NH Research

Regenerative Loads & Sources: Removing the Cost of Heat

Introduction to Regeneration

Traditional loads, either air-cooled or water-cooled, convert the unit-under-test's (UUT) output power into waste heat whereas regenerative loads recycles the UUT output power back onto the facility or UUT in the form of usable electricity. This allows the test system to lower the total electrical usage while significantly reducing waste heat. For example a regenerative load with > 90% efficiency would return more than 90% of the UUT's output power back to the facility and convert less than 10% of the UUT power into heat.

Traditional Loads?

An air- or water-cooled power resistor is the simplest form of load. A resistor has a fixed loading profile that follows Ohm's law ($I = V/R$) and converts 100% the discharge power ($P = V*I = V^2/R$) directly into heat. The maximum power that can be loaded depends on the resistor's rating.

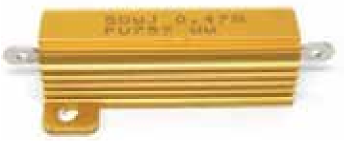

Figure 1: *Simple Load*

Air-cooled resistors dissipate the heat into the air. Air conditioning or fans are then used to remove the generated heat from the working area. In air conditioned laboratory settings, an air-cooled resistor can represent a very low cost, flexible, and simple load. However, the amount of heat generated by air-cooled resistors makes it impractical for high power testing or manufacturing environments.

"Regenerative loads recycle the UUT output power back to the facility or UUT in the form of usable electricity."

Water-cooled resistors have an electrically isolated water connection, allowing water to carry the heat away from the device. Unfortunately, the water may also contain additives or contaminants that can produce an electrical hazard if the resistor is damaged or if there is a leak to the connection. The requirement of a water connection limits where and when this type of device can be used.

Electronic Loads

An electronic load converts 100% of the discharge power ($P = V*I$) directly into heat. Unlike resistors, electronic loads are able to provide more sophisticated loading profiles such as constant current, constant voltage, and constant power, in addition to constant resistance. The load profile can be changed dynamically without disconnecting the UUT.

Figure 2: *DC Electronic Load*

Air-cooled electronic loads dissipate the waste heat into the air and can be used anywhere in a laboratory or manufacturing space as long as there is sufficient space or air-chiller capacity. Water-cooled electronic loads dissipate the waste heat through a water connection, which limits where these loads can be used. Testing may also get halted when the water-chiller system is under maintenance.

Regenerative Electronic Loads

Regenerative electronic loads convert discharge power (P = V*I) back into usable electricity for the facility, thereby increasing flexibility in two ways. First, the total power demand and associated electrical costs are reduced. Second, regeneration creates significantly less waste heat, which in turn reduces the energy and equipment required for facility cooling. This allows maximum flexibility when planning, upgrading, or rearranging laboratory or manufacturing workspaces.

Removing the Cost of Heat

Consider the power flow associated with a traditional load as shown in ***Figure 3***. Power is provided to the unit under test (UUT) from a facility connection. The output of the UUT is then loaded with a traditional load which converts this power into waste heat. Additional power is then required to operate a chiller to remove the waste heat from the workspace. Assuming the UUT has a conversion efficiency of 90% and provides a 100 kW output, the UUT would contribute 11.1 kW of waste heat due to conversion losses; and the load converts the 100 kW output directly into waste heat. A total of 111.1 kW turns into 379,123 BTUs of heat, which will require siginificant additional power to remove this heat from the workspace.

"Regeneration dramatically reduces waste heat resulting in operating cost savings and improved working conditions."

Figure 4 shows this same test scenario when using a regenerative load. In this scenario, the load returns the majority of the UUT output power back to the UUT or facility. The total amount of power required from the utility is then reduced as the UUT can use the power from both the utility connection and the power returned by the regenerative load. This directly reduces the total amount of power used by the facility to conduct the required testing, the amount of waste heat, and the power to remove the heat.

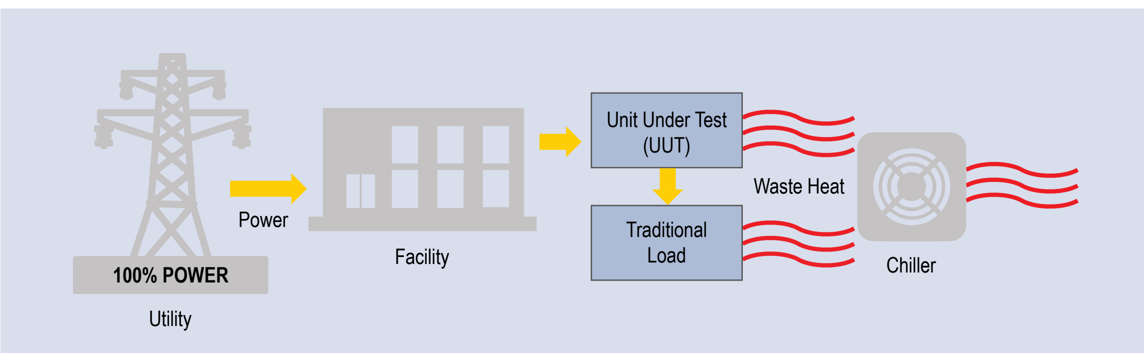

Figure 3: *Power flow using a traditional load*

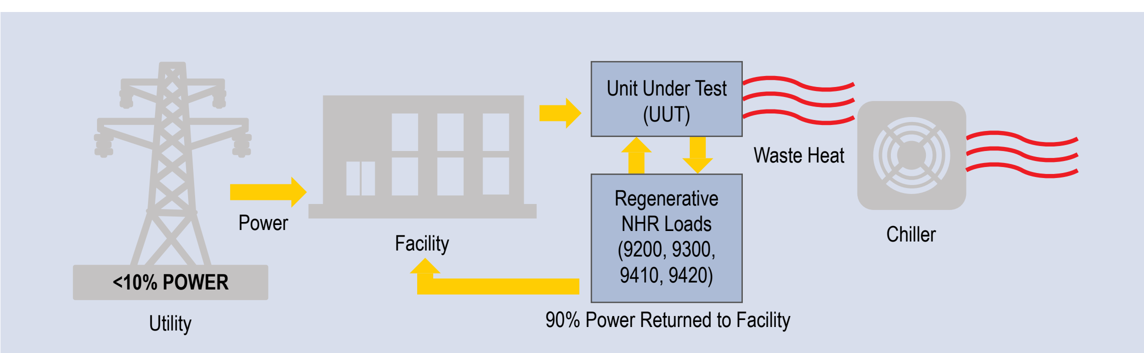

Figure 4: *Power flow using a regenerative load*

Replacing a traditional load with an 92% efficient regenerative load reduces both utility usage and generated heat by >82%. The UUT will still generate 11.11 kW of waste heat, due to conversion losses. However, the regenerative load returns 92 kW of UUT's output power to the facility and contributes only 8 W as waste heat. Total waste heat is reduced from 111.11 kW down to < 30 kW or from 379,123 BTUs down to 65,206 BTUs, requiring less chiller power to remove the waste heat from the workspace.

How Much Savings Can Be Achieved?

The UUT input power, formula 1, depends on its conversion efficiency.

$$\text{UUT Input Power} = \frac{\text{UUT Output Power}}{\text{UUT Conversion Efficiency}}$$

Formula 1: *UUT Input Power*

The UUT will draw power from the utility and any regenerative sources. Therefore the total utility power required noted in formula 2 will depend on the input power, amount of regenerated power, and power required to operate the chiller. Regeneration directly reduces the amount of input power required and will also reduce the amount of chiller power required.

> *"Regeneration reduces the UUT input power, utility power & chiller power required for testing."*

$$\text{Total Utility Power} = (\text{UUT Input Power} - \text{Regenerated Power}) + \text{Chiller Power}$$

Formula 2: *Total Utility Power*

The amount of chiller power required in formula 3 depends on how much power is converted to heat as well as the chillers type, size, and full/part loading energy efficiency ratios (EER). Industrial air-chillers at full load often reach an EER of 10 and similar water-chillers reach an EER of 20. Removing waste heat by an air-chiller requires approximately 34.12% more power, whereas a water-chiller requires approximately 17.06% more power.

$$\text{Chiller Power} = \frac{3412\,\frac{BTU}{kW}}{ERR} * (\text{UUT Input Power} - \text{Regenerated Power})$$

Formula 3: *Chiller Power Requirement*

This is a simplified example assuming a constant energy efficiency ratio for each chiller type. The actual energy efficiency can be affected by a number of factors including maintenance, seasonal weather patterns, and the amount of loading.

The table below compares the electrical utility costs associated with using an 85% efficient regenerative air-cooled load when compared to an air-cooled or water-cooled standard load. The example assumes a fixed electrical cost at $0.15/kWh. If the average electrical cost is known, the answer can be scaled to determine your operational costs.

LOAD TYPE	AIR COOLED REGENERATIVE	AIR COOLED TRADITIONAL	WATER COOLED TRADITIONAL
Power into Unit under test	111.1 kW	111.1 kW	
Power at the load	100 kW	100 kW	
Power regenerated by the load	92 kW	0 kW	
Total waste heat generated	19.1 kW	111.1 kW	
Waste Heat (BTUs)	65,206 BTUs	379,123 BTUs	
Chiller Power required	6.5 kW	37.9 kW	18.95 kW
Total Power Consumed	25.6 kW	149 kW	130.05 kW
Electricity cost 0.15/kWh – Per Hour	$ 3.84	$ 22.35	$ 19.51
Electricity cost 0.15/kWh – Per Day	$ 92.16	$ 536.40	$ 468.24
Electricity cost 0.15/kWh – Per Year	$ 33,638	$ 195,786	$ 170,908

Table 1: *Energy Costs Per Load Type*

COST SAVINGS FOR EACH 10KW OF LOADING	REGENERATION VS. AIR-COOLED LOAD	REGENERATION VS. WATER-COOLED
1 Year Savings	$ 162,148	$ 137,270
5 Year Savings	$ 810,740	$ 686,350

Table 2: *Energy Costs Savings per 100 kW*

Total Cost of Ownership

The total cost of ownership of traditional loads often includes far more than just the initial purchase of the load. Traditional loads imply more electrical usage and higher electrical usage may require electrical system upgrades to support additional test stations. Each new station will generate significant amount of waste heat, which may require facility modifications such as new air-handlers or water-chiller connection points. The chiller system may require upgrades to handle the increased waste heat, which may require permits from the local government. All these costs can be associated with simply trying to remove waste heat.

Regeneration returns the power to the facility or UUT instead of converting the power to waste heat. Traditional air-cooled and water-cooled loads also have hidden operational costs which include periodic maintenance cycles, annual inspection, and daily chiller record keeping. The cooling systems may be unavailable to perform annual maintenance to keep them running at peak efficiency, and testing may get halted during this shut down.

“Traditional loads have additional operational costs such as facility upgrades to manage higher electrical usage.”

NH Research's Regenerative Test Equipment

NH Research produces multiple Regenerative loads specifically designed for DC as well as AC loading. Each of these load models are modular allowing them to be expanded or used in parallel to meet future higher test-power needs. This modular loading design allows maximum flexibility in test by providing unmatched configuration options as well as future expandability.

NHR's regenerative loads include an advanced built-in digital measurement system. Voltage, current, power, and energy (Ah/kWh) measurements are immediately available. Additionally, all models include a waveform capture feature allowing a high-resolution capture of power related-events for detailed analysis.

Both AC and DC products are bi-directional allowing them to reverse power flow using the same internal electronics. For example, the NHR's battery test systems work as regenerative loads, charging systems, or can emulate batteries for the testing of battery related products. Similarly, NHR's 9430 Regenerative AC Load works as a true 4-quadrant AC load and can reverse power flow emulating a solar inverter or energy storage system. Finally, multi-layered independent safety features prevent damage to the UUT due to environmental and operator error. When the safety limit is crossed the test equipment shuts down and disconnects the UUT output as a failsafe.

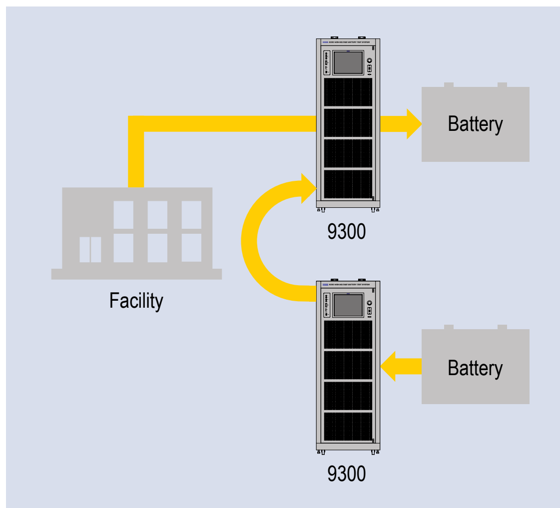

Figure 5: *9300 system requires less than 17 kW to charge & discharge two 100 kW batteries simultaneously.*

Energy savings through regeneration enables higher power testing unlike standard loads and power supplies. For example, consider a configuration consisting of two batteries, shown in ***Figure 5***, where one battery is discharged at 100 kW while charging the other battery at 100 kW. The total facility power required is less than 17 kW making up only the losses and significantly less than the power required to charge a single battery.

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