Smart Mobile Earthing Trolley (SET) to Operate Aluminium Smelter Potline with Fixed Null Point

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Abstract

Modern aluminium smelters are operated at high DC currents and potline voltages up to 2000 V. These pot lines are usually earthed at mid-point to bring the potential of the pot lines with respect to earth to a maximum of ± half of pot line voltage. Even though, the potroom aisles and the basement are designed to be at floating or earth-free potential, some activities, such as pot shell replacement and gutter cleaning require additional safeguards for the personnel which consist of moving the earthed point to the worksite. This is usually done with a Mobile Earthing Trolley (MET) which connects a specific pot busbar to a nearby earthing post on the pot line earthing circuit.

In EGA Al Taweelah, Smart Mobile Earthing Trolley (SET) was designed, using Programmable Logic Controller (PLC), a standard high speed DC circuit breaker and fuse as well as other standard electrical and electronic components. The standard components were built in for easy maintenance. All the components are rated for 60 °C ambient temperature.

SET maintains designated pot bus bar at earth potential and interrupts the connection to earth with high speed circuit breaker within 50 ms when a second ground occurs accidentally in the potline and causes high leakage current to flow through SET. SET monitors leakage currents continuously; this gives additional information on the condition of potline insulation to earth. All SET monitoring signals are available locally on HMI and are communicated to potline SCADA through wireless devices. Operator can also enter pot number, earthling trolley user mobile numbers on HMI with the option of predefined and customized SET users to receive alarms. SET status is available on the operating floor through wireless flasher and sounder. SET control power supply is derived through UPS which maintains SET in operation even in case of potline or auxiliary power failure.

Key words: Smart Mobile Earthing Trolley, Mobile Earthling Trolley, potline leakage current detector, potline electrical safety device, grounding trolley.

1. Introduction

An aluminium electrolysis potline is composed of many pots connected in series. Modern aluminium smelters, with the evolution of high amperage smelting technology, are operated at high DC voltages up to 2000 V and currents in the range of 400 kA to more than 600 kA with typical pot voltages in the range 4.0 V to 4.5 V DC. The high potline voltages impose extra

challenges to enhance and maintain high safety standards for the personnel working in potrooms. This demands high insulation between pots and ground and continuous monitoring of leakage currents between the potline and ground. The general principles of the electrical safety in potrooms have been explained before in [1]. Here we will describe the development, testing and implementation of the Smart Mobile Earthing Trolley (SET) at EGA, which is the central piece of equipment for electrical safety in potrooms.

The maximum voltage of the potline to ground can be reduced to one half of potline voltage by fixing the potline-to-ground potential to zero ("Null point") at the middle of the potline. This is achieved by using an earthing device. In modern potlines this device is mobile and is called Mobile Earthing Trolley (MET) which, as the name tells, can be displaced from its normal position at mid-point of the potline to any other pot to make it safer to work on as discussed further on. EGA has developed an innovative earthing trolley, called Smart Mobile Earthing Trolley (SET) which has many new advanced features which increase its reliability and electrical safety in the potlines. This equipment not only keeps the local potential to earth at zero and monitors leakage currents continuously, but also interacts with operators by providing warning messages in case of abnormalities in the potline that tell them to leave the workplace for their safety if high leakage currents or voltages are present.

An important advantage of having fixed instead of floating null point appears when a second ground occurs accidentally in the potline, for example due to a pot tap-out or equipment bridging to earth. If this earth is strong, large current will pass through it and through SET with which it makes a closed short-circuit; this current will open the high speed circuit breaker or burn out the fuse in SET and interrupt the circuit before the current reaches 200 – 300 A. At this moment the potline will be grounded at the short circuit location only, making the positive and negative voltages at the rectifier unbalanced. From this unbalance, the position of short-circuit to earth can be determined. This situation needs to be investigated and corrected quickly in order to restore the earthing trolley at mid-point of the pot line.

In principle any displacement of null point from the mid-point of the potline is undesirable as it increases pot voltage to ground above half of the pot line voltage in some pots, depending on where the short-circuit to earth occurs or where the earthing trolley is installed. In worst scenario the maximum pot voltage to earth can be full pot line voltage, this happens when the earthing trolley or a short circuit is at the first pot near the rectifier, either on the positive or negative side. An example is shown in Figure 1 for Potline 3 at EGA Al Taweelah which has 444 DX + Technology pots. The potline consists of two potrooms, each having 222 pots. The pots are intentionally grounded at the mid-point of the potline at Pot 222 using an earthing trolley. The potline voltage is 1900 V. In normal situation shown, the voltage of Pot A001 to earth is - 950 V and of Pot B001 is + 950 V. If Pot A001 is earthed, the voltage of Pot B001 to earth will be + 1900 V. If Pot B001 is earthed, the voltage of Pot A001 to earth will be - 1900 V.

2. Potroom Construction

Potrooms are built for maximum electrical safety in which the principle is to keep earth away from the working zones either by distance or by insulation. Figure 2 shows zones of different electrical potentials in the potrooms: Pot potential (red), Ground (or earth) potential (green) and floating potential (blue). Floating potential is an insulation layer between pot potential and ground potential. The role of insulators is to keep the pot and ground potential absolutely separated. In the potrooms, the earth free zone extends to a minimum height of 2.5 meters above operating floor level (columns encased in concrete and covered with insulating material). Pot room basement floor is built with special cement having very high electrical resistivity such as silica cement and is at floating potential when dry or free of metal spills.

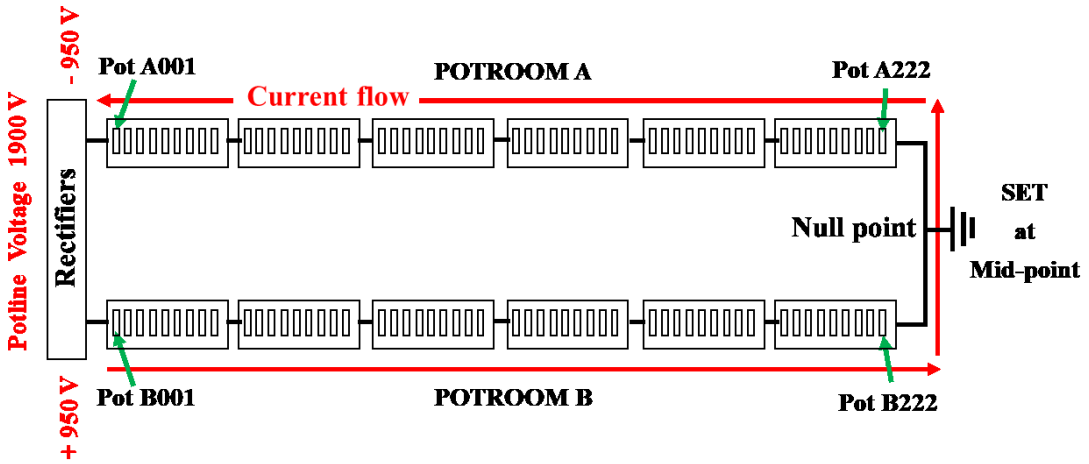

Figure 1. EGA Al Taweelah Potline 3 in normal operation with Smart Earthing Trolley (SET) at mid-point of the potline.

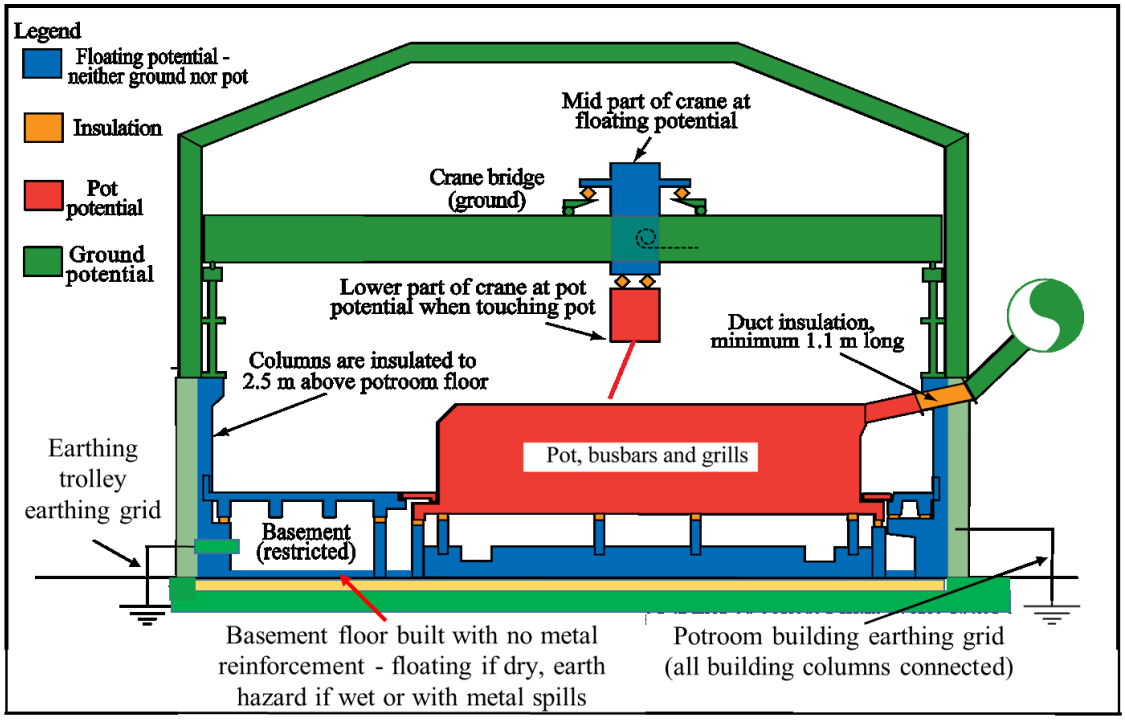

Figure 2. Potroom potentials and earthing networks (from [1], modified).

3. Pot Room Earthing and Equipment Power Supply

EGA Al Taweelah potrooms are built with two earthing grids as shown in Figure 2:

- Building earthing network that connects all building columns together, connected to earthing electrodes network on the duct side of the potroom.
- Earthing trolley network in the basement on the tap side of the potroom, which consists of earthing junction boxes fixed on every second building column and connected with a 120 mm^2 copper cable to the outside earthing network. The earthing trolley cable is long enough to connect any pot to one of these junction boxes.

Common to these two networks is earthing electrode network, created by laying an earthing copper cable of 120 mm^2 cross-section all around the potrooms. There are numerous earthing electrodes installed outside the pot room basement connected to the earthing network. Each of these electrodes is solid copper rod of 20 mm diameter and 1200 mm length, driven vertically into ground, with three rods connected in series buried under ground and connected through earth rod coupler to the earthing network. For earthing trolley connection, a 120 mm^2 cross-section earth cable is brought from this earthing network to the pot room basement and connected to a copper busbar installed inside each earthing junction box.

Grounded auxiliary AC power supply is not permitted in the potrooms or potroom basements. It is essential to have isolated power supply to all the electrical equipment in the pot room. This is achieved by having all power supplies derived through dedicated isolation transformers with ungrounded secondary winding. Ground fault monitors are installed on these isolation transformers to detect insulation failures on the transformer secondary circuit. These isolated transformers are installed in Electrical Rooms located outside the pot room. Due to long pot line, each section covering a maximum of 36 pots has one electrical room. 110 V AC auxiliary power sockets are available at every second column in the basement to provide power for SET at any designated pot.

4. Smart Earthing Trolley Construction

Smart earthing trolley (SET) consists of 3 major sections – low voltage (LV) control panel, high voltage (HV) power panel and rear mounted SET accessory panel. LV and HV panels are mounted together on an insulation sheet to isolate it from earthing trolley frame. Complete unit is mounted on four wheels to make the trolley mobile. For long distance SET is transported with a fork lift. For short distances within the section it is moved to the designated pot by a towing handle.

LV control panel consists of state of the art technology using Programmable Logic Controller (PLC), industrial grade UPS system fitted with built in long life maintenance-free battery units and control components. Light-emitting diode (LED) lamps are installed on the LV control panel door providing SET power circuit status. Human machine interface (HMI) is installed on the door for SET metering, user interface programming and is also used for fault diagnosis. Control switches are also located on the low voltage control panel door along with connectors for remote devices such as control pendant and remote flasher unit. HV power panel consists of high speed DC circuit breaker (HSCB) along with its control components, a back-up 315 A fuse, busbar mounted bidirectional ultra-high precision current transducer and voltage transducer. Separate pot line and earth sockets are installed on the HV panel for field power connections. All the components are adequately covered with protective shrouds to avoid direct contact with live parts. All the components installed inside low voltage control and HV power panels are designed and suitable to work for continuous operation in pot room basement environment. Low voltage control panel is fitted with panel A/C to maintain controlled temperature within the cabinet to reduce temperature stress on the components, thereby enhancing equipment reliability.

Accessory panel consists of cubicles to store power cables fitted with potline and earth plugs, control pendant, wireless flasher unit and bus bar clamps. Special personal protection equipment (PPE) and tools required to carry out safe connection and disconnection of SET such as - high voltage gloves (Class 1 as per NFPA – 70), insulating stick , face shield , electrical insulation rubber mat and insulated step to access the pot bus bars.

5. Smart Earthing Trolley Operation

In EGA Al Taweelah smelter earthing trolley is always connected at the center of the potline, i.e., at cell 222 in either A room or in B room in order to maintain null point at the middle of the potline unless some special activity requires the displacement of the trolley to another pot as explained below. Therefore, maximum voltage in each potroom with respect to earth will be equal to half of the potline voltage for most of the time as explained in Section 1.

There is high risk of electric shock during work in pot line basement in close vicinity of DC bus bars, where the operator can accidently bridge pot potential with ground potential. The risk is eliminated if earthing trolley is connected at that location. A partial list of activities which requires the local connection of the earthing trolley are:

- Potroom basement cleaning,
- Pot replacement,
- Cleaning of metal spills due to pot tap-outs,
- Any maintenance work on the pot bus bars,
- Work with water in the basement or on the potroom floor,
- Removal or installations of pot fume ducts.

After connecting the earthing trolley, the potential difference between that pot and earth is zero and the pot-to-earth potential of 5 adjacent pots on each side of the earthed pot is at acceptably low levels for work (in the range of 20 to 25 volts) so that accidentally if the worker bridges pot busbar and ground, he will not receive an electrical shock and his equipment might produce only a mild electrical arc.

At any given time only one point of potline is allowed to be grounded through earthing trolley. To connect earthing trolley at a new location, existing earthing trolley at the mid-point of pot line needs to be disconnected first and shifted to the designated pot. Once earthing trolley is positioned at the desired pot, the following sequence of operation is to be followed. This process requires mandatory PPE such HV gloves, rubber insulation mat, insulated step, face shield, etc.

1) Connect ground connection cable between earthing trolley and earth connection point.
2) Connect potline cable to the pot busbar and earthing trolley. The connection of potline cable on potline busbar must be made with telescopic insulation stick.
3) Connect 110 V AC auxiliary power supply to earthing trolley.
4) Check the indications and alarms on the LV cabinet front panel and HMI and rectify if any. (Note: If any other MET is connected and alarm message will pop up and will block breaker closing function).
5) Connect remote flasher unit and control pendant.
6) Enter mobile number on HMI for SET users to receive SMS.
7) Enter pot number and purpose of SET connection on HMI.
8) Close the high speed circuit breaker (HSCB) from remote pendant standing far away from the SET panel.
9) Check and confirm the status.
10) Turn the RUN switch on LV cabinet to turn on the local and remote flashers.

6. SET Safety and Protection Features

6.1. General Protections and Alerts

SET forces and maintains the pot line busbar voltage at ground potential at the point of installation, thereby decreasing the potential to safe working limits covering maximum of 5 pots on either side of grounded pot. With this, risk of major arcing, if accidental bridging takes place from these pots to ground is decreased. However SET as such is not personnel protective equipment. This means people working in pot room basement should always comply to rules and wear PPE as if full potline voltage would be present.

SET can be safely operated from far distance through remote pendant and Wi-Fi communication. This eliminates the risk of injury to the SET operating personnel in case of flash-over due to heavy current leakage from potline to earth.

SET has various protections to alert the potroom basement working crew in case of excess current leakages or sudden high voltage at the earthing point, so that they can be quickly notified to stop the activity and leave the area. SET continuously monitors current flow through the ground connection using a high accuracy and fast response bi-directional current transducer and is connected to the PLC as analog input. Pot voltage to ground is also monitored through high voltage transducer and is connected to the PLC as analog input. Both current and voltage signals are processed in the PLC for continuous monitoring and protection and these values are displayed on the HMI as well as on pot line SCADA through wireless communication network installed across pot room basement. These values are recorded in the form of historical trend for further analysis.

Figures 3 shows the positive potline to earth voltage during SET testing. Initially when SET was connected to Pot 222 at mid-point of the potline, the positive voltage at the rectifier was 950 V, one half of the potline voltage. When SET was disconnected to be displaced, the potline was floating and the natural null point established itself at about 15 to 18 pots away from the mid-point of the potline into the negative side to room A, thus making the positive rectifier voltage greater by about 60 -75 V. Then SET was connected to Pot 3B102 in potroom B, 102 pots away from the rectifier on the positive branch of the potline circuit and the positive voltage dropped to about 435 V. Needless to say, the negative voltage increased to 1465 V at the rectifier (Pot 3A001).

Net current in the grounding circuit at null point will be zero when positive and negative sides of pot line busbars are balanced. Current flow in the grounding connection is the result of unbalance in pot-to-earth resistances in the negative and positive side of the potline circuit and these values show if there are any problems with the potline insulation. Even in a balanced situation, there could be leakages of current from busbars to ground, however, they sum up into the null point in equal amount from positive and negative side of the potline circuit and they cancel each other. On the other hand, when SET is on a pot other than mid-point, the net currents through SET will not be zero as there are more pots on one side than on the other. An extreme example is shown in Figure 4 which shows leakage current to earth through SET when it was connected to Pot 3B001. In this position all pots are just on one side of SET and the leakage current is sum of the leakages of the whole potline of 444 pots in parallel. If all individual pot leakages were equal, the maximum value shown (0.79 A) would be the sum of 444 times 1.779 mA per pot. In Figure 4, the leakage current is zero until approximately 9:35 h, since until that time, SET was connected at mid-point. It appears that SET was connected for about 3 hours at Pot 3B001.

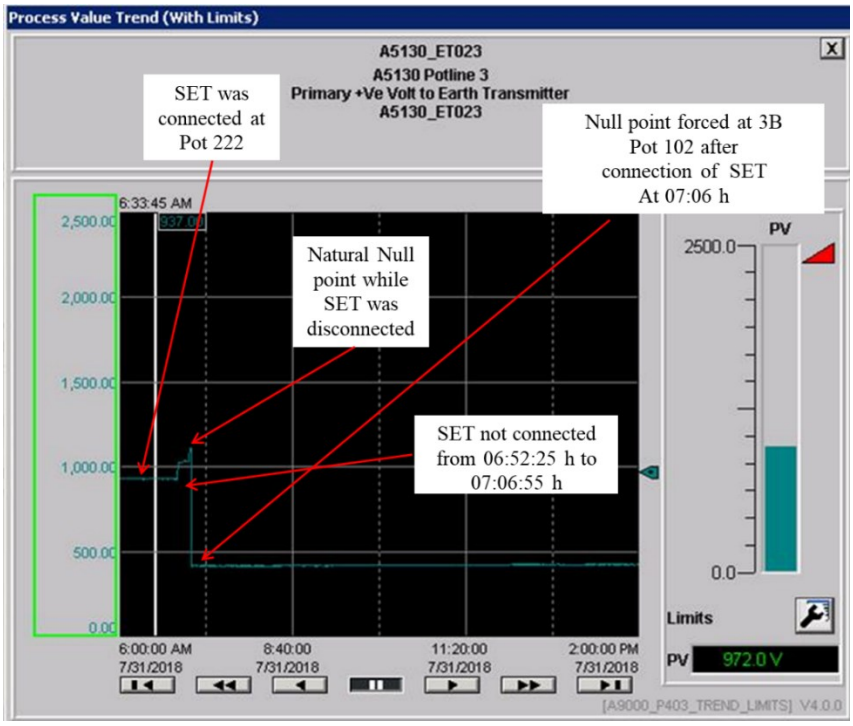

Figure 3. SET monitoring of rectifier positive potline-to-earth voltage.

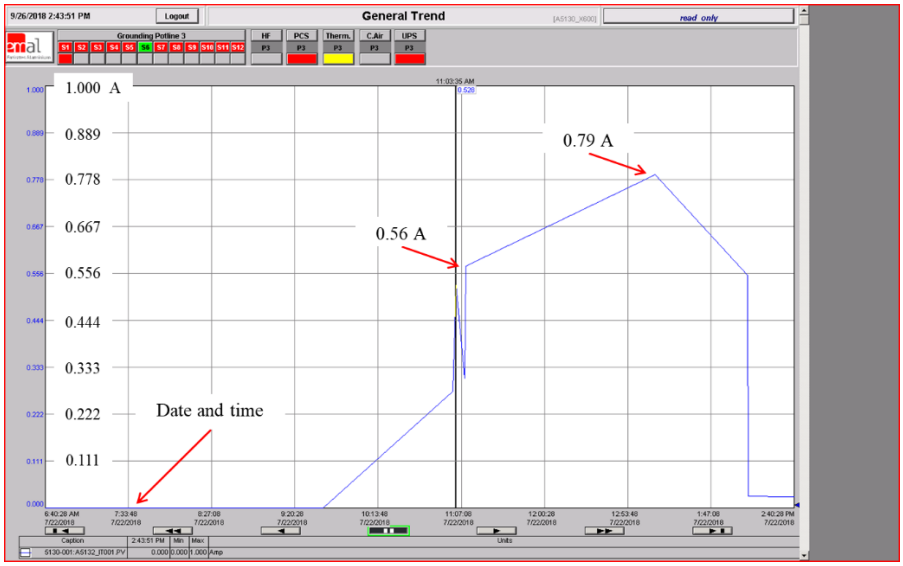

Figure 4. SCADA screen in potline control room, displaying continuous earth leakage current when SET was connected at pot 3B001 on 22/07/2018.

6.2. Protections by High Speed Circuit Breaker

As already said above, net current in the grounding circuit at null point will be zero when positive and negative sides of pot line busbars are balanced. Any accidental bridging from pot to ground at any place in the potline will result in short circuit current through SET and trigger alarms based on set values of currents. SET has four different levels of current detection and protection through these components such as DC CT, HSCB and 315 A fuse. In case high leakage currents are detected in the grounding connection, PLC will initiate trip command and high speed circuit breaker will be operated in less than 50 ms. Additionally DC CT detects net grounding current greater than 110 % of its rated capacity and initiates fast tripping of HSCB

through PLC. HSCB also has built-in instantaneous over-current protection. In case of very high instantaneous grounding currents, it will be interrupted by 315 A fuse and HSCB will be opened.

SET also has a feature of blocking HSCB from closing when high voltage more than the predefined set voltage is detected at the connecting location. This will caution pot line operations to investigate the root cause of such strong leakages which could expose the pot room operators to dangerous high voltages.

Earthing of pot line busbar at one point only is allowed. This is controlled by SET monitoring of the connection status of any other earthing trolleys installed in the same pot line and blocks closing of HSCB. It also provides alarm message on the HMI screen and sounder alarm will be activated.

All the components installed inside HV cabinet are very well protected through protective barriers from direct contact with live parts. In addition HV cabinet door opening is blocked if pot line plug is inserted, even if the HSCB is open.

6.3. Continuous Operation

During SET operation, if 110 V AC auxiliary supply trips, SET will continue maintaining the designated null point through built in UPS fitted with battery backup unit, safeguarding the basement workers from exposure to high voltage. Alarm will be initiated to communicate auxiliary supply failure along with hooter. During this situation LV cabinet A/C will not be in operation and LV cabinet temperature is expected to increase, depending on ambient temperature. However both LV & HV cabinet components are rated for 60 °C ambient temperature. Additionally temperatures LV and HV cabinet temperatures are continuously monitored and local alarms are generated, including SMS alerts to caution SET users. This will also be brought to the attention of maintenance team to investigate.

During SET operation when in service, PLC failure and any other component failure (other than 315 A fuse) will not trip the HSCB and null point will be still maintained for safety of workers in the basement, however there will be no alarms. SET users will be still protected against any high leakage currents through HSCB instantaneous overcurrent release and 315 A fuse.

7. Potline Battery Effect

Aluminium electrolysis is an electrochemical process and part of its voltage, about 1.8 V is back EMF, which remains on each pot at zero current during the power shut down. This voltage is like a battery. When the current drops to zero, the back EMF is about 1.6 V and this voltage is used for potline potential calculations as recommended in [2]. Thereafter, it rapidly decreases to 1 V and after a few minutes, more slowly to 0.5 V and even less, depending on how long the power shut-down lasts. It disappears only when the bath solidifies completely. With 1.6 V per pot initially, the potline voltage for 444 pots will be 610 V which is still very dangerous. This situation demands the use of all PPE and the adherence to all safe working practices during power shut down, the same as when the potline is live.

During the power shut-down, SET operation will not be affected and will continue to maintain the null point through its built-in UPS source with all the monitoring and protection parameters in operation. UPS built in battery provides more than 3 h autonomy to SET operation in-case of loss of main power. However in this situation LV cabinet A/C will not be in operation. As such all the LV and HV components, including UPS, PLC are designed to operate at 60 °C ambient temperature.

8. Smart and Advanced Features

SET has numerous advanced features which make it user friendly and effective communicative equipment. These include wireless visual alarm indication along with remote open and close command for HV circuit breaker.

Wireless panel may be located far away around 60 meters from SET panel and it will still be maintaining SET status. Another significant feature includes SMS notification. Any alarm / fault will be sent as SMS notification to the programmed mobiles of SET end users (Figure 5). This safety feature plays very important role for end users to take appropriate immediate actions as and when any alarm / fault appears on SET while working in the basement.

Figure 5. SMS notifications sent to the designated end users of SET.

SET front panel HMI can store more than 500 alarms with historical data-logging for analysis. Leakage current and voltage values can be stored in the form of trend for past 16 h .SET has event log facility where it saves data for past thirty events of SET locations.

Since SET is connected to SCADA network, it can detect the presence of other METs on same potline bus bar network. This feature is used to have an interlock to block SET connection if any other earthing trolley is in service. Interlock message will be displayed on front HMI panel.

8.1. HMI Pages

HMI pages provide all vital information which makes easy user interaction with SET. Figures 6 - 9 show various HMI screen displays.

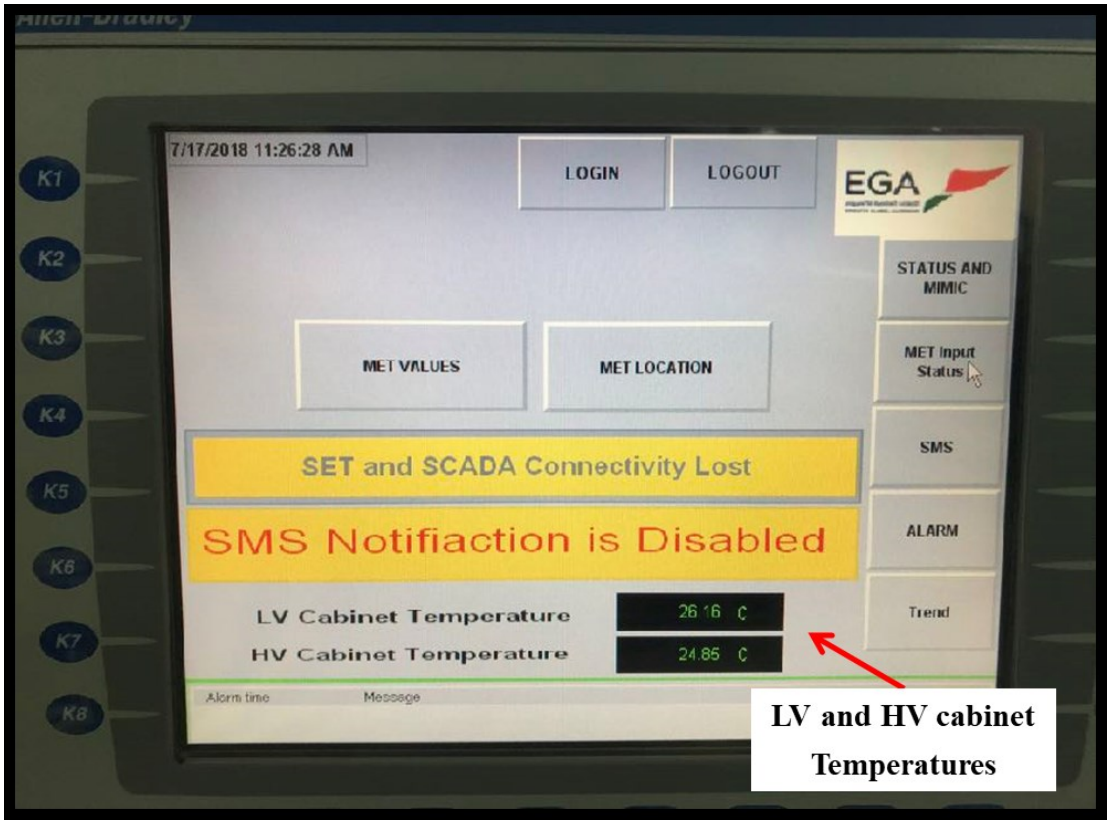

Figure 6. HMI Graphics display.

Figure 7. SET voltage and current display (left) and wireless flasher module (right).

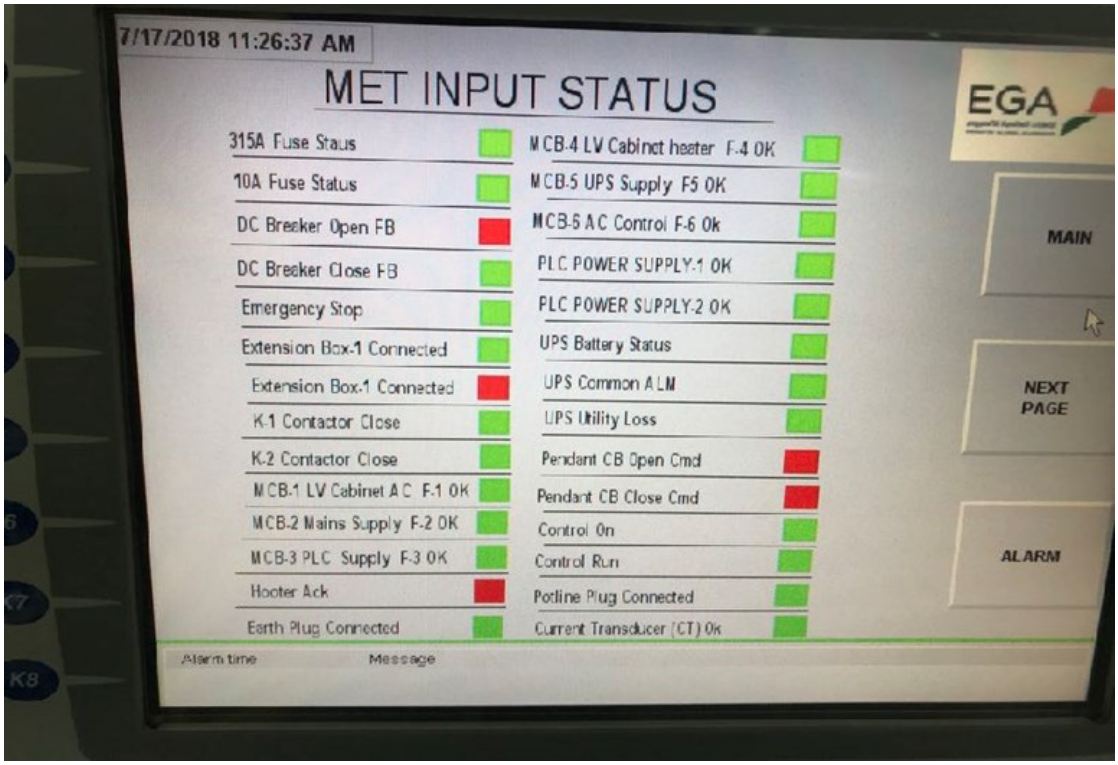

Figure 8. SET input / output status display.

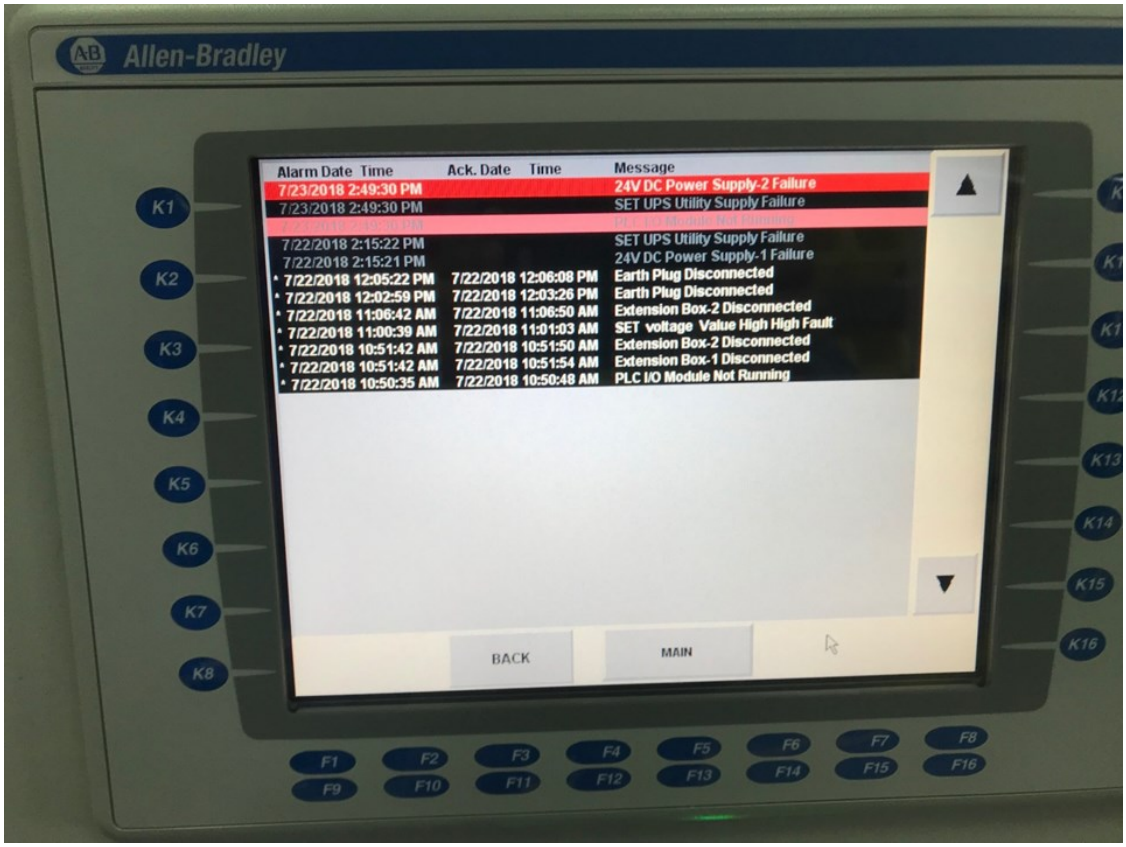

Figure 9. SET Alarm / Fault Screen display.

9. Personal Protective Equipment (PPE)

PPE for connecting SET, including the footwear, is usual PPE for potrooms. The footwear has to be electrically insulating footwear (British Standard BS EN ISO 20345:2004) or electric shock resistant footwear (American Standard ASTM F 2413 - 05 and Canadian Standard CSA Z195 - 02). In addition, electrically insulating gloves used for connecting SET, rated for Class 1 as per NFPA – 70 E, have to be used. Face shield, rubber mat and insulated step are rated for 2.5 kV. Gloves shall be inspected and tested for pin holes prior to each use.

10. Conclusions

As stated in [1], safe work environment in the pot rooms is generally provided by adopting special building construction materials, construction method, equipment insulation, PPE, safe working practices, training and hazard awareness. In spite of this, electrical hazards are created due to metal spillages, water ingress and high humidity causing insulation deterioration and eventually leading to insulation breakdowns. Electrical accidents happen when bridging occurs between pot potential and ground or between two different pot potentials.

The voltage from pot to ground in worst scenario can be as high as the entire pot line voltage which could be in the range of 1800 to 2000 V DC. With these voltages, workers carrying out regular pot room basement activities are at risk of being exposed to high voltages and it becomes critical to have continuous monitoring of insulation integrity of pot line and to decrease voltage to earth by using mobile earthing trolley. In this paper it is shown that fixed null point by earthing trolley is preferred to floating null point. This is achieved by connecting SET at the middle of the pot line for normal operation, thereby fixing the maximum pot- to-earth potential to ± half of potline voltage. For high risk activities in the pot room basement or on pot duct work, the local connection of the earthing trolley at the worksite increases electrical safety by bringing that pot potential-to-earth to zero.

SET is innovative potroom safety equipment with enhanced and reliable high voltage and leakage current protection, smart communication with SCADA and the operators, built with robust components and with user friendly operator interface. SET also maintains the null point during power shutdowns. Current leakage monitoring with smart alarm features, in case of abnormalities, enhances operator safety for work in the basement. However we must be aware that SET, like any other potline earthing trolley, is not personal protective equipment and even when it is connected at a work-site, usual potroom PPE has to be worn all the time, including during power shut-down.

10. References

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