A BATTERY MANAGEMENT SYSTEM FOR SODIUM-METAL CHLORIDE BATTERIES USED AS STANDBY BACKUP POWER IN TELECOMMUNICATION APPLICATIONS

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ABSTRACT

Advanced storage batteries employing sodium-metal chloride chemistry feature superior characteristics and performances as compared to conventional lead acid or nickel cadmium batteries, noticeably the gravimetric and volumetric energy densities. In addition, they are ideally suited for longevity in high temperature applications. However their long term reliability and their sensitivity to deviations from the optimal operating conditions, which might happen in a variety of float service conditions, have not been completely explored.

For these reasons it is necessary to provide an ancillary management system to maintain the battery within the best operating condition as much as possible and to prevent any risky condition being applied to the battery (e.g. over discharge, over charge or over temperature).

The paper describes a management system specifically designed for Sodium-Metal Chloride (SMC) batteries to be used in telecommunications applications, with the aim of (in order of importance):

1) ensuring the highest level of safety;
2) limiting the chances of battery disconnection in order to ensure the availability of back-up power;
3) employing diagnostic method to foresee potential problems and issue warning signals;
4) monitoring the battery operating conditions and recording the significant data for future investigation and analysis.

The design of the system will rely on a limited number of physical inputs (battery voltage, battery current, battery temperature, and ambient temperature) and will not require single cell measurements. It is concluded that when SMC batteries are equipped with a properly designed management system the overall reliability and safety of the battery system is greatly enhanced.

INTRODUCTION

The sodium-metal chloride chemistry is characterised by very high specific energies, 100% coulombic efficiency, good cycling capability, insensitivity to environmental operating temperatures, near zero self discharge and the absence of emissions. They are premium features, long awaited in standby backup power applications, and all provided by the SMC technology as long as it is operated within the recommended operating conditions (ROC).
However, in the field of standby backup power it is not uncommon that the presently used technologies (lead-acid and nickel-cadmium) should withstand small or large deviations from the ROC, because :

- inherent limitations in the variety of power supply systems to which they are connected;
- wrong settings of the power supply system;
- progressive drift from the set-points;
- known limitations which consequences are accepted for various reasons;
- defects or failures of any part of the battery system (individual cells or the entire battery).

Examples of deviations in float operated batteries are:

- the limited capability of controlling the charging current in the battery string;
- the limited or zero capability of controlling the individual charging current in paralleled multiple battery strings;
- the limited presence of battery disconnection devices to prevent overdischarges in case of prolonged power outages;
- the use of different chemistries or battery technologies with the same DC power supply system.

Conventional batteries benefit from decades of manufacturing, field experience, continuous improvement, all of which makes them robust enough to withstand small/medium deviations from ROC with minor effects. In the presence of large deviations, outside the Limit Operating Conditions (LOC), the penalty paid in most cases is the replacement of cells/batteries because of irreversible failures or damage.

It must be also remembered that in few cases extreme conditions being applied to these batteries led and can lead to hazardous situations, with chances of explosion, fire and aggressive/toxic substances released to the environment.
For historical reasons conventional batteries were, and still are, installed without any management system.

Only in recent times with the development of electronics are these systems available at a reasonable cost. Unfortunately, very few are able or willing to pay any additional price for employing these management systems in the highly competitive environment of conventional batteries.

Sodium-metal chloride technology, as well as most advanced chemistries, does not benefit from long-term experience and widespread diffusion in Standby power applications.

As a result, provisions should be taken when field deployment of such technologies is planned to prevent any risky condition being applied to the battery. In addition to the primary concern for safety, two simple considerations might explain this assumption:

- the fact that - when operated outside LOC - no additional useful power is available, and permanent damage is very likely, which in any case means loss of backup in the near future;
- the cost for replacement even in the case of individual cell failure is high.

In addition to these considerations, what has led FIAMM to develop a management system for SMC batteries on float operation is the concept of having something which ensures the highest level of safety and increases the overall reliability of the energy storage backup system. At this point some might argue that by adding more components, and particularly electronics, the reliability is lowered.
In general this is true but we will try to demonstrate that in a global concept of reliability with SMC batteries this statement can be slightly reviewed.

SHORT DESCRIPTION OF THE SODIUM-METAL CHLORIDE CHEMISTRY

Sodium/metal chloride cells feature a prismatic configuration, and use salt, nickel and iron as active materials. In the charged state, nickel chloride and iron chloride are present at the cathode (positive electrode) and sodium at the anode (negative electrode). β”alumina solid ceramic is used to separate the electrodes and, in combination with sodium tetrachloroaluminate ($NaAlCl_4$), it acts also as electrolyte allowing the flow of sodium ions.
The overall chemistry of the cell can be summarized as follows:

$$\underbrace{NiCl_2 + 2Na}_{\text{Charged state}} \leftrightarrow \underbrace{Ni + 2NaCl}_{\text{Discharged state}} \qquad OCV = 2.58\ V$$

$$\underbrace{FeCl_2 + 2Na}_{\text{Charged state}} \leftrightarrow \underbrace{Fe + 2NaCl}_{\text{Discharged state}} \qquad OCV = 2.35\ V$$

These reactions take place at a operating temperature range comprised between 250 °C (482°F) and 350 °C (662 °F).
At lower temperatures the electrical performances are greatly reduced and damage may occur to the cells if excessive current is drawn. At higher temperatures the degradation of cell components may reduce the overall life.

The cell assembly in enclosed in a hermetically sealed steel container which ensures an almost perfect thermal insulation..
As a result, in operation at 275°C (527 °F) the external surface is just a few degrees above the environment. The power needed to maintain the internal temperature is around 7 W / kWh of energy stored.

Fig. 1 shows the discharge characteristics of a 48 V 80 Ah SMC battery. It can be seen that the deliverable capacity is almost the same at the 10 A, 20 A and 40 A discharge rates. The voltage levels are of course different because of the effect of the battery internal resistance and consequently the delivered energy is somewhat lower at the higher rates.

Fig. 2 shows the internal temperature evolution during a discharge at the 40 Amp rate. It can be seen that, because of the almost perfect thermal insulation (and no provisions for cooling), there is a constant increase of the inner temperature till values which might exceed the LOCs. This behaviour is a good example of the importance of a proper battery management system coupled with the SMC battery. First, there is no need during a power outage to drain any power from the battery due to internal heating (the internal power dissipation is more than enough), and secondly during high rate discharges (two hours or less) all the parameters should be monitored and alert warnings should be issued well before the internal temperature reaches dangerous values. As a result with a proper management system there would be no capacity reduction due to internal heating at any discharge rate.

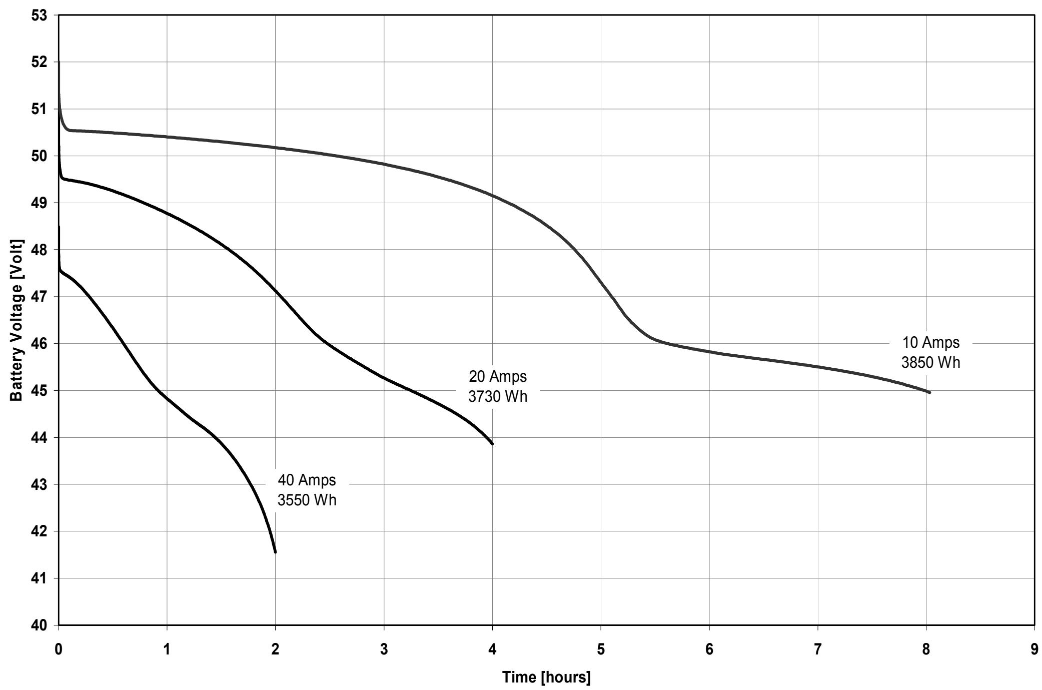

Fig. 1 - Discharge curves of a 40 Volt 80 Ah Sodium-Metal Chloride battery at 275°C internal temperature

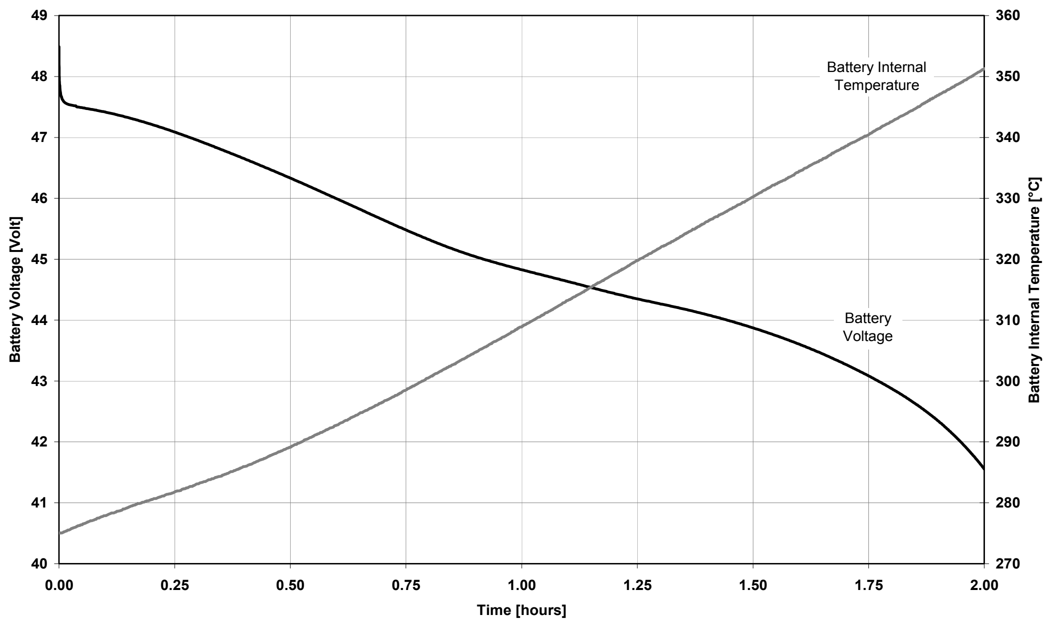

Fig. 2 - Increase of the battery internal temperature during a discharge at 40 Amps (approx. two hour rate)

Fig. 3 shows the charge characteristics of a 48 Volt 80 Ah SMC battery. As long as the voltage is limited to 52.4 Volts (2.62 V/cell) it is possible to recharge the battery without any limitation of the initial current. Once the capacity returned to the battery approaches the previously discharged capacity, the charge current reaches very low values, tending to zero. There is no need for any overcharge factor to recover the full capacity, as the coulombic efficiency is equal to one: there are no side reactions.

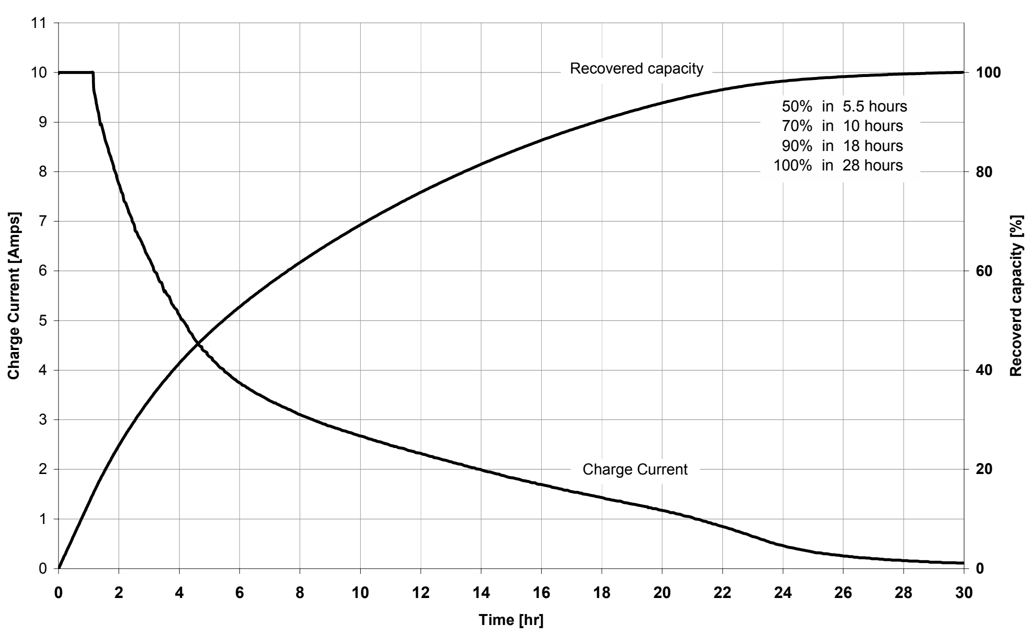

Fig. 3 - Charge characteristic of a 48 V 80 Ah SMC battery

The SMC battery can tolerate a certain degree of forced overcharge and overdischarge, typically 120% of rated value (1). Overcharges and overdischarges which exceed 120% may result in cell damage and should be avoided. It is extremely important that the management system prevents overcharges and overdischarges beyond 120% as these eventually will lead to permanent damage.

A GENERIC MANAGEMENT SYSTEM FOR A SMC BATTERY

The basic functions performed by a simple, generic management system of a SMC battery are:

- manage the battery heating device to keep the internal temperature within the recommended window;
- check that the bus voltage to which the battery is connected and the energy input/output remains within the LOC;
- prevent battery operation if the internal temperature falls outside the LOC;
- prevent battery operation if energy in/out exceeds the LOC;

If the power supply system cannot ensure stability of the bus voltage or significant voltage changes are likely by design (for instance automatic change to boost charge for conventional batteries), then in such cases the SMC battery might be subjected to conditions which would require the disconnection of the battery from the bus. It is clear that a SMC battery with a generic management system could then be installed only on selected backup power installations, where there is the possibility of setting of bus voltage and there is certainty that this value will remain stable under all the various charge operating conditions. In these installations the reliability of battery back up power would be at the highest levels since there is not need for microprocessors, etc. This could be a viable solution for modern charging systems, but would constitute an important limitation in using SMC for replacement scenarios where the bus voltage might not be properly adjusted, boost sequences are not disabled, voltages may have drifted on older equipment, etc.

A SMART MANAGEMENT SYSTEM FOR A SMC BATTERY

The right solution to these limitations is to provide the SMC battery with a Smart Management System (SMS) to make the battery universal, which means that it could operate in almost all the backup power installations without the worry about the characteristics of the DC power supply, adjusting the bus voltage, verifying if there is a boost charge level, etc. The SMS should manage properly the battery heating device, for instance switching it off during a discharge as seen above. In addition the SMS should check continuously the battery parameters detecting and alerting in advance every deviation which eventually would lead to a no service condition.

Clearly all these functions cannot be performed by a simple logic. At first glance it seems that all that is required is a microprocessor and a good deal of firmware loaded into the non volatile memory. Unfortunately it is not that simple. We all know that electronics and software are not 100% safe, there are noises which hang microprocessors, there are software bugs which sometimes pop out and start infinite loops, and there are subtle manufacturing defects in the components and in the printed circuit boards which effects are detected only with time. And we have to take into account these facts, even though the occurrences are very limited. We need to be prepared for the potential of the SMS not working.

An additional redundancy must be added to the SMS to take over control of the battery operation should the main processor fail. This redundancy relates to ensuring the presence of backup power, the protection against irreversible damage to the battery, and ultimately to safe operation.

PARAMETERS OF THE SMART MANAGEMENT SYSTEM

The key parameters on which the SMS is based are (see Fig.4 Block Diagram):

- internal battery temperature (two probes for redundancy)
- battery voltage
- DC bus voltage
- battery current
- additional data for diagnostic analysis

First of all it must be noted that, contrary to most lithium systems, there is no need of monitoring the voltage of each cell (2). Since SMC cells are not affected by large cell to cell deviations it is not necessary to implement an individual cell management system. Such systems would make the SMS very complicated and more susceptible to reliability issues.

FUNCTIONS OF THE BATTERY MANAGEMENT SYSTEM

In normal operation with all parameters within expected range:

- Battery Operation Enabling
- Heating Management
- Conditioning of the Power on Charge and on Float
- Data Acquisition
- Battery History Logging
- User Interface

Battery Operation Enabling: when all parameters are within the LOC's the battery is permanently connected to the DC Bus
Heating Management: power is taken from the DC bus to keep the internal temperature the desired temperature.
Conditioning of the Power on Charge and on Float: condition of the voltage and power input to the battery to the right levels, irrespective of the parameters of the DC power supply, so that the battery can operate with a DC bus voltage window from 53 to 56 Volts.
Data Acquisition: acquisition and processing of the battery data;
Battery History Logging: recording of the significant parameters and battery state during battery service for future use.
User Interface: communications port for setting of operational parameters, alarms levels, data download, optical panel for quick inspection of battery status.

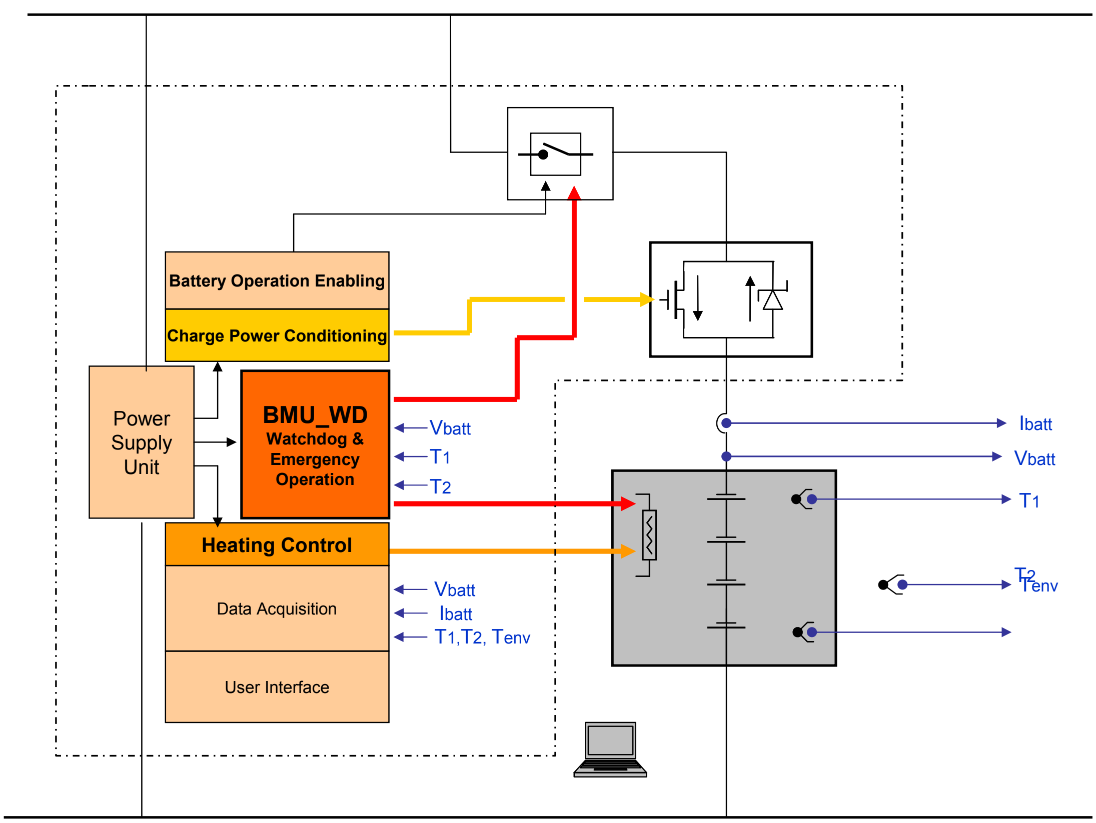

Fig. 4 - Block Diagram of the SMS for SMC battery.

Fig. 5 shows in a flow diagram the main loop which is performed by the SMS where it can be clearly seen that whenever an anomaly is detected, the sequence of early warning, warning, emergency countdown and only then battery shutdown is always performed. Considering that the continuous data acquisition and processing allows in most case to detect well in advance critical situations, there is the high degree of certainty that sudden battery disconnection are almost impossible to happen.

The sequence is here shortly described:

In the event of initial deviations of some operational parameters:

- Early Warnings Issue

In the event of unacceptable deviations from operational parameters:

- Emergency Warning
- Emergency Countdown
- Disabling of Battery Operation

In the event of failure of the main SMS logic:

- Warnings Issuing
- Temporary Emergency Operation

In Temporary Emergency Operation the safety logic runs independently checking that:

- the internal temperature is within the LOC and preventing battery operation if it falls outside the LOC
- the battery voltage is within the LOC and preventing battery operation if it falls outside

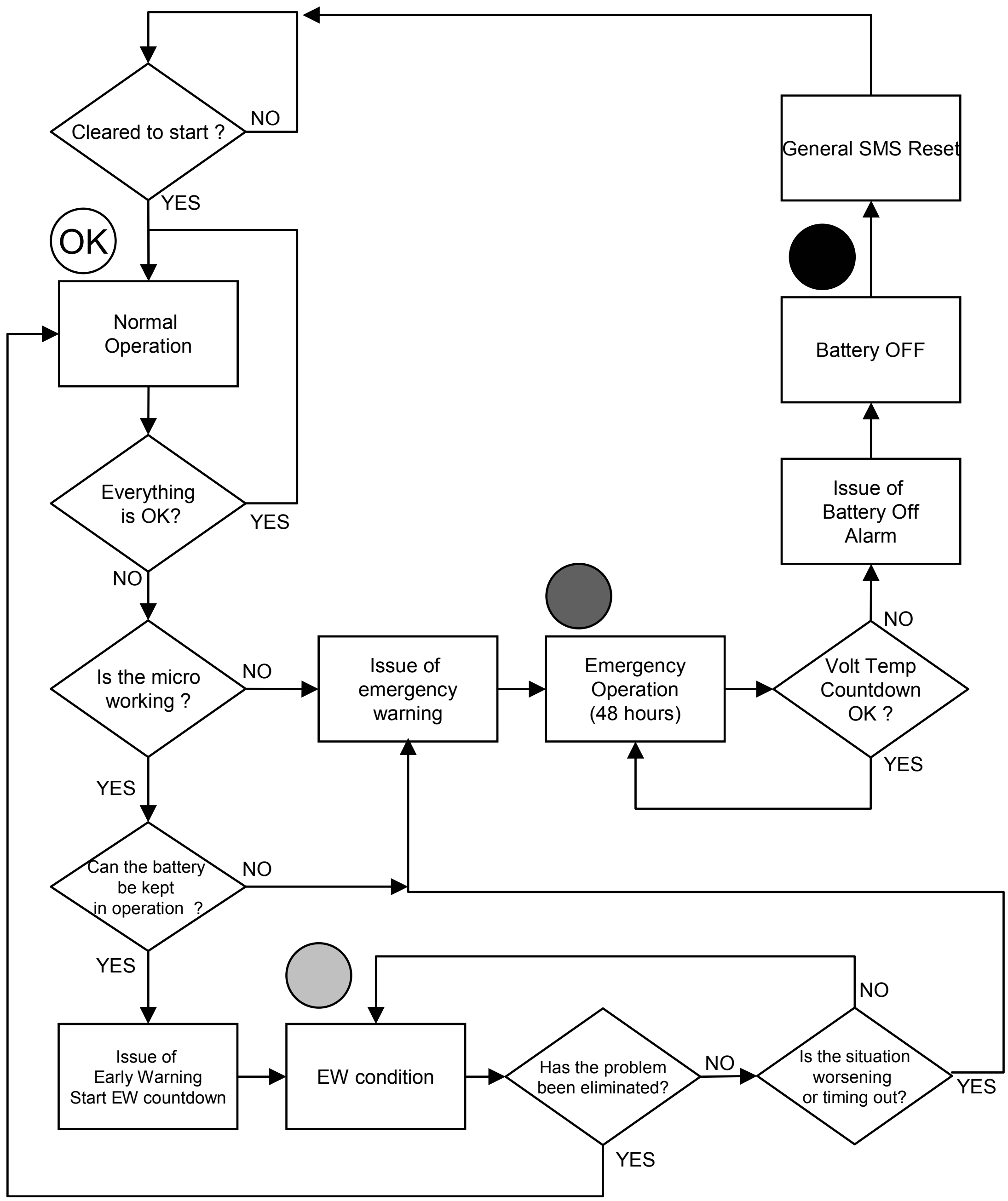

Fig. 5 Flowchart of main loop of the battery management system with sequence of operations in case of failures.

In case of failure of the master controller the safety logic performs independently the following additional actions:

- issue an alarm of malfunctioning;
- take over the battery thermal management at a simpler level
- start an emergency timer to preserve (24-48 hours indicatively) the backup power maintaining the battery operational during this period;
- disabling of Battery Operation

CONCLUSIONS

A smart management system is being developed by FIAMM for SMC battery to be used in standby float operation. The concept of the SMS is dictated by the two targets:

- ensure the backup power by maintaining the battery always operational and in case of failures at least allow enough time for servicing before shutting it down;
- ensure that the battery will never be driven into conditions which might potentially pose a threat to the safety of persons and goods.

The accumulated experience accumulated by FIAMM in the field of conventional battery backup power in standby operation proves very useful in implementing in the SMS provisions to manage all the small or large deviations which actually take place in the field.

REFERENCES

(1) *David Trickett, "Current Status of Health and Safety Issues of Sodium/Metal Chloride Batteries", National Renewable Energy Laboratories, US Department of Energy.*

(2) *A. Brenier, J. McDowall, C. Morin, "A new approach to the Qualification of Lithium Based Battery System", Proceedings of the 26th Intelec, Chicago September 19-23 2004.*