DIFFERENCES BETWEEN EMOS® SAFETY SYSTEM AND BALANCE VOLTAGE MONITORING SYSTEMS

White Paper

INTRODUCTION

Plant safety has always been a key concern for chlor-alkali companies, but it is becoming even more critical today due to zero-gap electrolyzers, as well as tightening environmental and workers safety regulations in most countries. Three main types of systems are available to safeguard membrane chlor-alkali plants against faults, with widely different levels of protection: balance voltage monitoring systems (BVMS), single cell voltage monitoring systems, and R2's EMOS® SIL2 safety system based on single cell voltage monitoring and on the analysis of the current-voltage-time relationship of individual cells versus the neighbor cells. This document describes the high-level operating principles of these types of systems, their key differences, and concludes with examples of how these systems react to three kinds of incidents.

PRINCIPLES OF OPERATION

Principle of Operation of Balance Voltage Monitoring System

Balance voltage monitoring systems (BVMS), also called voltage deviation systems (EDI), are the traditional method of providing protection to membrane electrolysers. The BVMS measures the voltage difference between the two halves of the electrolyser. If the voltage difference is greater or lower than a certain set point, the BVMS will automatically shut down the power source to prevent accident.

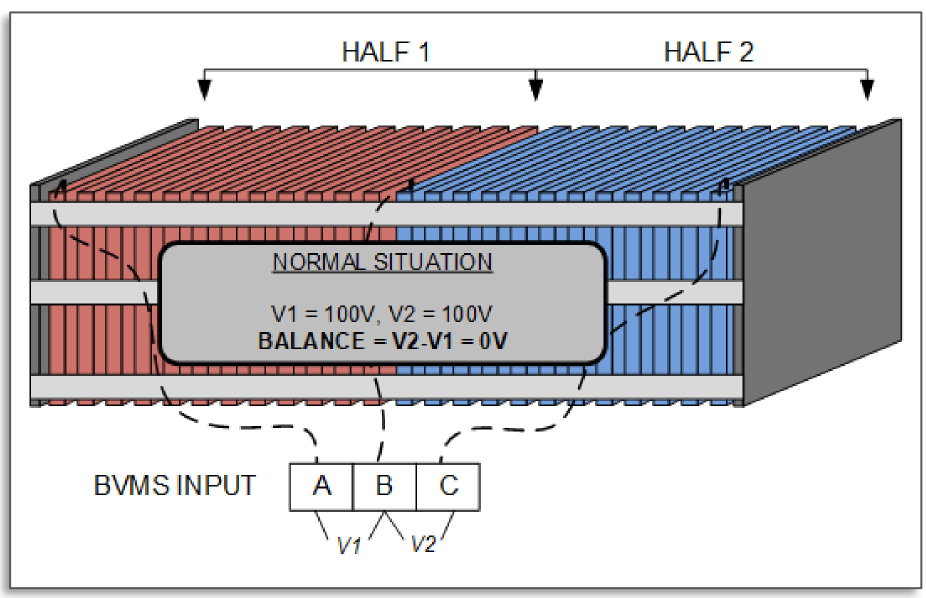

Figure 1: Principle of operation of BVMS system

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In some cases, a second algorithm is used: the rate of change of the voltage over time (dV/dt). The total electrolyser voltage is measured and if the total measurement changes too fast (in volts per second), the BVMS will automatically shut down the power source to prevent an accident.

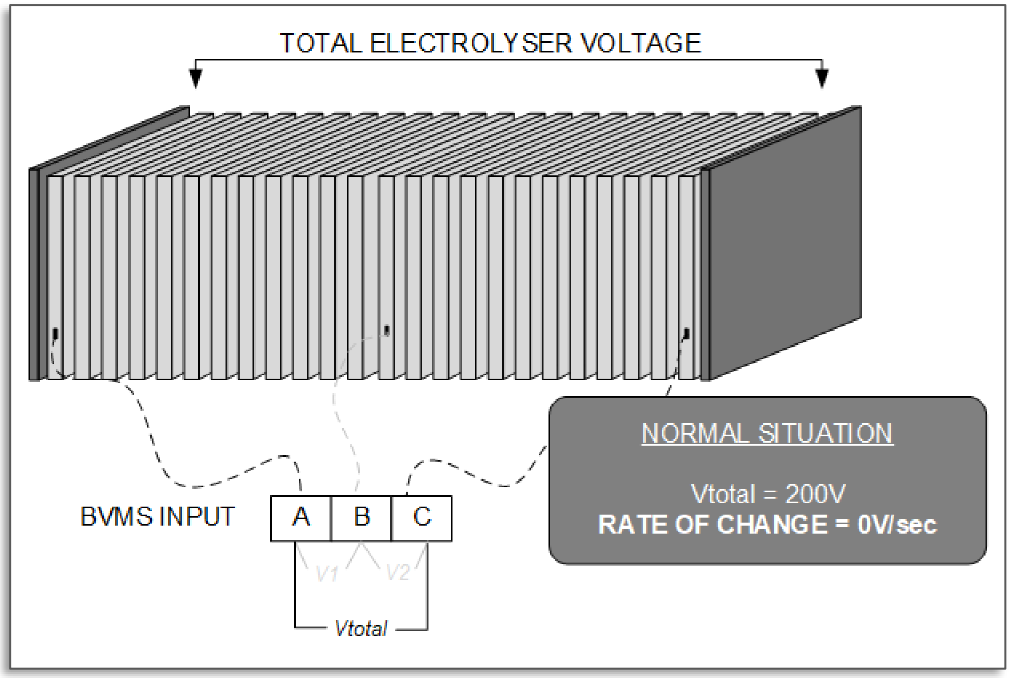

Figure 2: Rate of change measurement

Principle of Operation of Single Cell Voltage Monitoring System

Single cell voltage monitoring systems are based, as the name implies, on individual cell voltage measurement (Figure 3). If any of the individual cell voltage behaves dangerously, the electrolyser power supply is automatically stopped to prevent an accident. The trip level is a fixed HIHI value and offers no protection in the case of a dangerous LOLO value, due for instance to a short circuit or a membrane rupture. Moreover, a fixed HIHI trip only protects during normal operation at high load: it does not work during startups, shutdowns or operation at low loads.

Principle of Operation of EMOS® SIL2 Safety System

The goal of the EMOS® Safety System is to offer protection during all mode of operations and against all known events in a cell-room. It relies too on individual cell voltage monitoring, with the important addition of dynamic trips that are calculated in real-time and based on the analysis of the current-voltage-time relationship of individual cells versus the neighbor cells (Figure 4).

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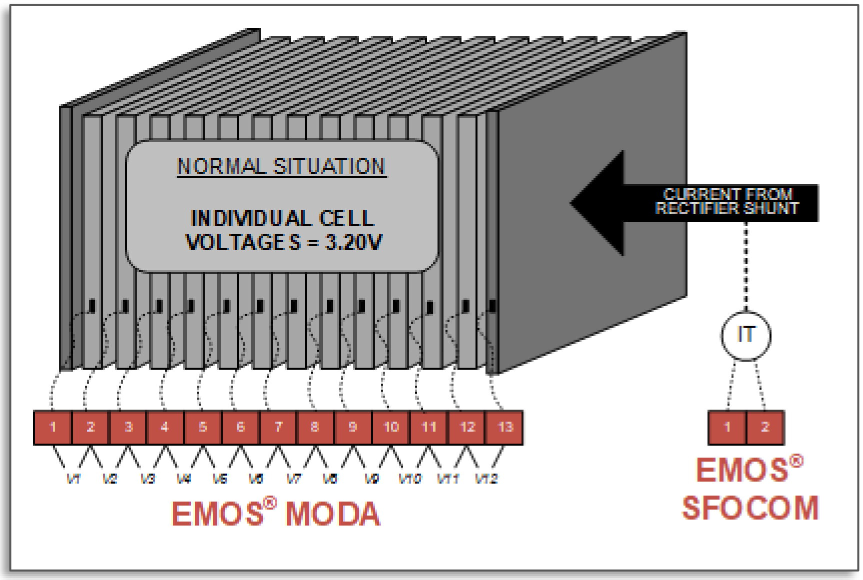

Figure 3: Single cell voltage measurement (the MODA is the intelligent sensor, and the SFOCOM is the logic solver located in the SILCAM)

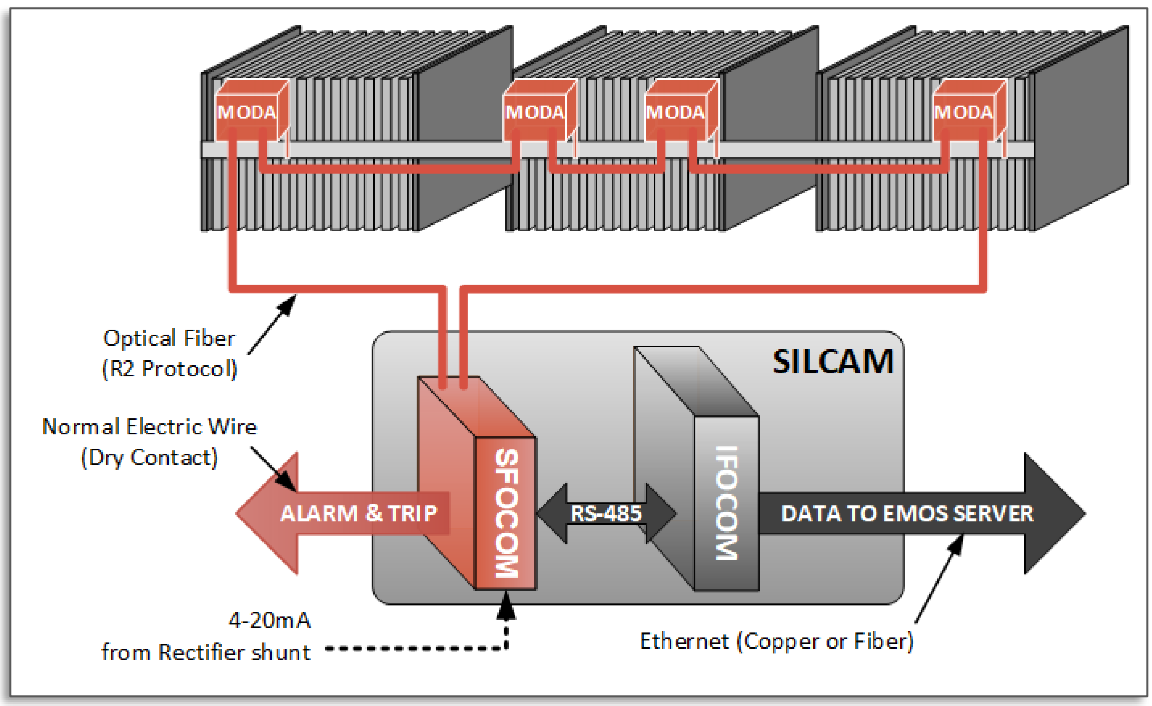

Figure 4: Block diagram of EMOS® SIL2 Safety System

DIFFERENCE #1: PROTECTION LEVEL

As shown in Figure 5, the trip levels of the BVMS do not vary with rectifier load, which means the BVMS system does not protect against faults when the electrolyser operates at lower loads, a potentially hazardous situation. In addition, the BVMS fixed trips are very high and will not offer sufficient protection if a cell boils. When changing load or when operating at lower loads (start-up), the operator will most likely "balance" the BVMS to avoid false trips. Therefore, if a single cell starts behaving abnormally during these circumstances, the event will most probably go undetected because of the lack of measurement granularity.
Moreover, a BVMS cannot protect against the worst incidents (membrane ruptures and short circuits) because the voltage decrease of the affected cell is compensated by the voltage increase of the neighbour cells. The total voltage change of the group of cells is then too small to be detected.

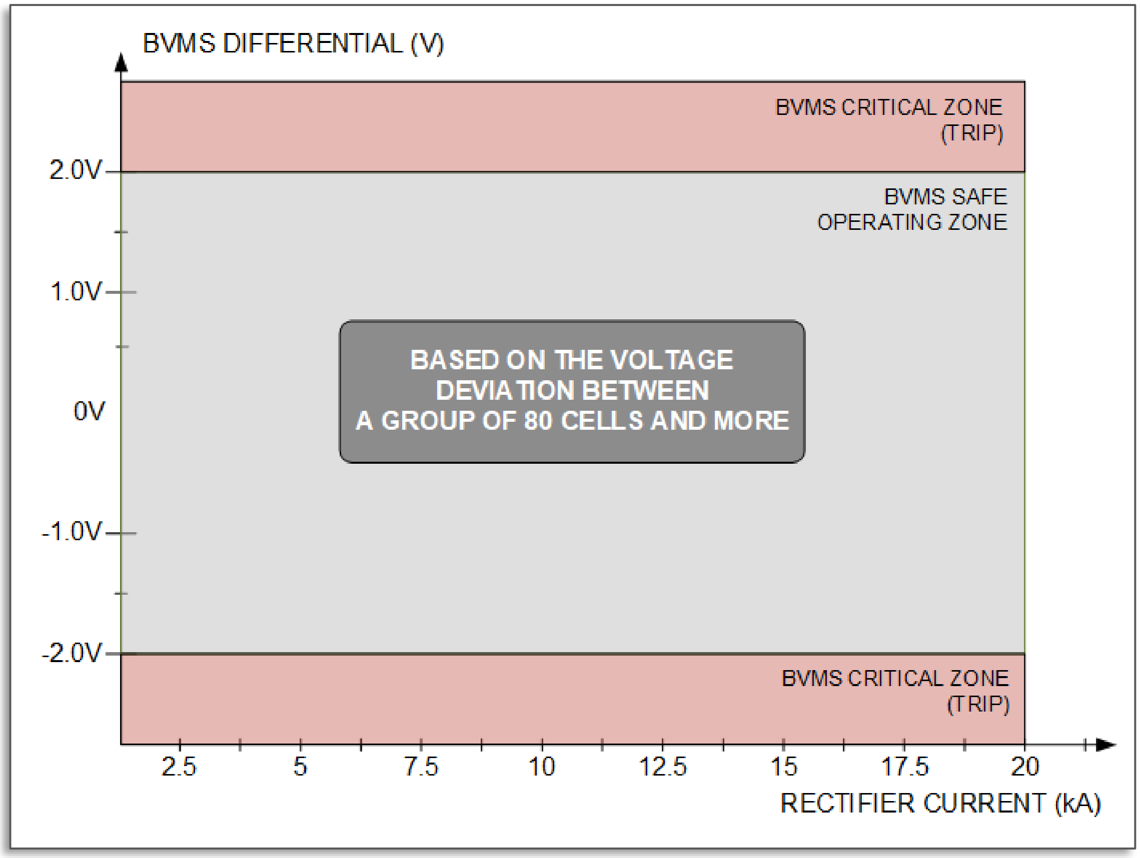

Figure 5: BVMS level of protection over the load range

On the other hand, the EMOS® safety system provides adequate level of protection at any point of operation, including startup and shutdown, because the trip levels change with the load and with the behavior of the neighbor cells. Figure 6 depicts the combined individual voltages limits of three algorithms that will be described in greater detail below. Because of these advanced algorithms, the EMOS® safety system adequately safeguards electrolyzers against membranes ruptures and short circuits.

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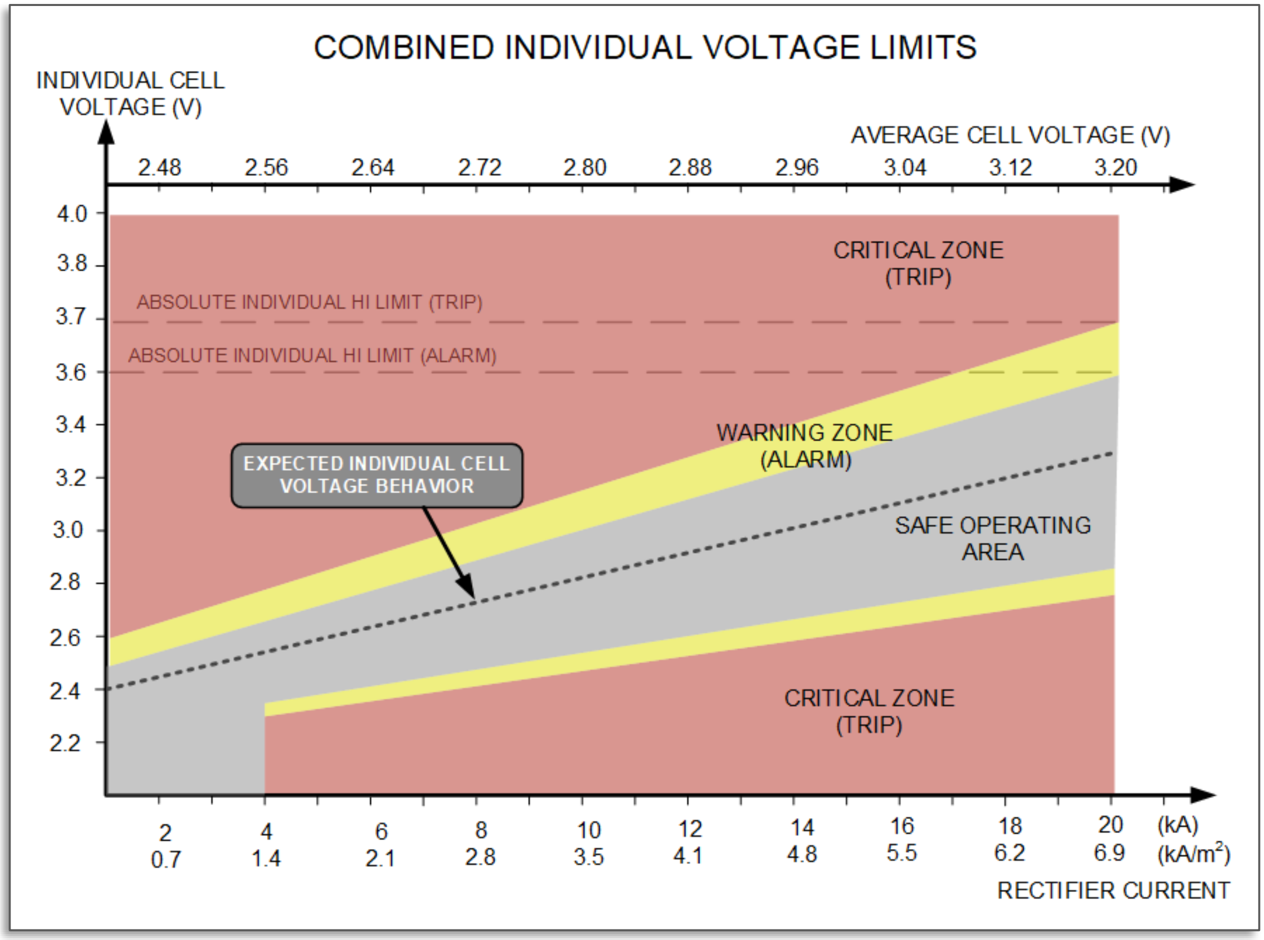

Figure 6: Combined individual voltages limits

Absolute individual HI/HIHI cell voltage limit

This is an older algorithm that has been replaced by better, newer algorithms (see below). The individual cell voltage limits are fixed regardless of the operating conditions (Figure 7). This algorithm offers suitable protection only when the electrolyser is operated at maximum load and when the event causes a voltage increase.

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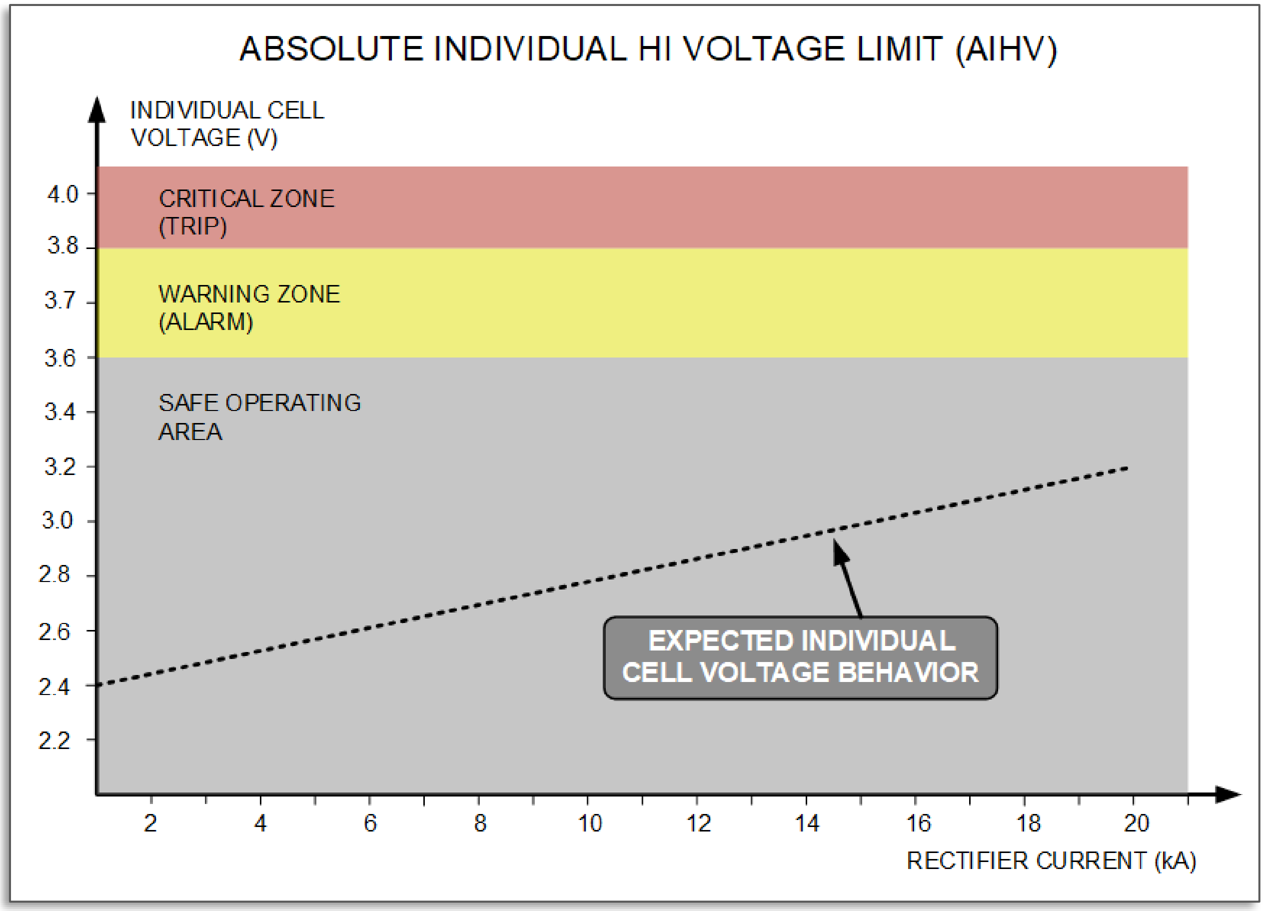

Figure 7: Absolute individual hi cell voltage limit

Thermal individual HI cell voltage limit

At maximum load, with all the cells around 3.2 V for example, it is acceptable that a single cell exhibits a voltage of 3.3 V. But when the electrolyser is operated at 50% load and the average cell voltage is 2.85 V, a cell voltage at 3.3 V dissipates a lot of excess energy, a really dangerous situation. The thermal individual high cell voltage limit is based on the amount of excess energy (heat) allowed for an individual cell: no more than 50% excess heat compared to the other cells of the electrolyser is tolerated. It offers suitable level of protection at any point of operation (Figure 8).

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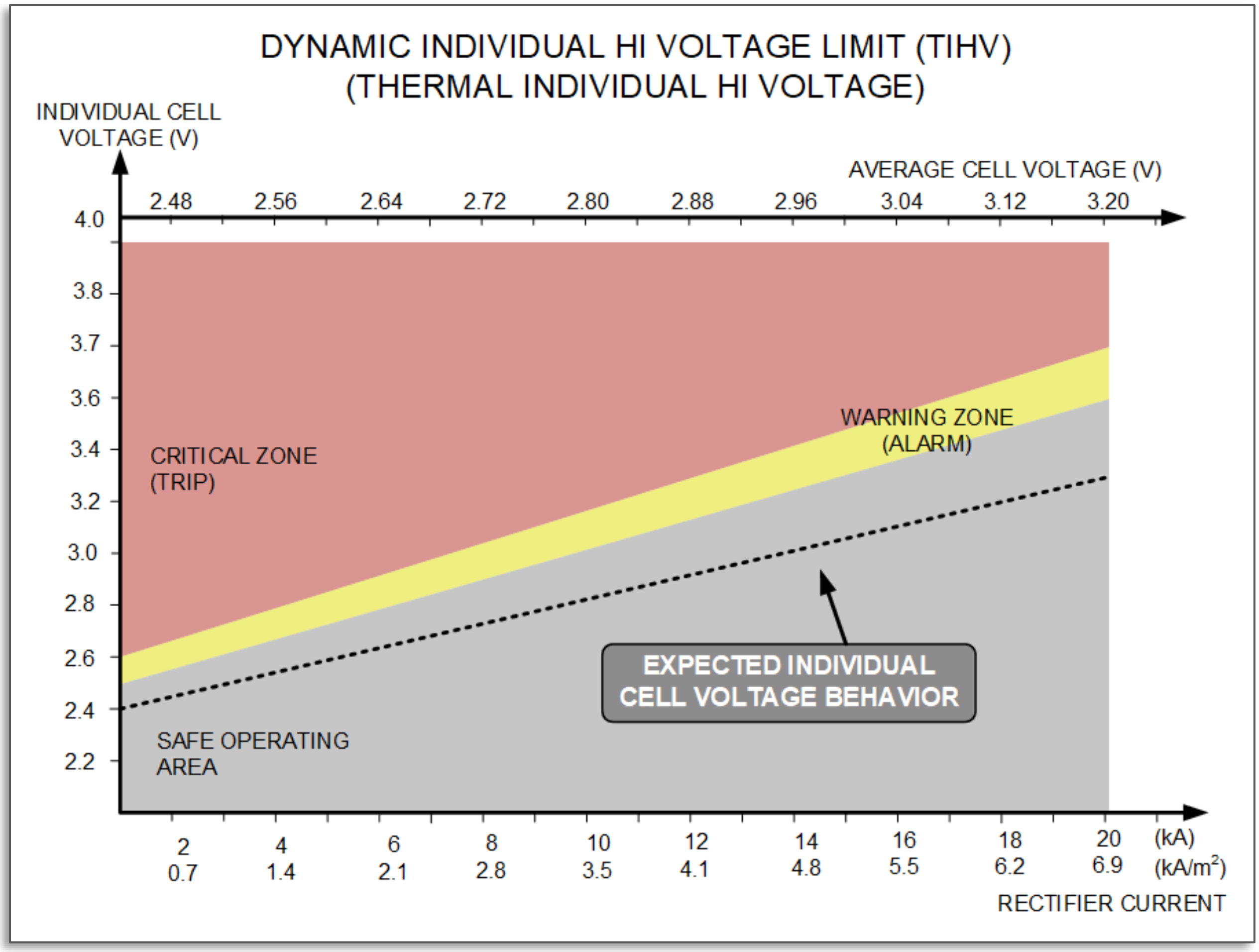

Figure 8: Thermal individual HI cell voltage limit

THERMAL INDIVIDUAL CELL VOLTAGE ALGORITHM PROTECTS AGAINST
✓ Cell Leakage
✓ Insufficient Electrolyte Feed
✓ Electrode Loss of Coating

Table 1: Incidents prevented by thermal individual cell voltage algorithm

Normalized individual LO cell voltage limit

The most fragile piece of equipment on the membrane electrolyser is the membrane. Membrane failure is very dangerous because a mixture of chlorine and hydrogen can explode. When a membrane ruptures the electrolyzer has to be idled as fast as possible.

The normalized individual low cell voltage limit provides protection against this possibility by tripping on low cell voltage (Figure 9). The limits are calculated in real-time and adjusted according to the electrolyser rate of operation.

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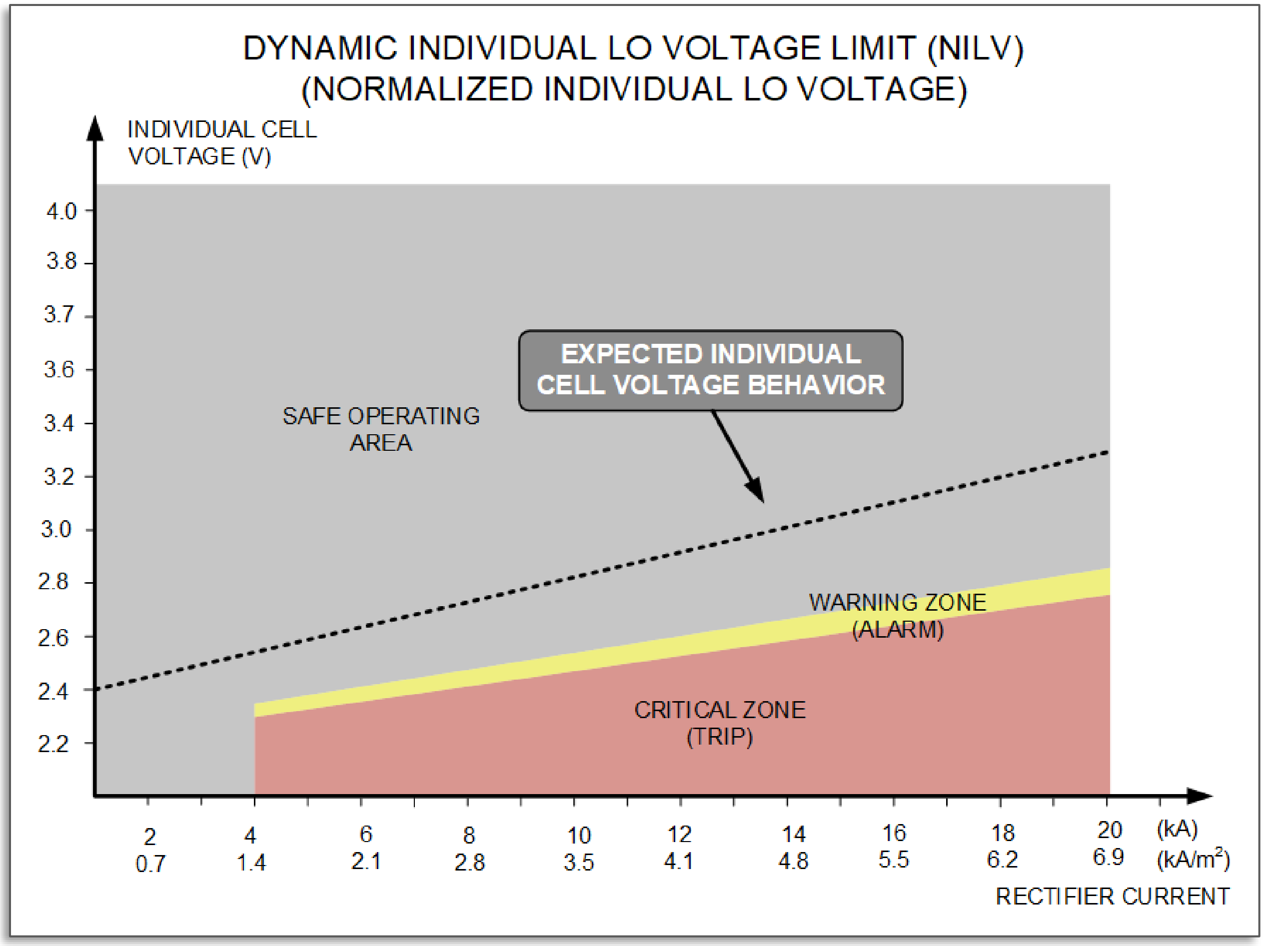

Figure 9: Normalized individual lo cell voltage limit

NORMALIZED INDIVIDUAL LO CELL VOLTAGE ALGORITHM PROTECTS AGAINST
✓ Membrane Pinhole
✓ Membrane Tear
✓ Membrane Blister
✓ Short-Circuit

Table 2: Incidents prevented by normalized individual lo cell voltage algorithm

Based on the previous discussion, it is clear that only the EMOS® safety system provides full protection against the most dangerous incidents, membrane ruptures and short circuits.

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DIFFERENCE #2: PROTECTION LEVEL DURING LOAD CHANGES

This second difference between a safety and a BVMS derives from difference #1: given that a BVMS system offers a minimum level of protection only at stable full load, it means that the BVMS is unusable during load changes, when many types of problems can occur. On the contrary, the EMOS ®safety systems remain fully operational during load changes.

DIFFERENCE #3: DETECTION OF DISCONNECTED WIRES

A voltage deviation system like a BVMS or single cell voltage monitoring system cannot distinguish between a safety hazard causing a decrease in voltage (like a membrane pinhole or tear) and a disconnected wire. Depending on the voltage difference between the two blocks, the electrolyzer could trip or not due to a disconnected wire, leading to unnecessary downtime (false trip).

On the other hand, the EMOS® safety system incorporates, for each group of 8 readings, a total measurement which determines the expected sum of the 8 readings. If the measured total is not equal to the algebraic sum of 8 single readings, all 8 cells are declared « bad » because the measurements cannot be considered reliable (absence of correlation). If a wire is disconnected from the cell, the expected system behavior is to read a cell voltage near 0 volts, resulting in the sum of the 8 voltages being different from the total reading (Figure 10). In consequence, the hardware fails-safe of the of EMOS® safety system will ensure the electrolyser does not trip due to a disconnected wire and will advise the operator by sending a hardware fault alarm.

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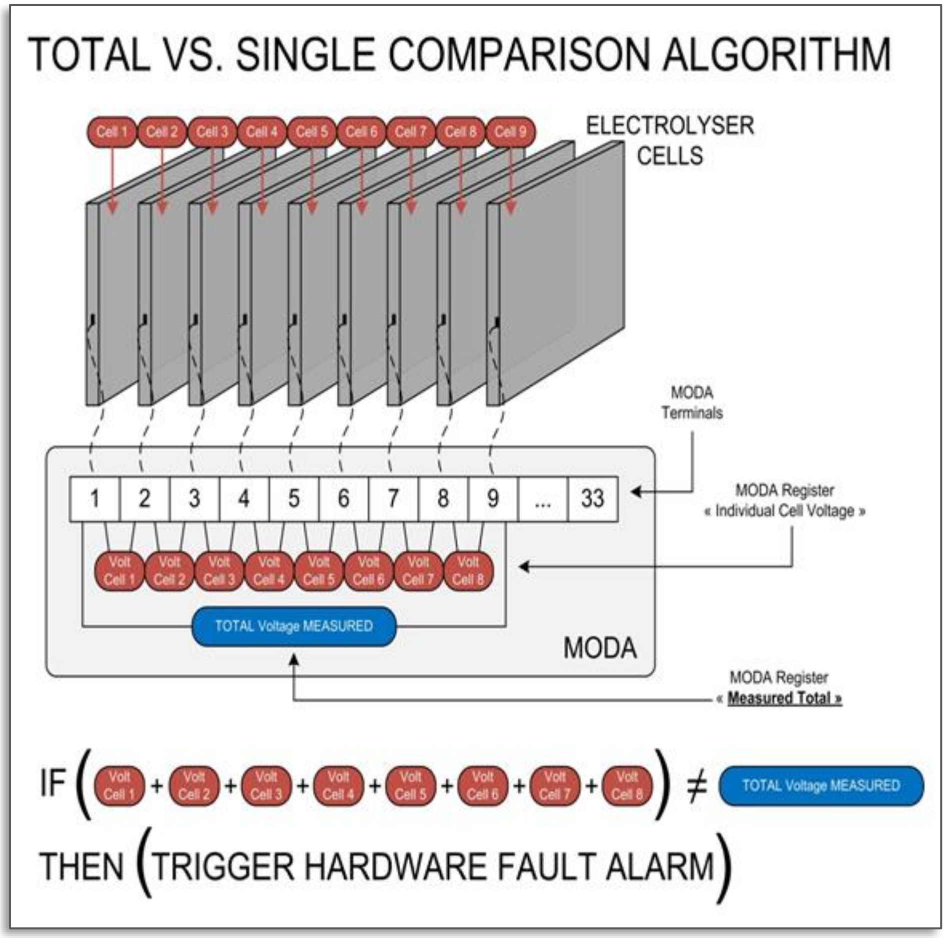

Figure 10: Detection of disconnected wires by EMOS® safety system

DIFFERENCES #4: POSSIBILITY OF FALSE TRIPS

The rectifier generates an important level of noise. The EMOS safety system features electrical noise filtering in order to increase the accuracy of the voltage reading. Furthermore, the EMOS® safety system have diagnostic routines to validate the measurements before tripping. Therefore, the likelihood of false trips is very low.

BVMS do not filter out the electrical noise, which entails that trip levels have to be widened to compensate for the high electrical noise. Accordingly, the level of protection is lower, and the risk of false trips still remains.

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EXAMPLE #1: LEAKING CELL

Let us now compare how the EMOS® safety system and BVMS react to specific incidents.

During normal operation (half operating capacity), one of the cells starts to leak. The leak is minor at first but rapidly worsens. At 50% load, the EMOS® safety system trip on Individual HIHI voltage is calculated at 3.20 V. For BVMS, it is still fixed at 2.00V (Differential). As shown in Table 2 and Figure 11, the EMOS® safety system trips much earlier than the BVMS, reducing the extent of the damage.

Sequence of Events					
TIME	CONDITION	EMOS (Individual Cell Voltage)		BVMS (Differential Cell Voltage)	
		Measured (V)	HI Trip (V)	Measured (V)	Trip (V)
T01	Normal Operating Condition	2.75	3.20	0.00	2.00
T02	Cell Starts Leaking	2.90		0.15	
T03	Leakage becomes Serious	3.05		0.30	
T04	Trip from EMOS® **(Increase of 0.5V)**	3.20		0.45	
T05	Trip from BVMS **(Increase of 2.0V)**	4.75		2.00	

Table 3: Sequence of events for leaking cell

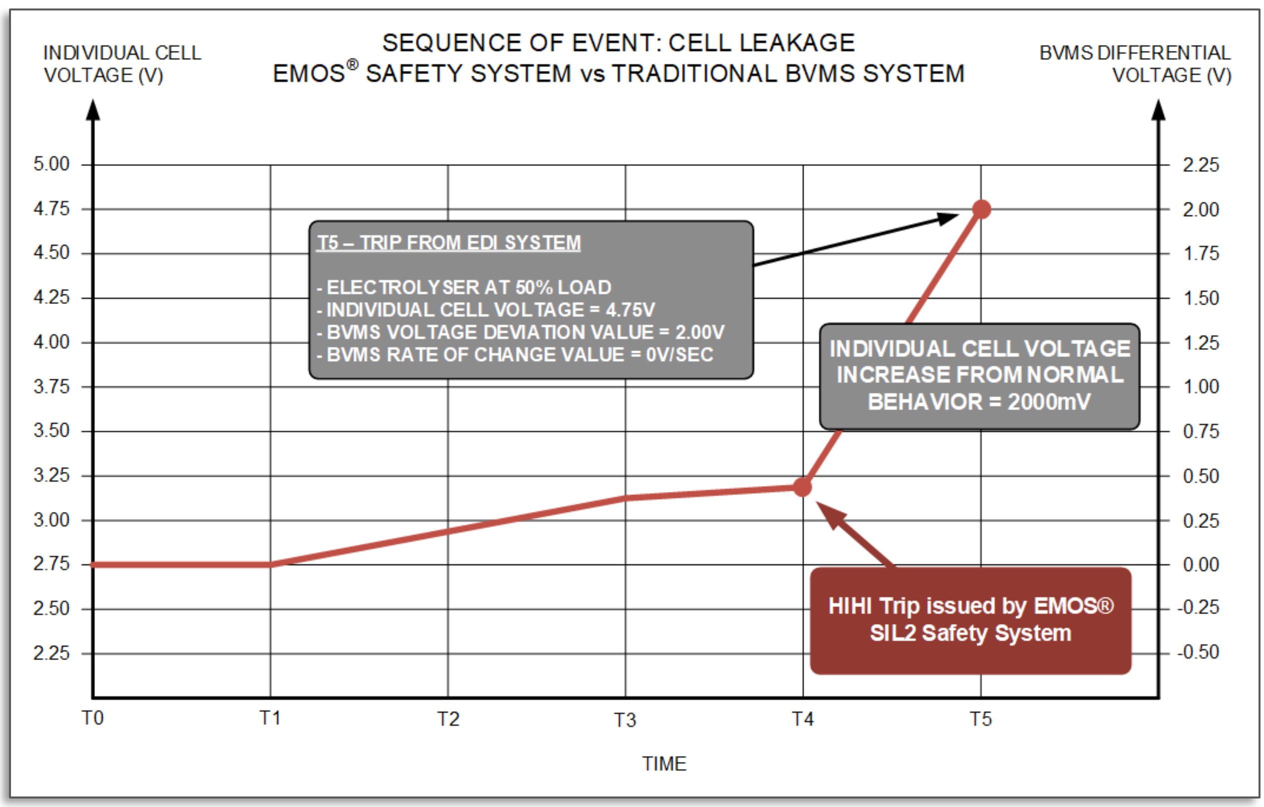

Figure 11: Sequence of events for leaking cell

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EXAMPLE #2: MEMBRANE FAILURE

During a load increase from 50% to 100% operating capacity, one of the membranes has a failure (it tears). This situation is very dangerous and the electrolyser should be stopped as soon as possible to avoid mixture of Cl_2 and H_2. Since the EMOS® safety system (individual cell voltage) remains operational throughout the load change, the membrane failure is detected rapidly and the electrolyzer trips. However, the BVMS never detects this severe hazard before it is disabled during load changes (Table 4) and because of the compensating voltage increase of the neighbor cells close to the one with a ruptured membrane (whose voltage goes down).

Sequence of Events					
TIME	CONDITION	EMOS (Individual Cell Volt.)		BVMS (Differential Cell Volt.)	
		Measured (V)	LO Trip (V)	Measured (V)	Trip (V)
T00	Steady Operation at 50% load.	2.75	2.50	0.00	
T01	Change of set point from 50% load to 100% load. Cell voltage starts to increase.	2.80	2.75	(Disabled)	2.00
T02	During the increase (now at 75% load), one of the membranes fails.	3.00		(Disabled)	
T02 to T03	Membrane failure causes the cell voltage to become dangerously low compared to the rest of the cells. EMOS® SIL2 Safety System trips on LOLO cell voltage **(VERY FAST)**.	2.74		(Disabled)	
T04	Now the load change is finished, rectifier is at 100% load, BVMS is put to zero and safety interlock is enabled. **(BVMS SET-POINT WAS NEVER REACHED BECAUSE THE BVMS INTERLOCKS ARE DISABLED DURING LOAD CHANGE)**	1.80		NEVER!	

Table 4: Sequence of events for membrane failure

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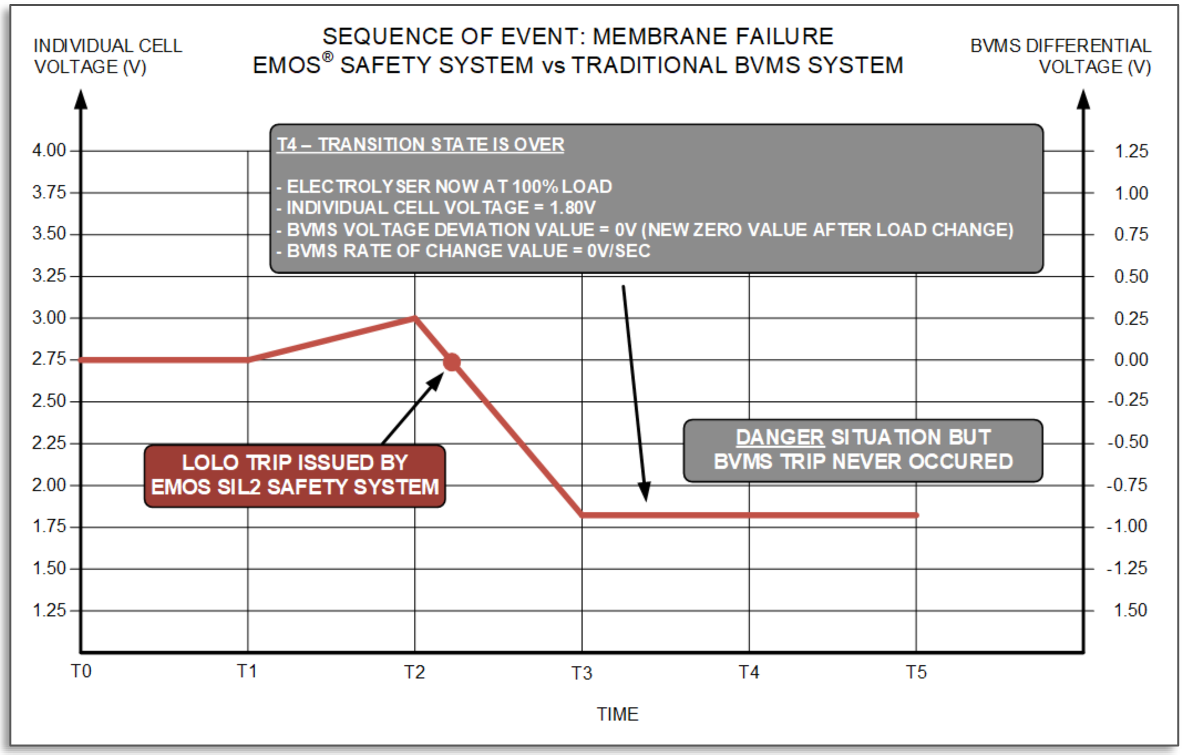

Figure 12: Sequence of events for membrane failure

EXAMPLE #3: SHORT CIRCUIT BETWEEN CELLS

A gasket failure at the catholyte outlet nozzle causes a small leakage. A wet “cauliflower” starts growing to the outlet nozzle of the neighbor cell. Then a short circuit occurs, the voltage of the cell decreases rapidly while the neighboring cell voltage increases due to an uneven current distribution. The EMOS® safety system immediately recognizes the situation and trips the electrolyser at 2.79V within 1 second of the short circuit. The BVMS has never triggered the trip as the event was too fast for the dV/dt sampling rate and the mirror effect of neighbor cell voltages prevented the detection by differential voltage. After 2 minutes, all voltages are normal again (cauliflower burned away) but the heat caused by the short circuit melts the catholyte hose. H_2 is released from the main header, and it starts burning. The incident is only exposed by the fire detector in cell room 10 minutes later. The plant will be offline for a long period.

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Sequence of Events					
TIME	CONDITION	EMOS (Individual Cell Volt.)		BVMS (Differential Cell Volt.)	
		Measured (V)	LO Trip (V)	Measured (V)	Trip (V)
T00	Normal operation at full load.	3.20	2.80	0.00	2.00
T01	Short circuit occurs, voltage of cell decreases, voltage of neighbor cells increases.	3.15		0.00	
T01 to T02	Trip from EMOS® SIL2 Safety System is issued within 1 second of short-circuit.	2.79		0.00	
T02	Cell temperature is kept very high because of uneven current distribution.	2.70		0.00	
T03 to T04	After 2 minutes all voltages are normal again. Hydrogen released from main header is burning!	3.20		0.00	

Table 5: Sequence of events for short circuit

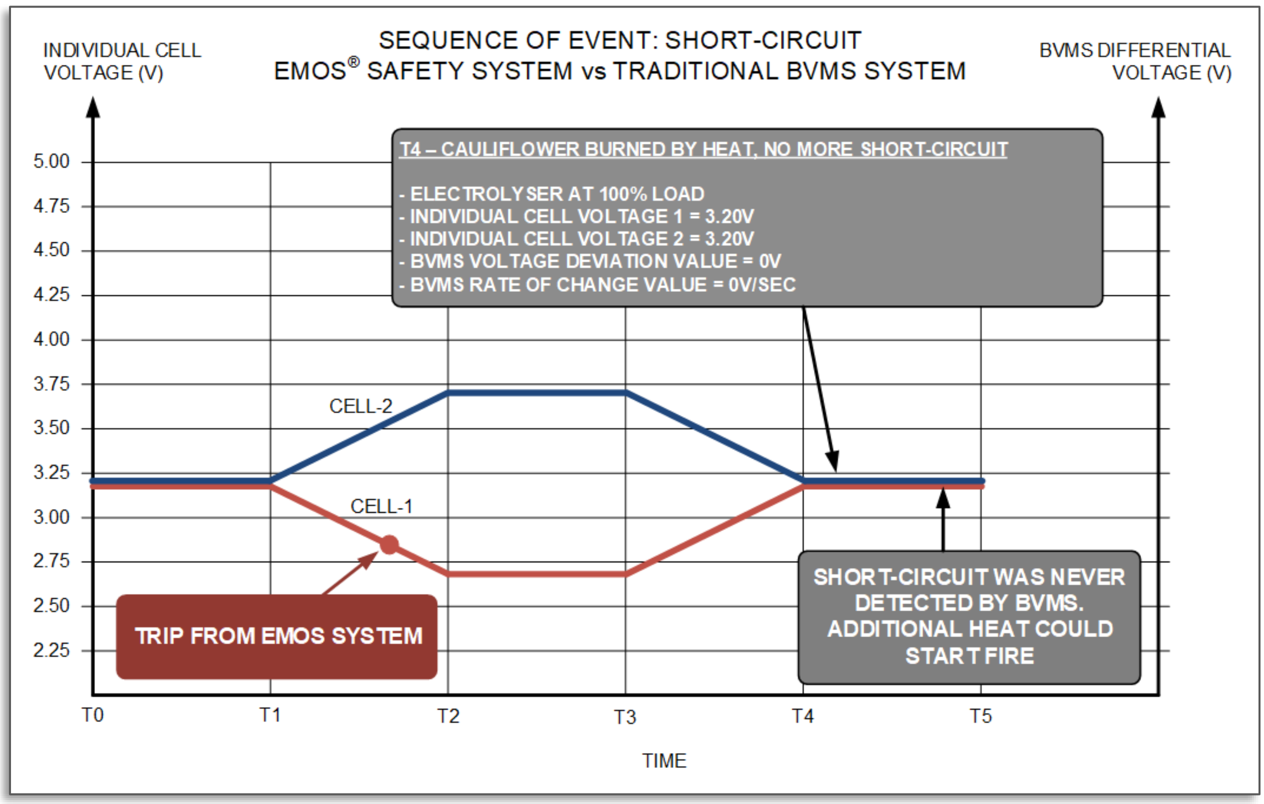

Figure 13: Sequence of events for short circuit

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CONCLUSION

As demonstrated above, the unique EMOS® safety systems offer a much more comprehensive electrolyser protection versus deviation systems (EDI / BVMS). Here is a summary of the key differences

FEATURES	EMOS® SAFETY SYSTEM	TRADITIONAL BVMS SYSTEM
Level of protection	Protection against all known causes of failure thanks to three algorithms	Limited to the detection of some problems only. Unusable during load changes.
Protection during load changes	Yes	No
Protection against major incidents (short circuits and membrane ruptures)	Yes, because of sophisticated algorithms.	No, because the voltage decrease of the affected cell is compensated by the voltage increase of the neighbour cells. The total voltage change of the group of cells is then too small to be detected.
Automatic detection of disconnected wires during normal operation	Yes, disconnected wire will be detected, but system won't trip because of validation algorithm.	No. Immediate Trip.
Trip Levels	Dynamic, they are calculated in real time to provide the proper level of protection at any point of operation.	Basic Protection Only.
Possibility of false trips	Very low possibility, the system has diagnostic routines to validate the measurements before tripping. Electrical noise is filtered	Probable, if operators forget to balance during load changes. Also more likely due to high electrical noise: trip levels must be widened to compensate, lowering the level of protection.
Additional Features:	- Automatic pinhole detection during startup and shutdown - Single cell temperature calculation - Root cause identification of incidents and recommendations of corrective action - Very precise characterization of each of the cell components independently (anode coating, membrane, cathode coating) to reduce power consumption and improve maintenance	None

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