SPINNING RESERVES

Timur M. Aydemir
Electrical and Electronics Eng. Department, Gazi University, Ankara, Turkey

Yalçın A. Göğüş
Department of Aerospace Engineering, METU, Ankara, Turkey

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Summary

In the event of unexpected failure of electrical power supply units or power transmission equipment consumers and utility grids have spare electrical power that is always ready and can act within seconds or keep the supply to the consumers uninterrupted. These are called spinning reserves and range from a few Watts to tens of megawatts. One needs spinning reserve also at utility power systems to control the frequency of the produced electricity.

Generally battery stations with DC/AC converters are preferred as spinning reserve. However the interruption of the main power supply lasts generally longer than ten seconds and it is economic to run emergency diesel-generator units, e.g. at an airport 4 units of 1.5 MW, after the action of the battery station. For special applications that need a large power supply and medium energy capacity, super flywheel may be advantageous. Although Ni/Cd batteries have high energy density, they are more expensive and should be considered in connection with cadmium recycling. For conventional applications

where reducing the investment cost is important, lead-acid batteries are still used. Super conducting magnetic energy storage is envisioned as future solution for large energy capacity and high power because of its low loss and sophisticated technology. The internal loss of capacitors and super capacitors is high. Hence neither of these has found practical application.

Unexpected increase of demand is compensated by increase of the power production by 3% to 5 % within few seconds at the supply side. Stopping the charging process of peak shaving energy storage units like pumped hydro power plants also serves as a spinning reserve.

1. Introduction

Although the word ‘spinning’ calls to mind a mechanical object, these reserves are for electrical power supplies and their practical applications may involve batteries.

Demand for electrical power varies and that power level continuing all the time is called base load. The maximum power level during a day is called “the peak load.” Storage of electrical energy to be used during the peak periods has great economic advantages (see *Storage of Electrical Energy*). However, spinning reserves have different functions: they have spare power ready to be supplied at any moment, i.e. within few seconds in the case of forced outages, break down, disconnection and for frequency control. Generally they are close to the consumer and avoid complete blackout; those for frequency control are close to the generation units. To understand which power supplies are suitable for this purpose; they should be reviewed regarding their dynamic characteristics. The state characteristics, i.e. at which level and how long can the power be supplied continuously is of second order importance because the need for the spinning reserve is for a short time (10 seconds to 30 min.) until the operating or dispatching reserves started. As another state characteristic the running costs are not of primary importance for spinning reserves either.

The dynamic characteristics of power supplies are related to their ability to be loaded or unloaded at a required rate. Nuclear power plants and conventional thermal (steam) plants have very slow dynamic characteristics, i.e. they need more than an hour to reach full production rate. Gas turbine power plants need a few minutes to 15 minutes to produce full power. Hence they are suitable to be used as operational reserves. Diesel engines have start-up times in the range 10 seconds to a few minutes; hence they are preferred as operational reserves in comparison to gas turbines.

Power supplies that need only a few seconds to produce full power and can last many minutes are preferred for spinning reserve applications.

The spinning reserves have stored energy. This stored energy can be supplied at a rather low rate for, say 30 minutes, until an operational reserve reaches its full load or it can be supplied at a much higher rate only for a few minutes until a diesel generator starts up. For spinning reserve applications of tens of MW the combination of stored energy with a diesel generator unit should be preferred. Depending on the specific needs super capacitors and superconducting magnetic energy storage may have advantages. However these systems have not yet seen practical applications.

2. Utility System as a Spinning Reserve

The three functions of the spinning reserves are to supply power for frequency control, to compensate loss of power due to breakdown or forced outage of a generation unit and to supply power to a group of consumers in case of disconnection. For the first and second functions the required power rate is very high and it is economically not feasible to build very large electrical energy storage plants only for this purpose. However, the power units of the utility system that are already running can serve as spinning reserve by increasing their output within few seconds, at a slight sacrifice of efficiency.

Power units have to run, even during the peak periods, at their design, or nominal, conditions. Satisfying all the safety regulations, the pressure, temperature and flow rate of working substance can be modulated to reach the maximum power of the generation unit. This power increase is in the range of 3-5 % of the nominal power and it can be achieved within few seconds.

In large interconnected systems, this spinning reserve is distributed to different generation units. The total power can be increased by two means. Firstly the power rate of the running plants will be reduced 3-5 % and their number will be increased, without causing any remarkable loss of efficiency. Secondly the capacity of the electrical energy storage units which are installed for peak shaving, i.e. that of pumped hydro, compressed air and flywheel power systems will be increased. Although starting up these plants to supply power to the utility grid requires several minutes, the stopping of energy charging process to these systems can be very quick. Within a few seconds it releases the power, which is being consumed for charging, and this acts as a spinning reserve.

Although the reliability of a utility power system securing which by means of spinning reserves is of primary importance, comparison of different alternatives considering economic factors is also important. The quality of the frequency control and the safety against unexpected loss of a generation unit will be evaluated with respect to the economics of the investment costs of new spinning reserve plants and the operating costs of manipulating the load factors of the running power plants. These evaluations and comparisons lead to the technical-economical solutions of utility power system spinning reserve problems.

3. Batteries

For electrical energy consumers at considerable distance far from power generation units the danger of disconnection due to unexpected natural or human hazards exist always. In such disconnection or equipment failure cases at least the crucial needs for electrical power should be satisfied uninterrupted, i.e. by spinning reserves or uninterrupted power supplies (UPS). Examples of UPS applications are in high buildings- the elevators, in hospitals- the illumination and ventilation of the operation theaters, in industry- certain equipment which will undergo irreparable damage in case of sudden interruption of power and in airports- the illumination of the airstrips and power supply for communication units.

Batteries are generally the first choice for such spinning reserve applications. They store energy in chemical form, and this energy is converted to electrical energy whenever needed. This conversion is a clean and silent process since it does not require any moving part.

A battery consists of two or more voltaic cells. Voltaic cells can be divided into two groups: primary cells and secondary cells. Primary cells non-rechargeable cells. Other names given to secondary cells are accumulator, secondary battery or storage cells. Accordingly, batteries are named to be primary or secondary (storage) batteries.

Primary batteries have to be properly discarded when they are totally discharged. While the chemical energy is being converted into electrical energy, some of the material is used and this material cannot be replenished. When all the energy is converted, the battery becomes useless. On the other hand, energy conversion in storage batteries is reversible. A discharged battery can be returned to its original state by passing a current through it in the direction that is opposite to that of the discharge current.

Common examples of primary and secondary batteries are dry cells and lead-acid batteries, respectively.

The main losses in batteries are due to irreversibility of current flow through the battery during charging and discharging, i.e. Joule heating, and short-circuiting during the storage period. These losses depend on the charging and discharging rate, temperature, etc.. Batteries have an overall efficiency of 65 to 75 percent.

Table 1 shows the utility applications of batteries and their corresponding energy capacity requirements. As seen from the table, very large capacities are required. This is accomplished by arranging the systems in configurations of series and parallel-connected modules.

	Energy Capacity, MWh	Average Discharge Time, hours	Maximum Discharge Rate, MW
Load leveling	> 45	4 to 8	> 10
Spinning Reserve	< 35	0.5 to 1	< 60
Frequency Regulation	< 5	0.25 to 0.75	< 20
Substation Applications	< 10	1 to 3	< 10

Table 1. The Utility Applications of Batteries and Their Corresponding Energy Capacity Requirements

3.1. Lead-acid Battery

The most widespread type of secondary battery is the lead-acid battery, which was invented in 1859. The anode (positive electrode) is lead dioxide (PbO_2) and the electrolyte is dilute sulfuric acid (H_2SO_4). The following reaction takes place during discharging:

anions (H^+) which reach the surface of anode combine with electrons which reach anode by moving through the external circuit and doing work:

$$PbO_2 + H_2SO_4 + 2\,H^+ + 2\,e^- \xrightleftharpoons[\text{Charging}]{\text{Discharging}} PbSO_4 + 2\,H_2O \qquad (1)$$

The cathode (-) is lead (Pb); it has the function to produce anions into the electrolyte and electrons into the external circuit

$$Pb + H_2SO_4 \xrightleftharpoons[\text{Charging}]{\text{Discharging}} Pb\,SO_4 + 2\,H^+ + 2\,e^- \qquad (2)$$

Reactions on both electrodes are as follows:

$$Pb + 2\,H_2SO_4 + PbO_2 \xrightleftharpoons[\text{Charging}]{\text{Discharging}} 2\,Pb\,SO_4 + 2\,H_2O$$

During discharging the processes run in the opposite direction.

In a charged battery the electrolyte contains more H_2SO_4 and its density is high; the discharged battery contains more H_2O hence it is less dense.

The potential difference between lead and lead dioxide is 2 Volts. Hence 1 coulomb charge (which is 1 A s) corresponds to 2 J of energy.

They are very cheap and reliable. Their disadvantage is their low specific energy.

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Biographical Sketches

M. Timur Aydemir received his B.Sc. and M.Sc. degrees in Electrical Engineering from Karadeniz Technical University, Trabzon, Turkey respectively, in 1983 and 1985. He worked at the same university as a research assistant between 1984 and 1988. He received his Ph.D. degree from the University of Wisconsin-Madison in 1995 and since then he has been working at Gazi University as an Assistant Professor. He teaches courses in the areas of Electric Machinery and Power Electronics. His research interests include low and high frequency power converters, electric machine dynamics and drives.

Yalçın Göğüş received his high school training in Ankara, his B.S. degree in 1958 and his PhD degree in 1964 at the Faculty of Mechanical Engineering of Technical University Munich. He was Alexander von Humboldt Fellow in the years 1959 to 1961. He joined METU (the Middle East Technical University, Ankara) in 1961 and was Professor of Mechanical Engineering in the years 1976 to 1982. After working for UNESCO as a specialist and Project Director at Makarere University, Uganda 1980 to 1986 he returned to the Department of Aerospace Engineering of METU. He was as NATO-Fellow at Brown University (1970) and as Visiting Professor at University of Gaziantep (1975), Technical University Munich (1979) and Technical University Istanbul (1999). He has written, translated or edited ten books and more than one hundred journal or conference papers and research reports. He was founding Chairman of Turkish Society for Thermal Sciences and Engineering and Editor-in-Chief of its scientific journal Isı (1976), Founding Vice-Chairman of International Centre for Applied Thermodynamics (1997) and Associate Editor-in-Chief of its *Int. J. of Thermodynamics* (1998-2004) He received academic awards. Since 2001 he is working as Emeritus Professor at METU in the fields applied thermodynamics and propulsion engineering. He contributed to EOLSS as Honorary Theme Editor on Energy Storage and author.