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The multiple role of energy storage in the industrial sector: Evidence from a Greek industrial facility

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Abstract

According to Directive 2012/27/EU concerning energy efficiency, emphasis should be given on the promotion of best energy practices in the industrial sector. Acknowledging this, the objective of the current study is to demonstrate the multiple role of industrial energy storage. More precisely, load management and arbitrage strategies are investigated through the development of a simulation algorithm. Considering also the characteristics of the Greek electricity market, results obtained from the application of the proposed algorithm to a Greek industrial facility designate the need for revising current electricity price rates and/or developing novel financial tools for the support of industrial energy storage.

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Keywords: industrial sector; load management; arbitrage; battery storage; spot electricity price

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1. Introduction

According to Directive 2012/27/EU concerning energy efficiency, emphasis should be given -among others- on the promotion of best energy practices in the industrial sector, responsible for almost 37% of the EU total electricity consumption and the appearance of daytime peak loads stretching the capacity of electrical grids [1]. At the same time, significant progress has been made over the past years in the field of energy storage [2-5]. Both mature and emerging technologies are found to support numerous applications (Figure 1), including integration of renewable energy sources (RES), transmission deferral, practice of arbitrage trading strategies, etc. At the same time, the dramatic drop of decentralized PV power generation costs further encourages employment of energy storage systems during the last years. On the other hand however, owed to the absence of a concrete support framework [6] and the fact that energy storage systems are a priori capital intensive solutions, market diffusion is not yet the one anticipated.

Acknowledging the above, the main objective of the current study concerns the examination of load management [7] and arbitrage [8] strategies practiced by battery storage in industrial facilities, considering that massive adoption of energy storage in the industrial sector may favor both industrial actors (through e.g. improved energy management and supply security) and the system grid (through e.g. peak shaving). Besides, adoption of such schemes paves also the way for large-scale RES penetration [9] within the existing infrastructure, by avoiding or deferring costly upgrade or extension of electricity grids.

To this end, by developing an appropriate load management and arbitrage simulation algorithm, the proposed strategies are accordingly tested, using as case study the industrial facilities of a Greek manufacturing company and the characteristics of the Greek electricity market. According to the results, despite the fact that the implementation of the proposed strategies leads to considerable reduction of the company's operational costs, the deriving gains cannot support similar investments. With this in mind, both revision of retail electricity price rates and development of novel financial support tools [6] are thought to be necessary in order to obtain potential benefits at the national grid level, coming from the massive adoption of energy storage solutions in the industrial sector.

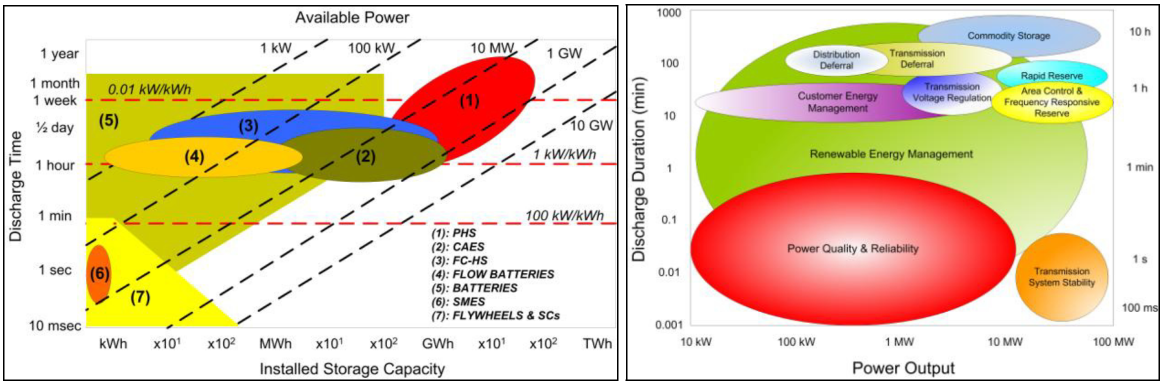

Fig. 1. (a) Mapping of contemporary energy storage technologies and; (b) application fields.

2. Methodology – proposed storage strategies

In order to introduce energy storage in the industrial sector, application of load shifting / peak shaving and arbitrage strategies is currently considered. More precisely, in case that retail price rates of electricity for industrial actors do not offer a stimulating price spread (between low and high load demand periods), interaction of the storage system with the local wholesale electricity market is suggested. In this way the system may –under a certain risk– appreciate lower price rates for purchasing energy during low demand periods. These amounts of energy used to charge the system can then be recovered to either practice load shifting and peak shaving (so as to avoid power costs owed to extreme peaks) or deliver (sell) energy back to the grid in order to take advantage of the increased spot electricity prices encountered during peak demand hours.

To this end, both load management (i.e. load shifting and peak shaving) and combined load management-arbitrage strategies are investigated. In doing so, the storage system is operated on a daily cycling basis while using price signals within certain time limits concerning buying and selling energy decisions, assuming also perfect prediction (or ex-post approach) of the next hour spot electricity price. During the analysis, variation of main parameters including the peak limit (i.e. the maximum peak load demand set under the implementation of the proposed strategy), the price signal concerning selling energy decisions and the battery storage capacity, is also investigated, while keeping the buying energy price signal fixed. Finally, for each of the examined combinations, power and energy cost savings achieved are recorded and a comparison between different configurations is provided.

3. Case study characteristics

3.1. Description of the Greek electricity market

The electricity generation system of Greece is divided in two main sectors, i.e. the mainland and the island sub-systems. As far as the mainland electricity grid (interconnected system) is concerned, centralized power generation is mainly based on indigenous lignite reserves [10]. In this regard, national dependence on fossil fuels is confirmed by the employment of approximately 6.1GW of steam turbines using indigenous lignite reserves, 2.3GW of combined cycle power plants using imported natural gas, and a total of 1.3GW of oil and gas based generation (gas turbines and internal combustion engines) mainly used for the service of non-interconnected Aegean island grids. Additionally, the mainland electricity grid is also supported by the operation of large hydropower plants that exceed 3GW and are used as peak shaving units, on top of which there are also two PHS plants of almost 700MW. Besides that, contribution of RES mostly derives from wind energy applications (~1.8GW) and PV installations (~2.5GW), while a small proportion corresponds to small-hydro, biogas and industrial waste installations.

At the same time, the Greek electricity market, although being deregulated since 2002, is largely monopolistic at both the wholesale and the retail level, with the greatest power generator-retailer holding approximately 90% of the local market share. In this regard, the spot price series for a period of four years (2009-2012) is given in Figure 2a, with the respective cumulative probability curve for the year 2012 alone provided in Figure 2b. Furthermore, price rates for industrial consumers provided by the greater market retailer (i.e. the former Public Power Corporation, PPC) are given in Table 1 [11]. According to the information provided, the flat retail price-spread between daytime and night-hours does not seem to encourage installation of energy storage to practice peak shaving with the use of energy stores drawn during night-time (Table 1). On the other hand, lower off-peak prices may even drop to the level of 30€/MWh in the spot market, while peak prices exceed 100€/MWh for about 2% of the time (Figure 2).

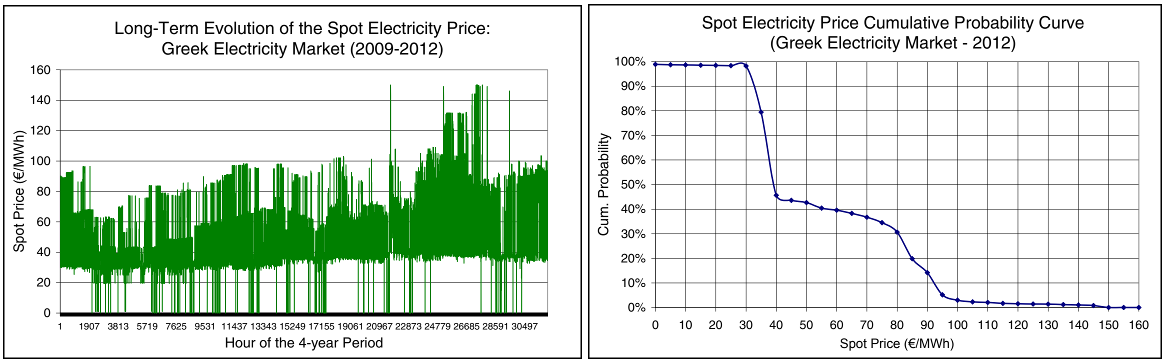

Fig. 2. (a) Long-term electricity spot price variation and; (b) cumulative probability curve for year 2012.

Considering this, the storage system is as already mentioned set to interact with the local wholesale market in order to draw energy amounts during off-peak hours that will then be used to either practice load management or arbitrage (delivery of energy back to the local grid during peak hours). However, the price for power is even more interesting, with storage systems potentially levelling out power consumption and reducing power costs significantly.

Table 1. Electricity price rates of PPC for the industrial sector (2012).

Time period	Power cost (*€/kW/month*)	Energy cost (*€/kWh*)
7:00 – 23:00 week-days	7.25	0.06388
23:00 – 7:00 week-days and the entire weekends	-	0.05015

3.2. Description of the industrial facility

The industrial facility currently used as case study belongs to the manufacturing company of Sunlight S.A. It ranks among the world's top manufacturers of energy products and systems, being specialized in the design, production and distribution of energy storage systems for industrial, consumer and advanced applications, energy power systems, green energy systems and energy-related services. The company's manufacturing plant is located in the area of Xanthi, Northern Greece, with its detailed mean hourly energy consumption for the year 2012 given in Figure 3a. At the same time, the cumulative probability density curve is also provided in Figure 3b, while further processing of load demand data follows in Figures 4a and 4b, where the average 24h load demand pattern and the respective six-4h period cumulative probability curves are depicted.

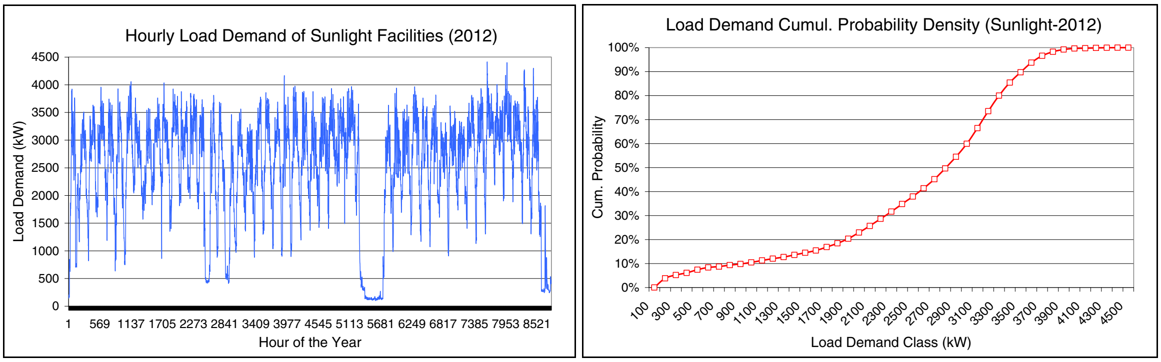

Fig. 3. (a) Hourly and; (b) cumulative probability density of load demand for Sunlight (2012).

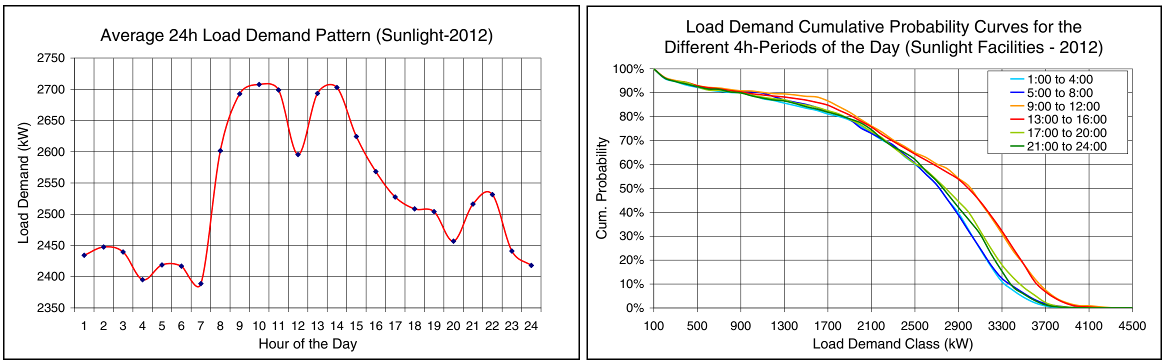

Fig. 4. (a) 24h average and; (b) six-4h cumulative probability curves of load demand for Sunlight (2012).

According to the load demand information, the annual peak demand marginally exceeds 4.4MW, with the respective year-round electricity consumption reaching approximately 22.2GWh and reducing remarkably during August owed to summer closure. Furthermore, peak load demand is normally encountered during morning and mid-day hours (i.e. between 9:00 and 15:00), while the probability for load demand to be higher than 3.9MW drops below 1% (Figures 3b and 4b).

4. Application results

Application results of the proposed strategies are accordingly presented, considering also that time periods selected within the day for the storage system to be charged and discharged are set to coincide with the respective low and high price periods of industrial rates (see also Tables 1 and 2, i.e. 23:00 to 7:00 for system charging and 7:00-23:00 for system discharging). Furthermore, a relatively high round-trip efficiency of 85% has been selected for the battery storage system to be used, while energy storage capacity examined refers to the useful / exploitable one, i.e. for the actual size of the battery storage to be given the maximum permitted depth of discharge should also be taken into account.

Table 2. Problem input parameters.

Input parameter	Assigned values
System daily charging period	23:00 – 7:00
System daily discharging period (peak shaving or arbitrage)	7:00 – 23:00
Useful storage capacity range of variation	500kWh – 2000kWh
Peak-limit range of variation	3200kW – 3900kW
Selling energy price signal range of variation	60€/MWh – 90€/MWh

Considering the above, Figure 5 presents application results for the first week of the year and the load management strategy, where energy stores are used exclusively to perform load shifting and peak shaving.

In the specific example, a maximum peak demand of 3.5MW is selected together with useful storage capacity of 3MWh (not examined in the parametrical analysis following), considering also that the buying energy price signal is set at 50€/MWh (i.e. the system is allowed to buy energy when electricity spot price is less or equal to 50€/MWh).

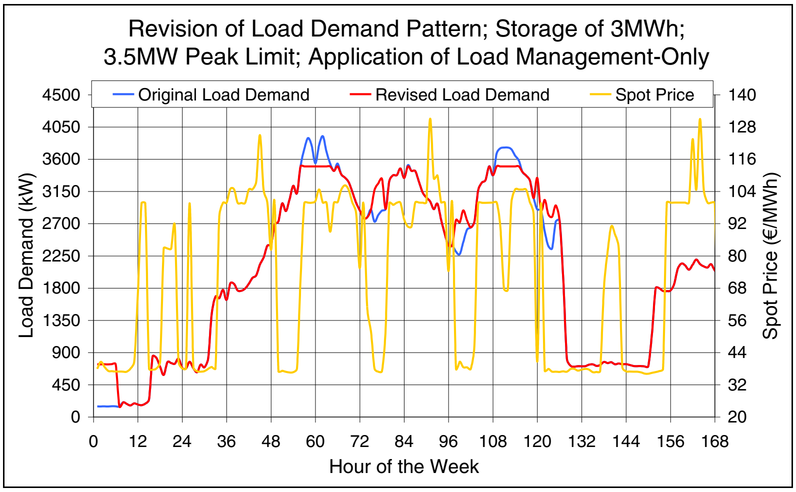

Fig. 5. Load demand pattern revision for the load shifting and peak shaving strategy.

As one may see, the revised load demand is modified so as to allow energy purchase during night hours (provided that the condition of the maximum buying price is fulfilled) in order to charge the battery system on the one hand, and peak shaving (above the 3.5MW limit) during daytime on the other.

Contrariwise, application of the combined load management and arbitrage strategy gives priority to arbitrage if during the discharging period the appearing spot price is equal to or found to exceed the minimum price limit set. This is better illustrated in Figure 6, where as one may see, load management is only partly performed for this first week of the year since the spot price during the charging period may exceed the currently set limit of 100€/MWh and thus activate the prioritized arbitrage strategy.

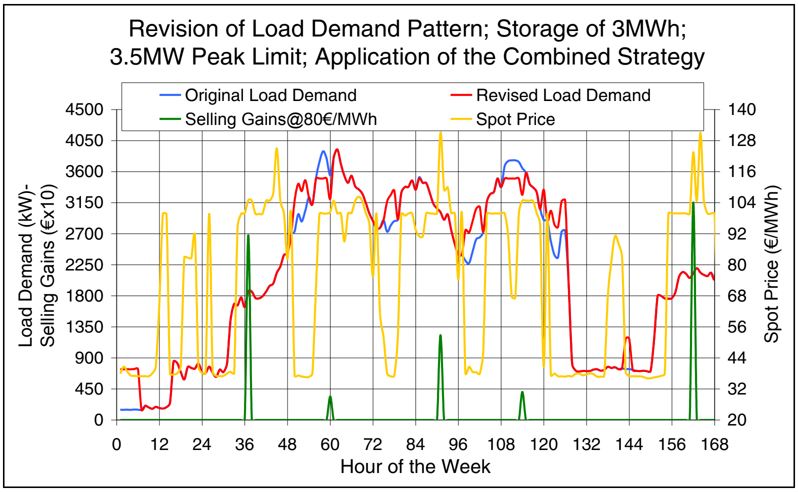

Fig. 6. Load demand pattern revision for the combined strategy.

Next, in Figure 7, power cost savings achieved by the implementation of the load management strategy are presented in relation to the variation of the useful energy storage capacity and the peak limit. Note that the specific savings concern operation cost reduction due to peak shaving and do not take into account the cost of input energy in order to charge the battery storage installation.

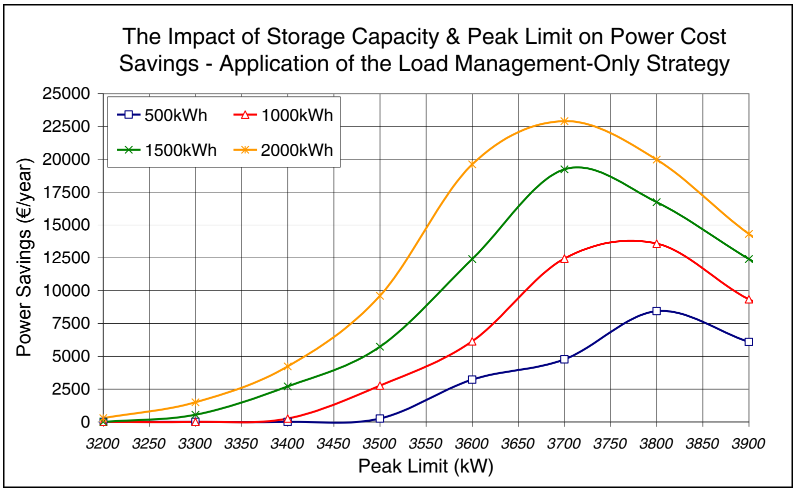

Fig. 7. Power cost savings in relation to peak limit and storage capacity variation.

In this context, increase of battery storage is as expected suggesting increase of power cost savings, reaching even 22500€/year for a 2MWh useful energy storage capacity, while at the same time encouraging for a decrease of the maximum peak limit set (since the maximum noted in each of the curves gradually shifts to lower peak limits as the useful energy storage capacity increases).

On top of power savings, in Figure 8 the respective energy gains are presented, taking into account both input energy expenses and sold energy revenues through arbitrage. The respective results are given in relation to the peak limit and the selling energy price signal variation, while for comparison purposes, the load management-only strategy is also included. According to the results, energy costs present an increase for the load management-only strategy (since energy is only purchased and not sold in that case) that tends to reduce as the peak limit increases.

On the other hand, it seems that although energy gains increase up to the price signal of 70€/MWh, they then reduce considerably, especially in the case of 90€/MWh where the high price signal set does not imply high frequency of selling energy actions. Finally, total annual gains being the sum of power cost savings and energy gains are provided in Figure 9.

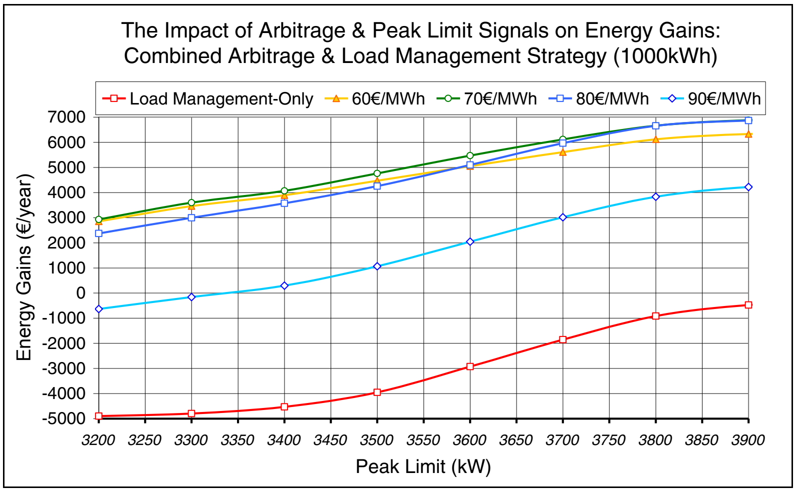

Fig. 8. Energy cost gains in relation to peak limit and selling energy price signal.

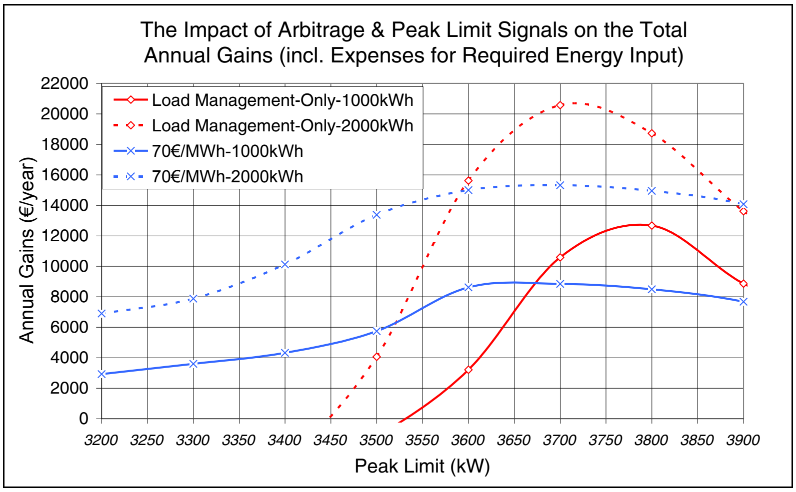

Fig. 9. Total gains in relation to peak limit, storage capacity and strategy selection variation.

Results are presented in relation to the peak limit, the storage capacity and the selected strategy variation. To this end, as one may see, the load management-only strategy provides higher gains that also come with reduced risk, provided however that the optimum peak shaving limit is determined. On the other hand, the combined load management and arbitrage strategy ensures lower gains in comparison to the respective load management-only maximum, presenting however little variation across the entire peak limit area examined.

5. Conclusions

Based on the development of a simulation algorithm, load management-only and combined load management and arbitrage energy storage strategies were currently investigated. The industrial facility of a Greek company was used as case study, aiming to demonstrate the potential benefits that could derive from the massive application of energy storage in the industrial sector. According to the results, industrial price rates of electricity along with the status of the Greek wholesale electricity market don't seem to encourage investments in energy storage at the moment (taking into account that mature battery storage energy and power costs are in the order of 200€/kWh and 500€/kW respectively).

On the other hand, the potential for energy management and the achievement of considerable gains at the industrial facility level is well reflected by the results of the specific study. Thus, it is believed that with the development and implementation of appropriate policy mechanisms and financial support measures, benefits deriving from the adoption of energy storage solutions in the industrial sector could be harvested at the national grid level. Besides that, investigation of more advanced energy storage strategies at the industry level could also encompass facilitation of on-site RES power generation, further advancing efforts towards optimum energy management in the specific sector.

Additionally, it is also worth analyzing different industrial consumers in detail, because the load patterns are very different. There are other consumers with significant higher differences between day and night time or even higher peak values. Therefore, this work can be advanced through the analysis of more load profiles that will result in a classification of different load patterns. The same is valid for the investigation of different battery storage systems, which could lead to the development of an integrated algorithm that can also incorporate the appropriate life-time and efficiency variation prediction models, based on the different type of battery storage and strategy each time examined, providing in this way the necessary tools in order to obtain an even more profound performance evaluation.

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