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DESIGN AND COST FEASIBILITY TO USE ELECTRICITY FROM THE GRID FOR KENGEN DRILLING RIGS

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ABSTRACT

KenGen owns and operate three land drilling rigs; one mechanical rig rated at 550 Hp and two electrical rigs rated at 2000 Hp, all stationed at Olkaria for drilling of geothermal wells. Among the operation expenses of drilling, the fuel cost component accounts for the largest part. This is due to the fact that drilling is a 24 hour energy intensive activity that rely on continuous operations of generators for supply of energy for motive power required by several equipment on the rig. Generators are known for their energy inefficiency due to various stages of conversion from chemical energy to mechanical energy and finally to electrical energy. Fuel efficiency is rarely achieved in rig generators due to intermittent load requirements brought by constant switching on and off of main working loads. This make generators consume more fuel than the comensurate electrical loads they carry. When the consumption is high, the expenses of fuel is high. Rig generators also have high maintenance costs due to their continuous operation. All these factors combined provide a genuine need to find alternative source of power to the rig. This is the essence of this project study.

1. INTRODUCTION

Drilling rigs are categorised, among other things, by the mode of motive power. There are mechanical rigs, hydraulic rigs, DC/DC electrical rigs and AC/DC electrical rigs. Mechanical rigs use dedicated diesel engines to provide the required motive force for the rotary table, draw works, mud pumps and other loads through systems of clutches and transmission. Hydraulic rigs use diesel engines to operate hydraulic pumps which provide power to the necessary equipment of the rig. DC/DC rigs use DC motors as source of motive power for its rotary equipment. These motors are powered by dedicated diesel electric generators. These systems of single function equipment have a high risk of halting the whole drilling operation in case of failure of one engine. The AC/DC electric rigs have diesel generators connected in parallel that generate alternating current that is fed into a SCR module for rectification. The output is a direct current of variable voltage level which is supplied to individual DC motors to provide motive power for rotary table, mud pumps and draw works. The generators also provide AC power needed for other AC loads such as top drives and auxiliary systems like mud tanks motors, rig and camp lighting, heating and air-conditioning. The number of generators running in parallel at any time varies with load requirement. In a typical drilling operation, one would find one or two generators running at a time depending on the ongoing drilling and pumping operations. It is always preferable to economize the use of generators to save fuel.

2. BACKGROUND

2.1 Olkaria geothermal generation capacity

Olkaria geothermal field is among the many geothermal fields in the Kenya rift valley that runs through the country from north to south as shown in Figure 1. The major geothermal prospects already identified are; Barrier, Namarunu, Emuruangogolak, Silali, Paka, Korosi, L. Baringo, L. Bogoria and Arus, Menengai, Eburru, Olkaria, Longonot, Suswa and L. Magadi (Omenda, 2010). KenGen is currently developing Olkaria and Eburru fields through drilling and construction of power plants. Ormat is also developing part of the Olkaria South-West Field. GDC on the other hand is developing the Menengai field where several production wells have been drilled.

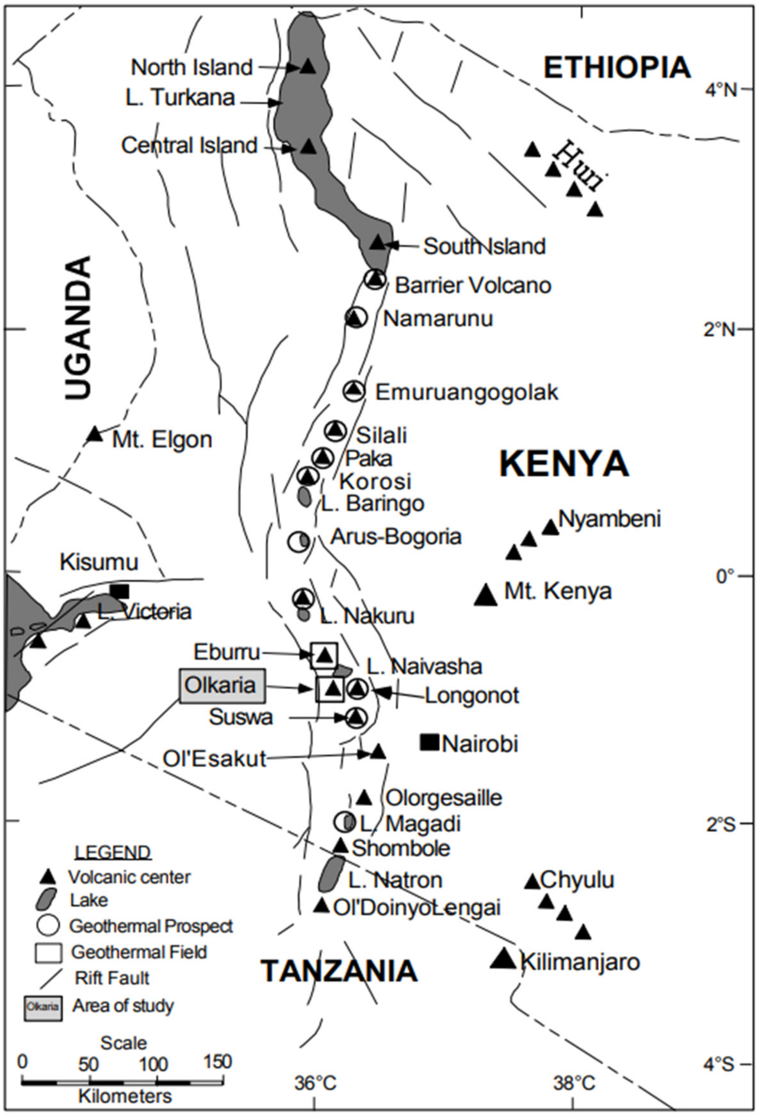

FIGURE 1: Geothermal Prospects in Kenya (Lagat, 2004)

The Olkaria geothermal field is divided into seven blocks, namely, Olkaria North-West field, Olkaria Central field, Olkaria North-East field, Olkaria South-West field, Olkaria East Production field, Olkaria Domes field and Olkaria South-East field, as shown in Figure 2. KenGen has developed part of these fields through drilling and construction of power plants and currently there are five conventional power plants generating a total of 430 MWe and seven wellhead power plants generating a total of 80.6 MWe. Eburru has a wellhead power plant installation currently generating 2.5 MWe (Makhanu, 2018).

There is an ongoing project for the Olkaria V 140 MWe power plant construction expected for commissioning in July 2019.

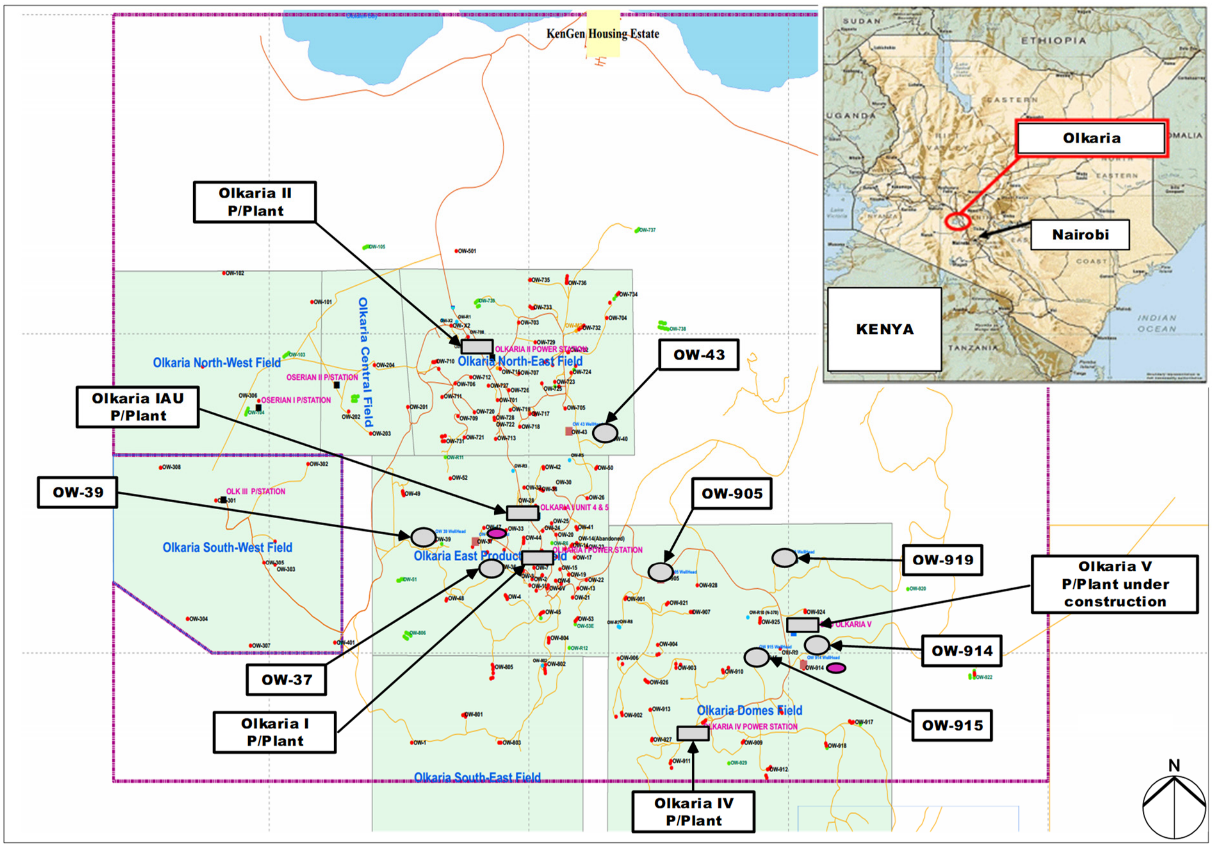

FIGURE 2: Olkaria fields and power plants (modified from Apiyo, 2016)

2.2 Drilling in Olkaria field

KenGen own and operate three land drilling rigs stationed in Olkaria. One rig, N370 has a capacity of 550 Hp and is purely mechanical. The other two rigs, KGN1 and KGN2, are electrical with a capacity 2000 Hp. Drilling is expected to continue in the Olkaria field through the optimization programme for power expansion. Make up wells and deepening of the existing shallow wells is also anticipated to be done in the future as maintenance for the power production. Drilling activities are energy intensive since the energy generating equipment for the required motive forces is always running and consuming a lot of fuel. The directly coupled diesel engines for the drawworks, mud pumps and rotary table in the mechanical rig consume diesel fuel just as the generators that produce electrical energy required by the specific motors serving the drawworks, mud pumps and top drive/rotary table in the electrical rig types. The rate of fuel consumption largely depends on the size of the diesel engines. Rigs with bigger capacities use bigger diesel engines and therefore more diesel fuel is expected to be consumed compared with rigs with relatively smaller capacities.

2.3 Electric rigs

Electric drilling rigs can be categorised by power modes as AC/AC or AC/DC. In the AC/AC electric rigs, the diesel generators produce AC current which is controlled using VFDs to achieve variable speeds of the operated equipment. While for AC/DC electric rig, the AC current produced by the diesel generators is converted to DC current by use of SCR, where speed control is achieved. The points of use of the variable power in both types of rigs are the drawworks, mud pumps and top drive/rotary kelly table. Other main electrical loads on the rig include the mud tanks handling motors, rig lighting and camp lighting systems. The power source generators are connected in parallel and the number of generators online depends on the power requirements of the rig. All these generators draw diesel fuel from a common day tank. The electric rigs owned and operated by KenGen in Olkaria are AC/DC. Each rig has four diesel generators connected in parallel supplying 3-phase power at 600 VAC, to a common busbar in the SCR module. In the SCR system, this power is converted to DC voltage and current that is variable from 0 - 750 VDC, which is supplied to the operated equipment. This variability of voltage enables speed control of the DC motors.

This report expounds the technical and financial feasibility of substituting power supply from rig diesel generators with power from the grid system. This power can be tapped from any of the existing wellhead power plants in the Olkaria fields or from a nearby medium voltage overhead power line. For flexibility of connection, power will be tapped at 11 kV, which is the voltage of generation in all the power plants in Olkaria. This will ensure that there will be no need to construct substations for the sole purpose of supplying power to the rig.

3. DESCRIPTION OF THE REQUIRED MAIN COMPONENTS

3.1 Transformer

Transformer is an electrical component that is designed to convert electrical voltage from one level to another. The conversion can be stepping up or stepping down the voltage of an alternating current. Power in a transformer is transmitted from the primary circuit to the secondary circuit by induction. For an efficient transformer, all the incoming power is transmitted to the outgoing circuit. The relationship of power transmission in an ideal (i.e. lossless) transformer is therefore given by the formula:

$$P_{incoming} = I_p V_p = P_{outgoing} = I_s V_s \quad (1)$$

Which in consideration to the number of turns in the primary (N_p) and secondary (N_s) windings the formula can be rewritten as:

$$\frac{V_s}{V_P} = \frac{N_s}{N_P} = \frac{I_P}{I_s} \quad (2)$$

The relationship in the equation above shows that when voltage is increased, current decreases by a similar factor for constant power. This is clearly represented as shown in the formula:

$$P = V_p I_p = V_s I_s \quad (3)$$

where P = Power;
V_p = Voltage on the primary winding;
V_s = Voltage on the secondary winding;
I_p = Current in the primary winding;
I_s = Current in the secondary winding;
N_P = Number of turns in the primary winding; and
N_s = Number of turns in the secondary winding.

The relationship between the primary and secondary circuits is that, the volt-amperes product in both windings are equal. Transformer capacity selection is therefore done by considering the primary voltage, secondary voltage and current requirements.

The technical design in this project for the power unit that will enable the powering of the rigs from the grid, will take into account the use of a transformer. This is a requirement to enable the changing of voltage levels of power from that of the grid where supply is tapped from to the level required by the rig systems.

3.2 Electrical cables

An electrical cable is an assembly of electrical conductors used to transmit power from point of supply to the point of use. The type of construction of the cable is done to withstand mechanical and thermal stresses as well as environmental conditions. The design and manufacture of a power cable is determined by several factors. The three main determinants are:

1. Working voltage which determines the thickness of the insulating material.
2. Current capacity which determines the cross-sectional area of the conductor material.
3. Ambient conditions which include exposure to chemicals, water, mechanical stresses and temperature. These determine the material and construction of the external sheath of the cable.

The power voltage ratings of a cable are indicated in the format:

$$U_o/U \tag{4}$$

where U_o = Cable rated r.m.s. power voltage between each conductor and earth; and
U = Cable rated r.m.s. power voltage between the three phase conductors.

When the power requirement of a circuit is known, the operating current I_b, can be calculated using the equation:

$$I_b = \frac{P}{\sqrt{3}\, U_b \operatorname{Cos} \phi} \tag{5}$$

where P = Power;
I_b = Operating current;
U_b = Operating three phase voltage (line–line); and
$\operatorname{Cos} \phi$ = Power factor.

All electrical conductors except super conductors have intrinsic resistance in them that is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area. This relationship is represented by the law of resistance equation:

$$R = \rho \frac{L}{a} \tag{6}$$

where R = Conductor resistance;
L = Conductor length;
a = Conductor cross-sectional area; and
ρ = Resistivity of conductor material.

When electric current flows through passive elements of a circuit there is a voltage drop due to internal resistance of the conductor material, across connectors and across contacts. This leads to loss of supplied energy through dissipation as heat, and voltage at the end of a conductor is lower than at the start. The voltage drop in a three phase circuit is given by equation 7 (Adams, 2015).

$$VD = \frac{\sqrt{3}\, K\, I\, L}{cmil} \tag{7}$$

where VD = Voltage drop;
I = Current of load;
K = Electrical resistivity (ohms-cmil/ft.);
L = Length of conductor in feet, (one-way); and
$cmil$ = Circular mil area of the conductor.

Electrical power cables will be used in the construction of the system that will power the rig using the supply from the grid. The above criteria will be used in determining the size and length of the power cable to be used. This is required to determine the economical length of cable that will not allow excessive voltage drop as well as choosing the right cable diameter that will be economical in price. The expected length of the cable that will be used in this analysis will range between 1000 m to 2000 m. It will be beneficial if a longer distance will be accommodated if cost of the cable will not make the project too expensive. The use of a longer cable will allow the tapping of power supply from existing overhead power supply lines that are a longer distance from the rig in the field. The other side of using longer cables, given that the cable diameter will have to be increased with the increase in cable length to minimize voltage drop, will be a proportional increase in its costs. This project aims at finding an economical balance for cable length, voltage drop and costs.

3.3 Circuit breakers

A circuit breaker is an electrical device that is designed to be automatically operated to break or make an electrical circuit with the aim of protecting it from excess current flow from a detected overload or short circuit. Circuit breakers are classified according to the features below:

1. Voltage application: Low, medium and high voltage circuit breakers.
2. Interruption medium: Air, oil, vacuum and SF6 circuit breakers. These form the main classes.
3. Structural features: Dead and live tank circuit breakers.
4. Installation location: Indoor and outdoor circuit breakers.

Circuit breakers will be used in the design of the interface system that will enable the use of grid electrical supply to power the rigs.

4. DESCRIPTION OF WORK

4.1 Data

To design an appropriate unit that will enable supply of power to the rig from the grid network, typical power consumption was gathered from the 2000 Hp electric land rigs drilling in Olkaria geothermal field. Recorded data on power consumption by the electrical loads at sampled intervals were used for analysis. The data are from both vertical and directional wells drilled up to the required 3000 m depth. Rig power is generated by diesel generators connected in parallel. KenGen rigs each have four main generators, and depending load requirement, which is dictated by the type of operation going on at any given time, one or two generators at maximum will be operating at the same time. Power generated by these diesel generators is consumed by the electrical equipment being operated at the rig at that particular time. The equipment has both AC and DC loads. The total power generated by the operational generators and the total power uptake at any given time represents the total instantaneous power requirement at the rig. The parallel generators feed in to a common electrical busbar at a potential of 600 V. The total current in the busbar represents the total electrical loads requirement at any given juncture. These readings were done at regular time intervals and recorded. The aim is to determine the current requirement distribution over the day and by extension over different drilling operations in the rig. A sampled generator electrical loading for 28^{th} June 2018, over a 24-hour period is given in Table 1. This was during the drilling of directional well OW-736D, at 2400 m depth.

From the Table 1, it can be seen that at every logging time, two generators were operational and two were on standby. The depth of 2400 m in a directional well gives a good representation of near maximum loading during a typical drilling process of a geothermal well.

The other set of data that was sourced from the drilling rigs in Olkaria were the records of fuel consumed at the well site during drilling. To get a true representation of the average rate of fuel consumption, fuel records spread over a period of two years is used in the analysis of this project. This record is given in Table 2.

TABLE 1: Rig generator electrical load requirement

<table>
<tr><th>Date</th><th>Logging Time</th><th>Genset No.</th><th>Voltage (V)</th><th>Phase A current (A)</th><th>Phase B current (A)</th><th>Phase C current (A)</th><th>Power factor</th><th>Average current (A)</th></tr>
<tr><td rowspan="20">28.6.2018</td><td rowspan="5">0900 Hrs</td><td>1</td><td>603</td><td>470</td><td>473</td><td>477</td><td>0.37</td><td>473</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>4</td><td>604</td><td>258</td><td>266</td><td>267</td><td>0.81</td><td>264</td></tr>
<tr><td colspan="6">Total</td><td>737</td></tr>
<tr><td rowspan="5">1400 Hrs</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>2</td><td>603</td><td>325</td><td>320</td><td>318</td><td>0.49</td><td>321</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>4</td><td>603</td><td>234</td><td>244</td><td>243</td><td>0.75</td><td>240</td></tr>
<tr><td colspan="6">Total</td><td>561</td></tr>
<tr><td rowspan="5">2100 Hrs</td><td>1</td><td>605</td><td>522</td><td>521</td><td>548</td><td>0.37</td><td>530</td></tr>
<tr><td>2</td><td>605</td><td>475</td><td>473</td><td>493</td><td>0.53</td><td>480</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td colspan="6">Total</td><td>1011</td></tr>
<tr><td rowspan="5">0200 Hrs</td><td>1</td><td>600</td><td>256</td><td>257</td><td>248</td><td>0.69</td><td>254</td></tr>
<tr><td>2</td><td>600</td><td>349</td><td>351</td><td>342</td><td>0.47</td><td>347</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td colspan="6">Total</td><td>601</td></tr>
</table>

TABLE 2: Rig fuel consumption

No.	Well drilled	Rig	Drilling days	Drilled depth	Total fuel consumed (L)	Average fuel / day
1	OW-724B	KGN1	134	2933	580,600	4,333
2	OW-740A	KGN1	102	3000	366,050	3,589
3	OW-739A	KGN2	71	2067	227,700	3,207
4	OW-53D	KGN2	92	3000	349,650	3,801
5	OW-807A	KGN2	118	2697	336,000	2,847
6	OW-205	KGN2	93	3000	243,504	2,618
7	OW-205A	KGN2	87	3000	336,600	3,869
8	OW-739A	KGN2	84	3000	260,000	3,095
9	OW-53D	KGN2	71	3000	318,000	4,479

Fuel at the rig site is used by both the diesel generators for power supply to electrical loads and by the air compressors and air booster used during the aerated drilling process. The aerated drilling is normally used in Olkaria geothermal field during drilling of the production section of the well, in most cases after 750 m depth of the well except when the lithology dictates a lower casing of 1200 m. The rig air compressors and air booster are engine driven with direct coupling to the compressing units. The fuel consumed during drilling of a particular well is therefore not entirely by the electric generators, but is shared with the air compressors. A previous rig energy audit report by the KenGen energy management team, indicated that fuel used at the rigs is 60% by electric generators and 40% by air compressors (Mukhongo, et al, 2017). This means that from the data above, the total fuel consumed in each corresponding well is 60% by the diesel generators, which is the subject of analysis in this project. The conclusion from the data is that: the average time it takes a rig to drill one well is approximately 84 days while the average diesel consumption per day is 3,500 litres of diesel fuel. Each rig is typically planned to drill at most five wells per year. This will form the basis of subsequent analysis in this project.

5. TECHNICAL DESIGN

5.1 Rig power system design

KenGen owns and operates two 2000 Hp electric land drilling rigs in Olkaria with a hook load of 450 tons. These rigs have the capability to drill up to a depth of 7000 m. The geothermal wells in Olkaria are being drilled to 3000 m, but there are proposals to drill up to 3500 m in future. Each rig employs four CAT 3512B generators rated at 1710 kVA, connected in parallel to supply a common electrical load. Depending on the kind of operation at the rig which dictates the power requirement, one or two generators will be running while the rest are on standby. The rig also has an auxiliary generator, CAT C18, rated at 500 kVA that is used during the rig start up process after mobilization. It is battery started and generates the initial power required to run the service air compressor for the main purposes of starting the main generators which are started pneumatically. Once the main generator is started, it provides the required electrical power for all equipment and the small generator is then switched off. This system is depicted in the single line diagram shown in Figure 3.

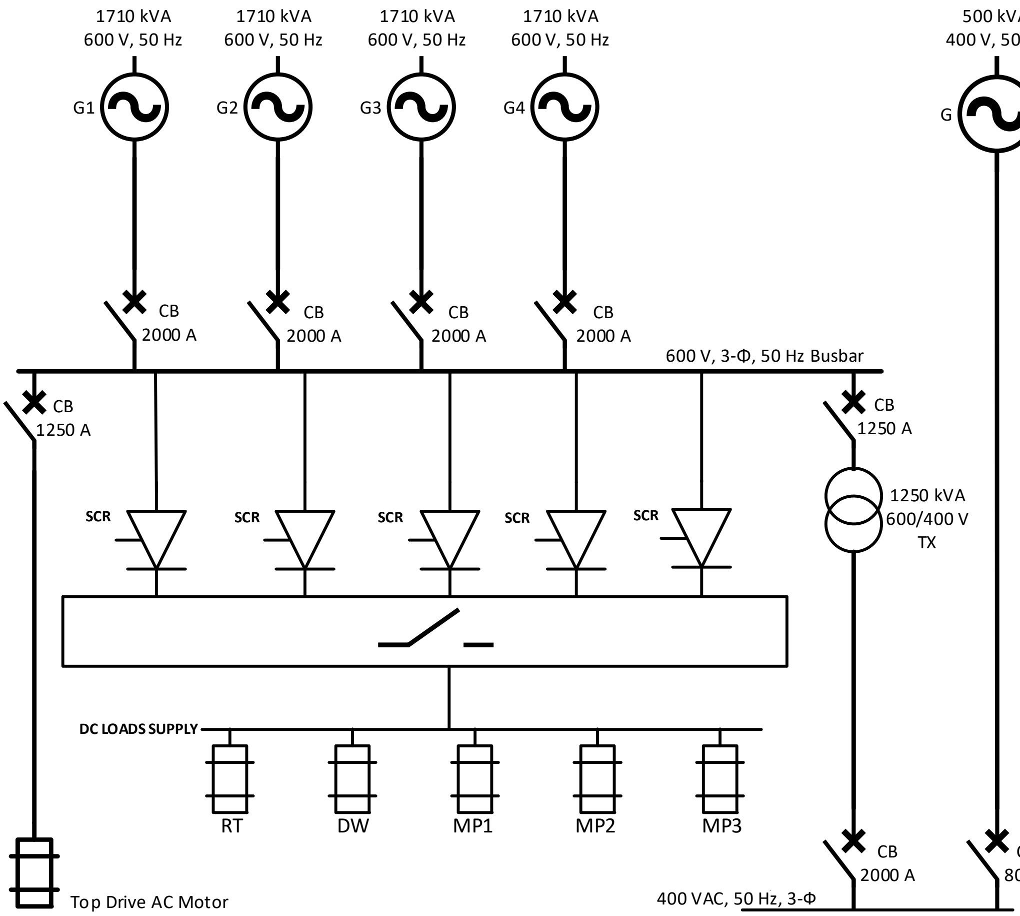

FIGURE 3: Existing rig power system

The aim of this project is to introduce the grid power supply and hook onto the 600 VAC busbar, parallel to the main generators. This will act as a substitute for the power from the main generators. This system is envisaged to be used whenever the rig is drilling within a radius of 2 km from any wellhead power plant in Olkaria geothermal field or when the rig is drilling close to an existing grid network of 11 kV which evacuates the wellhead power plants to the centralized main substations.

A voltage level of 11 kV is chosen in this design since it is the standard voltage of generation used in all power plants in Olkaria. It is of economic interest to do cost comparison between the current use of diesel generators for power supply and the proposed use of grid power supply. The grid supply will be

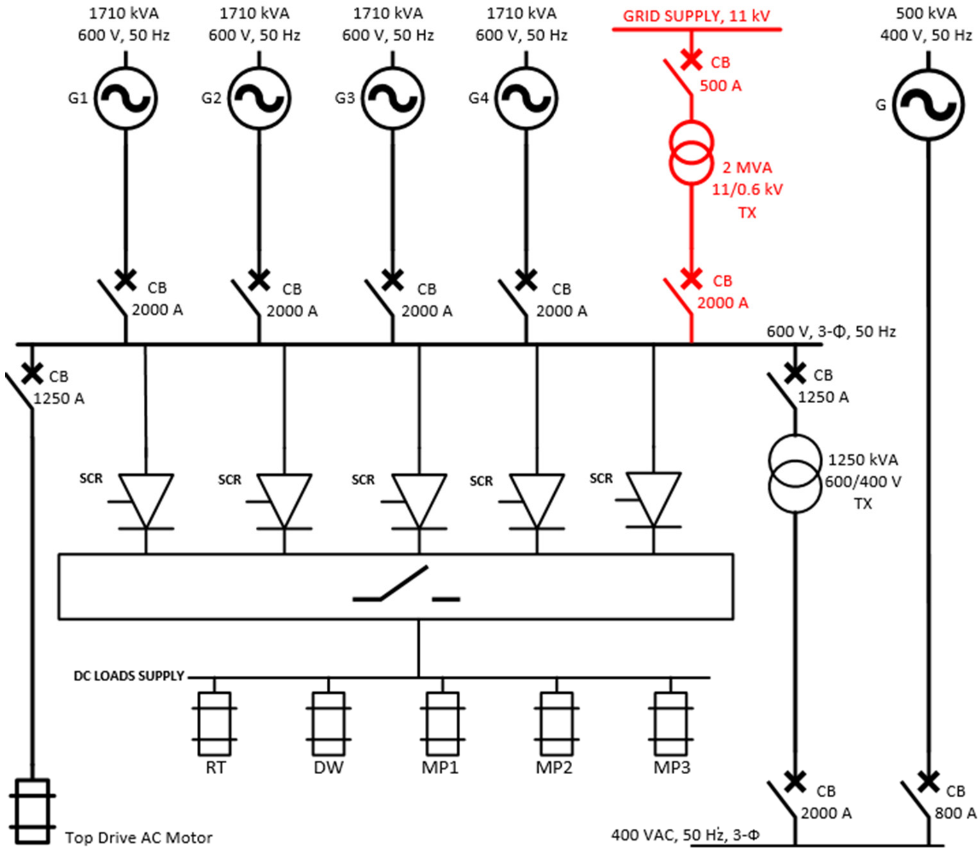

FIGURE 4: Grid connection to rig system

connected on to the rig system as shown in Figure 4.

Two different grid connection topologies will be considered in this paper. The approach is to consider different modes of connection that depend on the physical distance between the transformer and the main distribution board for the electrical loads.

5.2 Connection topologies

It is important to note that the rigs are mobile and are mobilized from one site to another in the effort to drill more wells to further production. The new system being proposed in this paper therefore considers this mobility as all systems should be able to be moved from one point to the next. The main components of the new system include the incomer electric cable, the transformer and switchgear. The transformer and the switchgear will be housed in a container while the cable will be reeled into a roll for ease of movement. Depending on the economic viabilities and ease of movement, two topologies are analysed in this report (Bolgov and Laanetu, 2016). The recommended practice is to locate the substation as close to the load centre as feasible so that the product of load and distance is at minimum as observed by Gönen (1987). One topology is to step down power from 11 kV to 0.6 kV at the point of grid connection and transmit power at 600 V using a 2000 m cable to the rig's electrical power system. This connection is depicted in Figure 5. The second topology connection, shown in Figure 6, entails

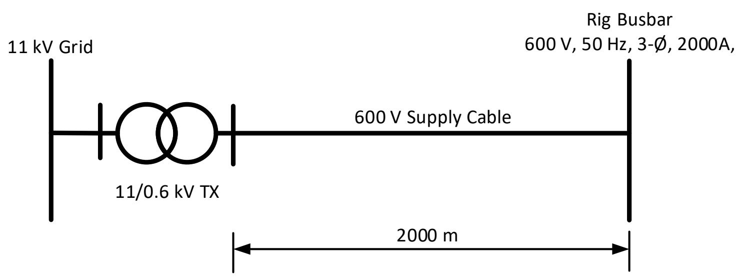

FIGURE 5: Transmission at 600 V level

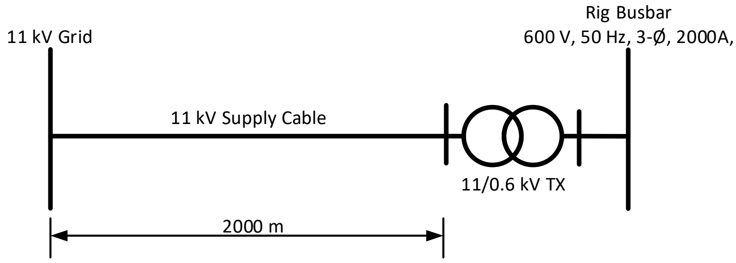

FIGURE 6: Transmission at 11 kV level

transmitting the grid power via a 2000 m cable at 11 kV and stepping down to 600 V at the rig site for connection to the rig power system.

Transmission of voltage over long distances requires a choice of voltage levels since it affects the effective voltage delivered at the end of the conductor used by the equipment.

Voltage drop in a conductor is a product of the conductor's internal resistance and the current flowing in it. On the other hand, resistance is directly proportional to the conductor length and inversely proportional to its cross-sectional area. These relationships are shown in Equations 6 and 7. IEC 60364 standards provide for a maximum allowable voltage drop of 5% for reasonably efficient operation, (Tison, 2013).

5.3 Voltage drop analysis and conductor sizing

Analysis of voltage drops were carried out on the two topologies above with a comparison on using a copper conductor and an aluminium conductor. The results of the analysis are as shown in Table 3.

TABLE 3a: Transmission at 11 kV using a copper conductor

Vd = (1.732 x K x I x L) /cmil

Nominal voltage (V)	Conductor size		Voltage drop (Vd)	% Vd	Effective voltage (V)
	mm²	cmil			
11,000	25	49720	398	3.62%	10,602
11,000	35	69390	285	2.59%	10,715
11,000	50	99380	199	1.81%	10,801
11,000	70	137900	143	1.30%	10,857

K = 12.9 Ω.cmil/ft
L = 2000 m
I = 135 A
1 m = 3.28 ft

TABLE 3b: Transmission at 11 kV using an aluminium conductor

Vd = (1.732 x K x I x L) /cmil

Nominal voltage (v)	Conductor size		Voltage drop (Vd)	% Vd	Effective voltage (V)
	mm²	cmil			
11,000	25	49720	654	5.95%	10,346
11,000	35	69390	469	4.26%	10,531
11,000	50	99380	327	2.97%	10,673
11,000	70	137900	236	2.14%	10,764

K = 21.2 Ω.cmil/ft
L = 2000 m
I = 135 A
1 m = 3.28 ft

TABLE 3c: Transmission at 0.6 kV using a copper conductor

Vd = (1.732 x K x I x L) /cmil

Nominal voltage (V)	Conductor size		Voltage drop (Vd)	% Vd	Effective voltage (V)
	mm²	cmil			
600	800	1555000	189	31.42%	411
600	900	1778000	165	27.48%	435
600	1000	1974000	148	24.75%	452
600	1100	2171000	135	22.50%	465
600	4951	9771251	30	5.00%	570

K = 12.9 Ω.cmil/ft
L = 2000 m
I = 2000 A
1 m = 3.28 ft

TABLE 3d: Transmission at 0.6 kV using aluminium conductor

Vd = (1.732 x K x I x L) /cmil

Nominal voltage (V)	Conductor size		Voltage drop (Vd)	% Vd	Effective voltage (V)
	mm²	cmil			
600	800	1555000	310	51.63%	290
600	900	1778000	271	45.16%	329
600	1000	1974000	244	40.67%	356
600	1100	2171000	222	36.98%	378
600	8136	16058180	30	5.00%	570

K =	21.2	Ω.cmil/ft
L =	2000	m
I =	2000	A
1 m =	3.28	ft

5.4 Results

The calculated analysis indicates that the voltage drop is greater when the current is high. The high current is occasioned by stepping down voltage in order to maintain constant transfer of power on both the primary and secondary sides of the transformer as indicated in equation 3. The load capacities on the secondary circuit of the transformer demand currents close to 2000 A. From the transformer correlation a primary current of 135 A is therefore used to support electrical loads of up to 2500 A on the secondary circuit. To counter the high drop of voltage, bigger conductor sizes are chosen to achieve a usable voltage at the end of the cable length. Bigger conductors come with the challenges of cost and handling. Since the system being studied in this project requires mobility, the size of equipment matters. The smaller it is, the more convenient it is for mobilization.

The option of stepping down voltage and transmitting at 0.6 kV is not a viable venture due to huge conductor sizes required to achieve a maximum allowable voltage drop of 5%. As different materials have different electrical resistances, using copper will require a conductor size of 4951 mm² while aluminium would require 8136 mm². The sheer physical sizes would not be convenient for handling. The price of such conductors will also be prohibitive and will make the project not economically viable.

The power losses in a conductor is a function of transmitted current. The higher the transmitted current, the higher the power loss. This relationship is given by the equation:

$$P_{\text{loss}} = I^2 R \tag{8}$$

where P_{loss} = Power loss;
I = Transmitted current in the conductor; and
R = Resistance of the conductor.

Electrical power loss occurs in cables due to resistance of the conductor during operation and is dissipated as heat energy. Transmission systems incur power losses of up to 4% as indicated by Schonek (2013). Equation 8 indicates that for the same amount of power, if electricity is transmitted at high voltage, current is reduced and hence the power lost from resistive losses is reduced. It is therefore advantageous to transmit voltage at 11 kV where the current is 135 A than to transmit at 0.6 kV where current is 2000 A.

In this project it will therefore be of economic interest, and technically astute to transmit power at 11 kV level and step down at the point of use. This will guide the subsequent study and narrow it down to a comparison of parameters in Table 3 (a) and (b). At a voltage level of 11 kV and primary current of 135 A, the required conductor sizes will be 25 mm^2 for copper material or 35 mm^2 for aluminium material.

Due to the mobility of the rig from one well location to another, the installation of the 11 kV supply cable from the grid will be on a temporary basis and the cable will be laid on the ground to avoid the tedious work of burying and removing it again for a rig move to another location. For the mechanical protection of the cable on the ground, some discarded well steel casings may be cut length-wise into halves and used to cover the cable on the ground, taking into account the size of the cables in relation to the size of the steel casing pipes in order to provide room for air circulation to avoid overheating.

In Olkaria, copper cables are prone to vandalism due to a high demand of copper material which has many uses in light industries. Vandals cut copper cables which they cart away as source of copper wire, and such incidences have been experienced before with cables in the field. To avoid such costly destruction, it is prudent to choose a different material than copper. For the purpose of this study and subsequent application, an aluminium cable is chosen as the preferred material. From the voltage drop calculation in Table 3 (b), the conductor is a 35 mm^2 XLPE aluminium cable. This cable delivers the required voltage and current at the end of the conductor even after application of a ground temperature correction factor of 0.93 as observed by Parmar (2014).

6. FINANCIAL ANALYSIS

This project study models the new system being developed as a stand-alone entity being operated as an income generating arm within the main company, KenGen. Its initial mode of financing is internal funding by the main company and hence zero loan interest rate will be considered in the financial model. Repayment is the payback period of the project investment. The main objective is to study if the entity will be self-sustaining and profitable on its own. If this will be the case, then the project will have proven its financial feasibility and worth for implementation.

6.1 Investment

The technical design resulted in the determination of equipment type and specifications. These parameters were used to determine the prices of the various components of the design. These prices were obtained from research reports and also from online websites of manufacturing companies. Table 4 shows prices and costs, some sourced from Bolgov and Janson (2016) and Indiamart (2018). The rates for taxes and levies were sourced from Kenya's KRA regulations (KRA, 2018).

TABLE 4: Prices of various components for the system

Item	Component	Unit of measure	Qty.	Unit price (USD)	Total price (USD)	Price source
1	Transformer	Pc	1	30,000	30,000	Bolgov and Janson, 2016
2	11 kV Cable	m	2000	40	80,000	Bolgov and Janson, 2016
3	11 kV Circuit Breaker	Pc	1	3,000	3,000	Indiamart
4	1 kV Circuit Breaker	Pc	1	1,000	1,000	Indiamart
5	Container, Panels & Acc.	LOT	1	40,000	40,000	Indiamart
6	Freight	LOT	1	2,000	2,000	Indiamart
7	Taxes & Levies	LOT	1	35%	53,900	KRA, 2018
8	Labour & Mark up	LOT	1	59%	90,860	Assumption
	Total cost of equipment				**300,760**	

From the Table 4, it can be deduced that the cost of the interface system will be USD 300,000.00. This represents the initial investment for the parent company KenGen to set up this business venture. To determine the viability of this business venture in the study, it is important to carry out a profitability analysis with a view to determine the two main indicative factors for a project which are Net Present Value (NPV) and Internal Rate of Return (IRR) as explained by Jensson (2006).

6.2 Net Present Value

The Net Present Value determines the present value of the investment through discounted sum of all cash flow earned by the project. It takes into account the time value of money and measures the value or worth added to the company by carrying out a project. It is the net result of adding the present value of cash inflows to the present value of cash outflows. This is presented as:

$$NPV(i) = \frac{A_0}{(1+i)^0} + \frac{A_1}{(1+i)^1} + \cdots + \frac{A_n}{(1+i)^n} = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n} \qquad (8)$$

where A_n = Net cash flow at the end of period n;
i = MARR (Minimum Attractive Rate of Return); and
N = Service life of the project.

When the NPV is positive, then the projected earnings generated by the investment is more than the anticipated costs, all in present currency. It is a profitable investment and therefore the project is worth pursuing. An investment with a negative NPV on the other hand will result in a net loss. The NPV rule by Investopedia, (2016), therefore dictates that the only investments that should be made are those with positive NPV values. Hence the decision rule for NPV is (Kalimbia, 2016):

If *NPV(i)* > 0 Accept investment;
If *NPV(i)* = 0 Remain indifferent to the investment; and
If *NPV(i)* < 0 Reject the investment.

6.3 Internal Rate of Return (IRR)

Internal Rate of Return (IRR) is the discount factor at which the net present value, NPV, of an investment is equal to zero. Using equation (8), NPV is assumed as zero and the discount rate is calculated, and that will be the IRR of the investment. This is represented as:

$$NPV(r) = \sum_{n=0}^{N} \frac{A_n}{(1+r)^n} = 0 \qquad (9)$$

where r = Internal Rate of Return.

The IRR indicates the return on investment and should be compared to MARR. The rule of thumb is therefore:

If *IRR > MARR* Accept project;
If *IRR = MARR* Remain indifferent to the project; and
If *IRR < MARR* Reject the project.

6.4 Project operation and maintenance

6.4.1 Project cost estimation

The investments indicated in Table 4, cater for requirements up to delivering an operating system, including initial installation, testing and commissioning on the rig at the first well site. The subsequent operation and maintenance will be borne by the parent company. There is a provision for working capital in the model for financial analysis. The objective of the study is to substitute the usage of diesel fuel as a source of energy during drilling through the utilization of this developed system. Savings from fuel consumption costs will therefore be an income to this business venture as well as the savings from the periodic generator engine service costs and maintenance spare parts. All these costs have been computed as an annual expenditure, and are therefore an annual income to the project. Table 5 shows the mathematical determination of the annual diesel fuel consumption. The information is from the drilling of various wells in Olkaria field by KenGen electric land drilling rigs. All the wells were drilled to the expected depth of 3000 m.

TABLE 5: Fuel consumption for various wells drilled in Olkaria

Item	Well Number	Well drilling days	Total fuel consumed (ltrs)	Drilled Depth (m)	Average Fuel used per day (ltr)	Drilling rig
1	OW-205A	87	336,600	3000	3,869	KGN2
2	OW-739A	84	260,000	3000	3,095	KGN2
3	OW-724B	134	580,600	2933	4,333	KGN1
4	OW-740A	102	366,050	3000	3,589	KGN1
5	OW-739A	71	227,700	2967	3,207	KGN2
6	OW-53D	92	349,650	3000	3,801	KGN2
7	OW-807A	118	336,000	3000	2,847	KGN2

It can be deduced from the table that for the seven wells drilled to a total depth of 3000 m, a total of 2,456,600 litres of diesel fuel were consumed by the rig generators and air compressors. From this, typical average consumption of diesel fuel per well is therefore 350,943 litres.

Usually it is planned and budgeted for each of the two 2000 Hp electric land rigs to drill five wells per year. For the purposes of this project analysis, a conservative figure of four wells per year will be used. The average fuel consumption per rig per year is therefore 1,403,771 litres. Using the current cost of diesel fuel in Kenya, which is at the equivalent of 1.00 USD per litre, the average total cost of the fuel component for drilling four wells per year using one rig in Olkaria is 1,400,000.00 USD. As stated earlier, the fuel consumed in the rig during the drilling of a geothermal well in Olkaria field is by both the diesel generators for provision of the required rig electrical power and by the air compressors for provision of compressed air used during aerated drilling process.

A KenGen internal report on the rigs energy audit (Mukhongo, et al, 2017), indicated that 60% of fuel is consumed by the diesel generators while 40% is by air compressors. This project will substitute the 60% component used on generators. Basing the calculation therefore on this quantity, the saving from fuel will be 840,000.00 USD. This will be treated as an annual income credited to the project. The savings from annual generator servicing costs are also added as income as indicated in Table 6. The

TABLE 6: Cost of generator service parts at different intervals

Parts description	Quantity	Cost of service at various intervals			
		Unit price (USD)	500 Hrs.	1000 Hrs.	2000 Hrs.
Belt	1	50			50
Element ass.	3	80	240	240	240
Element ass.	5	50	250	250	250
Regulator TE	4	110			440
Seal PIP	12	50			600
Seal	4	25			100
Element ass.	2	430		860	860
Element ass.	2	330		660	660
Seal	2	45			90
Seal-O-ring	4	55			220
Vee belt set	1	670			670
Engine oil	400	2.60	1,040.00	1,040	1,040
Labour	1	400	400.00	400	400
Total			**1,930**	**3,450**	**5,620**
Annual cost of maintenance service parts for one rig generator					**11,000**
Annual cost of maintenance service parts for four generators per rig					**44,000**

generators models are Caterpillar, hence the source of prices for these service parts is Mantrac (K) Limited, who are the authorised dealers of CAT equipment in East Africa.

From Table 6, the annual service cost for the four generators in a rig is 44,000 USD. Another annual saving is an estimate budget of 10,000.00 USD as provision for the procurement of spare parts for generators during breakdown maintenance. The three components add up to 894,000.00 USD, being an income to the project when it substitutes the rig generators. This amount is used in the financial model to determine the profitability of the venture.

It is also important to consider the expenses that come up as inputs to the project such as the variable and fixed costs. Variable expenses are a result of energy usage during drilling while fixed costs are operating expenses incurred irrespective of whether the system is in use or not. Operation and maintenance expenses are treated as fixed costs in the model for profitability assessment. The energy usage expense is an opportunity cost to the parent company, since the consumed electrical energy would have generated income through sales of electricity to the power utility company in Kenya. The consumed energy is quantified from the amount of diesel fuel consumed by the rig generators for the electrical power generated. Deduction from Table 5 shows that the annual consumption of diesel fuel for generation of electrical power per rig is 840,000 litres. Using the conversion factor of energy content in diesel fuel given by Deep Resource (2012) as 10.0 kWh per litre, the total energy consumed by the rig for drilling the four wells in a year is 8.4 GWh.

Three scenarios are considered for the opportunity cost under the different power purchase agreement (PPA) tariffs existing in Olkaria. The existing tariffs are 2.00 USD Cents/kWh for Olkaria I power plant, 6.80 USD Cents/kWh for Olkaria IAU, II and IV power plants and 8.80 USD Cents/kWh for the Wellhead power plants. Using the tariff for the wellhead power plants presents the most pessimistic cost of energy usage applicable to the project. This component of opportunity cost becomes a variable cost input into the model for profitability assessment. Appendix I shows screen shots from the profitability model. The fixed cost input to the project is the mobilization, operation and maintenance expenses totalling to 13,000.00 USD per year. Mobilizing the system with every rig move incurs expenditure. A hypothetical 4-point rig move within the furthest geothermal fields in Olkaria, representing the four wells that are drilled annually by each rig, is used. The pricing of mobilization has been sourced as a quotation from a rig move service provider company, for transporting one truck load. The system will be containerized and mobilized as truck loads during rig moves. The criteria used for the determination of mobilization costs is attached in Appendix II. This expense together with maintenance expenses for the system will form the fixed cost in the financial model.

6.5 Discussion on the economic feasibility of the project

6.5.1 Project assumptions

The components of the model for the profitability assessment starts with a breakdown of the investment to main components such as buildings, equipment and other investments. A working capital is also provided. The assumptions made in this project's financial feasibility are given below:

- The planning horizon for the project is 10 years. This is adequately indicative of the performance of the business;
- All annual costs associated with the generators are an income to the resulting system of this project;
- Financing is fully by equity, therefore, loan interest rate is 0% since the investment is internally funded at 300,000 USD, while the discounting rate is 15%. This is the minimum acceptable rate of return (MARR);
- Straight-line method of depreciation is applied where the housing structures depreciate at 4%, and equipment and other investments at 12.5%;
- The debtors are 25% of the turnover while creditors are 15% of variable cost;

- Income tax is charged at 16% as per the Kenya finance Act, 2018;
- The project is a business arm of a government owned company and hence no dividends are paid out; and
- Inventory build-up as spares for the new system totals to 10,000 USD.

6.5.2 Summary of results

6.5.2.1 Scenario I

This scenario investigates the opportunity cost for using power from the wellhead power plant whose PPA tariff is 8.80 USD cents/kWh so the cost of energy usage is 741,000 USD per year. This is the most pessimistic case. From the profitability assessment model, the following conclusions can be made about the project under study in this scenario:

- *The Net Present Value (NPV)*
  The NPV at 15% MARR is positive, (NPV > 0), which is the main indicator on the viability of the project under this scenario. Using power from the Wellhead power plant will still be beneficial to the main company.
- *Internal Rate of Return (IRR)*
  The IRR for equity is 33% which is greater than the MARR of 15%. Since IRR > MARR, then the project should be accepted as the investment in this scenario is worth venturing into. Table 7 indicates a summary of the main results of the investment for a planning horizon of 10 years and a discounting rate of 15% under this scenario of using power from Wellhead power plants. The project therefore has good returns and is a feasible investment.
- *Payback period (PB)*
  The payback period is achieved on the fourth year of operation, i.e. 2023. This can be seen in Figure 7.

TABLE 7: Main results for scenario I

Discounting rate	15%	
Planning horizon	10 yrs	
	Total Cap.	**Equity**
NPV of cash flow	252	252
Internal rate	33%	33%
External rate	23%	23%
Capital/equity after 10 yrs		9.5

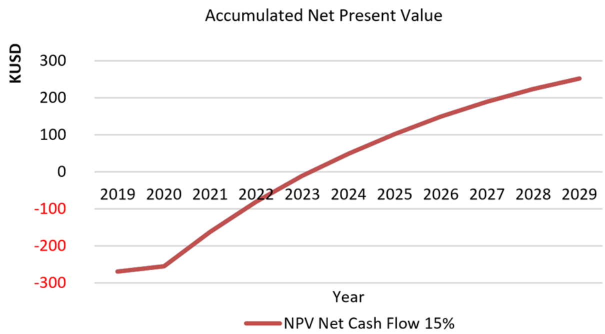

FIGURE 7: Accumulated NPV for scenario I

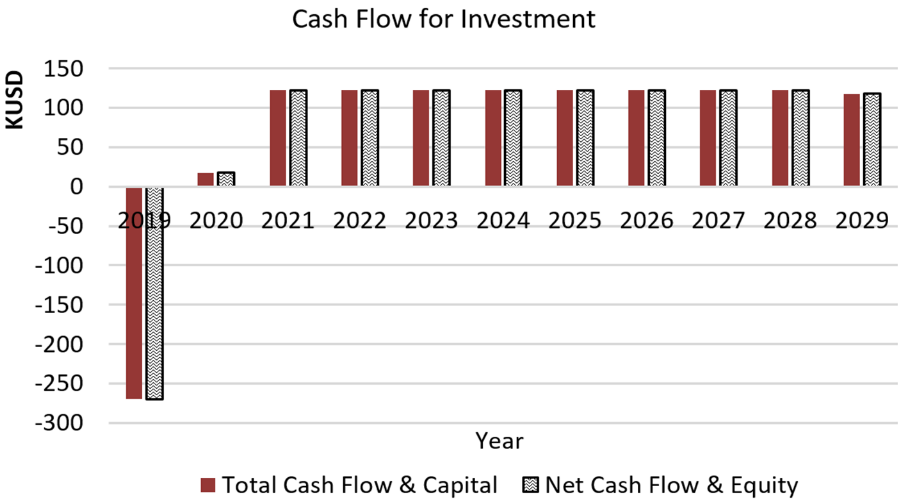

FIGURE 8: Financial cash flow for scenario I

The cash flow is negative in the first year of 2019 as indicated in the Figure 8, as this is the year of actual investment being made. The negative graph shows the outflow of cash.

6.5.2.2 Scenario II

This scenario investigates the opportunity cost for using power from either Olkaria IAU, II or IV power plants whose existing PPA tariff is 6.80 USD cents/kWh. The cost of energy usage is 572,000 USD per year and the below results can be deduced from this scenario:

- *The Net Present Value (NPV)*
  The NPV at 15% MARR is positive, (NPV > 0), which is the main indicator of the viability of the project under this scenario. Using power from Olkaria IAU, II or IV power plants is still beneficial to the main company.

- *Internal Rate of Return (IRR)*
  The IRR for equity is 81%, which is greater than the MARR of 15%. Since IRR > MARR, the investment under this scenario is viable. Table 8 indicates a summary of the main results of the investment for a planning horizon of 10 years and a discounting rate of 15% under the scenario of using power from Olkaria IAU, II or IV power plants. The project therefore has good returns and is a feasible investment.

- *Payback period (PB)*
  The payback period is achieved on the second year of operation, i.e. 2021. This can be seen in Figure 9.

The cash flow is negative in the first year of 2019 as indicated in the Figure 10, as this is the year of actual investment being made. The negative graph shows the outflow of cash.

TABLE 8: Main results for scenario II

Discounting rate	15%	
Planning horizon	10 yrs	
	Total cap.	**Equity**
NPV of cash flow	966	966
Internal rate	81%	81%
External rate	34%	34%
Capital/equity after 10 yrs		19.9

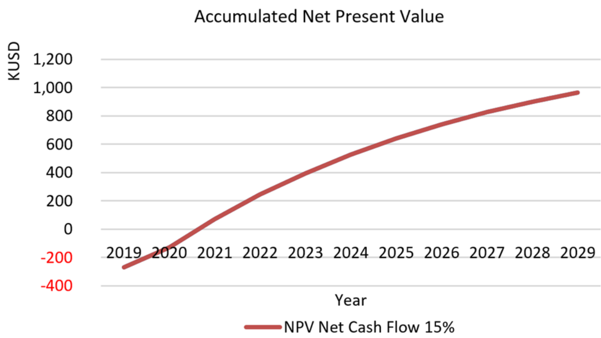

FIGURE 9: Accumulated NPV for scenario II

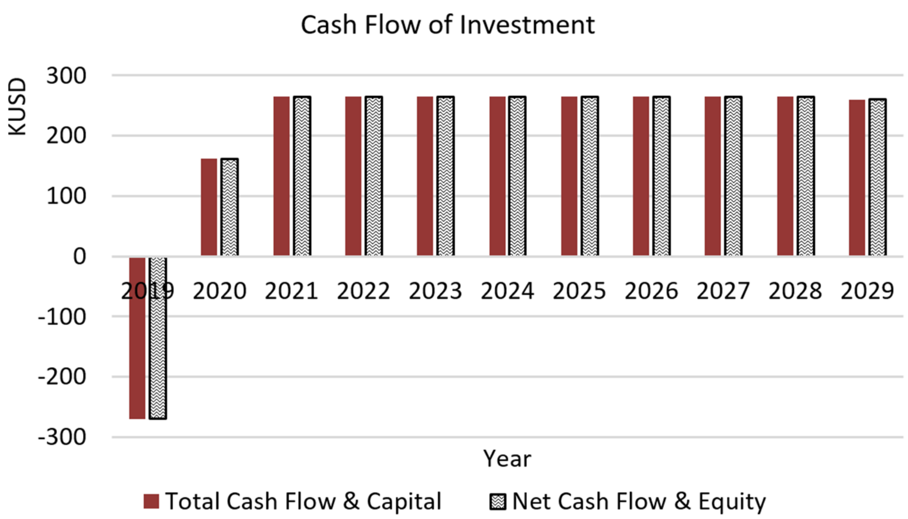

FIGURE 10: Financial cash flow for scenario II

6.5.2.3 Scenario III

This scenario investigates the opportunity cost for using power from Olkaria I power plant whose existing PPA tariff is 2.00 USD cents/kWh. The cost of energy usage is 168,000 USD per year. This is the least pessimistic case. From the profitability assessment model, the following conclusions can be made about the project under study in this scenario:

- *The Net Present Value (NPV)*
  The NPV at 15% MARR is positive, (NPV > 0), which is the main indicator of the viability of the project under this scenario. Using power from the Olkaria I power plant makes this project most profitable to the company due to the high net present value.

- *Internal Rate of Return (IRR)*
  The IRR for equity is 199% which is greater than the MARR of 15%. Since the IRR > MARR, the investment in this project is very attractive. Table 9 indicates a summary of the main results of the investment for a planning horizon of 10 years and a discounting rate of 15%. The project therefore has good returns and is a feasible investment by the main company.

- *Payback Period (PB)*
  The payback period is achieved on the first year of operation, i.e. 2020. This can be seen in Figure 11.

The cash flow is negative in the first year of 2019 as indicated in Figure 12, as this is the year of actual investment being made. The negative graph shows the outflow of cash.

TABLE 9: Main results for scenario III

Discounting Rate	15%	
Planning Horizon	10 yrs	
	Total cap.	**Equity**
NPV of Cash Flow	2673	2673
Internal Rate	199%	199%
External Rate	46%	46%
Capital/Equity after 10 yrs		43.8

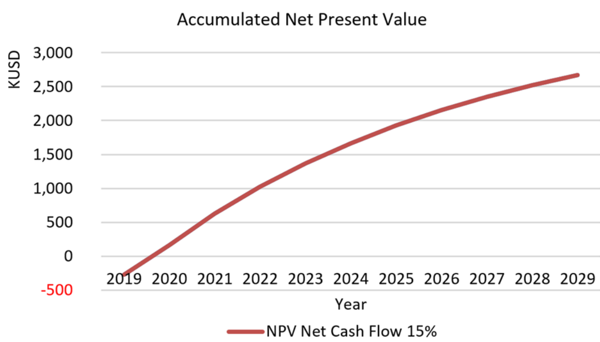

FIGURE 11: Accumulated NPV for scenario III

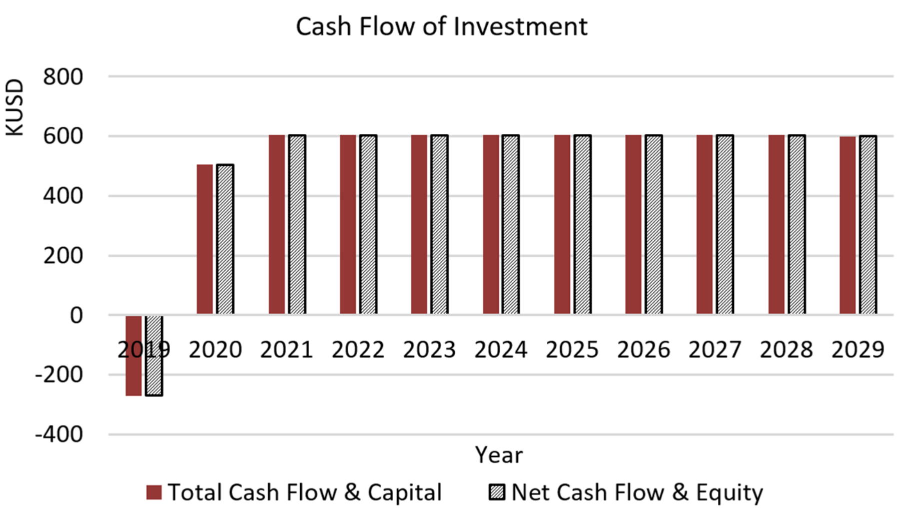

FIGURE 12: Financial cash flow for scenario III

7. CONCLUSIONS

The three scenarios that were analysed in the financial assessment model have all resulted in positive net present values (NPVs) and internal rate of returns greater than the minimum acceptable rate of return. These results have therefore given a clean bill of health to this project study, which makes it more exciting when looked at with a mind privy to the enormous benefits it brings. This system has technical, economic and environmental benefits. One unit, housed in a 20-foot container taking up the operation of four large generators means a four-time reduction in maintenance challenges and a proportional reduction of stock of spares. The monetary savings from fuel costs is also very attractive as an investment to the company. It will even be more beneficial to the company when both rigs are equipped with a similar system. Given that the payback period ranges from one to four years depending on the power plant from which the power is tapped, the initial unit can finance the acquisition of the second unit for the other rig.

Another benefit that the system brings is the environmental conservation that will be achieved when the diesel engines are switched off. Study has shown that the combustion of fossil fuel in diesel engines releases hazardous contaminants and greenhouse gases including particulate matter that are damaging to the environment. The amount of carbon dioxide (CO_2) emissions depends on the consumption of diesel fuel by the engine. One litre of consumed diesel produces approximately 2.3 kg of carbon dioxide (AutoSmart, 2014).

The study has restricted the length of the 11 kV electrical supply cable to 2 km, being the optimal distance that balances access to quality power supply to the rig and keeping a reasonably modular system to allow easy handling to benefit regular mobilization. The actual design will determine and choose between the production of a continuous 2 km cable or having it in pieces of 1 km each. As the cable will be rolled in to a reel, there is the possibility of operating the system while part of the cable is still coiled, especially when the distance between the rig and the grid supply is short. This may cause overheating of the cable and damage to its insulation.

It is important to note that the existing diesel generators will still be kept on standby despite the use of the new system. This is to cater for any eventuality should a prolonged power outage on the grid occur. It is even more critical when the drilled depth has progressed so much that there is a risk of a stuck pipe should the mud pumps stop operating for a prolonged time. It takes about 7 minutes, from practice in Olkaria, to start and bring a generator online.

This study has focused on a project to develop a system that will enable the connection of power from the grid to power the rigs in Olkaria. This achievement will save only 60% of the fuel delivered to the rigs. The other 40% of the fuel is consumed by the air compressors and boosters used during aerated drilling. This equipment uses diesel engines, and there is therefore a need to replace them with air compressors that run on electric motors. The design of the interface system is robust enough to handle additional electrical loads in the future should this replacement of diesel engine air compressors with motor driven air compressors become a success.

The specifications for the equipment developed in this study will be used as the bill of materials during the eventual development and construction of the system. These will also be used in the procurement process.

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Finally, I would like to take this opportunity to thank the Almighty God for the gift of life and good health and for the much He has blessed me. God bless you all.

NOMENCLATURE

AC	=	Alternating Current
DC	=	Direct Current
GWh	=	Gigawatt Hour
IRR	=	Internal Rate of Return
KRA	=	Kenya Revenue Authority
KUSD	=	Thousand United States Dollars
LLC	=	Limited Liability Company
NEC	=	National Electrical Code
NPV	=	Net Present Value
PPA	=	Power Purchase Agreement
r.m.s	=	Root means square
SCR	=	Silicon Controlled Rectifier
VFD	=	Variable Frequency Drives
XLPE	=	Cross Linked Polyethylene

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APPENDIX I: Screen shots from the profitability model

Assumptions and Results

		2019	
Investment:		KUSD	
Buildings		40	
Equipment	100%	170	
Other		60	
Total		270	
Financing:			
Working Capital		30	
Total Financing		300	
Equity	100%	100%	
Loan Repayments	100%	1	year
Loan Interest	100%	0%	

Discounting Rate	15%	
Planning Horizon	10	years

	Total Cap.	Equity
NPV of Cash Flow	252	252
Internal Rate	33%	33%
External Rate	23%	23%
Capital/Equity after 10 years		9.5
Minimum Cash Acct	30	

Operations:		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	
Quantity (fuel savings)	100%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Units/year
Value of fuel	100%	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	KUSD

Variable Cost	100%	741	KUSD/year
Fixed Cost	100%	13	KUSD/year
Inventory Build-up		10	
Debtors	25%	of turnover	
Creditors	15%	of variable cost	
Dividend	0%	of profit	
Depreciation Buildings	4%	KenGen Financial statement	
Depreciation Equipm.	13%	KenGen Financial statement	
Depreciation Other	13%	KenGen Financial statement	
Loan Managem. Fees	0%		
Income Tax	16%	Kenya Finance Act 2018	

FIGURE 1: Assumptions and results for scenario I

Assumptions and Results

		2019	
Investment:		KUSD	
Buildings		40	
Equipment	100%	170	
Other		60	
Total		270	
Financing:			
Working Capital		30	
Total Financing		300	
Equity	100%	100%	
Loan Repayments	100%	1	year
Loan Interest	100%	0%	

Discounting Rate	15%	
Planning Horizon	10	years

	Total Cap.	Equity
NPV of Cash Flow	966	966
Internal Rate	81%	81%
External Rate	34%	34%
Capital/Equity after 10 years		19.9
Minimum Cash Acct	30	

Operations:		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	
Quantity (fuel savings)	100%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Units/year
Value of fuel	100%	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	KUSD

Variable Cost	100%	572	KUSD/year
Fixed Cost	100%	13	KUSD/year
Inventory Build-up		10	
Debtors	25%	of turnover	
Creditors	15%	of variable cost	
Dividend	0%	of profit	
Depreciation Buildings	4%	KenGen Financial statement	
Depreciation Equipm.	13%	KenGen Financial statement	
Depreciation Other	13%	KenGen Financial statement	
Loan Managem. Fees	0%		
Income Tax	16%	Kenya Finance Act 2018	

FIGURE 2: Assumptions and results for scenario II

Assumptions and Results

		2019	
Investment:		KUSD	
Buildings		40	
Equipment	100%	170	
Other		60	
Total		270	
Financing:			
Working Capital		30	
Total Financing		300	
Equity	100%	100%	
Loan Repayments	100%	1	year
Loan Interest	100%	0%	

Discounting Rate	15%	
Planning Horizon	10	years

	Total Cap.	Equity
NPV of Cash Flow	2673	2673
Internal Rate	199%	199%
External Rate	46%	46%
Capital/Equity after 10 years		43.8
Minimum Cash Acct	30	

Operations:		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	
Quantity (fuel savings)	100%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Units/year
Value of fuel	100%	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	894.0	KUSD

Variable Cost	100%	168	KUSD/year
Fixed Cost	100%	13	KUSD/year
Inventory Build-up		10	
Debtors	25%	of turnover	
Creditors	15%	of variable cost	
Dividend	0%	of profit	
Depreciation Buildings	4%	KenGen Financial statement	
Depreciation Equipm.	13%	KenGen Financial statement	
Depreciation Other	13%	KenGen Financial statement	
Loan Managem. Fees	0%		
Income Tax	16%	Kenya Finance Act 2018	

FIGURE 3: Assumptions and results for scenario III

APPENDIX II: Determination of mobilization costs

1 RIG DIESEL GENERATORS ANNUAL SERVICING

Parts Description	Quantity	COST OF SERVICE AT VARIOUS INTERVALS			
		Unit Price (USD)	500 HRS	1000 HRS	2000 HRS
Belt	1	50.00			50.00
Element Ass.	3	80.00	240.00	240.00	240.00
Element Ass.	5	50.00	250.00	250.00	250.00
Regulator TE	4	110.00			440.00
Seal PIP	12	50.00			600.00
Seal	4	25.00			100.00
Element Ass.	2	430.00		860.00	860.00
Element Ass.	2	330.00		660.00	660.00
Seal	2	45.00			90.00
Seal-O-Ring	4	55.00			220.00
Vee Belt SET	1	670.00			670.00
Engine Oil	400	2.60	1,040.00	1,040.00	1,040.00
Labour	1	400.00	400.00	400.00	400.00
			1,930.00	3,450.00	5,620.00
Annual cost of maintenance for one rig generator					11,000.00
Annual cost of maintenance for four generators per rig					**44,000.00 USD**

2 COST OF MOBILIZING THE NEW SYSTEM DURING RIG MOVE

(a)	Truck load mobilization within well locations in Olkaria North-East and Olkaria East fields. (Distances within 7 km)	600.00
(b)	Truck load mobilization from well locations in Olkaria North-East or Olkaria East fields to Olkaria Domes fields. (Distances within 15 km)	800.00
(c)	Truck load mobilization within well locations in Olkaria Domes fields. (Distances within 6 km)	500.00
(d)	Truck load mobilization back from well locations in Olkaria Domes field to Olkaria North-East or Olkaria East fields. (Distances within 15 km)	800.00
	Typical cost of mobilization for one truck load during drilling of 4 wells per rig per year	**2,700.00 USD**

FIGURE 1: Generator service cost and system mobilization cost

Item	**Well Number**	**Well drilling days**	**Total fuel consumed (ltrs)**	**Drilled Depth**	**Average Fuel per day**	**Drilling rig**
1	OW-205A	87	336,600	3000	3,869	KGN2
2	OW-739A	84	260,000	3000	3,095	KGN2
3	OW-724B	134	580,600	2933	4,333	KGN1
4	OW-740A	102	366,050	3000	3,589	KGN1
5	OW-739A	71	227,700	2967	3,207	KGN2
6	OW-53D	92	349,650	3000	3,801	KGN2
7	OW-807A	118	336,000	3000	2,847	KGN2

TOTAL	7 Wells	2,456,600	Litres	
Average Fuel consumption per Well		350,943	Litres per well	
Average wells drilling per rig per year		4	Wells	
Average Fuel Consumed per rig per year		1,403,771	Litres per year	
Cost of Diesel Fuel in Kenya		1.00	USD/Litre	
Typical cost of fuel per rig per year		**1,400,000.00**	USD	60% Of diesel fuel used by generators for rig power generation.
				40% Of diesel fuel used by Compressors durign aerated drilling
Energy content conversion in fuel		10.0	kWh/Litre of diesel fuel	
Rig electrical energy requirement		14,037,714	kWh/year	Converted from the fuel consumed
Energy tariff for Wellhead power plant		8.80	USD Cents/kWh	Existing feed in PPA tariff for Wellhead power plant
Opprtunity Cost for powering rig from grid		**741,191.31**	USD per year	
	Rounded off to	**741,000.00**	USD per year	

FIGURE 2: Determination of opportunity cost