Name	Plant	
	Olkaria 1AU	**Olkaria IV**
Production wells	20	21
Hot reinjection wells	5	5
Cold reinjection wells	2	2
Average enthalpies (KJ/kg)	2275	1940
Vent station capacity (T/hr)	1046	800

Table 2: Steam field characteristics

3.2 Steam turbine and generators

The turbines are tandem compound, single cylinder double flow type. They have a double inlet flow of steam with the guarantee conditions as shown in Table 3 below:

Item Name	Plant	
	Olkaria 1AU	**Olkaria IV**
Throttle steam pressure (bara)	4.80	5.80
Throttle steam temp. (°C)	150.3	157.5
Exhaust pressure (mbara)	75	75
Output (kW)	75,260	74,924

Table 3: Guaranteed steam turbine parameters

The generators are horizontal cylindrical rotor synchronous type rated at 88.55MVA with a brushless type excitation with permanent magnetic generator. The major components within the steam turbine generator are: gland steam, lubrication and control system, synchronous generator, automatic voltage regulator, Digital Electro Hydraulic Control (DEHC) and turbine supervisory instruments. Operational limitation of the turbine are on shaft eccentricity, shaft vibration, shell and differential expansion, lubricating system and permissible time for off frequency operation among others.

3.3 Condenser

The condensers are advanced direct contact type. Its specifications include steam flow of 490T/h at NCG content of 1.503%, temperatures of 40.13°C and exhaust pressures of 0.075bara. The condenser is composed of an extension neck, expansion joints, nozzles, shell, packings and hotwell. The extension neck provides a smooth transition from the turbine exhaust to the packing area while the expansion joint provides relief for condenser/turbine exhaust thermal expansion. Packing is arranged to control steam

velocity so as to prevent excessive pressure drop. Gas and associated vapour collect in the gas cooling area where they are extracted by the gas removal system. Cooling water from the cooling tower is directly injected into the exhaust steam through the jet nozzles by differential pressure between cooling tower and condenser. Water level in the condenser is maintained by two level control valves positioned downstream of the hot well pumps.

3.4 Steam scrubber

The steam scrubbers are cyclonic separator type and they provide steam dryness of 99.98% which is a steam turbine generator requirement during normal operation. They are equipped with a waste condensate vessel where the condensate separated is collected temporarily before being discharged to the cooling tower through spargers. At rated condition, the pressure drop through the steam scrubber is less than 0.1barg.

3.5 Cooling towers

The cooling towers are mechanical induced draft and counter flow type. Each plant has two cooling towers with eight on-line cells per Unit. The cooling towers comprise of fan stacks, fan blades, floating type drive shafts, drift eliminators, gear reducers, motors, PVC type films, distribution pipes and spray nozzles. Their characteristics are as per Table 4 below.

	Plant Specification	
Item Name	**Olkaria 1AU**	**Olkaria IV**
Total design water flow (m^3/h per Unit)	18600	17520
Hot water temperature (°C)	37.3	37.3
Cold water temperature (°C)	23.0	23.0
Temperature range (°C)	14.3	14.3
Thermal duty (MW/Unit)	307	289

Table 4: Cooling tower characteristics

3.6 Gas extraction system

The power plants employ a hybrid system of gas extraction whereby each Unit has 1st stage, 2nd stage, 3rd stage gas ejectors and two liquid ring vacuum pumps. The 3rd stage ejector is a redundancy for the liquid ring vacuum pumps. The gas extraction system establishes and maintains vacuum in the condenser to aid continuous flow of steam and removal of non- condensable gas from condenser during both start up and full operation. This system also comprises of separators, inter condensers and after condenser. Main steam provides the motive force for operating these ejectors and cooling water is provided in the inter-condensers and vacuum pumps by auxiliary cooling water pumps.

4. POWER PLANT COMMISSIONING

The power plant commissioning was carried out systematically after completion of mechanical, electrical, instrumentation and structural installations. The generating Units at Olkaria IV were commissioned in July 2014 and August 2014 respectively. The Units at Olkaria 1AU were commissioned in October 2014 and January 2015 respectively. Figure 3 below shows a summary of the commissioning procedure (Judkins, 2016). This summary covers the power plant systems only.

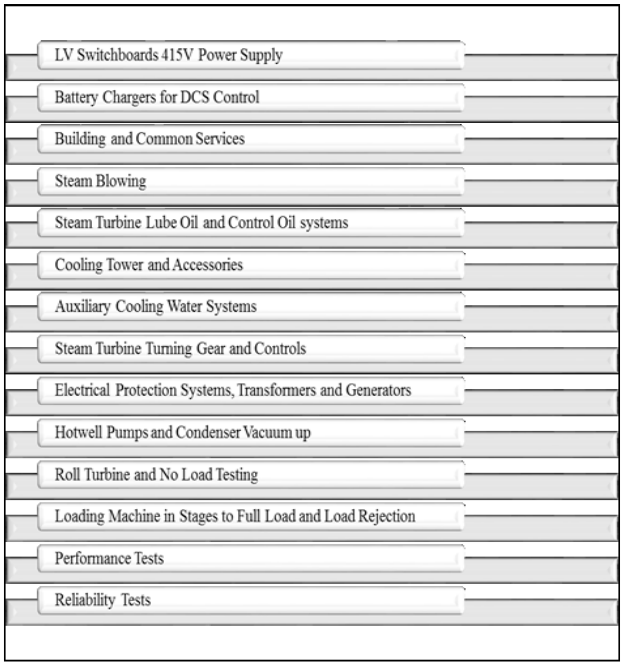


Figure 4: Summarized commissioning procedure

Both power plants commenced their commissioning by livening the low voltage switch boards using 415V construction power supply so as to enable start-up of the Distributed Control System (DCS), battery chargers and batteries were tested. Common services such as the four compressors, fire pumps and two emergency diesel generators were tested to confirm dependability. The steam blowing process for main and auxiliary steam piping was undertaken while removing any temporary piping and connecting permanent pipework.

To ensure turbine reliability, the turbine lube oil and control systems were flushed and the turning gears commissioned. The control valves were also tested and initial settings confirmed. The circulating water system consisting of auxiliary cooling water pipework and cooling towers was inspected for leaks while the hotwell pumps were tested on recirculation to the condenser.

The electrical protection systems, transformers and generators were tested and the medium voltage switchboards livened. Various pumps including vacuum, hotwell and auxiliary were tested prior to rolling the turbine and carrying out no-load tests. So as to guarantee system availability to the off taker and the country at large, tests such as performance, full load, load rejection and reliability runs were conducted.



Figure 5: Commissioning fire pumps at Olkaria IV

5. CHALLENGES ENCOUNTERED AND SOLUTIONS

Various challenges were experienced thus affecting project commissioning timelines. These challenges are failure of glass reinforced plastic pipes, pressure let down station silencers and steam scrubber internals. Additionally, there was excessive pressure drop through the main steam strainers and turbine first stage nozzles which meant that the turbine efficiencies or steam rates did not meet contract requirements.

5.1 Failure of glass reinforced polyester pipe (GRP)

Cooling water from the cooling tower is conveyed to the condenser by use of glass reinforced polyester (GRP) pipes. The same is also used to channel hotwell discharge and residue gas to the cooling tower. GRP was preferred due to low operating and maintenance costs, high corrosion resistance, high stiffness, low weight, compatibility with other materials and high structural load capacity. The soils at Olkaria have near zero cohesion and this required strict consideration during compaction since the pipes were buried. However, heavy downpour or flooding led to saturation of pipe beddings which resulted to subsidence and eventual failure as shown in Figure 5 below. This required immense attention as this meant excavating the affected areas to access the pipe cracks. KenGen PLC is in the process of finding alternative ways of conveying cooling water such as avoiding buried pipework.



Figure 6: Cracked pipe and repair process

5.2 Failure of pressure let down station silencers

Partly through the project execution phase, analysis of data for new wells that had been drilled showed that the fluids had higher silica concentrations. At that point in time, the turbine design, piping design and procurement processes were at an advanced stage. Since it was unfeasible to redesign the piping systems for pressures higher than the existing design pressure, and to change the turbine systems to cope with higher pressures, it was decided to raise the steam separation pressures as high as feasible, and provide control valves to drop the steam field pressure to the contracted turbine inlet pressure. The separation pressures were raised to 10 barg and pressure let down control valves, silencers and de-superheating valves installed.

After completion of the tie in of the pressure let down station with the plant steam line, it was noted that there was a significant pressure drop in the steam lines. This was attributed to faulty silencers which were removed and replaced with temporary spools as shown in Figure 6 below.



Figure 7: Silencer replacement at the pressure let down station

5.3 Underperformance of steam turbine generator

Olkaria IV provisional performance test gave a net power output of 66.8 MW which was way below the requirement. Toshiba, who are the Original Equipment Manufacturers (OEM) found excessive pressure drop through the main steam strainers and turbine first stage nozzles. New strainers were installed and the desired power net output of 70MW obtained. However, the turbine efficiency or steam rate did not meet contract requirements. This led to modification of the first stage nozzles whereby the Performance Test was successful. Generating Units for both plants were then modified by the OEM accordingly.

5.4 Steam scrubber internal faults

During commissioning of Olkaria 1AU, unusual reverberations in Unit 4 steam scrubber was observed. The unit was shut down and inspection revealed that the vortex tube and smoothing sleeve weld seam had failed. Repair was done in conjunction with the manufacturer (Cameron International Corporation, 2015). However, this did not last as after about six months of operation, the defect reoccurred. Inspections showed that all scrubbers at both power plants were affected. Further analysis showed this was as a result of a poor weld detail implemented as part of the first repair. A comprehensive repair methodology was adopted and the scrubbers returned to service.

6. LESSONS LEARNED AND CONCLUSION

Implementation of the 280MW geothermal power plants project was a clear indication that the Government of Kenya is willing to bear part of the risks involved when developing geothermal energy resources. This is perceived through funding such projects so as to negate overreliance on hydro power which is susceptible to being affected by weather pattern changes. Furthermore, it promotes economic growth as products and services are availed in a sustainable, cost effective, and affordable manner to all sectors of the economy.

From this project, KenGen PLC has taken strides in developing its workforce and other resources to undertake new geothermal projects such as the ongoing commissioning of Olkaria V power plant which is expected to add 158MW into the national grid by the end of 2019. The company has also expressed interest in developing an energy industrial park within its geothermal concessional area. This enhances effectiveness in meeting power demand and development of the manufacturing sector through cheap and renewable sources. KenGen PLC is also in the process of developing an energy recovery strategy for the existing pressure let down stations in the 280MW power plants. This will translate to more geothermal power output for the country with minimum investment given that substantial investments associated with steam exploration, drilling and steam field development are avoided. The 280MW power plant projects also bring out opportunities for improving components such as glass reinforced polyester pipes, scrubbers and cooling towers in future installations. This will considerably reduce commissioning errors and total project completion time.

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