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BATTERY LOAD-LEVELLING: ACTIVITIES IN THE FEDERAL REPUBLIC OF GERMANY AND THE REPUBLIC OF SOUTH AFRICA

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Introduction

In recent years, lead/acid battery technology has progressed to a stage where it can now be utilized in a variety of electrical power-supply applications. The field ranges from very small packages of a few kW up to large installations of several hundred MW. Trans-regional utilities can be involved as well as industrial manufacturers, mining companies, and even rural communities and farms. The author's company has undertaken activities in this area with the development of a large utility plant in West Berlin. A second plant will be constructed at a gold-mine shaft in the Republic of South Africa. Further projects are also under consideration.

BEWAG battery-storage plant

A research study, financed by the Government of the F.R.G., was conducted during 1981 - 1986 with the object of developing a lead/acid battery for:

(i) operation in a frequency-controlled mode in an insulated network, *i.e.*, of the type employed by BEWAG in West Berlin;

(ii) provision of instantaneous reserve as either a supplement to, or a substitute for, a conventional power-regulation generator unit.

The main characteristics of the devised battery are given in Table 1; the data correspond to the Berlin facility. By 1984, the results of the study encouraged the involved companies, namely, BEWAG, HAGEN Batteries, and AEG, to commence construction of the first large battery storage plant (BSP) in the world. The plant was built in 1986 and commissioned in January 1987.

Figure 1 shows the electrical circuit. The ratings are:

- 17 MW for instantaneous reserve
- 2 × ±8.5 MW for frequency control
- 14.4 MW h energy capacity at $C/5$ discharge.

Twelve battery strings are connected in parallel on a common d.c. busbar of 1.2 kV nominal voltage. Four converter branches are connected in parallel; each pair is combined to a 12-pulse configuration by an appropriate converter transformer. A phase shift is provided between the

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TABLE 1

Characteristics of BEWAG lead/acid battery

Parameter	Cell of 10 plate pairs
High current capability (kA)	2.2
Deep discharge duty (%)	5
High charge/discharge cycling	minute-wise continuously
High energy efficiency (%)	87
High energy turnover	6000 × 80%
Long life duration (years)	> 10
Low maintenance requirements, no specific service due to special automatic functions	
— water refilling	
— electrolyte agitation	
— voltage monitoring	
— temperature monitoring	
— equalization charging	

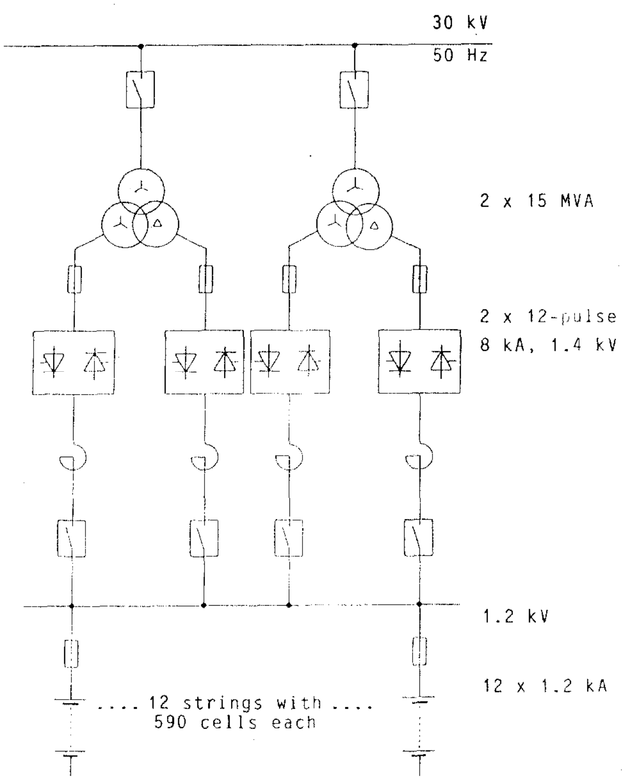

Fig. 1. Diagram of main circuit of BSP at BEWAG, West Berlin.

two 12-pulse groups so that a 24-pulse reaction on the network is achieved. The converters must be capable of providing full power under all operational situations for ±10% system voltage and ±20% battery voltage ranges. For the 17 MW plant rating, this results in an installed converter capacity of about 30 MW in either direction of power flow.

During normal service, the BSP operates in a frequency-controlled mode at 0 to ±8.5 MW, with one converter group in operation and the other on standby. For instantaneous reserve, both groups supply full power to the system for approximately 20 - 25 min.

The plant layout is shown in Fig. 2. The building consists of two sections: one contains the battery strings (4 strings of 118 battery modules each per floor); the other (upper) section houses the electrical plant with the battery auxiliary equipment. The building volume is 7600 m^3 and the space requirement is 660 m^2.

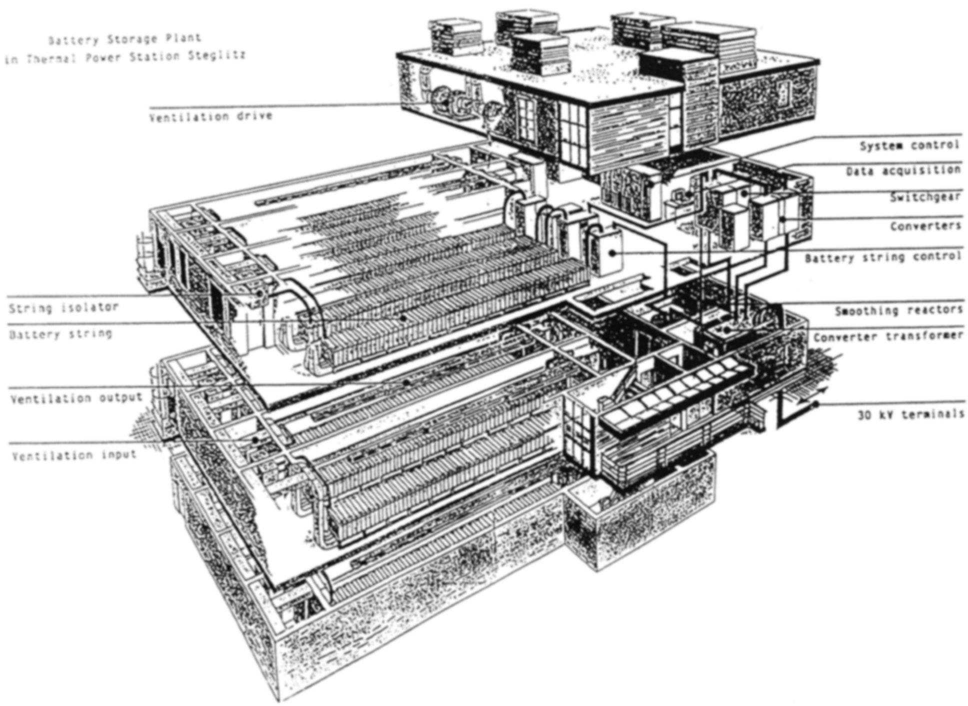

Fig. 2. Layout arrangement of BSP at BEWAG, West Berlin.

Battery performance during the initial six months of operation has been excellent. The duties of the frequency-controlled mode have been fulfilled without difficulty. A typical power recording is shown in Fig. 3. The curve illustrates the strong rate of charge/discharge cycling within short periods. The failure and outage rate of the plant has been very low, despite the fact that "teething troubles" would have been understandable during the initial stages of operation. The energy efficiency, measured over a one-week period,

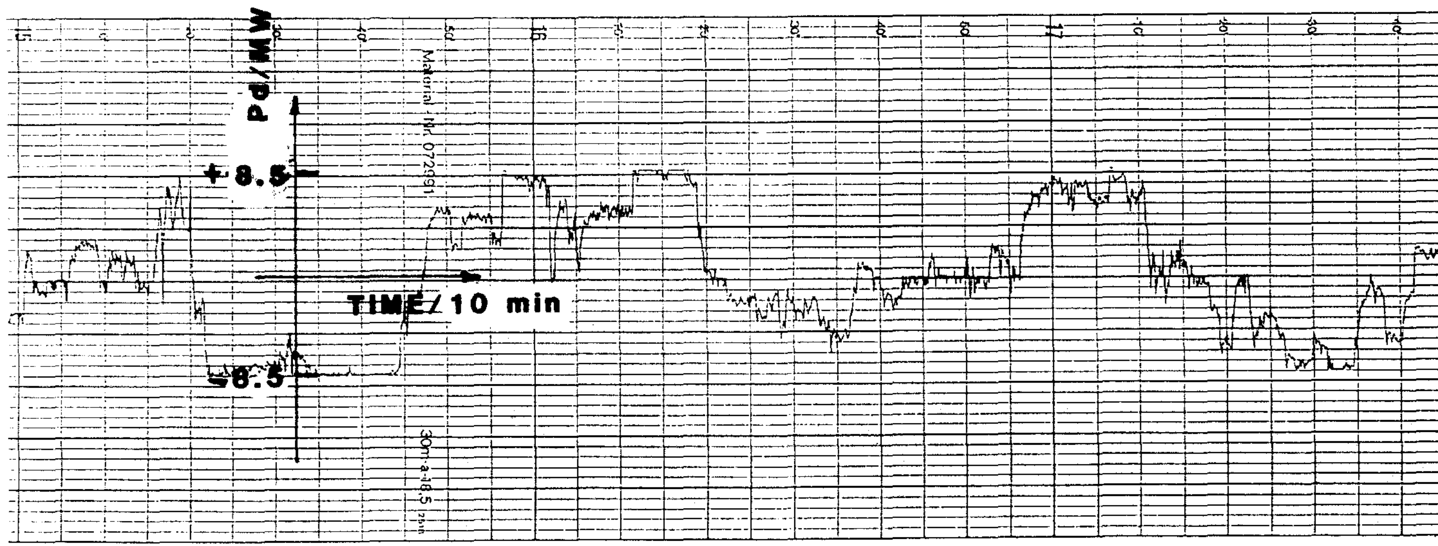

Fig. 3. Normal continuous operation in frequency control mode of BSP at BEWAG, West Berlin.

is 87%; this is higher than that anticipated (84%). Residual system frequency deviations are close to ±0.1 Hz, lower than the original target of ±0.2 Hz.

Due to the excellent overall performance, BEWAG has now decided to reduce part of its spinning reserve — also in regulation units — thus saving considerable service and maintenance costs.

BEWAG is firmly convinced that installation of the BSP has been the right step from both a technical and an economical point of view. Purchase of four further BSPs of the West Berlin type and size is planned.

Vaal Reefs battery-storage plant

In January 1987, Anglo American Corporation awarded contracts to a local battery manufacturer (acting on licence from HAGEN Batteries) and to AEG for a BSP to be constructed at a gold-mine shaft at Vaal Reefs, south of Johannesburg. This contract served as an alternative to the purchase of an emergency-power diesel-generator set.

Figure 4 shows the winder system configuration with:

(i) main power infeed from the 132 kV level;

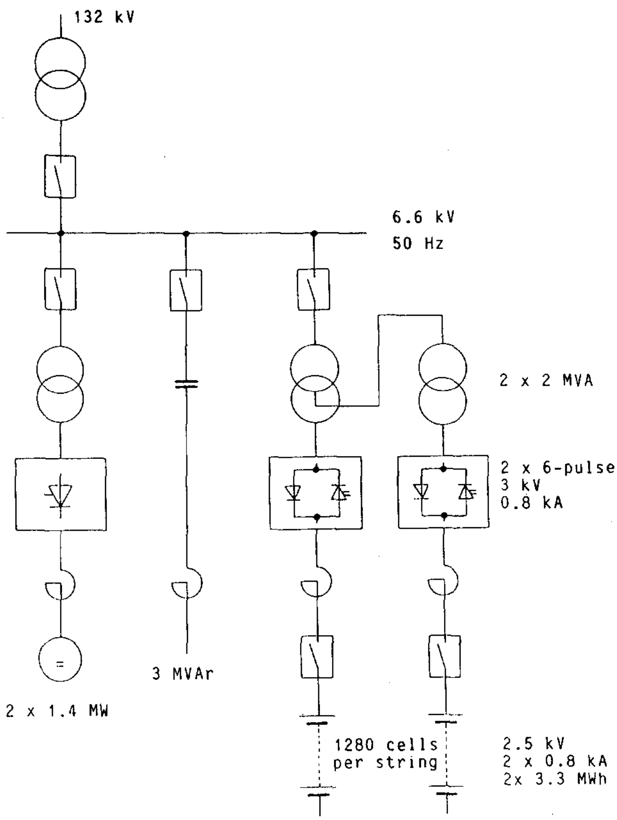

Fig. 4. Diagram of main circuit of BSP at Vaal Reefs.

(ii) winder drive circuit;
(iii) harmonic filters;
(iv) BSP.

The BSP consists of two separate d.c. circuits that are combined by a special transformer configuration in order to achieve 12-pulse reaction on the 6.6 kV a.c. busbar. The converters are of the forced commutated type and can therefore operate independently of the network; each converter is rated at 2.4 MW. Details of the two separate and identical battery strings are given in Table 2.

TABLE 2

Characteristics of Vaal Reefs BSP

Nominal voltage (kV)	2.5
Maximum voltage (kV)	3.0
Maximum voltage at equalizing charge (kV)	3.6
Minimum voltage (kV)	2.1
Nominal current (A)	800
Nominal power (MW)	2.0
Energy capacity at $C/3$ rate (MW h)	3.3
Number of cells in series	1280
Charge capacity per cell (A h)	1500

The layout is shown in Fig. 5. The equipment is installed at ground level, since the facility is located in a rural area and ground values are not decisive. The 53.4 m long building has a footprint of about 500 m^2.

The duties of the Vaal Reefs BSP are described in Fig. 6. They are, in order of priority:

(i) emergency power supply;
(ii) load levelling;
(iii) power-factor correction and voltage regulation.

Emergency power supply is required in the advent of breakdown in the main power supply. The BSP is capable of conducting 50 winder cycles within 6 h. The forced-commutated converter is controlled in such a way that it follows exactly the load curve of the winder with respect to real and reactive power. A particular advantage, by comparison with a diesel generator, is that the negative real power during deceleration can be utilized for intermediate battery recharging.

The load-levelling mode is turned on during peak load periods of the day. Power supply from the battery can be adjusted at 0 - 4 MW for 1 - 3 h. Battery recharging is carried out during the night.

Power-factor correction and voltage regulation are possible due to the forced-commutation principle of the converter. Since the inverter output

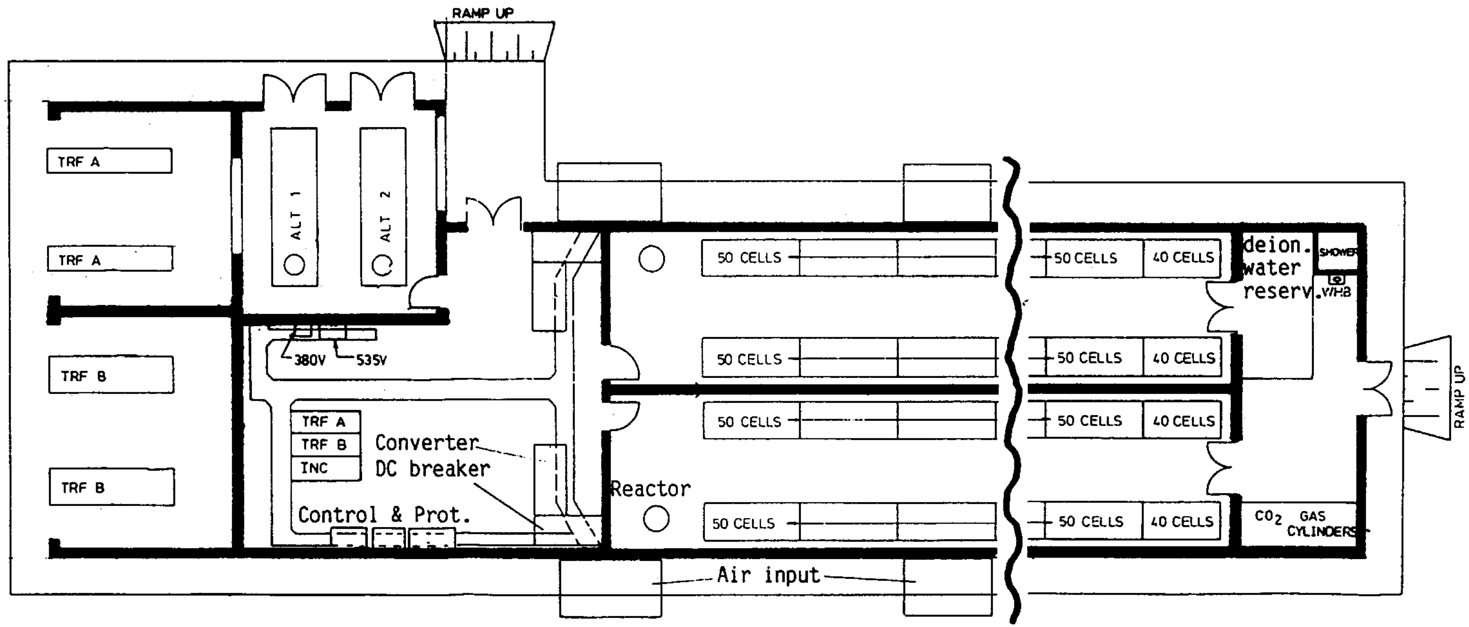

Fig. 5. Layout arrangement of BSP at Vaal Reefs.

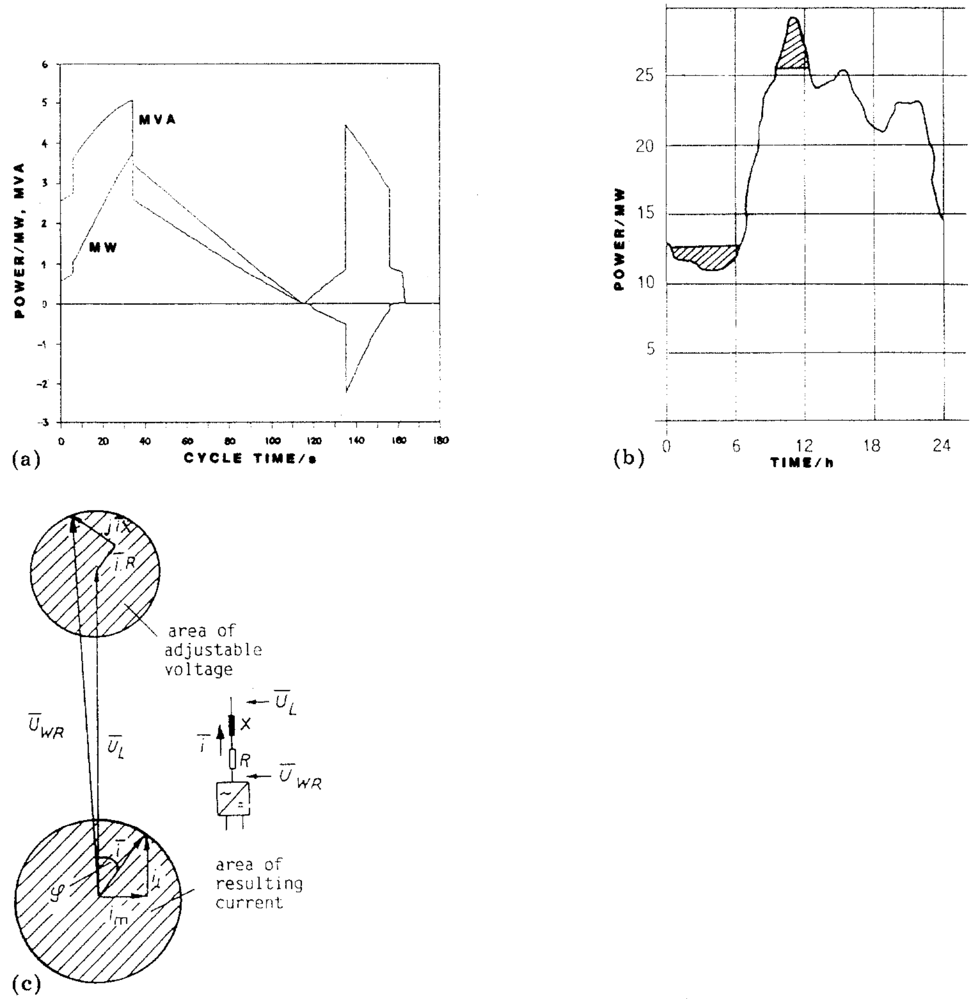

Fig. 6. Service functions of BSP at Vaal Reefs. (a) Emergency power supply ±4 MV A. (b) Load levelling ±4 MW. (c) Power factor correction and voltage regulation ±4 MV Ar.

voltage is freely adjustable within the indicated area (Fig. 6(c)), the resulting current vector can operate in all four quadrants. This enables control of the phase angle between 0 and 360 °electrical and thus the output power can be adjusted not only at 0 to ±4 MW, but also at 0 to ±4 MVAr (*i.e.*, capacitive and inductive).

The service practice will be that the BSP is normally in the voltage regulation mode. During load-levelling, a certain MW level in the range 0 to 4 MW will be set. A residual margin in MVAr's, up to the limit of 4 MV A apparent power, will also be used to carry out voltage control during load-levelling periods.

This great flexibility in the combination of different operation modes offers a number of possibilities for various applications. This should also be

TABLE 3

Simplified cost comparison between diesel generator and BSP; 4 MW rating, 20 years service time

Item		Cost ($DM \times 10^6$)
Diesel generator		
— investment		4.5
— maintenance DM 1700.-/month		0.4
	Total	4.9
Battery storage plant (BSP)		
— investment		6.0
— replacement of battery after 10 years		2.1
— financing of investment, difference from diesel		0.6
— peak load lopping with 2 MW, 0.14 DM/kW per month		−6.7
— saving dynamic VAR-compensation investment		−0.5
	Total	1.5

taken into account for economical feasibility studies. Table 3 gives an estimate of the economics of such a BSP in the case of a typical mining application. The comparison with a diesel generator indicates clearly the remarkable advantage due to the load-levelling capability.

Conclusions

In many cases, technical and economical comparisons with conventional techniques places a BSP in a favourable position. This, however, is not in accordance with the small number of real projects constructed or on order. It is very likely that discussions with possible users of the BSP technique will be intensified. Through these discussions, a wide range of likely applications will be identified and necessary improvements in the electrical power supply will be implemented.