

## **Battery energy storage systems**

### **High availability and improved fire protection**

Today, battery energy storage systems (BESS) make a decisive contribution to electromobility, to the (island) supply of outlying areas, to the integration of renewable energies, to the optimisation of energy use and grid system services. Falling system and technology costs, especially for lithium-ion batteries, support this development as an alternative to conventional storage technology such as pumped storage power plants.

Two forms for larger industrial battery energy storage systems (BESS) have been established for energy producers, industry and grid operators. On the one hand, BESS are partly freely planned and housed in buildings or halls, and on the other hand turnkey container solutions. Depending on the application, such BESS are characterised by a high energy storage capacity (kWh to MWh) or a high-power capability ( $\geq 500$  kW). The use of a transformer for grid connection is also characteristic.

### **Focus on high availability and fire protection**

Power generation as well as transmission and distribution networks undoubtedly constitute an important infrastructure on whose operation the economy in general and industry, public institutions and private households depend. Battery energy storage systems play a key role in these critical infrastructures as critical system services for applications such as peak load shifting and primary control reserve (frequency regulation). In addition, they increasingly give renewable energy generation plants properties of dispatchable conventional generation technology. This significantly improves and guarantees plannability, which would not be possible without storage technology.

System availability therefore also depends on the availability of the used BESS. A decisive criterion of a BESS is therefore its high availability.

The fire load is directly related to the stored energy of a lithium-ion battery. The higher the stored energy, the longer and greater the potential fire. Once a fire has started, it usually does not end until the stored energy has been consumed or released. A fire can be caused by electrical, mechanical or thermal faults.

For this reason, manufacturers of BESS provide comprehensive precautions for fire protection and are constantly looking for new or improved fire protection solutions.

### **... also relevant for other sectors**

High availability and fire protection are not only the focus of battery energy storage systems. High availability and fire protection also play an equally important role in long-established industries and applications. For example, in

- hospitals,
- chemical or processing industry,
- paper and wood processing,
- mining,
- the railway signalling technology,
- data centres,
- automation,
- control circuits.

When setting up the electrical supply system, an unearthed network (IT system) is used. Thus, the basis for high availability and improved fire protection is already laid in the system design.

## Battery energy storage systems - potential in system design

In order to take advantage of the inherent benefits such as high availability and improved fire protection of an unearthed IT system, it must be planned into the system design. This planning decision is simplified by the fact that a transformer can be used in industrial battery energy storage systems due to a higher output (e.g.  $\geq 500$  kW) or when connected to a higher voltage level. This isolates the BESS galvanically from the mains. In addition, the DC circuit between the battery and the inverter is usually designed as an unearthed network.

A characteristic of an IT system is that the active conductors have no connection to earth. Enclosures of the electrical systems are still earthed. Figure 1 shows the simplified schematic structure of an industrial battery energy storage system - consisting of the core components batteries, battery management system (BMS), inverter and transformer. All yellow components concern the monitoring technology. The electrical network is designed as an IT system. The active AC and DC conductors have no connection to earth. The earthing of the devices is not shown here.

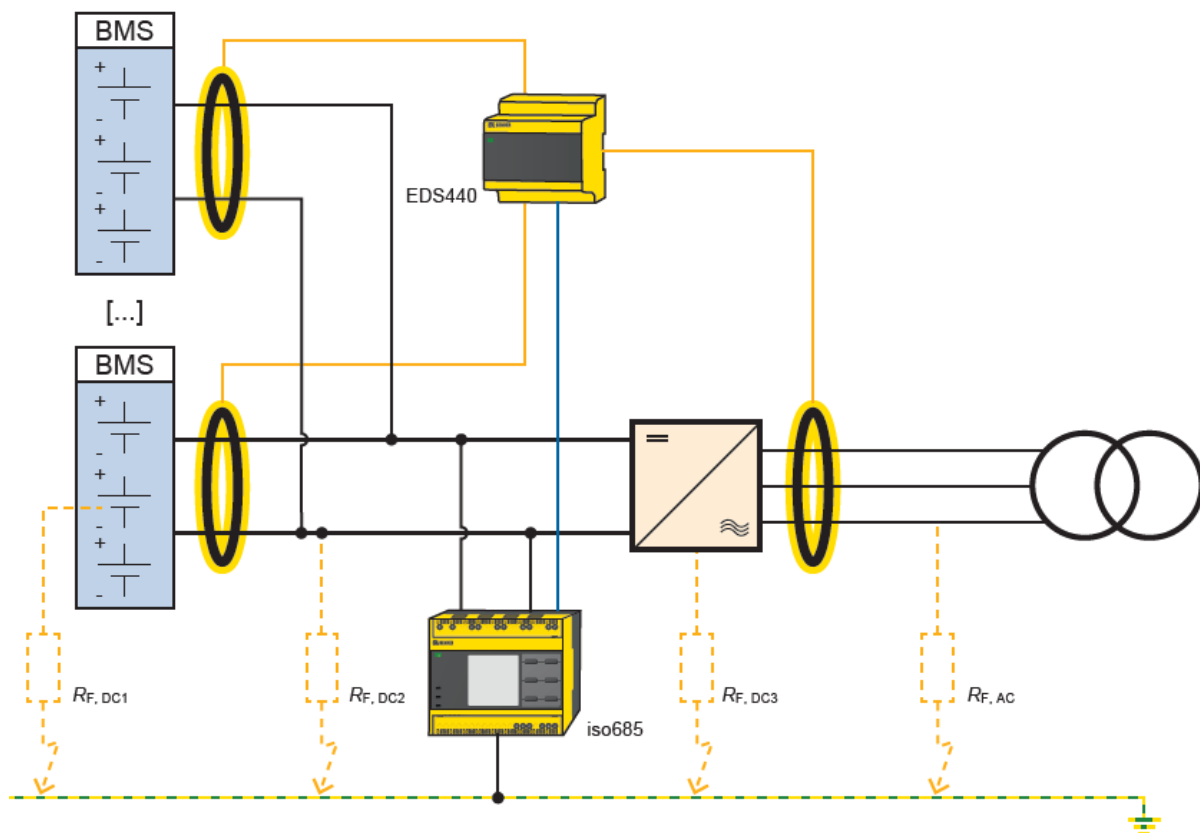


Figure 1: Schematic structure of a battery energy storage system

Battery modules are connected in series and combined in so-called racks. The series connection results in a higher system voltage. The parallel connection of several racks increases performance and storage capacity. The three-phase inverter performs the bidirectional conversion of the energy (DC  $\leftrightarrow$  AC) and is, in addition to the battery itself, decisive for the power flow and performance.

The use of a transformer is characteristic on the one hand due to the connection to a higher voltage level and on the other hand due to the higher power ( $\geq 500$  kW). Finally, this reduces line losses as well. The transformer galvanically insulates the battery energy storage system from the connected mains. Usually, the DC circuit between the battery and the inverter is designed as an unearthed network.

If earthing is provided, this is usually done at the transformer.

However, it is recommended that the AC circuit between the inverter and the transformer is not earthed. In some cases, this is already specified via the transformer switching group, e.g. Dd or Yd. This creates an IT system for the entire battery energy storage system. As explained below, this IT system offers higher availability and improved fire protection for the BESS.

## IT System - high availability and improved fire protection

High availability is guaranteed by the fact that the first fault to earth does not cause the system to shut down. The IT system can theoretically be operated up to the second fault. In practice, however, this time advantage is used to find the insulation fault during operation, for example by means of an insulation fault locating system (IFLS), and then to eliminate it in a proactively planned maintenance.

Improved fire protection compared to an earthed system is achieved by the fact that no fault current flows or can flow at the first fault. In a battery energy storage system, an impulsive load of the batteries with a high fault current, even if only short-term, is thus avoided.

## Fault scenario in the IT system

In addition to the core components, Figure 1 also shows the possible fault locations to earth. Faults to earth may occur

- in the AC circuit between inverter and transformer ( $R_{F,AC}$ ),
- in a cell or series connection of batteries ( $R_{F,DC1}$ ),
- in the DC circuit between battery and inverter ( $R_{F,DC2}$ )
- and in the DC bus of the inverter ( $R_{F,DC3}$ ).

The first fault in an IT system establishes a connection to earth. Depending on the value of the fault and the insulation level, the line-earth voltage of the faulty conductor decreases on the one hand, and the line-earth voltage or voltages in the healthy conductors increases on the other. In the extreme case of a saturated fault ( $0\ \Omega$ ), the voltage drops to almost 0 V and the voltage increases to the line-line voltage.

Due to the earth connection not being carried out, no circuit can occur during the first fault. The system can still be operated despite the first fault.

## Insulation monitoring in the IT system

If an IT system is used, the IEC 60364-4-1 standard requires the use of an insulation monitoring device (IMD) in accordance with product standard IEC 61557-8. Such a device is characterized by an active measurement method. The insulation monitoring device is represented in Figure 1 by an ISOMETER® of type iso685.

Its use is recommended even if no normative specification is made in this respect. An insulation monitoring device can be an alternative to an earth fault monitoring relay, which uses the resulting unbalance voltage or zero-sequence voltage (passive measurement method) as the only measurement criterion for an earth fault. Symmetrical insulation faults and DC faults cannot be detected by such relays. However, symmetrical insulation faults often occur in control circuits and DC voltage networks such as those found in battery energy storage systems. In the mentioned power class ( $\geq 500\ \text{kW}$ ), a common mode voltage can lead to additional negative influences on such relays.

An active measuring method is characterized by the fact that the insulation monitoring device, connected between the active conductors and earth, overlays the mains with a measuring voltage. The insulation resistance of the system is then calculated from the measuring current. A decrease in insulation or even an insulation fault is thus detected.

Because the insulation resistance is permanently determined, it allows the derivation of trend curves and possible predictions.

In particular, the detection of insulation degradation generates an information and time advantage for the operator, see Figure 2. Maintenance work for insulation fault location and removal can be planned proactively. This avoids reactive intervention due to unexpected downtime.

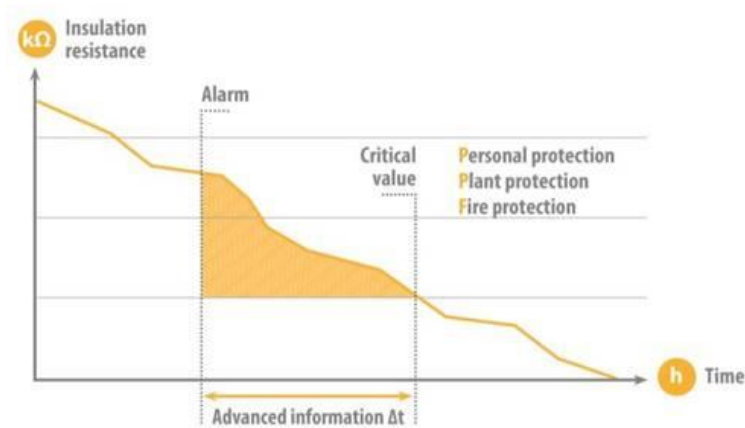


Figure 2: Information and time advantage through active insulation monitoring in the IT system

A battery energy storage system represents a mixed AC and DC network, which are coupled together via the inverter. An insulation monitoring device with active measurement is capable of simultaneously monitoring both the DC and AC networks when the inverter is in operation. Detected insulation faults are classified by the device for better containment, e.g. in AC or DC+ and DC-.

## Insulation fault location

An insulation fault location system (IFLS) requires a locating current injector (LCI), an insulation fault locator (IFL) and one or more locating current sensors (LCS). Depending on the type of the insulation monitoring device, a locating current injector can already be integrated into the insulation monitoring device. In Figure 1, the insulation fault locator is represented by an ISOSCAN® of type EDS440. The locating current injector is integrated into the ISOMETER® of type iso685.

Like the insulation monitoring device, the insulation fault locator is inserted between the active conductors and earth in the system or connected to them. The locating current injector imprints a test current into the system for search purposes. The test current flows via the active conductors through the locating current sensors via the fault location and the earth connection back to the locating current injector. In the event of a fault, the test current sensor detects the impressed test current and the insulation fault locator reports the fault location accordingly. In healthy paths, no test current is registered by the locating current sensors.

A distinction is made between manual (mobile) and automatic (permanently installed) insulation fault detection systems. Combinations are also possible.

The advantage of a fixed and automated system is that the insulation fault location is automatically triggered by an insulation monitoring device, e.g. if the value falls below a response value. The detected fault locations can then be retrieved via a communication system.

A permanently installed and automated IFLS is ideal for monitoring the battery energy storage system up to and including the battery racks. Insulation faults and their locations are automatically detected and displayed. This reduces the time and effort required for maintenance work significantly. Troubleshooting activities can be defined, scheduled and implemented earlier.

Manual and mobile insulation fault location can then be used for granular localization of insulation faults within a rack. The challenge in this area is the cable routing of the two active conductors, which must be routed together through a measuring current clamp.

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4

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