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On High-Temperature Dynamometer Test Stand Development

Miles Skinner, Devon Kesseli, Scott Lambert, Ben McGilton, Casper Labuschagne, Petr Sindler, and Lee Jay Fingersh

National Laboratory of the Rockies

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March 2026

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15013 Denver West Parkway
Golden, CO 80401
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Executive Summary

The repetitive pulsed electric drill (RePED-250) is a novel prototype geothermal drilling method that requires a high temperature alternator to produce power down well. The RePED-250 alternator has been designed and built to operate at 35 kilowatts (kW) under 250°C ambient temperature conditions. The operating efficiency is measured using a 225 kW motor to drive the machine in a back-to-back configuration. The goal of this test is to determine if the RePED-250 alternator can deliver 35 kW at a rotational speed of 1,000 revolutions per minute (rpm) while operating at 250°C ambient temperature and have a minimum efficiency of 60%. Dynamometer testing of a high-temperature alternator for geothermal drilling presents several unique challenges, especially around maintaining and managing the various sources and types of energy passing through the system without impacting data quality. The objectives of this report are to (1) describe the test stand in detail, the relative orientation of each major component, and the data acquisition system and (2) discuss the behavior of the test stand components such that this report can serve as a reference document for future projects.

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1 Introduction

The repetitive pulsed electric drill (RePED-250) is a novel prototype geothermal drilling method that requires a high temperature alternator to produce power down well. The RePED-250 alternator has been designed and built to operate at 35 kilowatts (kW) under 250°C ambient temperature conditions. The operating efficiency is measured using a 225 kW motor to drive the machine in a back-to-back configuration. The alternator is heated to temperatures up to 250°C and loaded using an adjustable bidirectional AC power supply. The goal is to determine if the RePED-250 alternator can deliver 35 kW at a rotational speed of 1,000 revolutions per minute (rpm) while operating at 250°C ambient temperature and have a minimum efficiency of 60%.

Dynamometer testing of a high-temperature alternator for geothermal drilling presents several unique challenges, especially around maintaining and managing the various sources and types of energy passing through the system without impacting data quality. To accomplish these objectives, a custom test stand was designed. It included an insulated housing with temperature rated input/output ports, high-temperature electrical enclosures rated for the expected currents and voltages, and data acquisition (DAQ) systems to collect time-synced data from various sensors distributed throughout the test stand.

The objectives of this report are to (1) describe the test stand in detail, the relative orientation of each major component, and the DAQ system and (2) discuss the behavior of the components such that this report can serve as a reference document for future projects. The authors believe this document can greatly speed up the design, setup, and commissioning of similar dynamometer test stands in the future to reduce cost and lower the barrier to energy for future projects.

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2 RePED-250 Alternator Test Stand

2.1 Stand Overview

A high-level diagram of the test stand is shown in Figure 1. This system is simple with only a few major components. For clarity, minor components such as low-voltage power supplies and electrical disconnects have been omitted. The arrows and coloring in the diagram are used to differentiate the type and direction of energy flow through the system. The diagram identifies what components are connected and what each component is sending to the next. Here, black indicates command signals, orange is mechanical energy from the drive shafts, blue is electrical energy (specific voltage and currents omitted), red is thermal energy, and green indicates data signals.

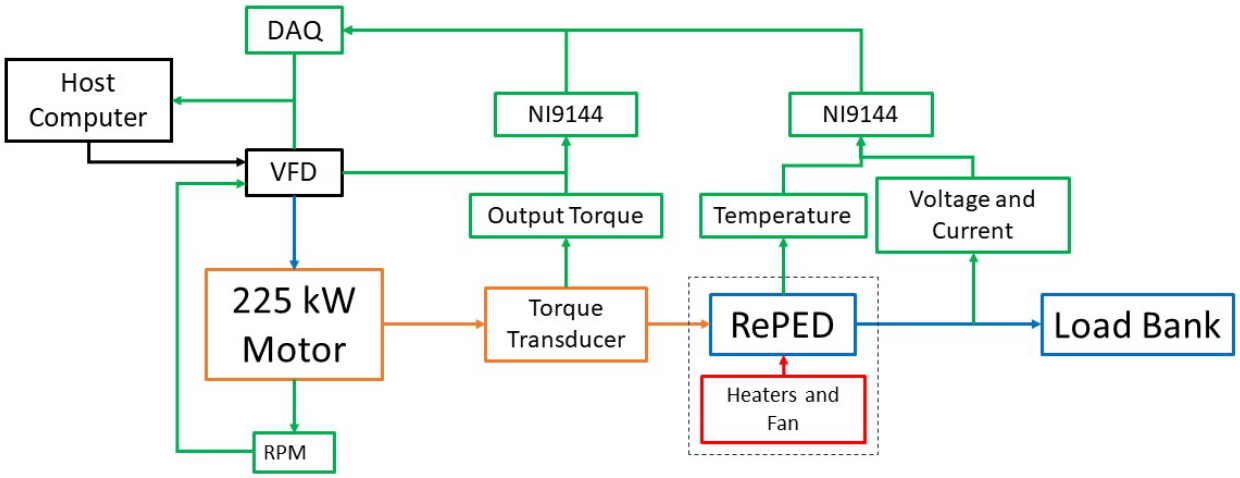

Figure 1. Conceptual block diagram showing signal and energy flow throughout the RePED-250 alternator test stand. The insulated housing is shown as a dotted line. Black indicates command signals, orange indicates mechanical energy direction, blue represents electrical signals and power, red indicates thermal energy direction, and green indicates data signals.

Figure 2 shows the as-built test stand with the notable equipment labeled. The alternator is connected to the 225 kW dynamometer motor through a contactless torque transducer and a custom-designed drive shaft. The RePED-250 alternator is contained inside the insulated housing to maximize thermal stability. A series of heaters, described below, are also wrapped around the RePED-250 alternator to assist with preheating and thermal stability. The opposite side of the test stand is shown in Figure 3. This side supports the landings for the RePED-250 alternator's three-phase power output and DAQ. The dynamometer and generator DAQ systems will be discussed below.

The dynamometer is powered by a 225 kW three-phase AC motor supplied by a 480-volt (V), 50 ampere (A) connection. The motor is controlled by an ABB ACS880 series variable frequency drive (VFD). The drive is supplied by an ACS880-207-0400A-5 supply unit, and the motor is driven by an ACS880-107-0440A-5 drive unit. Motor output torque is measured with a Lebow model 1105-10k torque transducer with a maximum speed and torque rating of 8,500 rpm and 1,130 newton-meters (Nm) (Honeywell 2006). The driveshaft is a custom automotive-type universal joint driveshaft with the ability to compensate for small misalignments between the

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motor and the RePED-250 alternator. The universal joints are 1350 series with 1,680 Nm maximum torque rating. This yielded a factor of safety larger than 2 times, so it was deemed acceptable. Single flex-disk style shaft couplings are used between the rotating components. The visible yellow guarding is to prevent accidental contact with rotating components.

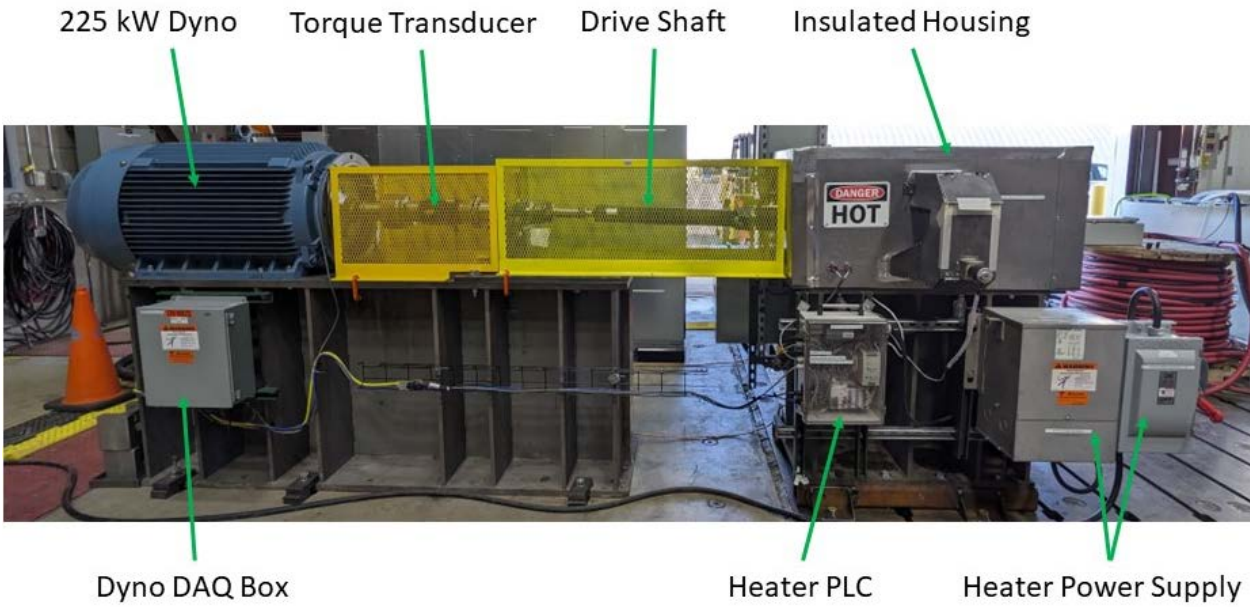

Figure 2. Side profile of the test stand with labels.

Image by Miles Skinner, National Laboratory of the Rockies

The insulated housing is constructed from 22-gauge bent sheet metal with Rockwool Comfortbatt R15 housing insulation glued to the inside. The insulation temperature rating of 1,000°C was more than adequate for the 300°C maximum temperature operation of the alternator under testing (Rockwool 2020). The heaters were expected to draw 5 kW during operation.

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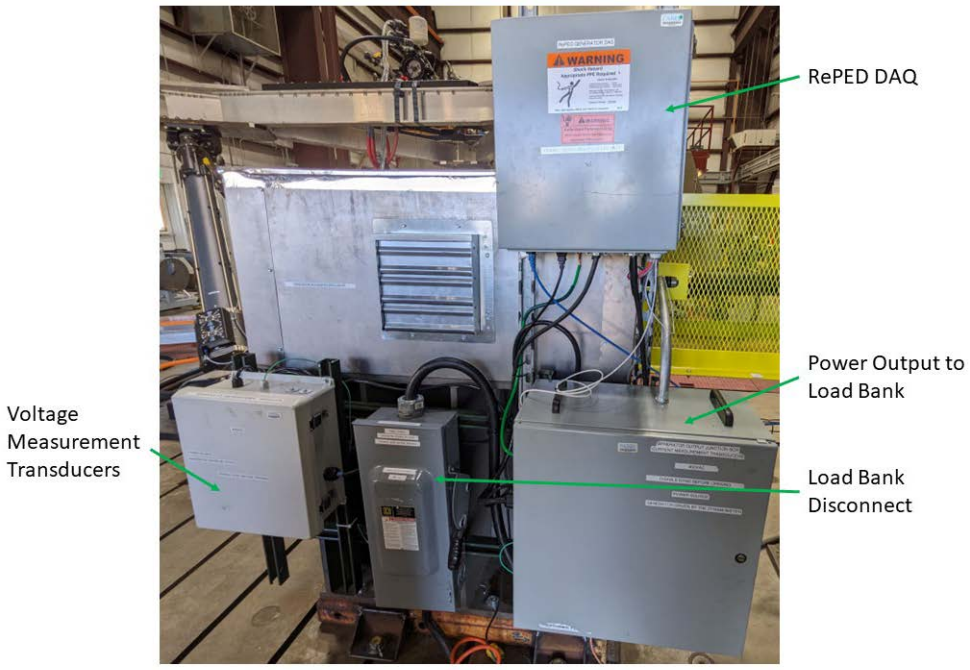

Figure 3. Back side of the RePED-250 alternator test stand showing DAQ system enclosures, voltage measurements, and power output enclosures.

Image by Miles Skinner, National Laboratory of the Rockies

Figure 3 shows the opposite side of the test stand. Here, the three-phase raw AC power output from the RePED-250 alternator is connected to a resistive load bank through low-resistive copper bus bars, shown in Figure 4. Electric power output from the RePED-250 alternator is handled with three 10 American Wire Gauge (AWG) high-temperature wires—Gore magnetic wire rated up to 260°C (W. L. Gore & Associations 2021). Internal National Laboratory of the Rockies testing demonstrated that these wires can operate at up to 316°C for up to 3 hours. These wires are expected to carry a maximum of 480 volts alternating current (VAC) root-mean-square (RMS) and 50 A. It is possible for these wires to generate significant heat during operation and reach a temperature of 300°C. This exceeds the wire's rated temperature; however, this is the highest rated readily available wire, and the risks are mitigated by active cooling of the enclosure and monitoring. It was important to use temperature-rated terminals and actively cool the bus bars with the inlet and exhaust fans shown on the left and right side of the enclosure. Within the alternator output junction box, the output wires are connected to large copper buses with high-temperature-rated terminal ends to accommodate the possible heating. The bus bars are isolated from the enclosure with electrical and thermal insulating spacers. The three-phase load bank connection is made with 4-AWG cables rated for the expected volage and current. Current and voltage transducers are also fixed to this end of the bus bars to protect them from excessive heating. Additionally, temperatures within the enclosure are monitored continuously to ensure safe operation.

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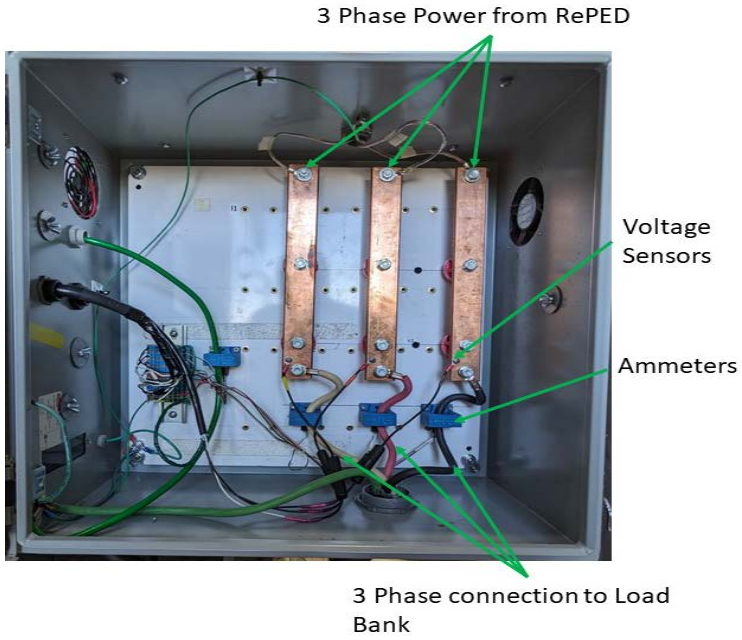

Figure 4. High-temperature alternator output junction box showing the connection between the RePED-250 alternator 10-AWG wires, copper buses, and 2-AWG load bank cables. Also visible are the current and voltage sensors.

Image by Miles Skinner, National Laboratory of the Rockies

2.2 Housing Insulation and Heating

To establish and maintain the necessary testing temperature, the RePED-250 alternator is wrapped in eight resistive heating elements controlled by a programable logic controller (PLC). These are flexible resistive tape-type heating elements (4550T142 McMaster-Carr, Elmhurst, IL) with rated maximum temperature and power of 760°C and 624 watts (W) each, respectively. They are fixed to the RePED-250 alternator's outer surface with moisture activated fiberglass plaster tape. The heaters and fan were controlled by a CLICK Plus C2-03CPU-2 PLC. This unit also controls a small fan that circulates air within the insulated housing to create a more uniform heating environment. The heating and fan units are fed by an XP Power DNR120 power supply inside the PLC enclosure, shown on the far right of Figure 2.

The logic circuit for the heaters is shown in Figure 5. The most notable features of this circuit are the two independent fault detection systems. An emergency stop button (Estop) and thermal cutoff switch were placed in series with the PLC control signal. The Estop is a manual interlock that can be triggered by the operators. The thermal cutoff switch monitors the housing temperature and can automatically engage the interlock in the event of thermal runaway. Essentially, the fault detection interlock acts as a Boolean Or gate, disabling the heating system if either the Estop or cutoff switch is triggered. Due to the elevated temperatures and long test durations, it was critical to establish this logic circuit to maintain the desired temperatures while protecting equipment and personnel.

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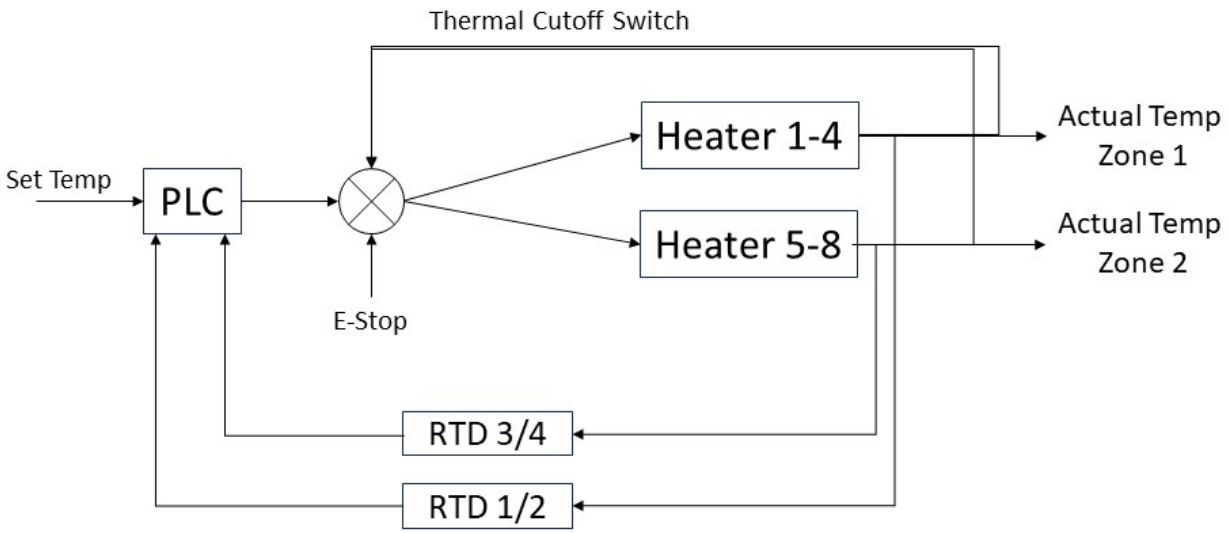

Figure 5. Heater control logic circuit. The PLC control signal is connected in series with two independent error detectors, an E-stop switch and a thermal cutoff switch. Either of these can disable the entire circuit in the event of a fault.

The heating elements are wrapped tightly around the RePED-250 alternator in eight concentric rings organized into two groups. The first four rings cover the middle two quarters of alternator's axial length while the second four rings cover the first and last quarter. Due to heat sinking into the fixture (Figure 6), the ends of the alternator are expected to require more heating to maintain the desired temperature. Creating two heating zones provides a greater degree of temperature control.

The housing is lined with Rockwool Comfortbatt R15 fire resistant insulation rated up to 1,000°C. A solid model of the inside of the housing with the RePED-250 alternator is shown in Figure 6. To reduce conduction out of the alternator through the fixture, a series of ceramic insulating spacers are bolted to either end of the RePED-250 alternator and mounted to the adjustment plate. The spacers float in the plate to compensate for differential thermal expansion of the alternator and fixture. The adjustment plates can slide vertically to create an air gap between the aluminum fixture and the alternator's outer wall. A thin, high-temperature ceramic pipe insulating strip was placed in this air gap to minimize convective heat transfer between those two surfaces. With this setup, the only conduction path is from the high-temperature alternator into the ceramic spacers, then into the fixture. Convection cannot be eliminated, but the relatively small internal volume and the fan were intended to create a uniform stable housing temperature. The shaft coupling protruded through a small hole in the front of the housing (not shown) and connected to the rest of the drivetrain visible in Figure 2.

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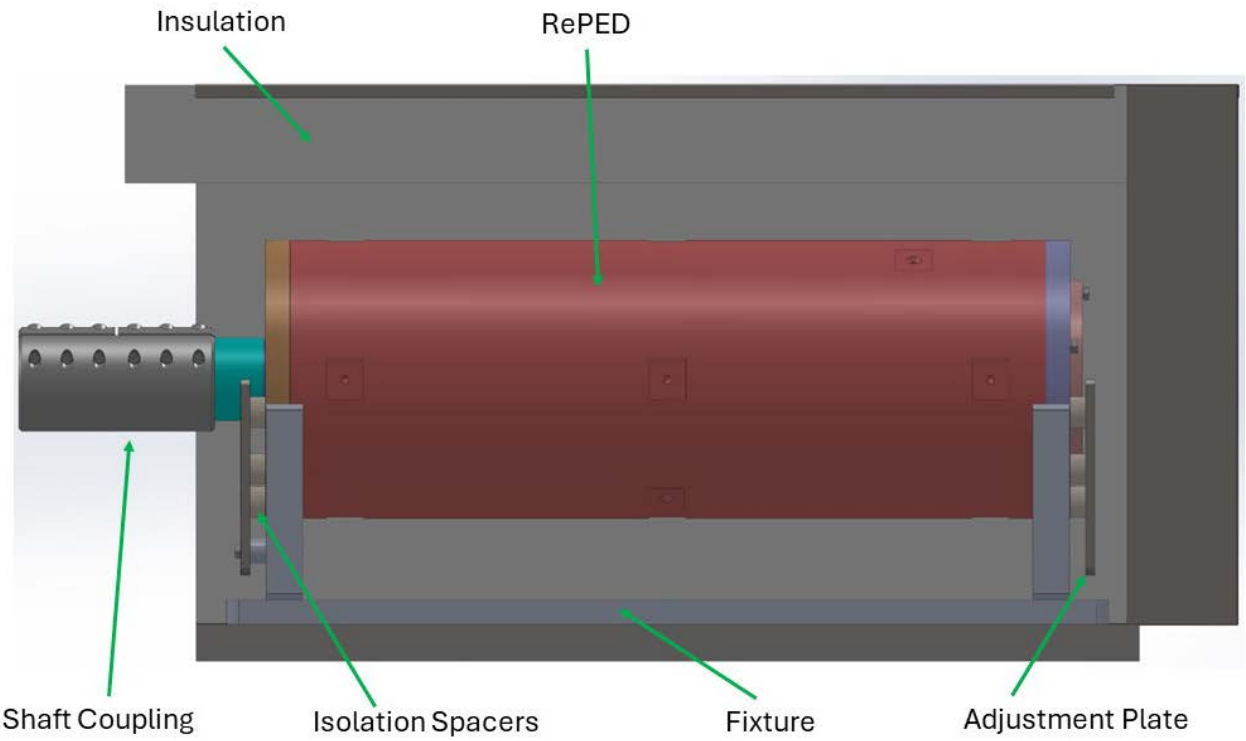

Figure 6. Solid model assembly of the housing with the RePED-250 alternator. The side walls and front have been removed for clarity. Major components have been labeled.

To determine the heat transfer through the insulation, several assumptions are made. First, this analysis will focus on a 2D simplification representing heat transfer through the vertical walls of the housing. The inside and outside surface temperatures of the housing are assumed to be 300°C and 25°C, respectively. The sheet metal exterior is assumed to have perfect heat transfer between the insulation and the air. The air is assumed to be an ideal gas. Finally, free convection is assumed between the outside surface of the housing and the air. Heat flux through the insulation is given by

$$\phi = \frac{\Delta T}{R} \tag{1}$$

where ϕ is the heat flux in watts per square meter ($\frac{\mathrm{W}}{\mathrm{m}^2}$), ΔT is the temperature gradient, and R is the thermal resistance in $\frac{\mathrm{K \cdot m}^2}{\mathrm{W}}$ (where K is kelvin). The heat transfer away from the wall is given as

$$\frac{\dot{Q}}{A} = h(T_s - T_\infty) \tag{2}$$

$$\frac{\dot{Q}}{hA} - T_\infty = T_s \tag{3}$$

where $\frac{\dot{Q}}{A}$ is the free convection away from the surface in $\frac{\mathrm{W}}{\mathrm{m}^2}$, h is the thermal conductivity, and T_s and T_∞ are the surface and ambient temperatures in K, respectively. Given the complexities of

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fluid flow, obtaining a simple analytical solution is difficult, so it is common to assume an empirical value for the heat transfer coefficient. In this case, it is best to assume a small value for h because this will minimize heat transfer away from the surface and maximize potential heating of the wall. Therefore, h is assumed to be $10 \frac{\mathrm{W}}{\mathrm{K \cdot m^2}}$. From (2) the expected wall surface temperature of the housing is found by solving for T_s.

With (1) and (3), the expected housing wall surface temperature can be found for any temperature difference between the atmosphere and inside of the housing. With a temperature difference of 275 K and an R value of 15, the anticipated heat flux is $18.33 \frac{\mathrm{W}}{\mathrm{m^2}}$, resulting in a surface temperature of 26.83°C.

A diagram of the convection fan and air duct is shown in Figure 7. The fan draws hot air from the top of the housing and redistributes it to the bottom to create a more uniform thermal distribution within the housing. The duct also has an external louver, which can be opened if necessary to allow cold ambient air into the housing to cool the system more rapidly. The fan is powered by a small 24-V motor with a maximum rotational speed of 6,000 RPM. The fan itself is a 15-centimeter (cm) diameter stamped aluminum fan blade with a maximum rated 4,000 RPM and can move $9 \frac{\mathrm{m^3}}{\mathrm{min}}$ of air. The internal volume of the housing is 0.2 $\mathrm{m^3}$; therefore, this fan can circulate the entire volume of the housing 30 times per minute.

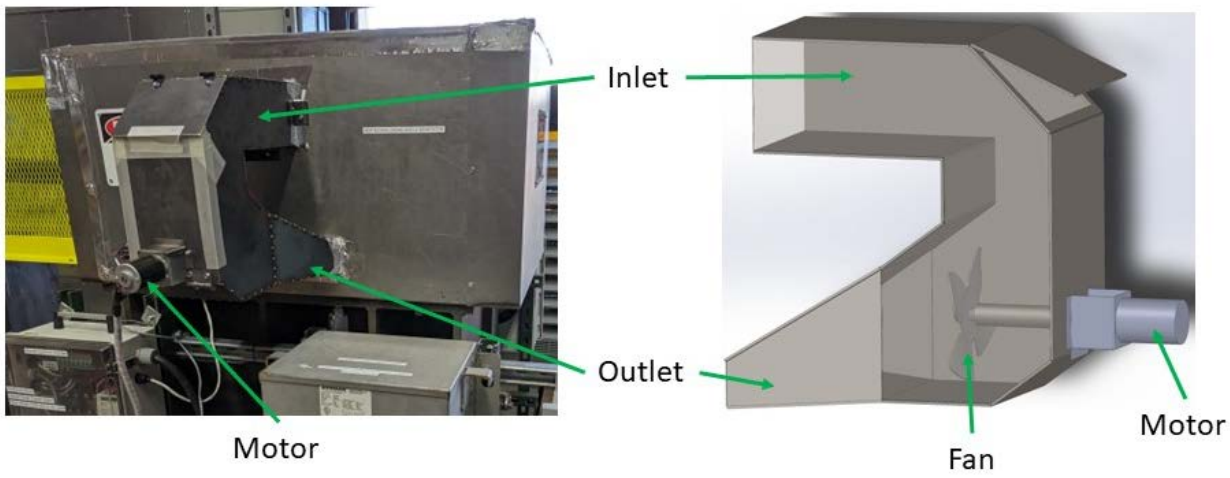

Figure 7. Diagram of the solid model and as-built fan and duct assembly used to create a uniform thermal distribution within the housing.

Image by Miles Skinner, National Laboratory of the Rockies

2.3 Sensors and Data Acquisition

The RePED-250 alternator, as-built from the manufacturer, has 10 k-type thermocouples installed throughout the length of the stator to measure the internal temperature. The thermocouples, resistive temperature devices (RTD), and current and voltage transducers are connected to NI 9211, NI 9217, and NI 9239 cards, respectively. These are mounted in an NI 9144 chassis. A block diagram of the heating and feedback system is shown in Figure 8. For

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simplicity, a single line diagram for each sensor is not included; however, proper wiring diagrams for thermocouples, RTDs, and transducers are available from National Instruments (National Instruments 2023; 2024a; 2024b). A CLICK PLC (Automation Direct n.d.) manages the feedback from the RTDs to control the heater temperatures. The current transducers used for this work were LEM HAL 100-S. These are Hall effect 100-A range transducers with voltage output. The voltage measurement transducers were Verivolt IsoBlock V-1c (1,000 V:10 V) units with a 1,000 V (AC or DC) range and 10-VDC output.

The dynamometer-alternator shaft torque was measured with a Lebow 1105-10k torque transducer (1,130 Nm capacity) connected to NI 9237 bridge input module. The dynamometer speed was measured by a BEI HS25 encoder. This encoder was directly connected to the ABB 880 variable frequency drive to provide control feedback.

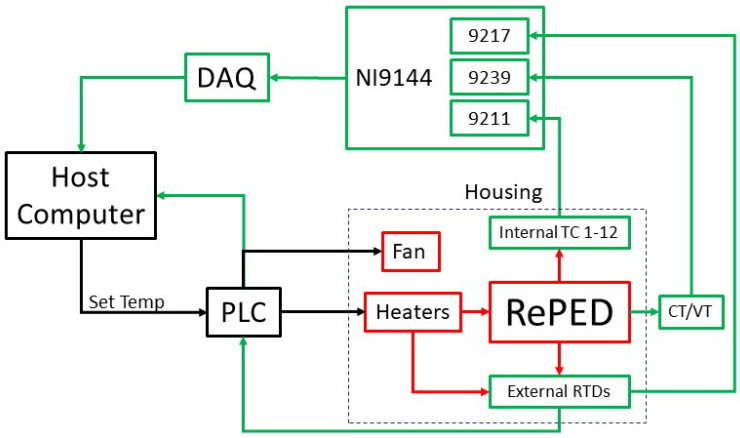

Figure 8. Conceptual block diagram of the heaters, thermocouples, RTDs, and feedback loop. Green indicates data, black indicates control signals, and red shows thermal energy flux. The abbreviations CT and VT are current transducer and voltage transducer, respectively. Note, the RePED-250 alternator also generates heat internally from resistive losses.

Data were collected in two groups, fast and slow, through an EtherCAT network controlled with a custom LabVIEW program. The fast group recorded data at 1,000 hertz (Hz) and included the voltage, current, motor speed, and torque data. The slow group recorded data at 100 Hz and included the thermocouples and RTDs. Given the alternator's size and thermal mass, the thermal response time was expected to be relatively slow; therefore, the slower sample rate reduced file sizes without decreasing resolution. However, a higher sample rate was deemed necessary to accurately record the dynamometer behavior and the alternator's electrical performance.

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3 Test Stand Verification

Preliminary sensor data were collected to verify all sensors were functioning properly prior to testing and to validate the thermal housing operation. These data are not meant to characterize the RePED-250 alternator but to demonstrate that the test stand performs as expected.

3.1 Thermal Stability

Temperature measurements were recorded from the thermocouples and RTDs during operation to validate their performance. These measurements are shown in Figure 9. The internal thermocouples, denoted by $T_{winding}$, measure rapid heat generation due to resistive joule heating. The RTDs in Zone 1, $T_{stator\text{-}Z1}$, measure the temperature on either end of the RePED-250 alternator closest to the fixture. The temperature is consistently lower here because of heat sinking into the fixture. While efforts were made to minimize this heat loss, it could not be prevented altogether. The temperature in Zone 2, $T_{stator\text{-}Z2}$, near the middle of the RePED-250 alternator, does not rise as quickly as the temperature of the windings because of the RePED-250 alternator's thermal mass. After approximately 3 hours, the external temperature normalizes with the internal temperature measured in the windings. Stable temperature readings from all thermocouples and RTDs across this temperature range indicate the sensors are functioning as intended.

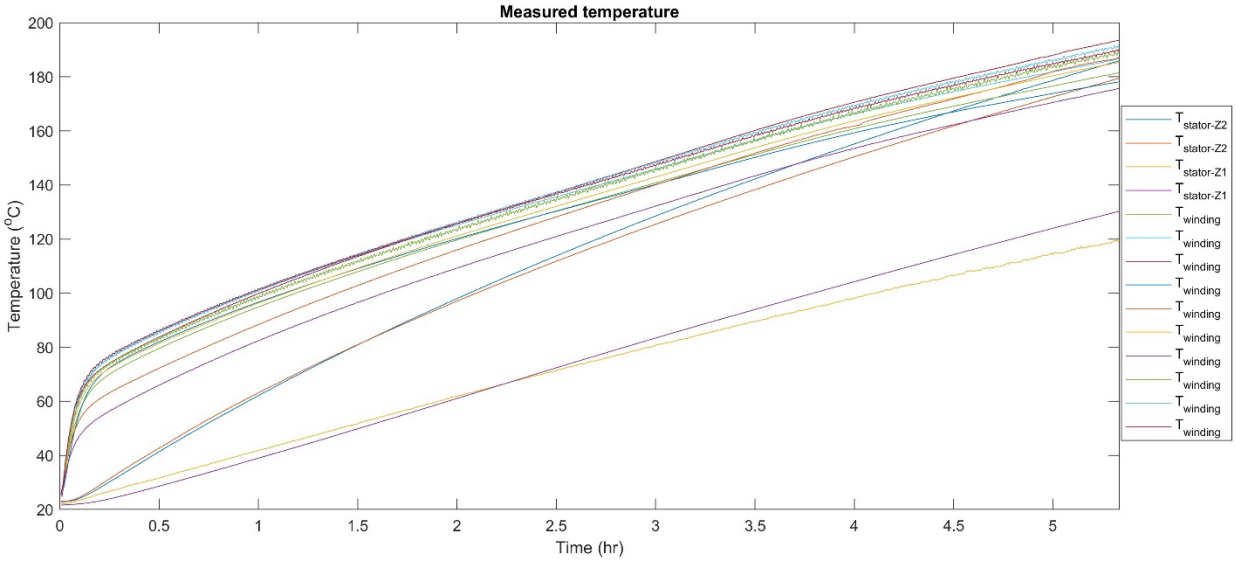

Figure 9. Temperature rise of the RePED-250 alternator during operation. The RTDs in Zone 1 can be clearly seen on either end of the RePED-250 alternator while those in the middle are in Zone 2.

3.2 Dynamometer Measurements

3.2.1 Voltage and Current

The voltage and current transducers were also successfully able to record the three-phase output from the RePED-250 alternator. Voltage for each phase was recorded at 300 V and 80 A under nominal operating speeds and temperatures. Figure 10 shows the output from a single phase for clarity, but all three phases showed similar results.

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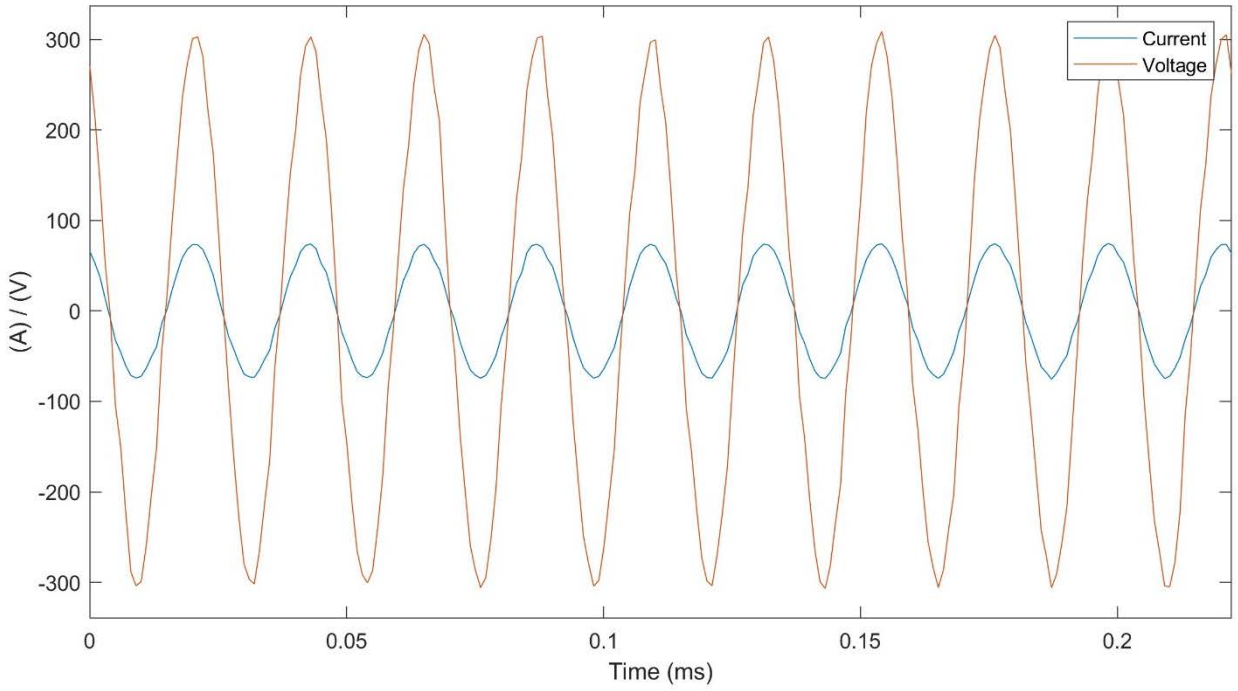

Figure 10. Voltage and current measurements from the appropriate sensors. Only one of three sensors is shown for clarity; the other phases produced similar results.

3.2.2 Speed and Torque

The input power is directly proportional to the speed and torque of the motor, both of which were measured using the test stand. Similarly, the output power is determined from the measured voltage and current produced by the alternator. The measured results for the input and output power of the alternator are shown in Figure 11 The input and output power measurements correlate well with the finite element analysis predicted performance of the RePED-250 alternator (Labuschagne et al. 2025); therefore, the sensors and data acquisition system are accepted as functioning properly. The offset between the measured and predicted results are caused by frictional losses in the system between the motor and alternator, which were not accounted for in the finite element analysis of the alternator, only the iron core losses and resistive losses in the windings were accounted for.

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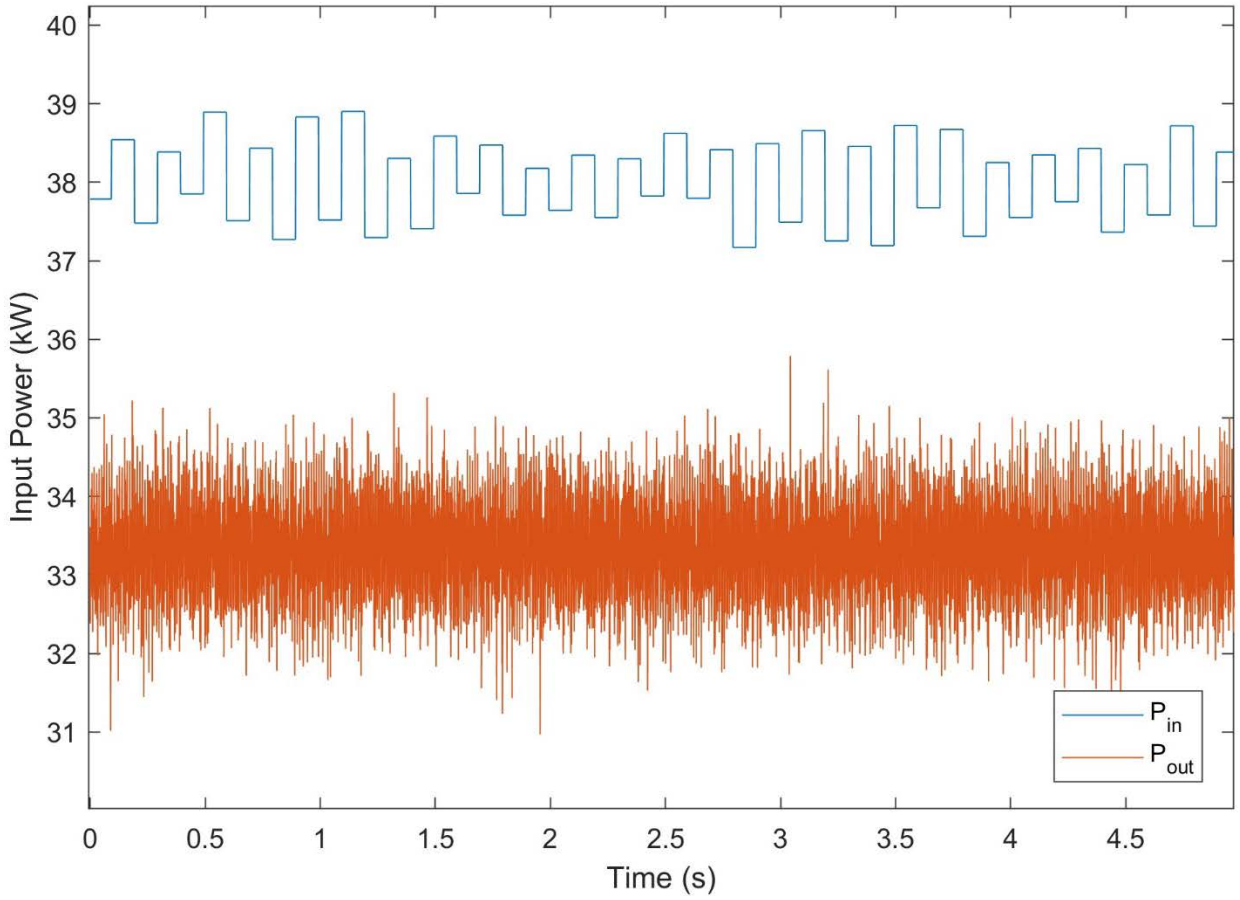

Figure 11. Input and output power measurements. Input power is calculated from the input torque and speed measured by the dynamometer torque and speed. Output power is calculated from the voltage and current measurements.

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4 Conclusions

Conducting high-temperature dynamometer testing of the alternator presented several unique challenges related to safety concerns, temperature control requirements, and data collection. To address the temperature control requirements, an insulated housing and isolation fixture were designed and fabricated. Theoretical calculations and empirical measurements showed the housing could maintain the desired temperature and minimize risk to personnel. Along with the thermal insulation, a convection fan was added to the housing to recirculate hot air around the housing, and heating elements were wrapped around the RePED-250 alternator. The fan and heating elements were controlled by a PLC.

Developing the DAQ system also required paying special attention to the temperature, expected voltages, and expected currents. A high-temperature electrical enclosure was constructed with active cooling over the bus bars to prevent overheating the electrical connections. Data were collected for the 10 thermocouples and 4 RTDs at 100 Hz, and the voltage, current, speed, and torque were recorded at 1,000 Hz. This test stand successfully completed the more than 50 hours of testing, the full regime required for the RePED-250 project.

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