OPERATIONAL ASPECTS OF SUPERCONDUCTIVE MAGNETIC ENERGY STORAGE (SMES)

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Abstract

The use of superconducting magnetic energy storage (SMES)[1] is assessed from an operational point of view. The useable storage size for an SMES unit is determined for real utility load demand curves of previous years. The SMES size to be added in the future then becomes an extrapolated size from the size that would have been suitable in past years. Some general conclusions are: SMES should be used for large scale load-leveling rather than small scale peaking; the most likely duty cycle is 8 hours charging at night and 15 hours discharging during day time; the high efficiency (98%) of storage leads to lifetime 15% fuel cost benefits vs. intermediate cycling generation and 30% fuel cost benefits vs. all other storage; and SMES is a new source of ± spinning reserve with rapid 50 msec complete power reversal.

Introduction

An SMES solenoid of superconductive turns stores energy without ohmic losses in the coil and loses only 2% energy in the round trip through the ac/dc conversion system.[2] The objective of this paper is to describe a method to determine the useful size of SMES in a given actual utility system. An economic analysis of adding SMES to a utility in comparison to alternative expansion plans could then be made. It will become clear from the following exposition that SMES requires considerations closely allied to daily power dispatch, and that its high efficiency of storage and rapid power reversal lead to new uses unique to SMES.

Load Curve Analysis

A method to analyze previous years' load curves for storage use opportunities is presented. The example chosen is the combined 1982 total load curve of four Wisconsin companies: Wisconsin Electric Power Co., Wisconsin Power and Light Co., Wisconsin Public Service Co., and Madison Gas and Electric Co.[3] Let the yearly hour by hour load be $P = P(t)$ and the average daily power be $\bar{P}(T)$, see Fig. 1 with areas A = B. Since the efficiency of the storage unit is not 100%, the energy stored at night is equal to the energy delivered during the day plus the energy lost. Based on that, a new daily average load $Y = Y(T)$ is calculated as follows:

$$Y(T) = \bar{P}(T) + \frac{1-\eta}{0.8+1.2\eta}\,\frac{1}{t'_3 - t'_1}\int_{t'_1}^{t'_3}(P-\bar{P})\,dt \qquad (1)$$

where η is the efficiency, and t'_1 and t'_3 are times shown in Fig. 1. The maximum daily storage $D_s(T)$ is

$$D_s(T) = \int_{t_1}^{t_2}(P - Y)\,dt\,. \qquad (2)$$

$D_s(T)$ is the maximum size energy storage unit needed on a specific day so that the power generated all day is constant and equal to $Y(T)$. Rearranging the daily storage $D_s(T)$ for 365 days in a descending order gives the daily storage duration curve, Fig. 2. Figure 2 shows storage size as a function of the number of days a unit of this size is used at full capacity in 1982. From this curve a storage unit size is selected based on the number of days per year it could operate at full capacity.

Once a size S is chosen, an iteration technique is used to calculate the new (residual) load curve $Z(t)$, see Fig. 3. The procedure is two-fold: to find the largest $Y_c(T)$ that satisfies the conditions:

$$\int_{t_{c_1}(T)}^{t_{c_2}(T)}(P - Y_c)\,dt \le S \qquad (3)$$

$$t_{c_1}(T) \ge t_1(T)$$

$$t_{c_2}(T) \le t_2(T)\,,$$

where the notation is taken from Fig. 3. Next find the smallest $Y_d(T)$ that satisfies the conditions:

$$\int_{t_{d_1}(T)}^{t_{d_2}(T)}(P - Y_d)\,dt \le \eta S \qquad (4)$$

$$t_{d_1}(T) \ge t_2(T)$$

$$t_{d_2}(T) \le t_3(T)$$

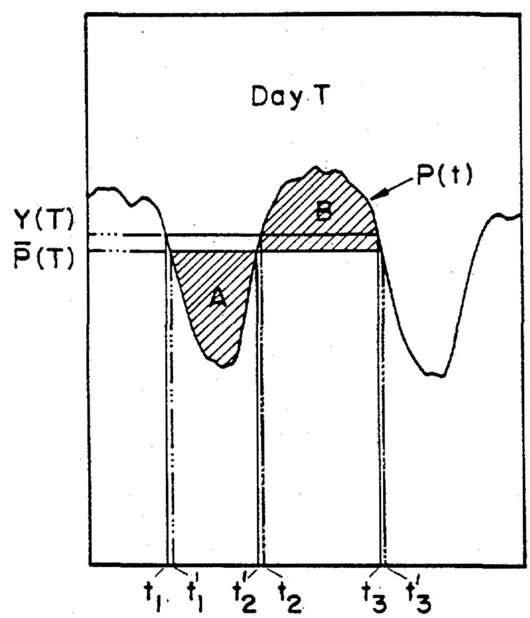

Fig. 1 Load Curve for Day T. $\bar{P}(T)$ is average load. $Y(T)$ is the weighted average load with storage losses taken in consideration.

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The new load curve $Z(t)$ is calculated as follows

for $t_{c_1}(T) \leq t \leq t_{c_2}(T)$ $\quad Z(t) = Y_c(T)$,

for $t_{d_1}(T) \leq t \leq t_{d_2}(T)$ $\quad Z(t) = Y_d(T)$,

and for all other values of t $\quad Z(t) = P(t)$.

Rearranging $Z(t)$ in a descending order, a load duration curve is obtained (Fig. 4).

SMES Size Selection

To select the various sizes of a SMES for a given electric utility system, the load and generation characteristics of the utility system must be examined. SMES provides a supply option which will allow the generation to be scheduled to its most efficient point while the SMES "follows" the variations in the customer loads placed on the utility system. The basic variations in system demands occur on a diurnal basis. The hour-to-hour variation in system demands from a daily maximum to a daily minimum is the basis for an application of SMES. Actual 1982 hourly demands along with actual generation characteristics are used in the simulation of a SMES dispatched system.

From Fig. 2 it is seen that a 3000 MWh SMES unit could have operated a maximum charge-discharge cycle 365 days per year to level demands. A 6500 MWh SMES unit could have operated a maximum charge-discharge cycle on weekdays 250 days per year. In addition a 6500 MWh SMES unit could have operated partial 70% charge-discharge cycles on weekends.

With the iteration scheme described earlier, see Fig. 1, the 1982 actual resultant annual load duration curve is derived for the use of 6500 MWh SMES, see Fig. 4. This curve shows the impact a 6500 MWh SMES has on the system annual load duration curves. The larger the SMES storage capacity in MWh, the more energy production from the system's generation capacity is shifted to the minimum load periods.

Figures 5 and 6 show the effect of a 6500 MWh SMES unit on the weekly loads for a typical summer peak (annual peak) and typical winter/spring load periods respectively. For the summer peak week, it would have been possible to set the power generation requirements on only two settings a day and a SMES unit would follow the customer load. This would have resulted in an easier operation, less cycling of the generation units and a saving in the power cost. This saving in power generation cost is achieved by meeting the high load demand during the day with the low cost base or intermediate load generation during the night. The penalty paid for this transfer of energy from low demand side nights to high demand days is less than 2% in the case of SMES. For the winter/spring typical week (Fig. 6) the 6500 MWh SMES unit levelized the generation requirements to a much closer two setting per weekday. The weekend is held constant, but at a lower level to account for reduced weekend demands.

Conclusions

The SMES simulation provides an optional way of meeting peak period demand through direct storage of electrical energy. This supply management capability can provide better utilization of base-load capacity. The planner has to consider the redistribution of energy between minimum and peak usage periods. Even though load management is a complimentary means to reduce usage during daily peak periods there will always remain a residual of higher hourly demands during daytime hours for which a supply management device such as SMES can be used to better optimize generation capacity. It is this residual energy that the planner must consider for a supply management option available through SMES.

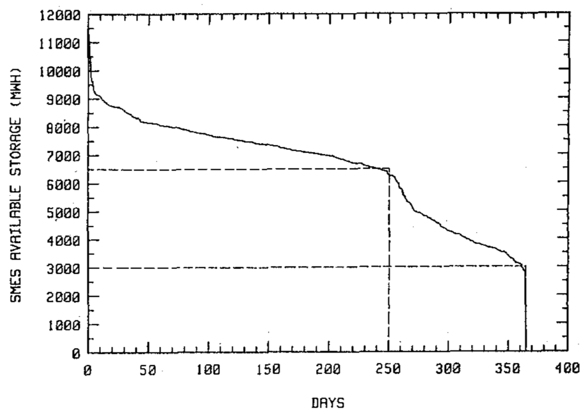

Fig. 2 Storage size S vs. days of use per year for the four Wisconsin utilities in 1982.

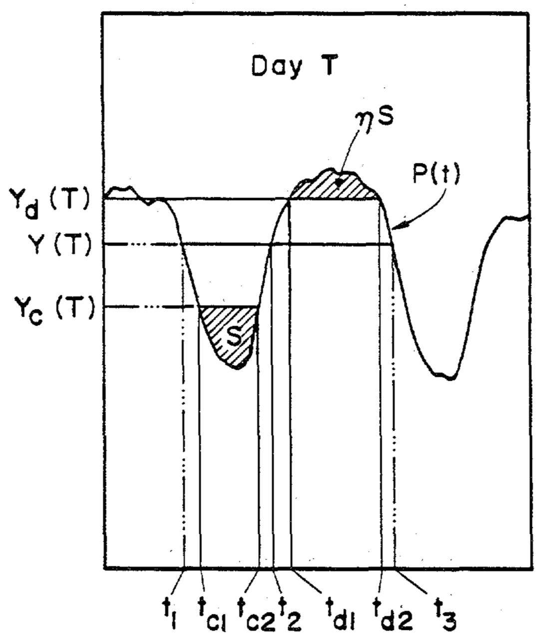

Fig. 3 Load levels for storage size S.

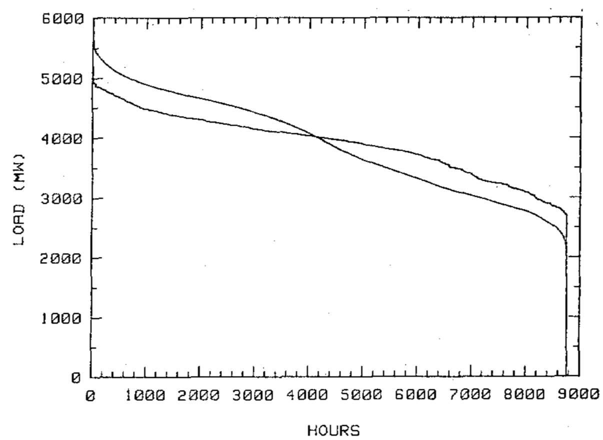

Fig. 4 Load duration curves with and without 6500 MWh SMES for the combined four utilities of Wisconsin (WEPCO, WPL, MGE).

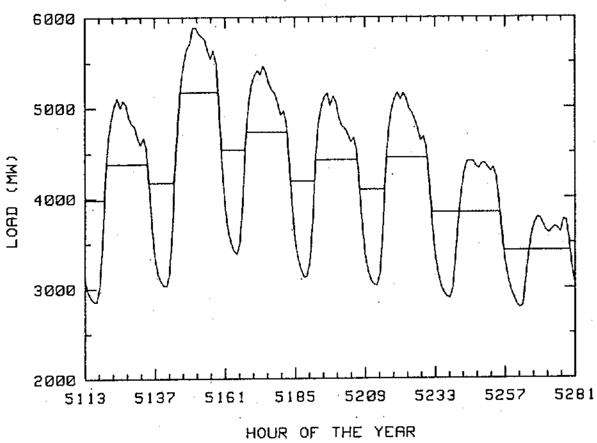

Fig. 5 Summer peak load week with and without 6500 MWh SMES.

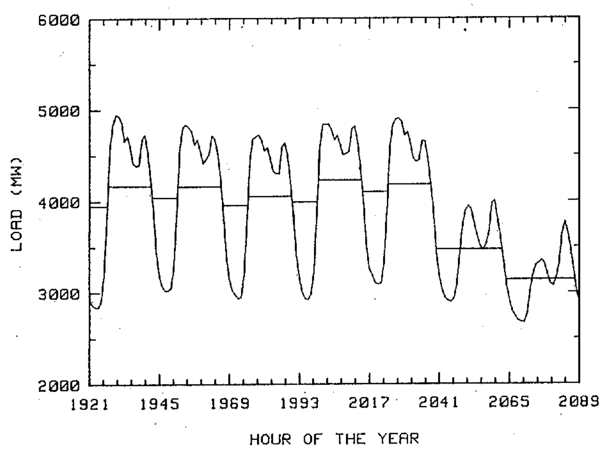

Fig. 6 Typical winter/spring load (March) with 6500 MWh SMES.

Since the "power capacity" of a SMES is variable (within limits of the system connecting it to the electrical system and its relatively inexpensive converter capacity) the ability to provide instant ± power capacity during operational difficulties is also an important ability of a SMES system. That and its "load following" characteristic present a new operational tool for power system operators in meeting the customers' ever changing demand for electrical energy.

The planning method used may be of general interest for electric power utilities. The merit is that actual load curves during the previous year or years are analyzed for sizing SMES. Then for future years the assumption of load growth percentage with approximately the same load patterns becomes a recommendation for the SMES sizes chosen to be scaled accordingly. In some cases this is an easier and more accurate procedure than extrapolating load curves for which future storage studies are to be made.

The final conclusion is that SMES with its high efficiency variable power output seems more amenable than other storage systems to the actual iteration method of adding/substracting the stored energy per day. This creates two daily flat generation output curves; one for the daytime and the other for nightime. Such flat demand curves are less easily obtained from other storage or cycling options. The planning method presented here is thought to be more useful for SMES than existing block loading programs which emphasize constant power use.

References

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3. Preliminary results for MG and E were presented at a workshop on "Benefits of Storage Plant Operations", 1984, Editor G. M. Karadi, University of Wisconsin-Milwaukee, 1984.