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Design of Wind and PV-Solar Energy Hybrid System for TEM Equipment in Geophysical Exploration for Geothermal Energy.

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Keywords

Hybridization, Sustainability, Optimization and Versatility, Viability, Transient Electromagnetic Method

ABSTRACT

The research was tailored to optimize the design of a hybrid system that is powered by wind and solar energy in sustaining the power requirements of the Transient Electromagnetic Method (TEM) instrumentation. The issue addressed by the research was the unsustainability aspect of the batteries during TEM data collection. Therefore, the research tried to come up with an alternative that involved making power from wind and solar resources to power the TEM equipment. The research design began by doing a quantification analysis of both wind and solar resources in the geothermal area. In addition, a terrain and security analysis was done. Lastly, a hybrid system was designed considering its component specification that was governed by the wind and solar characteristics of the geothermal area under study. The sole aim was to solve issues faced with one form of green energy, geothermal energy, with other forms of green energy, wind and solar energy. The end result was the design of a revised final hybrid system that was able to sustain the power requirements of the TEM equipment during data collection in a geophysical survey with the available natural wind and solar resources in the Olkaria Geothermal field. From the analysis, it was evident that design of the hybrid system will primarily depend on the availability of the wind and solar resources in the area under study and the power requirements of the application being powered by the hybrid system.

1. Introduction

1.1 Background Information

Since the inception of the electrical resistivity methods as a technique for surface exploration, researchers have devised several methods that can be used to power the instrumentation. Generators and batteries have been the predominant sources of electricity that are used to power the equipment. However, due to the extensive surface exploration exercises carried out in remote areas of a geothermal prospect, most geoscientists prefer the use of wet cell deep cycle batteries. The latter are deemed to be portable and effectively and efficiently used more so in terrain that is not easily accessible. However, most of the electrical methods consume a lot of power from batteries that do not last long enough hence either the geoscientist has to carry a lot of batteries for backup or look for a conventional power to recharge the wet cell batteries. Both alternatives can be hectic and frustrating especially if the surface exploration survey is done in locales that are not near a charging location that is connected to the national grid. In that regard, there is an increasing need for more research to ensure that powering of the instrumentation is not a challenge.

The study was tailored from an observation made during surface exploration of the Eburru geothermal prospect by KenGen Company. To curb the issue, the idea of testing the versatility of the hybrid system powered by wind and solar energy was necessary. The hybrid system has been used in other applications such as powering of street lights and in water pumps. However, no conclusive application has been done in the geophysical application more so in solving the unsustainable batteries challenge faced by geophysicists during their surface exploration works. Hence, the research was tailored to add knowledge and expertise in the geothermal industry practice specifically in the geophysical exploration works.

1.1 General Objective

To optimize a hybrid system utilizing wind and solar energy for powering the TEM equipment for geothermal exploration.

1.1.1 Specific Objectives

1. To determine the quality and quantity of wind and solar resources in the geothermal prospect areas.
2. To determine the viability of the designed system to the geothermal field prospects.
3. To compare the current power requirements of the TEM equipment during data collection with that of the optimized hybrid system.

1.2 Significance of the study

The main aim of the study was to address the main challenges experienced during the electrical resistivity surface exploration methods for geothermal energy. The main challenge being the current lack of sustainable sources of power for the surface exploration instrumentation. Other challenges included the portability of heavy equipment in inaccessible rough terrain and forestation. Therefore, there was need to come up with solutions to address such challenges in the geophysical surface exploration of geothermal energy. One viable solution was designing a system that could use natural sources of green energy such as wind and solar energy. The design would enable the geophysicists to recharge the batteries in the geothermal field prospects.

1.3 Scope of the study

The locality for testing the hybrid system would be at the geothermal field prospects along the Kenyan Rift. The choice of selection was to determine whether the system was viable to operate optimally with the natural resources in the locales based on solar radiation and wind

speeds. The project would be centered more on designing the system, determining its total power output and its applicability in powering the Transient Electromagnetic Method.

1.4 Limitations

1. The unpredictable nature of the weather patterns in the location where the system would be used to collect data could result in inconsistent and unreliable power outputs from the wind rotor and the solar panel.
2. Data collection based on the power output of the solar panel could affected by the location of data collection if the temperature exceeded the standard temperature of 25°C. Any degree above the afro-mentioned temperature would result in a decrease in the efficiency of the solar panel by 0.5% of the total output per every degree above the standard temperature.
3. The lack of TEM equipment to test vis-a-vis the designed hybrid system. Hence, it resulted in relying on the secondary information on the working voltage and current of the TEM equipment.
4. The rough terrain and highly vegetative characteristics of some geothermal field prospects could affect the proposed system ability to interact with solar radiation and wind streams. Such challenges could have a negative impact on the performance of the system in terms of power output.
5. Since the system would be tried and tested in terrains that are remote, the system would face security concerns hence threatening the longevity of the system.

2.0 Literature Review

2.1 Historical Developments on the hybridized system

In Kenya, the Machakos County Government had installed a group of hybrid streetlight system along the Athi river by-pass in the Nairobi-Mombasa road. The system configuration included the use of the Horizontal Axis Wind turbine and two solar panels underneath the wind turbine. However, the design resulted in shading on the solar panel and that resulted in some instances of shading on the solar panel. Hence, there were periods of the year where the intensity of LED lights of the system was dim or at times off due to lack of sufficient power produced by the hybrid system. In addition, the county government did not consider the security necessity of the systems. In that regard, most of the solar panels and wind turbines have been vandalized due to insecurity along Athi river location, Machakos County. As such, that led to the epic failure of the county’s capital intensive project.

Figure 2.1: Hybrid streetlight system in Athi River, Machakos County, Kenya

The Department of Electrical Engineering at the Barcelona College of Industrial Engineering in Spain have innovated and designed a streetlight system that uses wind and solar energy. The innovation was a collaboration with the Eolgreen Company that took place for a period of four years. After successfully developing a prototype of the system and doing their tests and analyses, they discovered that the system was 20 percent cheaper to run than using the conventional source of power. The finding was attributed to the use of the Light Emitting Diode being powered by the system's battery which was charged by the wind and solar energy harnessed and converted into electricity by the design. The wind turbine would start generating electricity at wind speeds of 1.7m/s while moving at 10 to 200 rpm with a maximum power output of 400W. However, the configuration of the VAWT affected the performance of the solar panel. The setback necessitated the engineers in the Barcelona College to reconfigure the design for the optimal performance of the hybridized system. The project collaboration between the two parties indicated the need for further research on the designing, usage and economic feasibility of the hybridized system if correctly designed and maintained, Sanchez (2014).

Figure 2.2: Instances of shading at the pioneer stage construction of the Self-Sustaining Streetlight in Barcelona, Spain, Sanchez (2014).

In 2014, Nikols Jankovich, an entrepreneur, led a team of experts in designing of the hybridized streetlight system powered by wind and solar energy called the “Twerly” in South Africa. The nature of the system was modular where the governing principle of the design was self-sustainability that was achieved through the use of natural resources such as wind and solar energy. In addition, all the proponents constituting the system could be easily be added or removed from the pole for maintenance purposes. The wind energy tapped by the twerly system is harnessed by the Savonius Rotor, a type of Vertical Axis Wind Turbine (VAWT). The advantage of this type of wind turbine was that it was able to rotate and generate power in the presence of wind at wind speeds of as low as 6m/s to charge the Twerly batteries. However, the successful adoption of this design in the world market was a challenge due to the costly price of the VAWT. As a result, there is need to research in testing the versatility of the system in relation to its application to geophysical methods in surface exploration in the geothermal filed prospects.

Figure 2.3: Twerly Streetlight in South Africa, Nikols (2014)

3.0 Methodology

3.1 Quality and Quantity of the Wind and Solar Resources in Olkaria

For the system to work and produce meaningful power, the natural resource in the area was supposed to be abundant. Since the proposed system would be self-sustained by solar and wind resources, an analysis of the wind resource and solar irradiance in the area was done. It was analyzed through the statistical approach of determining the monthly mean of the wind speeds and solar insolation parameters in a year. The aim was to determine the potential of the area in terms of abundance of wind and solar resources. However, a monthly analysis of the abundance of the resource was determined to recommend on the times of the year the system would be able to produce sufficient power to supply the TEM equipment. The data was obtained from the weather stations that were located along the Olkaria geothermal field prospect. If the natural resources were sufficient, the design of the hybrid system commenced.

3.2 Viability of the Hybrid System; Terrain and security design

The system required precise locations along the geothermal field prospect that were near ideal environment for it to effectively interact with the natural energy resources. In addition, the locations acted as base stations and were to be spread evenly along the geothermal field prospect. The idea was to ensure that the base stations would be accessible irrespective of the current location where the survey was conducted. Also, it was to ensure that there was maximum power output from the system to sustain the charging the TEM batteries. Hence to

accomplish these, the Terrain Maps of the geothermal field prospect were useful in designing the base station locations.
However, the design took into consideration that the proposed system worked round the clock during the TEM survey hence the design of the security of the system was mandatory. Therefore, the base stations required security personnel co-existing in camp tents adjacent to the proposed hybrid system. The role of the personnel was to guard the system and often check the charging progress of the batteries as they charge during the night by the wind. Hence, the design of base stations was vital for the hybrid system to supply maximum power and to form sites for security points.

3.3 Hybrid System Design

The general design tried to determine the interface between the amount of wind and solar resources in the geothermal field and the power requirements of the TEM instrumentation during data collection. The interface was the hybrid system that converted the natural resources (solar and wind) to useful energy that was used to power the TEM instrumentation during data collection. Hence, the design considered both (cut-in and cut-out) wind speeds and the solar insolation of the area. The wind and solar resource quality and quantity and were matched with the already available wind turbines and solar panels with their associated components in their circuitry found in the local market. The parameters under consideration included the closed Circuit Current I_{SC}, Open Circuit Voltage V_{OC}, Maximum Voltage V_{MAX}, Maximum Current I_{MAX}, Maximum Power, P_{MAX} for the solar panels to be used. In the case of wind turbines the specifications under consideration were cut-in and cut-out wind speeds, the maximum power output, the rotor diameter, type of wind turbine to be used and the weight of the turbine. The determination of the appropriate wind turbine and solar panel depended on the abundance of the natural resources. The higher the natural resource, the higher percentage of the energy generating component that constituted the proposed hybrid system. Such was determined after analysis of the wind speeds and solar irradiation obtained from weather stations available in the Olkaria geothermal field prospect. It should be noted that the design of the hybrid system was primarily governed by the power requirements of the TEM equipment during data collection. As such, the optimization of the proposed hybrid system was to meet TEM power requirements and be able to versatile enough to be used in a typical geothermal field prospect in terms of its portability. In addition, the versatility of the hybrid system was be done by determining the power output of the preliminary design, as shown in table 4.4, and checked whether it satisfied the power requirements of TEM equipment. The determination would govern the optimization of the proposed hybrid system to meet the power requirements of the TEM equipment.

4.0 Results and Discussions

4.1 Quality and Quantity of the Wind and Solar Resources in Olkaria

Data used for the analysis of quality and quantity of the natural resources was obtained for the weather stations located in the Olkaria geothermal field. The wind speed trend, as shown in table 4.1, indicated that during the day, the wind speeds were surprisingly higher (2.6-3.1m/s) than at night-time (1.3-2.0m/s). The solar insolation of Olkaria had values during the day range was 328-489W/m^2 ,as shown in table 4.2 However, it was expected that there was no solar insolation at night (1800hrs-0600hrs).

Table 4.1: Monthly Average Quantities of Wind Speeds and Solar Radiation at Olkaria Geothermal Field.

Month	Monthly Average Wind Speed (m/s)	Day-time [0600hrs-1800hrs] Average Wind Speed (m/s)	Night-time [1800hrs-0600hrs] Average Wind Speed (m/s)	Day-time [0600hrs-1800hrs] Average Solar Insolation (W/m^2)	Night-time [1800hrs-0600hrs] Average Solar Irradiance (W/m^2)
January	2.0815	2.793	1.370	488.76	0
February	2.203	2.796	1.610	466.56	0
March	2.391	2.970	1.812	481.93	0
April	2.482	3.198	1.766	382.49	0
May	2.569	3.078	2.060	383.79	0
June	2.395	3.160	1.630	328.29	0
July	2.274	2.867	1.680	351.61	0
August	2.365	3.074	1.655	403.15	0
September	2.229	2.980	1.478	456.03	0
October	2.116	2.900	1.331	388.79	0
November	1.969	2.63	1.308	341.05	0
December	2.090	2.790	1.389	387.78	0

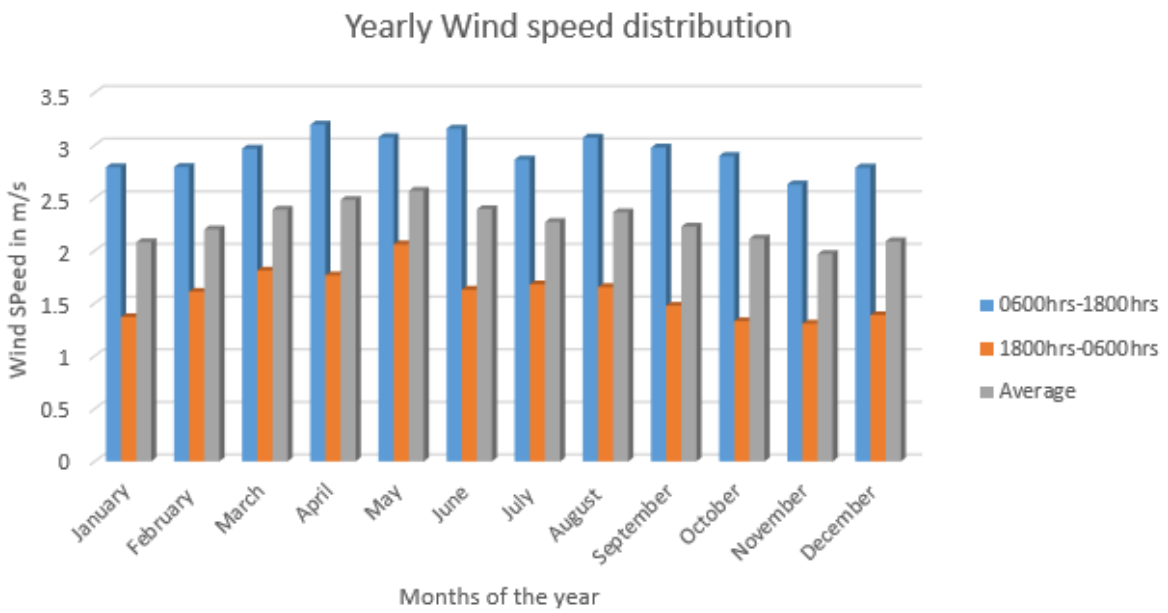

Figure 4.2: Yearly wind speeds distribution of the monthly average quantities of wind speeds in the Olkaria geothermal field.

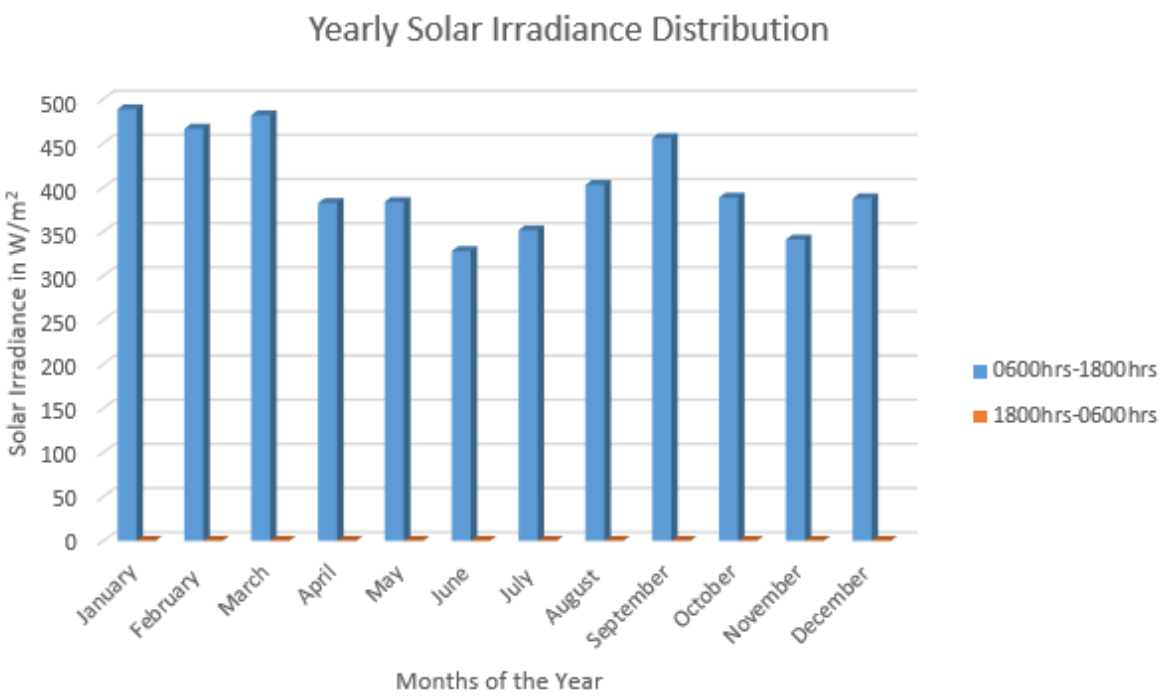

Figure 4.3: Yearly wind speeds distribution of the monthly average quantities of solar insolation in the Olkaria geothermal field.

Further analysis indicated that there was a negative correlation between the quality and quantity of wind and solar. Between the months of January and March (Trend 1), as shown in figures 3.1 and 3.2, the trend indicated that the solar insolation was increasing and having the highest insolation values of the year (488W/m^2). However, during the same period, the values of wind speeds where low (2.085m/s) as compared 2.5m/s experienced mid-year. In the months between April and September (trend 2), as shown in tables and figures 4.1 and 4.2, the quality and quantity of wind were the best during the year (2.9-3.2m/s). However, during the same period, the solar insolation quality was the poorest, 328W/m^2. From October to December (trend 3), as shown in figures 4.1 and 4.2, quality of wind speeds decrease (2.5m/s) and the value of solar insolation increases gradually to values approximately 350W/m^2.
The various trends exhibited by the quality and quantity of the wind and solar resources were vital in determining whether the amount of energy from the natural resources can be used to produce sufficient electricity to supply the TEM equipment. In addition, from the wind speeds and solar insolation values, one can use them to determine the optimal hybrid system components that can work best in such environmental conditions.

4.2 Viability of the Hybrid System; Terrain and security design

An analysis of the hybrid system viability involved the use of the topographical Digital Elevation Maps as shown below in figure 3.3. The analysis involved determining regions of high elevation using the contour lines in the Olkaria Geothermal field. Important to note was that before such analysis was done, the geothermal field was divided into different regions to aid in the terrain analysis of the field and also to ensure that the placement of all base stations was all inclusive in the geothermal field.

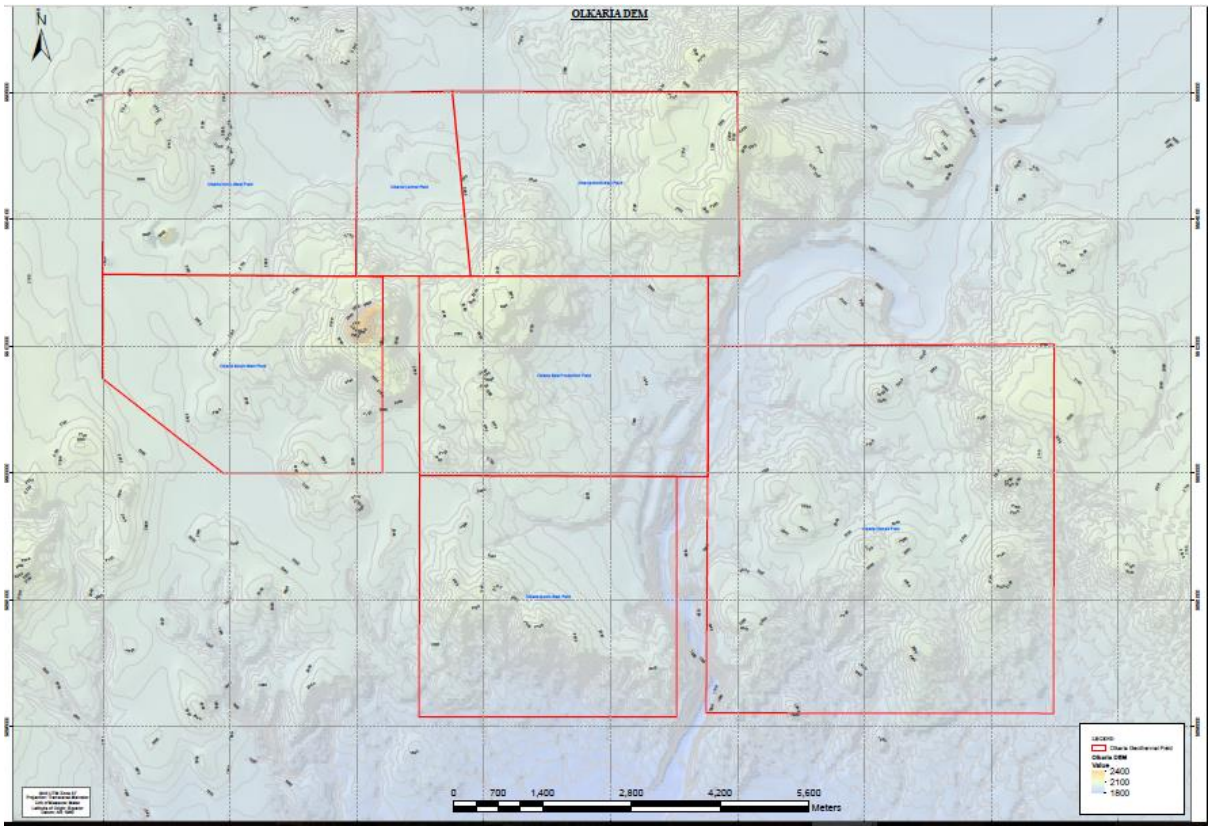

Figure 4.4: The subdivided Topographical Digital Elevation Model of Olkaria Geothermal Field.

Some of the common observations made involved considering the contour line values whereby high contour values ranged between 2100-2450 m.a.s.l. Such regions were taken as viable sights for base station location since the idea is, the higher the terrain relative to its surroundings, the more interaction between the natural resources and the hybrid system in realizing the power requirements of the TEM equipment. The elevated regions in most of the parts of the geothermal field have belts that had varying orientations. However, in some low elevation regions, there are concentrated regions that have the highest elevation values of 3000 m.a.s.l. Such concentrated regions form the highest regions in the Olkaria geothermal field and form the best sites for the location of the base stations of the hybrid system. It should be noted that the base stations also formed sites for security. The reason was to cut cost of labor in that the individual guarding the hybrid system would also be responsible for monitoring the charging of batteries overnight.

4.3 Hybrid and Capacity system design

The hybrid and capacity design was done in accordance with the quality of wind and solar resources and the power requirements of TEM equipment. The aim was to design a hybrid system that could act as an interface of converting the energy of the natural resources in Olkaria to sufficient electricity that can sustain the power requirements of one sounding of the TEM equipment. As such, the capacity design of the system was done using the wind power and solar insolation equations vis a vis the different trends of the year as shown in figures 4.1 and 4.2. First, an analysis of the power requirements of TEM was done and a comparison was made with the power capacity of the preliminary hybrid design as shown below.

4.3.1 TEM Power Requirements

Data acquisition of TEM equipment requires 3 batteries. Each battery has a voltage of 12V and supplies power to TEM transmitter at a base load of 60Ah and are connected in series. Since most geothermal prospects have rough terrain, the survey involves data acquisition of

one sounding. Complete data collection of one sounding takes a duration of 10 minutes depending on characteristics of the subsurface under survey. The turn over from one location of TEM data acquisition to another takes a duration of one and a half hours.
With the above parameters, the TEM power requirements was calculated as follows;

1. The total voltage of transmitting current round the TEM loop is given by 12V*3batteries= 36V since the battery connection is in series.
2. Determination of the amount of constant current consumed by the TEM configuration from the batteries during data collection; if in one hour, the rate of constant current supplied is 60A in one hour, therefore, in a duration of 10 minutes the amount of constant current supplied to TEM equipment during data collection is 10A.
3. Therefore, to determine the total power requirements of the TEM configuration in one sounding is given by; Power= (Total Voltage of Batteries)*(Total Constant Current). In that regard total TEM power requirements per sounding= (36V)*(10A) = 360W.

4.3.2 Power capacity of the preliminary hybrid system

a) Wind Power

Findings; Parameters

An analysis of the quality and quantity of the wind resource indicates that wind speeds at Olkaria range between 1.3m/s to 3.2m/s. The average air density of Olkaria is 1.254kg/m^3 and area of a wind rotor with a cut-in wind speed of 1m/s (Blade radius of 1.558m) and a hub height of 11.558m in accordance to Park Wake's Model, Cheng and Zhu (2014). The efficiency of the wind turbine is 59.3%. The above parameters aids to quantify the amount of wind power available at Olkaria.
The above parameters are related to the wind power equation as follows;

$P=0.5*\rho*A*V^3*C_P$

Where P= Wind Power, A=area swept by rotor blades, V= velocity of wind, ρ= Air Density, C_P = power co-efficiency/ wind turbine efficiency

Table 4.2: Average daily Wind Power in Olkaria Geothermal Field

Month	Day-time [0600hrs-1800hrs] Average Wind Speed (m/s)	Night-time [1800hrs-0600hrs] Average Wind Speed (m/s)	Day-time [0600hrs-1800hrs] Average Wind Power (Watts)	Night-time [1800hrs-0600hrs] Average Wind Power (Watts)	Average Total Wind Power per day (Watts)
January	2.793	1.370	61.80	7.294	69.09
February	2.796	1.610	61.99	11.84	73.82
March	2.970	1.812	74.31	16.88	91.18
April	3.198	1.766	92.76	15.62	108.38
May	3.078	2.060	82.71	24.79	107.5
June	3.160	1.630	89.50	12.28	101.78
July	2.867	1.680	66.84	13.44	80.28
August	3.074	1.655	82.39	12.86	95.25
September	2.980	1.478	75.06	9.156	84.21
October	2.900	1.331	69.17	6.689	75.86
November	2.63	1.308	51.59	6.345	57.94
December	2.790	1.389	61.6	7.602	69.20

b) Solar Power

The area of the solar panel to be used was 0.5696m^2 (solar panel dimensions= 64cm by 89cm) with the solar efficiency of 15%-20%. The angle of tilt is 28 ° and the coefficient of loses as 0.75 default value. The above parameters aided to quantify the capacity of solar power from solar irradiance at Olkaria Geothermal field. The number of solar panels used per unit of the preliminary hybrid system were two.

The above parameters will be related with the formula below to determine the month daily solar capacity.

E= A*r*H*PR

Where, E=Energy in kWh, A= Total Solar panel Area (m^2), r= Solar panel Efficiency, H= Average solar radiation on the tilted panels (W/m^2), PR= Coefficient of losses (0.75)

Table 4.3: Average daily Solar Power in Olkaria Geothermal Field

Month	Day-time [0600hrs-1800hrs] Average Solar Irradiance (W/m^2)	Total Solar Power per day (Watts)
January	488.76	41.76
February	466.56	39.84
March	481.93	41.18
April	382.49	32.68
May	383.79	32.8
June	328.29	28.04
July	351.61	30.04
August	403.15	34.44
September	456.03	38.96
October	388.79	33.2
November	341.05	29.12
December	387.78	33.12

c) Total Wind and Solar Capacity of one unit of the preliminary hybrid system.
It involved the summation of the power capacities of wind and solar power per day as shown in table 4.4.

Table 4.4: Total Daily Hybrid capacity of the preliminary hybrid system in Olkaria Geothermal Field

Month	Total Solar power on a daily basis (Watts)	Total Wind Power on a daily basis(Watts)	Total Capacity of the hybrid system on a daily basis (Watts)
January	41.76	69.09	110.85
February	39.84	73.82	113.66
March	41.18	91.18	132.36
April	32.68	108.38	141.06
May	32.8	107.5	140.3
June	28.04	101.78	129.82
July	30.04	80.28	110.68
August	34.44	95.25	129.69
September	38.96	84.21	123.17
October	33.2	75.86	109.06
November	29.12	57.94	87.06
December	33.12	69.20	102.32

It was evident that, using the preliminary design, the power supplied by the system (87-141W), as shown in table 4.4, was lower than the 360W required for one TEM sounding.

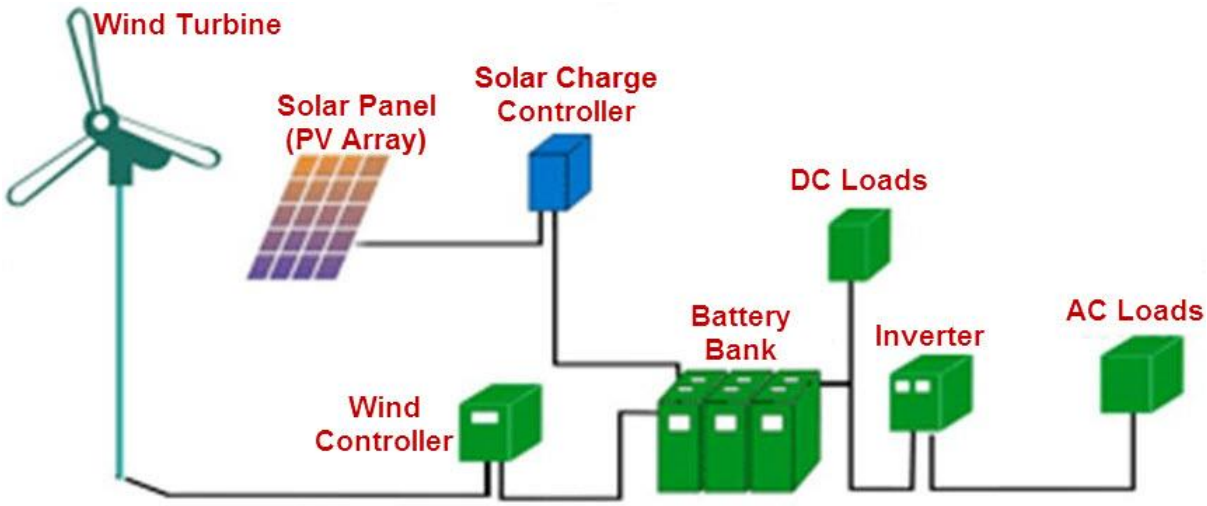

Figure 4.4: Schematic Diagram of the basic layout of the preliminary design of hybrid system.

Therefore, this necessitated the testing of the versatility of the system by adjusting the variable components of the analysis such as increasing the number of turbines and area of the solar panels used.

d) Power Capacity of the revised final hybrid system.

It was evident that with the preliminary hybrid system design of two solar panels and a wind turbine could not satisfy the power requirements of one TEM sounding. In that regard, an analysis of the versatility of the design needed to be tested. Since wind power contribution to hybrid system capacity was high, there was need to add two other wind turbines in the preliminary design and reconfigure the layout of the hub tower to ensure optimal power generation by the wind turbines and solar panels. In addition, the area of the solar panel was increased from an area of 0.5696m^2 (panel dimension 0.64m by 0.89m) to an area of 1.2816m^2 (panel dimension of 0.96m by1.335m), as shown in figure 4.5. Below are the final capacity of the optimized hybrid system.

Table 4.5: Average Revised Daily Solar Power in Olkaria Geothermal Field

Month	Day-time [0600hrs-1800hrs] Average Solar Irradiance (W/m^2)	Total Revised Solar Power per day (Watts)	Total Revised Wind Power per day (Watts) [(power capacity of one turbine)*(3)]	Total Capacity of the Revised Final Hybrid System
January	488.76	93.96	207.27	301.23
February	466.56	89.69	221.46	311.15
March	481.93	92.65	273.54	366.19
April	382.49	73.52	325.14	398.66
May	383.79	73.78	322.50	396.28
June	328.29	63.16	305.34	368.5
July	351.61	67.59	240.84	308.43
August	403.15	77.50	285.75	363.25
September	456.03	87.67	252.63	340.3
October	388.79	74.74	227.58	302.32
November	341.05	65.56	173.82	239.38
December	387.78	74.54	207.60	282.14

Considering the power analysis from table 4.5, it was clear that between the months of March to June, the revised hybrid system could provide sufficient to realize TEM power requirements (366-398)W. Between the months of September to February the optimized hybrid system has lower power capacities (239-340)W. As such, exploration works can be done between the months of March to June every other year. However, in the event that there is need to perform TEM exploration works in any other different time period (September to February), an addition of another unit of the preliminary hybrid system (87-141) W could boost the power deficit of the optimized hybrid system. However, the cost implications would be dire during this period of the year.

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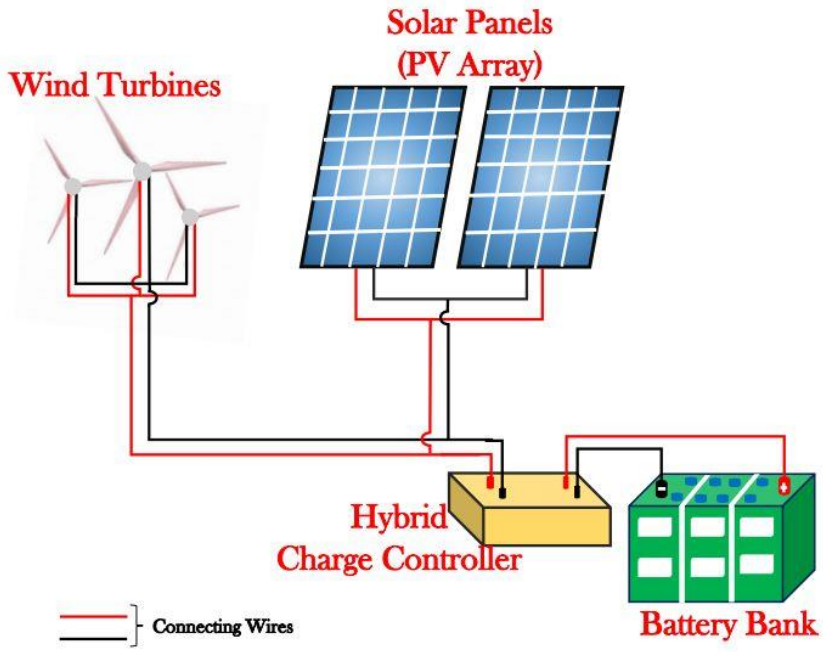

Figure 4.5: Schematic Diagram of the basic layout of the revised final design of hybrid system

The design of the hybrid system component specifications was governed by aspects such as portability, the compatibility of the electrical components in terms of voltage and power, and the wind speed (as low as 1m/s) and solar insolation characteristics (330-489W/m^2).
The revised final hybrid system passed all the above criteria hence further justifying the need for its adoption in addressing the unsustainability aspect of the geophysical wet cell batteries.

e) Wind and Solar Panel Specifications

Table 4.6: Wind Turbine and its Components specifications

Characteristic	**Description**
Wind Turbine Model	The Wind Luce YWL-500
Start-up wind speed	1m/s
Cut-in Wind Speed	1.0-1.5m/s
Charging Wind Speed	1.5-2.5m/s
Rated Power	500W
Rated Wind Speed	12.5m/s
Survival Wind Speed	50m/s
Maximum Output	800W at 16m/s (generator without controller)
Braking System	Electromagnetic Braking System
Mass	17.5kg
Rotor Diameter	1.558m
Generator	Three Phase permanent magnet inner rotor coreless generator
Output	12V Battery Charging
Controller	Hybrid Controller (PV 500W + Wind 500W), with a LCD display and has a weight of 2kg
Blades	3 wooden blades, Polyurethane coating
Main Body	Aluminum, Acrylic Resin Paint
Wind Vane	Polycarbonate t=6

Figure 4.6: The Wind Luce YWL-500 wind turbine by A-WING INTERNATIONAL

Table 4.7: Solar Panel and its Components specifications

Characteristic	Description
Model name	Mitsubishi, PV-MLE26OHD
Panel Dimension	0.96m*1.335m
Maximum Power Rating (P_{max})	260W
Open Circuit Voltage (V_{OC})	38.0V
Short Circuit Current (I_{SC})	8.98A
Module efficiency	15.7%-20.1%
Mass	20Kg

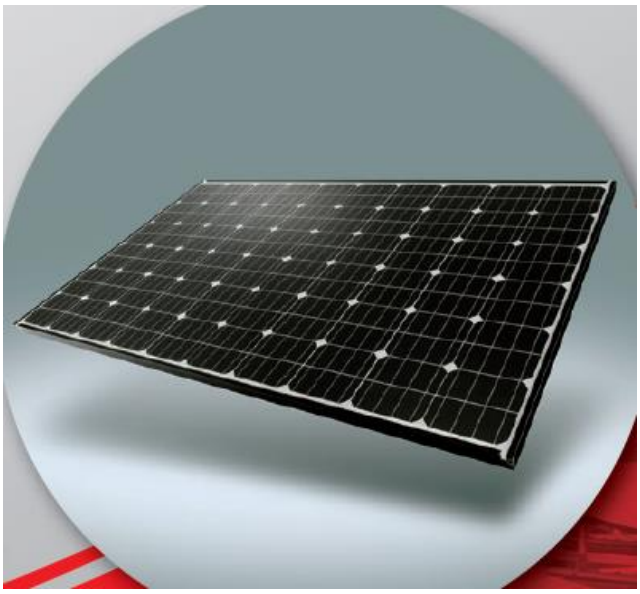

Figure 4.7: The PV-MLE26OHD solar panel by Mitsubishi

4.4 Key Findings that make significant contributions to existing knowledge

Before installing a hybrid system, there is need to do a qualitative and quantitative analysis of the location. The aim is to be able to quantify the amount expected power from the hybrid system and also determine the specification of the components that work best in the area's wind and solar resource characteristics.

Challenges experienced in geoscientific exploration can be solved using the localization concept. It implies that geoscientists and their technicians should be able make use of the natural resources. For instance, geophysicists can address the unsustainability aspect of the batteries used during the geophysical survey by making use of the hybrid system. It utilizes wind and solar which are forms of renewable energy. Hence, it leads to a situation where challenges experienced by one form of renewable energy (geothermal) are solved by other forms of renewable energy (wind and solar energy).

One cannot quantify the importance of using clean energy in an economic perspective. This implies that one cannot neglect clean sources of energy due to the expense that comes with it. Opting for cheap sources energy that pollute the environment, use of generators, and have bigger negative impacts, more severe than economic implications. As such, in the world of

energy, policies that govern energy generation should be quantified on the significance they have to environment and not the capital involved in generating the energy.

4.5 Conclusion

From the analysis of wind and solar energy in Olkaria, a representative geothermal field along the Kenya rift, it is evident that the resources are abundant to meet power requirements of most of the geophysical methods. However, from the analysis of the power output of the preliminary design of the hybrid system, its power output did not meet the 360W power requirements of the TEM equipment. Through optimization of the preliminary design, it resulted to the revised final design, the power requirements of TEM were met (300W-400W) within the same Olkaria geothermal field station. It therefore implies that meeting power requirements of geophysical methods not only depends on the quality and quantity of wind and solar resources in the area but also the location of the hybrid system (base stations) and the design of the hybrid system.

4.6 Recommendations

The adoption of the hybrid design needs to consider the following recommendations to ensure its smooth operations in the geothermal field prospect. While determining the quality and quantity of the wind and solar resources in the area, the sample size of wind speeds and solar insolation should be approximately 10-15years. This is due to the uncertainty of weather patterns brought about by climate change. The increased time period for analysis will result to a conclusive interpretation of the wind and solar trends in a year and aid in making informed decisions on the design of the hybrid system and the periods of the year when the system will supply optimal power that meets the TEM equipment power requirements.
During the design of the system, more specifically in component sizing, the type of components selected should not only consider the characteristics of the natural resources but also its weight. A key feature of the design is its portability in the geothermal field prospect, as such, the components of the hybrid system should be light but structurally strong.
The connection and operation of the hybrid system should be done in the presence of an expert who will be in-charge of ensuring that the components of the hybrid system are properly mounted. In addition, the expert will monitor the rate at which the hybrid system is charging the batteries and know whether the power generated will sustain the TEM power requirements.
In the decision making process of determining the method of meeting power requirements of TEM equipment, simplicity should not be a tool used choose an alternative. The analysis should undertake a sensitivity analysis to determine the long term implications in terms of rate pollution to the environment and the economics of scale involved with the selected alternative.
Lastly, the best approach in designing the hybrid system involves determining the quality of wind and solar resources in the area and determine the amount of power that can be extracted. Then, determine the power requirements of the equipment, TEM instrumentation. Afterwards, design an interface, hybrid system, which can convert the natural energy resources in the geothermal field prospect into sufficient power for its application.

4.7 Further Research Suggestions

The following are the areas that needs further research:
Further studies and analysis needs to be done in determining whether the hybrid system can effectively and efficiently work in other geothermal field prospects along the Kenya rift and other parts of the word. This would aid to determine whether the system can be universally

adopted in addressing the unsustainability aspect of batteries during geo-scientific exploration exploits.
A versatility test of the hybrid system should be carried out to determine whether the hybrid system can be optimized further to supply power in all the geophysical methods. Other areas where the versatility can be tested is the hybrid system powering the stand alone systems along the geothermal production line such as the reservoir monitoring equipment.
Lastly, an economic analysis should be done on the implementation of the hybrid system in geophysical exploration survey to enhance its adoption by the major geothermal players in the world.

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