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Research Manuscript

Experimental Investigation on Recovery of Micro Hydropower Dump Load through Oil Heating System

Joseph H. Kihedu†, Goefrey E. Mnkemi, and Cuthbert Z.M. Kimambo

Department of Mechanical and Industrial Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania
†Corresponding author: kihedu@udsm.ac.tz

ORCID: https://orcid.org/0000-0002-7371-2688

ABSTRACT

Micro hydropower power generates electrical energy to meet connected electrical demand, that normally fluctuates causing imbalances. Electronic load controller is then used to balance power system by diverting surplus generated power to the dump load commonly resistive load such as bulk water heater. This study investigated use of oil heating system as a replacement for conventional resistive dump load. In comparison to water, oil has high thermal retention therefore can serve as good thermal media. Dump load range ranged between 17 kW to 78 kW. A 6-kW electrical heater was used for laboratory oil heating system from which heated oil attained about 10,791 MJ in 31.5 minutes. Thermal stratification between upper layers and the lower layers of oil in storage tank decreases from 3.8℃ to 3.4℃ as oil temperature increases from 100℃ to 200℃, respectively. Energy dissipated through dump load from micro hydropower plants is sufficient for domestic energy consumption including cooking.

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INTRODUCTION

More than 80% of the population in developing countries lives in village without access grid connected electricity (Kumar et al, 2017). Standalone micro hydro power plants are used to provide electricity for some of small communities isolated from the electricity grid (El Hamdaouy et al, 2020). These power plants provide electricity for lamps, radios, televisions and other small electrical appliances (Riaz, 2018). In such rural settlements, 90% of total energy required for cooking is obtained from bio-fuels and fossil fuels (Bhave and Kale, 2020). Under such scenario, women and children spend significant amount of time for firewood collection (Roodsari and Nowicki, 2018). In addition to wastage of time, air bone diseases and climatic changes are accelerated by use of fossil and bio-fuels (Alva et al, 2018).

When micro hydropower systems are used to generate power, drawbacks such as variations in water flow into the turbine (Ali et al, 2018), causes power system to operate out of desired voltage and frequency ranges (Ali et al, 2019). Likewise, electricity demand is subjected to hourly, daily and seasonal fluctuation that causes power mismatch between the supply and power demand (Alam and Chopra, 2020). To maintain power system stability, Electronic Load Controller are used to divert surplus power to the dump load parallel with consumer load (Paudel and Wasti, 2018). When power consumption is low, surplus power generated get dissipated through resistive dump load so as to balance the power system. About 50% of total power generated by standalone micro hydropower gets lost in dump load, yet customers pay for this loss as service charges **(**Yan, 2019).

This paper investigated on potential use of oil heating system as a dump load. The motivation for the study in that oil can be used to store surplus power in form of thermal energy. The stored energy can be used for low grade heating application including cooking. Moreover, oil heating system can contribute to increase in efficiency of micro hydropower system.

METHODS AND MATERIALS

Field work

Field work was done at Arusha Nation Park in Arusha region, in Tanzania. The micro hydropower plant taken case study for this research is located about 7 km from the Ngongare main gate. Cross flow turbine local made is pulley coupled with three phase 100kVA synchronous generator as shown in Figure 1. The micro hydropower system type is run-of-a-river scheme with 40 m designed head, 83 m penstock length, 0.5 $m^3 sec^{-1}$ average flow rate with underground transmission line. Other technical specifications for the Arusha Nation Park hydropower plant are shown in Table 1.

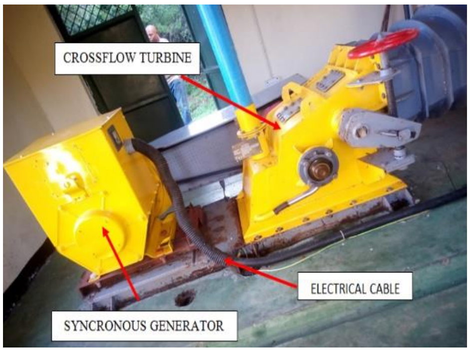

Figure 1: Crossflow turbine and synchronous generator for micro hydropower plant at Arusha National Park.

Table 1: Technical specifications for the Arusha Nation Park hydropower plant

S/N	Item	Unit	Quantity / Descriptions
1.	Design Head	m	40
2.	Head race	m	600
3.	Penstock length	m	83
4.	Penstock diameter	mm	500
5.	Penstock materials used		Mild steel
6.	Turbine type		Cross flow
7.	Turbine material used		Mild steel
8.	Runner diameter	mm	300
9.	Runner length	mm	460
10.	Number of runner disc	pcs	3
11.	Number of runner blades	pcs	20
12.	Blade angle		30º
13.	Runner shaft diameter	mm	65
14.	Runner pull diameter	mm	700
15.	Generator capacity	kVA	100
16.	Generator power factor	p.f.	0.8
17.	Generator terminal phase voltage	V	415
18.	Generator shaft diameter	mm	70
19.	Generator pull diameter	mm	250
20.	Flow rate	m3/sec	0.5
21.	Generator transformer	kVA	100
22.	Transformer power factor	P. f	0.95
23.	Transmitted voltage level	kV	11
24.	Distribution transformer	kVA	25

At Arusha National Park hydropower site, air heater rated at 96 kW is used as a dump load (Figure 2). Normally, dump loads for micro hydropower plants are electrical resistive loads sized equal or slightly greater than generator capacity. A dump load is designed such that it can absorb and dissipate excess power (Mallik and Ahmed, 2018). Usually, air and water heater are commonly used as working fluid for dump loads. However, applications such as water pumping, battery charging, refrigeration and heat storage system may also be used as a dump load (Prayogo, 2019).

Figure 2: Electrical heater dump load at Arusha National Park hydropower site.

Chauvin Arnoux 8334B power quality analyser, PQA, was used to record surplus power as shown in Figure 3. Chauvin PQA has current and voltage probes that were connected to each phase. Care was taken to avoid short circuit as the installation was carried out in live circuit. The PQA was set to record measured values at an interval of 2 min for five days including a weekend. Personal computer was used to execute and download data.

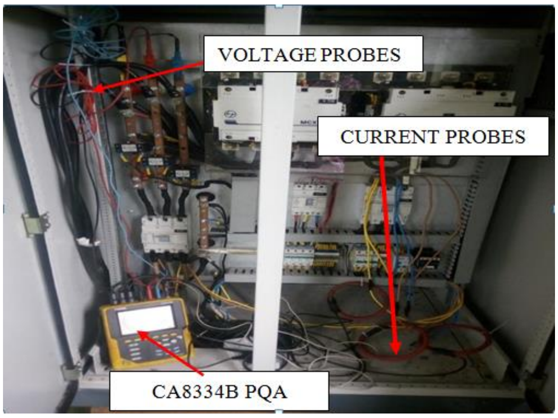

Figure 3: Connection of Chauvin Arnoux 8334B power quality analyser for recording of surplus power.

Laboratory work

The main components and materials of laboratory scale oil heating system included electrical heaters, heating tanks, heat exchanger, temperature measurement system, pump, control panel, frame and a pair of 50 L tanks of Total Seriola 1510 oil. Figure 4 shows conceptual framework for the oil heating system used for this study.

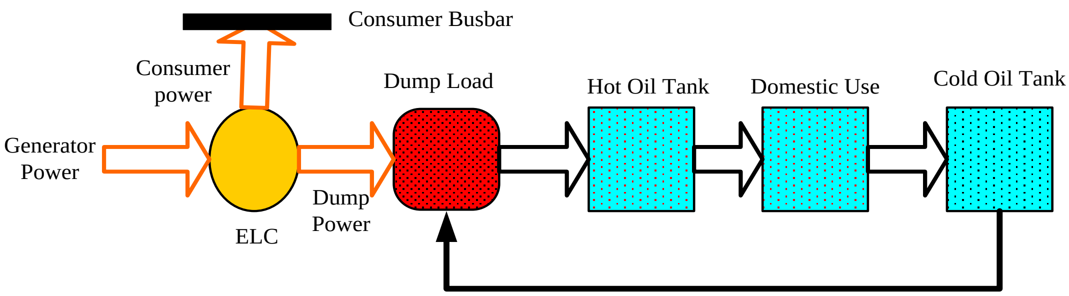

Figure 4: Conceptual framework for laboratory oil heating system.

A control panel was used to control power supply to the oil heating system. It comprised of two contactors, start and stop button, PID Temperature Controller. PID Temperature Controller was used to monitor temperature by receiving signal through thermocouple dipped to the oil inside the heating tank.

The maximum energy dissipated by oil heater to the oil, $Q_{el}(t)$ in Joules was determined by the equation:

$$Q_{el}(t) = I_h^2 R_h t \quad (1)$$

where t is time in seconds, I_h is rated current of the oil heater in Amperes, and R_h is the rated resistance of the oil heater measured in Ohms.

Expected change in temperature from energy dissipated, ΔT in °C, was then determined as:

$$\Delta T = \frac{Q_{el}}{\rho V C} \quad (2)$$

where ρ is density of oil in kg/m^3, Vis the volume of oil in m^{3}and C is the heat capacity of the oil in J/kg °C.

Therefore, resulting final temperature of the heated oil T_f in °C can be estimated from change in temperature ΔT in °C and ambient temperature T_{amb} ΔT in °C as:

$$T_f = \Delta T + T_{amb} \quad (3)$$

Experimental setup used for this study is shown in the Figure 5. The pump was turned ON to push Total Seriola 1510 oil through the pipe to the cold oil storage tank located at the top. The valve between the cold oil storage tank at the top and oil heating tank located at the middle was opened to allow only 40 L of oil to flow by gravity. Three thermocouples were connected to a TC-08 data logger interfaced with a desktop computer. The TC-08 data logger was configured to record temperature at an interval of 10 seconds. The electrical heater was connected to a 220V AC main supply via contactor switch. PID temperature controller was switching ON after a manual set-up of the desired temperature. Total Seriola 1510 oil was then heated-up to the desired value when PID temperature controller automatically switched OFF the electrical heater. These procedures were repeated for final desired temperature value of 100 °C, 150 °C and 200°C.

RESULTS AND DISCUSSIONS

Results from the fieldwork

Figure 6 shows that power consumed by the dump load was as high as 17 kW out of 100 kW rated power generation, persisting between 1500 to 2100 hours. In addition to that, highest dump load above 18 kW was observed between 0500 and 0700 hours in the morning.

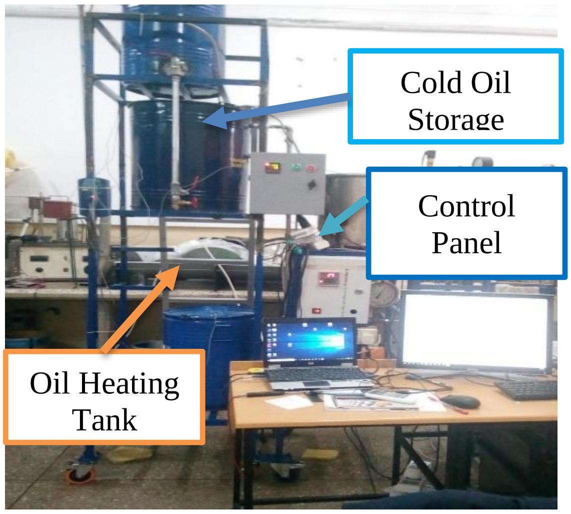

Figure 5: Oil heating system used as experimental setup for this study.

Consequently, frequency decreased to 45.6 Hz in response to the rapid increase in power consumption against almost constant water flow rate. Meanwhile, dump load was as low as 12 kW between 0900 and 1400 hours followed by average of 14 kW dump load between 2200 and 0900 hours.

Results from laboratory experiments

Figure 7 shows the variation of Total Seriola 1510 oil temperature towards desired value of 100 °C, with respect to time. Rapid increase in temperature was observed at the middle of the tank in response with the electrical heater operation. Due to thermal stratification (Jamil, 2016; Neupauer and Kupiec, 2017; Ashmore et al, 2018), behaviours in Total Seriola 1510 oil, as it is the case other types of oils, the highest temperature difference between the top and bottom oil layers in the heating tank was 15 °C which occurred during heating process as temperature of oil gradually increases. Meanwhile, the lowest temperature difference between the top and bottom oil layers was 3.9°C as temperature approaches desired value of 100 ℃. The energy absorbed by oil was calculated and found to be 4.450 MJ attained after 660 seconds of heating.

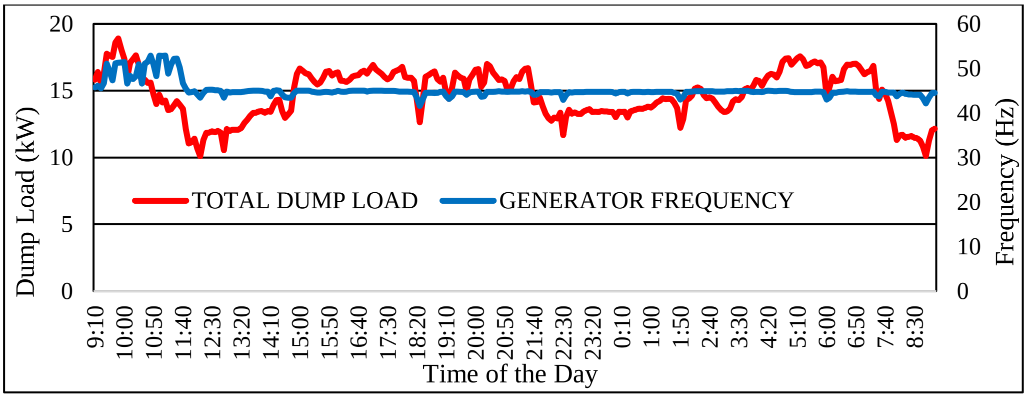

Figure 6: Dump load profile from Arusha National Park hydropower site.

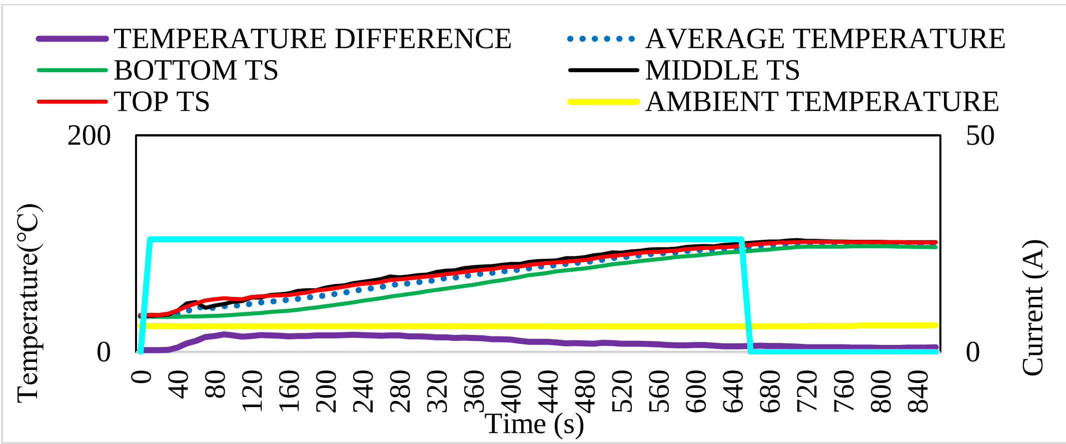

Figure 7: Oil heated to desired temperature of 100℃.

Figure 8 shows the variation of Total Seriola 1510 oil temperature towards desired value of 150 ℃, with respect to time. Due to thermal stratification (Jamil, 2016; Neupauer and Kupiec, 2017; Ashmore et al, 2018), the highest temperature difference between the top and bottom oil layers in the heating tank decreased to 14.6°C which occurred during heating process as temperature of oil gradually increases. Meanwhile, the lowest temperature difference between the top and bottom oil layers decreased to 3.5 ℃ as temperature approaches desired value of 150 ℃. The energy absorbed by oil was calculated and found to be 8.044 MJ attained after 1,300 seconds of heating. Figure 9 shows the variation of Total Seriola 1510 oil temperature towards desired value of 200 ℃, with respect to time. Due to thermal stratification (Jamil, 2016; Neupauer and Kupiec, 2017; Ashmore et al, 2018), the highest temperature difference between the top and bottom oil layers in the heating tank was 14.5 ℃ which occurred during heating process as temperature of oil gradually increases. Meanwhile, the lowest temperature difference between the top and bottom oil layers was 3.4°C as temperature approaches desired value of 200 ℃. The energy absorbed by oil was calculated and found to be 10.791 MJ attained after 1,890 seconds of heating.

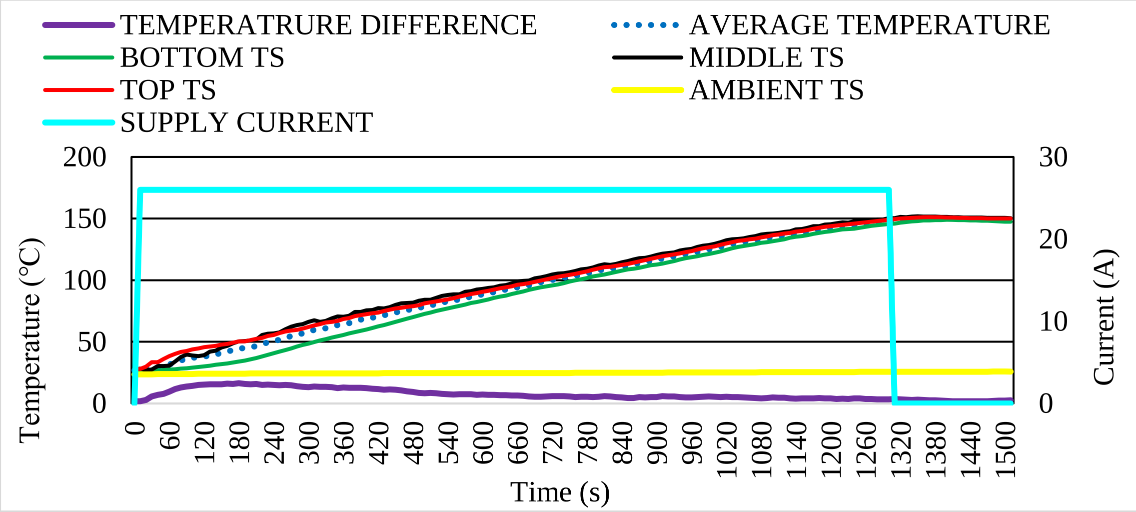

Figure 8: Oil heated to desired temperature of 150℃.

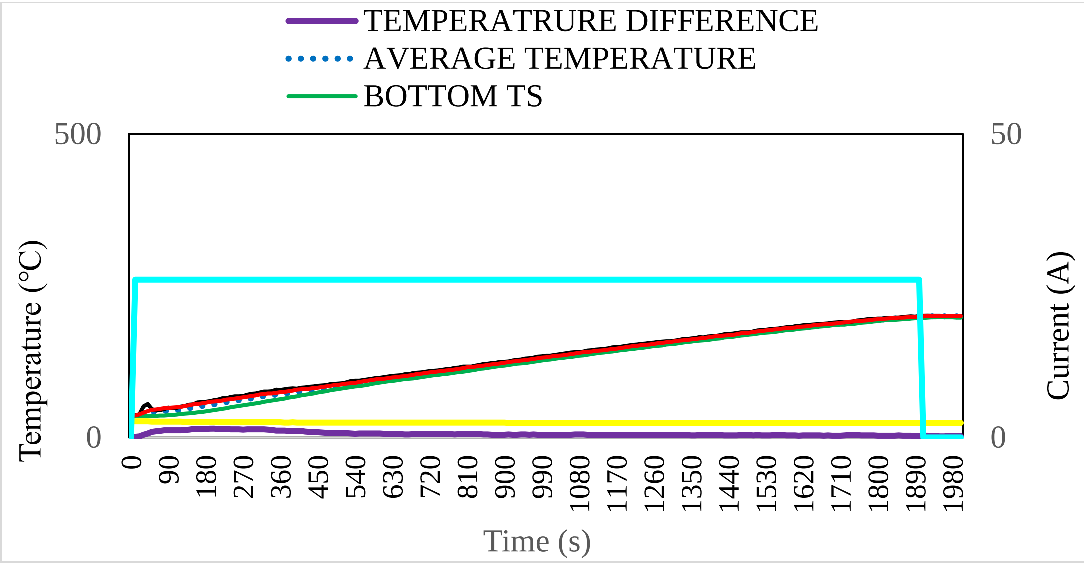

Figure 9: Oil heated to desired temperature of 200℃.

Discussion of the results

Thermal stratification occurs during heating of Total Seriola 1510 oil, as it is the case other types of oils. The experimental results show that oil thermal stratification decreases with increase in temperature (Jamil, 2016; Neupauer and Kupiec, 2017; Ashmore et al, 2018). At 200℃, the highest energy absorbed by 40 L of oil is about 10.791 MJ. This is approximately half of 20.4 MJ dissipated by dump load connected to one phase of the micro hydropower plant at Arusha National Park in 60 minutes only. This energy is enough to raise temperature of 40 L of Total Seriola 1510 oil from room temperature to 200℃ which is sufficient for typical domestic energy consumption purposes including cooking (Ashmore et al, 2018).

CONCLUSION AND RECOMMENDATION

Oil heating system is one of the suitable and an efficient method of absorbing excess power generated from micro hydroelectric power system. Employing the use of oil heating system for domestic applications, instead of water heating as dump load will increase micro hydropower efficiency. The results from field data show that dump load experiences 18kW peak. On the other side, Total Seriola 1510 oil heating system shows that oil acquired 4.450 MJ, 8.044 MJ and 10.791 MJ when heated to 100℃, 150℃ and 200℃ respectively. From the study, the temperature profiles show large temperature difference between the top and the bottom layers of oil during heating process as temperature of oil gradually increases. However, temperature difference decreases at high temperatures. This implies that oil thermal stratifications decrease as temperature rises. It is recommended that further investigation on dump load utilization for thermal application be done at micro hydropower site. Also, energy dissipated through dump load from micro hydropower plants may be sufficient for typical domestic energy consumption including cooking.

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NONMENCLATURE

ELC Electronic Load Controller
PCM Phase Change Material
P_h Rated power for electrical heater
PID Proportional Integral Derivative
PQA Power Quality Analyzer
I_h Rated current for electrical heater

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