White Paper

High efficiency UPS systems for a power-hungry world

Active Power CleanSource® UPS

OBJECTIVE

This paper will discuss the vast differences in efficiencies of various three phase uninterruptible power supply (UPS) systems available in the marketplace and demonstrate, through laboratory studies and actual field measurements, that flywheel based UPS systems, such as those manufactured by Active Power, Inc., provide dramatically better efficiency across the board than conventional double-conversion UPS with batteries. This higher efficiency can result in tens to hundreds of thousands of dollars in annual cost savings for typical data centers.

INTRODUCTION

UPS systems provide power conditioning and backup power to mission critical facilities such as data centers, broadcast centers and hospitals. UPS systems protect these sites from voltage fluctuations such as surges and sags or frequency fluctuations, and also provide ride-through or temporary power to bridge the gap between a power outage and the restoration of utility power or the switch to a backup generator.

The UPS uses a form of short-term (seconds to minutes) energy storage to assist in power conditioning and power bridging in the event of a complete outage. The most common and practical DC energy storage forms are chemical batteries (i.e., lead acid, NiCd, NiMH, etc.), flywheels and ultra-capacitors. To perform its two functions, a UPS requires energy – in this case electricity.

The industry measures UPS efficiency as power out divided by power in, with the UPS consuming a portion of the input power. The amount of energy consumed by the UPS represents energy lost or inefficiency. UPS inefficiency can waste 10% or more of utility input within the UPS itself, and is a significant concern for data center operators, utilities, and policy makers. UPS inefficiency amounts to hundreds of thousands of kilowatt hours per year wasted in the process of protecting even a medium sized mission critical load.

More efficient UPS systems such as Active Power's CleanSource UPS can help reduce electrical waste and cost. Proven in the lab and field to reach at least 96% efficiency at loads as low as 40%, CleanSource UPS can reduce data center energy losses by multiple megawatts and hundreds of thousands of dollars annually compared to double-conversion UPS systems, while meeting or exceeding the power quality and system reliability of other topologies.

UPS EFFICIENCY DEFINED

The efficiency of a UPS, as defined by the International Electrotechnical Committee, is "the ratio of (active) output power to (active) input power under defined operating conditions," where defined operating conditions refer to a specific percent load and load type (linear/resistive versus non-linear).[1] Active power is measured in watts or kilowatts.

IMPORTANCE OF UPS EFFICIENCY

Measuring the total power draw of data centers is a complex undertaking. Rapid advances in the power efficiency of server operations alongside M+E infrastructure operational efficiency and dynamic changes in the nature of IT loads make the calculation of cumulative energy use extremely difficult. Plus, the market itself is changing with many different types of data center emerging.

The latest data center category is the emergence of Edge data centers. However even traditional data centers are changing. They range from owned and operated enterprise data centers, the rapidly growing commercial colocation sector and the cloud scale facilities that are coming online or planned.

In the US in 2016 the Federal Energy Management Program of the U.S. Department of Energy under the Lawrence Berkeley National Laboratory Contract published a study titled: "United States Data Center Energy Usage Report"

https://eta-publications.lbl.gov/sites/default/files/lbnl-1005775_v2.pdf

It measured IT power demand from servers, storage, networking equipment and infrastructure.

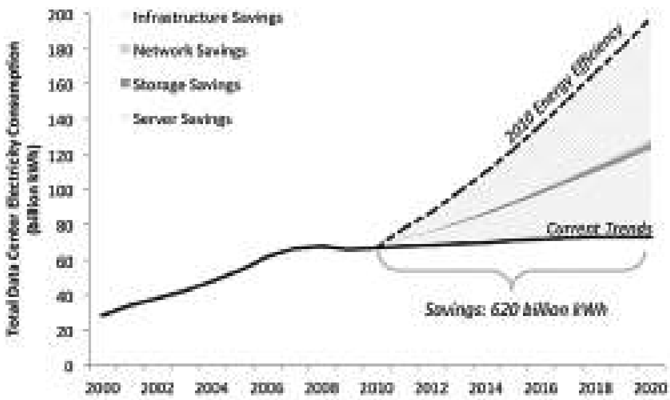

Figure 1. Data Center Electricity Consumption in Current Trends and 2010 Energy Efficiency Scenarios.

The 2010 Energy Efficiency scenario assumes that data center energy-related design and operational efforts do not continue past 2010, which indicates that current trend energy efficiency practices will have saved 620 billion kWh of electricity over the period 2010-2020.

Looking forward from its 2016 perspective the report said: "The significant energy efficiency improvements in the design and operation of data centers over the past decade have allowed U.S. data center energy use to remain nearly constant while simultaneously meeting a drastic increase in demand for data center services. However, the data available at the time of this study limited the scope of future projection to 2020. The key efficiency strategies identified in this report, improved PUE, increased server utilization rates, and better power proportionality all have theoretical and practical limits and the current rate of improvement indicates that these limits may be reached in the not too distant future.

This report highlights the success of the data center industry to stabilize electricity demand, but further investigation and technological breakthroughs in energy efficiency across the ICT equipment spectrum will be needed to insure that success is not simply a plateau before an increase in electricity demand resumes at a rate proportional to future growth of data center services.

What is clear is that energy saving at every point of the power chain, and especially at the UPS, is becoming more important.

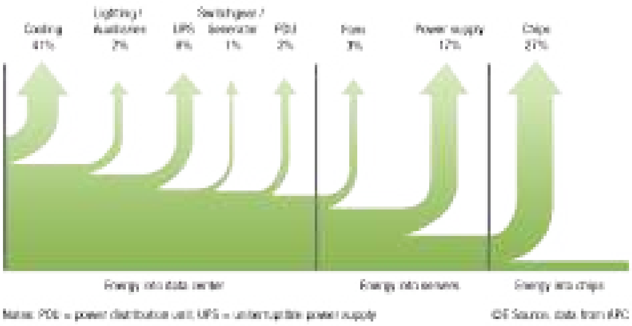

Figure 2. Sources of Data Center Power Use

At the individual data center level, improving UPS system efficiency offers direct, 24-hour-aday, energy savings, both within the UPS itself and indirectly through lower heat loads and even reduced building transformer losses. When a full data center equipment load is served through a UPS system, even a small improvement in system efficiency can yield large annual cost savings. Pacific Gas & Electric (PG&E) estimates a 15,000 square foot data center with IT equipment operating at 50 W per square foot requires 6.9 MWh of energy annually for the IT equipment. If the UPS system supplying that power has its efficiency improved by just 5 percentage points, the annual energy bill will be reduced by 384,000 kWh, or about $38,000 at $0.10 / kWh, plus significant additional savings from the reduced cooling load.[5]

COOLING REQUIREMENTS AS A FUNCTION OF EFFICIENCY

When evaluating a UPS and its efficiency, it is important to keep in mind the first law of thermodynamics that "energy can neither be created nor destroyed." With respect to UPS systems, the difference in active input and output power represents heat loss as a result of the activity the UPS performs. Heat interferes with the environmental conditions in a defined space such as an electrical room and will ultimately drive the temperature up and potentially cause short- or long-term damage to equipment as it exceeds designed temperature thresholds.[6] A sound design of an electrical room includes an air-conditioning or precision cooling system to maintain a certain temperature band. The lower the efficiency of the UPS, the more heat is generated and the more cooling is required in the room, driving up capital costs and the ongoing operational expenses of the cooling system. As a general rule of thumb for an efficient centralized cooling plant, it takes 0.33 kW of power to cool 1 kW of heat. As a result, the operational cost of a low efficiency UPS is further exacerbated by the additional cooling cost.

FACTORS IMPACTING UPS EFFICIENCY

There are two key factors influencing UPS system efficiency: the topology of the UPS system itself, and the design of the data center's power supply and distribution, which determines the load factor of the UPS.

UPS TOPOLOGY

The design of the UPS system itself has a significant impact on efficiency. Put simply, some UPS designs are inherently more efficient than others. There are two major topologies in use today in mission critical facilities – parallel online (also known as line interactive) and double-conversion.

Parallel online. Parallel online UPS systems place the inverter and charger circuitry or transformers in parallel with the AC utility signal. This design allows a parallel online UPS to compensate for over- or under-voltages in the incoming utility power and, with the right electronics, to eliminate transients, voltage fluctuations or other disturbances. When utility power is unavailable or reaches unacceptable limits, a parallel online UPS enters stored energy mode. The UPS disconnects the load from utility power and reroutes this load with a static switch to backup power, provided by a battery or flywheel through the inverter.

Power Conditioning. To properly understand the differences between double-conversion and parallel online topology, we first have to understand what UPS systems are protecting against.

The Institute of Electrical and Electronics Engineers (IEEE) Standard 1159-1995 defines seven categories of power quality disturbances, such as transients, sags, swells and frequency variations. Depending on the quality of the power being delivered to the facility by the utility, one or more of these disturbances may occur frequently. At a minimum, the power conditioning function of the UPS ensures output power transmitted to the IT load is well within the tolerance of the IT power supplies.[7] It does this by correcting utility power quality disturbances and delivering conditioned power to the critical load.

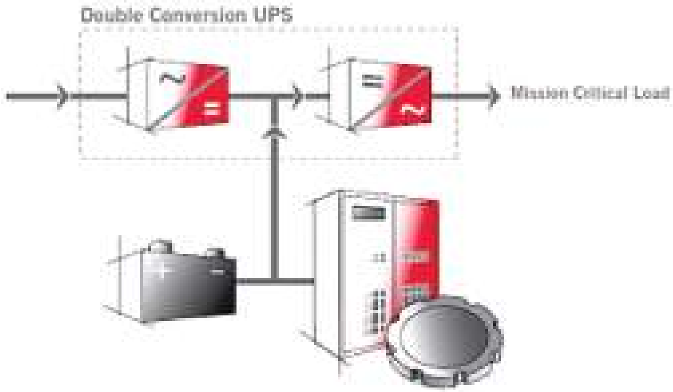

Figure 4. Double-Conversion UPS Architecture

With a double conversion UPS, all power is rectified from AC to DC and inverted from DC to AC, ensuring a perfect sine wave and frequency protection on the output and protecting against all seven types of disturbances. This approach both exceeds the requirements of modern IT equipment power supplies – which do not always require a perfectly conditioned load – and uses a significant amount of energy.

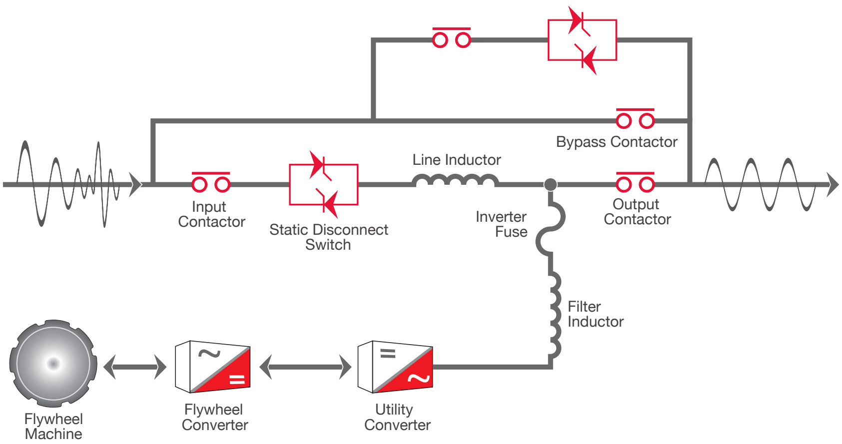

Figure 3. Parallel Online Architecture

The parallel online UPS offered by Active Power address most disturbance types in an almost identical fashion to a double-conversion UPS. Active Power's CleanSource UPS uses a fast acting microprocessor and fast voltage transient discharge window which samples the incoming 16.67 msec sine wave every 40 microseconds and mitigates any transients with output filter capacitors. Reviewing the simplified one-line diagram for the parallel online flywheel UPS, it is apparent the flywheel output electrical path is almost identical to the double conversion UPS. (Compare Figures 2 and 3, above.)

The most common objection to the parallel online UPS design is frequency regulation because it is mains-synchronized: whatever the frequency on the input is what the frequency on the output will be. Active Power addresses this using the same microprocessor, set to allow as little as +/- 0.2% frequency fluctuation to pass through by using the flywheel to compensate during these events.

Ultimately, the parallel online topology is a simpler design with fewer components that is inherently more efficient while providing the same protection to the mission critical load on the output. Double conversion UPS systems condition more than required by today's IT equipment at the expense of efficiency. As shown below, flywheel based parallel online UPS systems have been proven in laboratory tests and field studies to have materially higher energy efficiencies than double conversion systems across all load factors.

In addition to the higher efficiency of the UPS topology, flywheel systems use less energy maintaining temperature and other atmospheric conditions than conventional double conversion UPS with batteries. The CleanSource UPS available from Active Power supports a wide temperature operating range (0 – 40° Celsius), so it does not need to be housed in a temperature controlled battery room. And it takes up less than half the space of an equivalent rated set of batteries. Combined, this results in a significant reduction in cooling energy requirements compared to battery UPS systems.

Eco-mode. In recent years, UPS vendors have developed an alternative operating model, known as "eco-mode" or "soft mode," for their double conversion systems as a way to improve efficiency. In eco-mode, a standard double-conversion UPS keeps only the inverter module on, while the active input power is routed through its bypass circuit, not the main electrical path originally intended for full power conditioning and backup. Only in the event of an outage, momentary or extended, will the UPS switch the input power from bypass to the rectifier and inverter. Vendors promoting this mode claim their efficiency at 98 to 99% across a wide range of loads.

Logically, a UPS running in this "eco-mode" would reduce its losses quite significantly given that it is performing less work. But it achieves high efficiency only by almost completely abandoning its power conditioning function. A UPS operating in eco-mode protects against only a full interruption of utility input. The other six IEEE defined power disturbances are not corrected because no power conditioning is taking place. Through active sensing of the bypass path, the UPS will sample the active input power, but will generally feed most of the power straight through, provided there are no interruptions. In the event of an interruption to the UPS input, it will, through fast switching, switch from the bypass path to supplying power directly from its DC energy storage (usually chemical batteries) through the inverter. But no other disturbances are addressed or remedied, so the quality of the active output power is dramatically reduced, leaving the mission critical load exposed and potentially causing long-term damage of the protected load.

An often overlooked aspect of the viability of eco-mode is its reliability in a demand situation, where demand is defined as an interruption of the incoming utility.

Presumably, the UPS would switch from bypass mode to DC energy storage, providing power in a narrow band of time. However, it is commonly understood that an electrical switching device represents the single most likely cause of a failure in a UPS. Risk-assessment consulting firm MTechnology, Inc., concluded through the use of probabilistic risk assessment (PRA) that an automatic transfer switch, for instance, participates in about 95% of expected system failures as it represents a single point of failure.[8] That is the equivalent mean-time-between-failure (MTBF) of 100,000 hours for a complex electromechanical component. This switch within an eco-mode UPS represents an equivalent single point of failure; applying MTechnology's analysis raises significant reliability questions of the eco-mode UPS approach.

In sum, while a standard double conversion UPS wastes too much energy to condition power compared to parallel online systems like Active Power's, a UPS in eco-mode achieves efficiency equivalent to Active Power's only by sacrificing too much functionality. The increased probability of failure and the absence of power conditioning make a double-conversion UPS working in "eco-mode" inferior to parallel online UPS topology like Active Power's CleanSource UPS.

UPS LOAD FACTOR

UPS systems in mission critical environments typically operate between 30% and 80% of rated capacity depending on the level of redundancy designed into the electrical system.

In facilities with the highest required redundancy, UPS systems are deployed in 2N configurations: the load of the facility is shared between two UPS systems so that if one fails, the other will still supply the data center's critical load. In this configuration, the entire mission critical load cannot be more than half of the UPS capacity installed. Under normal operating conditions the UPS equipment never operates at more than 50% load.

Typically, these designs end up operating at 30% to 40% of UPS capacity because common practice dictates that UPS systems should not be run at 100% capacity even in abnormal operating conditions, and data centers are usually designed with excess capacity to permit growth over time.

In an N+1 configuration, one or more UPS systems work as a spare, providing redundancy to support the full load should any one of the UPS systems fail. In an N+1 system having three UPS modules, the design load cannot exceed 66% of the installed UPS capacity, and under current design standard will usually not exceed 90% of that level, or 60% of installed capacity, when the data center is fully populated. If the data center is not fully populated, loads can range from 40-60%.

UPS efficiency varies with the amount of active power being supplied to a load and tends to decrease at partial load. The efficiency drops significantly at lower loads because the UPS generally has a base consumption or fixed "overhead" of power use, similar to a car at idle. The base consumption is driven by its control circuits, air circulation and charging currents, which remain virtually constant regardless of loading. Power used in the conditioning of active output power is almost directly proportional to the load protected, so as the load increases the base consumption has less and less of an impact on energy efficiency.

Energy efficiency at various loads for Active Power's CleanSource UPS system and a typical double-conversion UPS system with batteries are summarized in Figure 5, below.

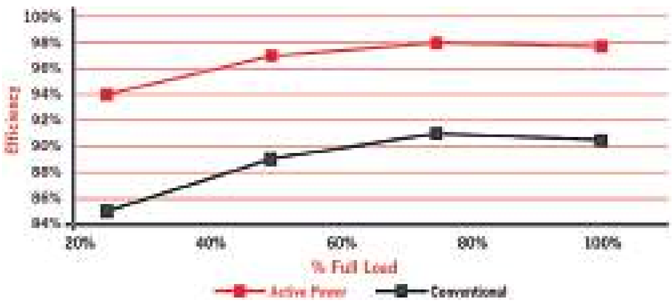

Figure 5. UPS Efficiency Compared

VENDOR CLAIMS – FACT VERSUS FICTION

Many UPS vendors publish an energy efficiency as part of their product documentation. Most vendors publish a single "up to" efficiency rating for their system in ideal conditions, generally 75 to 100% of rated active output.[9] With users and operators being very energy conscious in the buying process, some UPS vendors post far too optimistic efficiencies of their UPS systems to attract buyers. This is not to say the claims are untruthful, but rather they are practically impossible to replicate in a properly designed mission critical infrastructure at the end user site. There is a need to be cautious and critical of the data provided since it can change dramatically as options (such as filters and transformers in the case of double-conversion UPS with batteries) are added.

Even when vendors provide efficiency ratings across a range of loads, those ratings often prove to be impossible to replicate when tested in controlled situations or measured in the field as described below. By contrast, the flywheel UPS from Active Power has proven 98% efficiency at 100% loads, and 96% efficiency in 2N redundant / 40% loads, as shown below.

EMPIRICAL RESULTS: LABORATORY TESTS

A study by Lawrence Berkeley National Laboratory (LBNL) examined the energy efficiency of the different UPS topologies across various load conditions.[10]

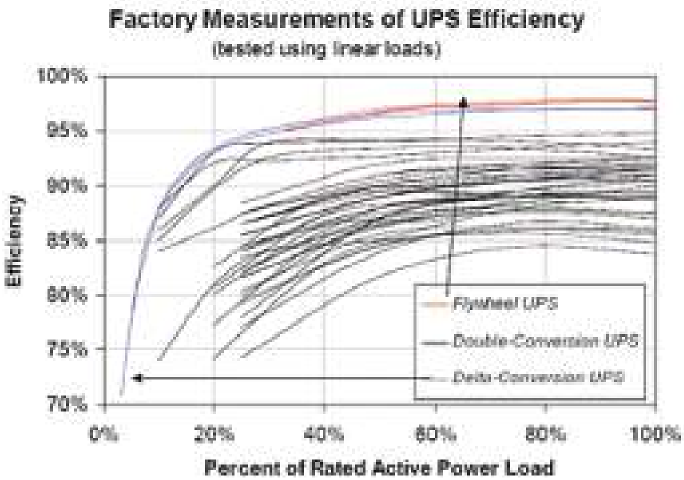

Figure 6. Factory Measurements of UPS Efficiency Source: LBNL

Flywheel UPS systems like Active Power demonstrated efficiencies of 95% at 33% loads, rising to 98% at loads above 70%. By contrast, double-conversion UPS systems showed a wide range of much lower efficiencies, with most exhibiting 80 to 90% efficiency at 33% load and 85 to 94% efficiency at 50% load. The most efficient double-conversion UPS approached 95% only as loads exceeded 75% with most still clustered at 85 to 92% efficiency.[11]

These results led both LBNL and PG&E to strongly endorse flywheel UPS technology to improve data center energy efficiency.[12]

EMPIRICAL RESULTS: FIELD EVALUATION

The energy efficiency of the flywheel UPS topology has been shown to match lab results in real data center deployments, which is more than can be said for double-conversion systems.

The Silicon Valley Leadership Group (SLVG) compared actual UPS electrical losses in four large scale production data centers with comparable load factors, two with double-conversion UPS systems, one with flywheel UPS systems and one with mechanically coupled rotary UPS systems.[13]

The double-conversion battery systems deployed at the Yahoo! sites performed well below their lab ideals. The Space Park facility showed 91% UPS efficiency at 58% load versus its 94% vendor claim. At the Wenatchee, WA data center, the double conversion UPS was just 77% efficient (again versus claimed 94%) when the load dropped to 44%. Over 29% of input energy was lost at the UPS at this site.

By contrast, the Active Power system deployed by NetApp performed to lab testing expectations – over 96% efficiency at just 45.5% load.

The SLVG study then calculated the electricity costs of the two battery-based systems versus the savings that could have been achieved had they used a more efficient flywheel system.

Moving to a 97% efficient flywheel system in both double-conversion static UPS sites would have reduced Yahoo!'s energy costs by more than $822,426 annually – a reduction of UPS energy costs of more than 80%.

ACTIVE POWER
DRIVEN BY MOTION

SITE	VENDOR/DESIGN	OUTPUT	UPS LOAD	UPS EFFICIENCY
Yahoo Space Park	12 Liebert 750 kVA static UPS	4.6 MW	58.6%	91.1%
Yahoo Wenatchee	8 Liebert 750 kVA static UPS	2.4 MW	44.4%	77.1%
Yahoo! Quincy	5 Hitec 1625 kVA rotary UPS	3.4 MW	43.6%	91.1%
NetApp Building 11	2 Active Power 900 kVA flywheel UPS	570 kW	45.5%	96.1%

Table 1: Data Center Case Study Comparative Efficiency. Source: SLV G

SITE	COST/KWH	ANNUAL UPS POWER LOSS	ANNUAL ELECTRICITY COST	ANNUAL POWER LOSS WITH FLYWHEEL (97% EFFICIENCY)	ANNUAL ELECTRICITY COST	ANNUAL SAVINGS (%)
Yahoo Space Park	0.10	3.9MW	$391,172	1.2MW	$123,836	$267,336 (68%)
Yahoo Wenatchee	0.10	6.2MW	$619,609	0.6MW	$64,519	$555,090 (90%)
Total			$1,010,781		$188,355	$822,428 (81%)

Table 2: Case Study Projected Efficiency Savings from Active Power UPS Source: SLV G

CONCLUSION

Data center energy consumption is a significant and growing concern for operators, utilities and policy makers. Inefficient UPS systems can contribute to this concern with 10% or more of utility input going to electrical waste within the UPS itself. Flywheel-based parallel online UPS systems such as Active Power's CleanSource UPS can be part of the solution.

Proven in the lab and field to reach at least 96% efficiency at loads as low as 40%, CleanSource® UPS can reduce data center energy losses by multiple megawatts and hundreds of thousands of dollars annually compared to double-conversion UPS systems, while meeting or exceeding the power quality and system reliability of other topologies.

1 IEC 62040-3, Testing Procedures for UPS Systems. International Electrotechnical Committee. April, 30, 2004, at 52.
2 U.S. EPA, Report to Congress on Server and Data Center Energy Efficiency, Public Law 109-431, Aug. 2, 2007, at 7.
3 Id. at 53, Table 3-5.
4 M. Ton, B. Fortenberry, and W. Tschudi, Lawrence Berkeley National Laboratories, DC Power for Improved Data Center Efficiency, March
5 PG&E, High Performance Data Centers, Jan. 2006, at 55. http://hightech.lbl.gov/documents/data_centers/06_datacenters-pge.pdf
6 The industry rule of thumb is that every 10°C increase in temperature doubles the component failure rate of IT equipment.
7 These tolerances are defined in the Information Technology Industry Council (ITIC) power acceptability curve.
8 See Active Power White Paper #103, Reliability Assessment of Integrated Flywheel UPS versus Double-Conversion UPS with Batteries.
9 See, e.g., Liebert's NX and Series 610 products highlights at http://www.liebert.com/product_pages/SecondaryCategory.aspx?id=4&hz=60;
11 See also id. at 21, Table 4. Note double conversion UPS systems were tested in standard operating mode only; eco-mode claims were not evaluated.
12 Id. at 21; PG&E, High Performance Data Centers, Jan. 2006, at 53.
13 R. Pfefer, Silicon Valley Leadership Group, Data Center Benchmarking.

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