2019 International Symposium on Lightning Protection (XV SIPDA), São Paulo, Brazil, 30th September – 4th October 2019.

Lightning Monitoring System, a case study applied to the Iron ore Minning. An approach to meeting standards IEC 62793-5, IEC 62713, IEC 62305 / NBR-5419

Waterson dos Santos Soares
Electrical Engineering Supervision
Electrical and Fuel Engineering Management VALE S.A
Itabira, Brazil
waterson.soares@vale.com

Fabricio Omar Gomes Fonseca
Electrical Engineering Supervision
Electrical and Fuel Engineering Management VALE S.A
Itabira, Brazil
fabricio.fonseca@vale.com

***Abstract*— In order to comply with the technical standards, it is necessary to use a contract with a company specializing in the monitoring of lightning discharges, as well as the emission of lightning discharge alerts, so that employees must be provided with information on these climatic conditions, and safety guidance for decision-making, regarding the permanence in their normal activities, or interruption of their activities and search for safe shelter. Thinking about this, the Electrical Engineering team investigated in the market an equipment with capacity to measure electric field to install in its operations of iron ore mining, always aiming the human protection and continuity of its operations. For this, it was necessary to know the normative requirements for specification of electric field sensor, and to develop integration of this with the operations through PIMS (Plant Information System) / PI Vision system (Plant Information Vision System), and this be integrated with the company contracted responsible for the emission of the alerts of lightning discharges. This integration was built by the mining company, using the alerts issued by the contracted company and the local electric field measurements of each mine. It is object of this, to correlate these data, validating to the application, as well as to help the company contracted in the decision making, before the emission of the lightning discharge alerts. As a result, lightning alert systems will be optimized before firing for areas at the start and end alerts.**

Keywords - electric field; ligthning discharge; PIMS system; PI Vision; warning of lightning discharges; optimization of lightning alerts; electric field measurement system.

I. INTRODUCTION

Always thinking about protecting people and the reliability of the iron ore mining, the miner hires an outsourced company to carry out the monitoring of lightning discharges every day of the week, throughout the year. This service is performed by a team of meteorologists who work in this work regime to meet the demand of the mining company. The contractor has full-time help desk, to meet the needs and support to the coverage areas, due to the questions regarding the climatic conditions. It is known that there are many operational doubts regarding the phenomenon of lightning discharges, as well as if one should proceed, faced with this phenomenon known only by a specialist.

Initially the contractor sent the alerts to the areas, and there were some divergences in the time of sending, and receiving the alerts. In this case, the Electrical Engineering has specified an electric field meter in response to [1], to feed the contractor with this local measurement, where now, before the contracted company sends the alerts, it accesses the electric field sensor data, and accompanies the evolution of the electric field. Subsequently the contracted company sends the alerts, like green, yellow or red.

This process of installation, integration of field sensors with field network, integration of data with PIMS, publication in PI-Vision, and monitoring of the consoles through a robot developed and integrated through mobile application to receive automatic messages of the status of equipment communication.

The electric field sensors used correspond to [1] in the classification question. They are class A instruments, where it detects the entire life cycle of the cumulonimbus storm. The three main phases of electrical discharge formation are: building, mature, dissipation, according to Figure 1.0. The DC frequency range (static or near-static electric fields) is used. The technique used is the FSM (Field Strength Measurement), its typical range is 20 km, and the application is for the short-range early warning system.

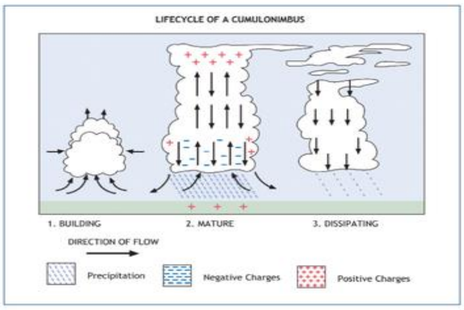

Fig. 1. Storm Life Cycle

II. METODOLOGY USED IN VALE COMPANY

The alarm method used was elaborated according to the guidelines of [1], which includes 3 steps: Definition of areas, criteria to perform alarm, communication of alarm information.

The location of the electric field sensors was defined based on the choice of strategic points so that all of them have a coverage of the mine, plant and office areas of the beneficiation plants, according to Figure 2.0. It shows a screen developed in the PIMS system, where all electric field and temperature sensors are monitored. These change their color status for each type of alert. When it is green, the area of interest is released for work. The yellow color means that it is in alert state of attention, where the employee is released to work, but workers should be on alert during the execution of their activities, as this alert can change state at any time, can evolve to red, or may go back to green. If it turns red, it means that it is at maximum risk of lightning. In this alert, workers should seek safe shelter.

The safety place is one where it has an LPS (lightning protection system), earthing system, or similar system to the Faraday cage. This shelter must meet the requirements required by [2], [3], [4], [6], [7], [8], where a study was carried out through risk analysis, protection type, design and installation complying with regulatory and technical standards. A shelter can be a building, shed, vehicle (automobile, truck, mine drill, mine excavator), among others.

The status of this information in Figure 2.0 is the respective information provided by the company Climatempo which today is the company responsible for sending the alerts (green, yellow and red). The yellow alert is issued by Climatempo when lightning occurs within a radius of the mine's point of interest (coordinate of the monitored point) between 11 and 30 km. The red alert is issued when lightning strikes less than or equal to 10 km away from the georeferenced coordinate of the mine. The green alert is issued when the area is cleared for work, normal conditions.

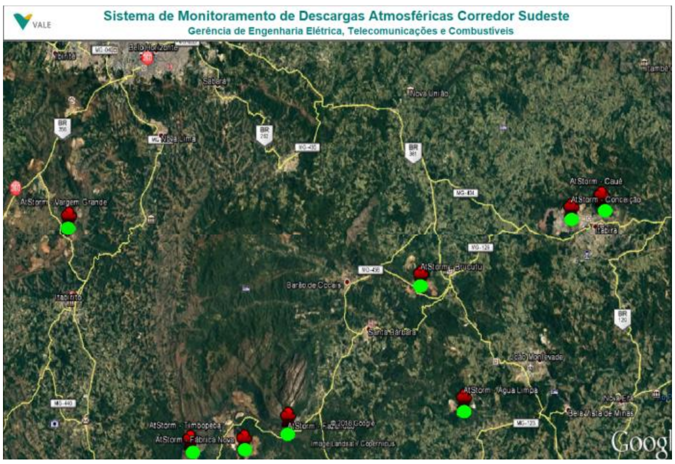

Fig. 2. Image of the Lightning Discharge Monitoring System (LDMS)

The alarms of lightning discharges were elaborated according to the guidelines presented in item 6.3 of [1], which defines the general criteria for initialization and termination of the alarms. Before sending the alarms for VALE company, at the initial moment, the meteorologist of the contracted company, follows the variables monitored. An alarm is initialized when there are significant changes in the monitored information provided by the monitored geographic coordinate / area (area of interest), and in its surroundings as defined in contract with the company generating the alarms. These alarms are generated based on the combination of some storm monitoring criteria, for example: one or more cloud-ground discharges (CG), one or more intra-cloud discharges (IC), a certain level of electrostatic field, electrostatic field polarity, field presence magnetic, relative air humidity, temperature, cloud density, combination of these criteria, and evaluation by the meteorologist.

III. ELECTRIC FIELD MEASUREMENT SYSTEM (EFMS)

EFMS is configured to generate alarms at 4 levels, as shown in Table 1.0.

TABLE I. TABLE 1.0 - EFMS LEVELS OF ALARMS

Configured Alarm Levels of the Electrical Field Measurement System		
Levels of Alarms	***Electric Field Value***	***Description***
Level 0	< 3kV/m	No alert
Level 1	3 to 4 kV/m	Alert
Level 2	4 to 7 kV/m	Emergency
Level 3	> 7kV/m	Maximum risk

Standard [1] states that time must be available to conduct preventive measures before the event related to lightning discharge in the target area may occur. In our facilities, operational procedures have been created, to which we have established the necessary criteria and these are defined in the scope of contract with the company generating warnings. In order to avoid frequent and unnecessary alarms, the storm monitoring system employs a dwell time to maintain the alarm, even when the alarm criteria have not been met. If the set values for the dwell time are too long, the alarm closing time will increase significantly, thus increasing the corresponding costs (depending on the application). It should be noted that systems capable of accurately detecting the end of an alarm by means other than the occurrence of lightning discharges in the monitoring area (such as class A sensors of electrostatic field meters) may not employ dwell time for to end the alarm, instead of using this criterion, the total duration of the alarm corresponding to the interval between the start of the alarm and the dwell time. To meet this standard, the contractor works on a 24/7 basis for analysis and intervention before the alarms are issued to VALE company.

In [1], it is defined that the alarms must be clear and have their protocol. It must be set to ensure that alarm information reaches the end user correctly, clarifying that problems in this communication may result in unavailability or poor alarm quality.

The standard [5], guides us regarding the safety procedure for the reduction of risks outside a structure. With that in mind, we use the alert system (Green, Yellow, Red), these are issued by the contracted company that works every day of the week. The contractor has a meteorologist to assist VALE company through a Help-Desk. This meteorologist receives the information from weather radars, field sensors, atmospheric pressure, relative humidity, wind speed and direction, temperature. It evaluates this information before making any decision to send alerts.

The company VALE installed 8 electric field sensors at strategic points in its mines, with the objective of monitoring the evolution of the electric field and local temperature. With this information, the contracted company before sending the discharge alert, it follows the evolution of the local electric field and makes the decision to send the alert or not. With this, the alert system was optimized both at the beginning of the red alert issuance and in the issuance of the green alert releasing the areas for normal operation.

The standards [6], [7], [8] guide us for protection against lightning discharges, this standard has 4 modules to which it is the reference used in Brazil. It is divided into general principles, risk management, physical damage structures and life-threatening, electrical and electronic systems built into the structure. All facilities must meet the requirements required by the standards. The use of the shelter and / or safe path during red alerts is foreseen in internal procedures, and these are periodically inspected and documented according to the established and foreseen criteria for the facilities, as provided in [9]. NBR-5419 is well aligned with the criteria / guidelines established by IEC 62305.

IV. ANALYSYS AND RESULTS

The Electric Field Monitoring System (EFMS) was developed to monitor the evolution of the electric field, assist decision making in situations involving people in open areas, avoid material losses and damage to people, prevent loss of continuity in iron ore mining, assisting in decision making in situations involving people in open areas, works as complementary information. The EFMS allowed configuration of the alarm levels as shown in Table 1.0.

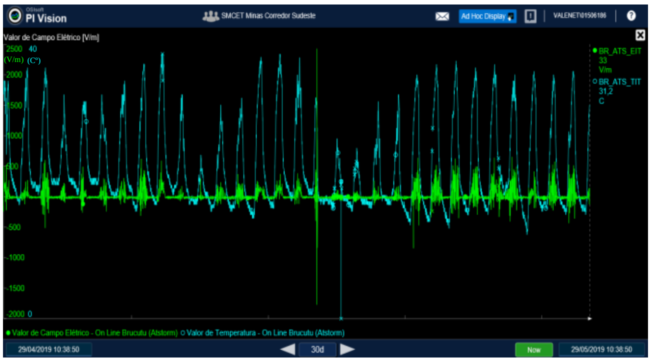

Fig. 3. Electrical Field and Temperature Measurement over 30 days. The green color shows the variation of the electrical field (V/m); The blue color shows the temperature variation (ºC).

Considering necessity of lightning discharges prediction, the electric field and temperature sensors are installed in containers, the installations where they have an air conditioning system, uninterrupted power system, and these are interconnected in an Ethernet network, so that the measurements are recorded through PIMS system, which can be viewed internally to the mining company through the PI system (Plant Information System). For external access or via smartphone, this must be through the PI-Vision system via WEB. Figure 3.0 shows a PI-Vision screen in a 30-day measurement window, where the maximum electric field value was 2.5kV / m, and the maximum temperature was 40 degrees Celsius.

The console and electric field sensor used for the measurements is ATStorm v.02 from the Applicaciones Tecnológicas company, it is fully equipped with electronic components and does not require special maintenance. Your alarm levels can be set like Figure 1.0. The Figure 1.0 shows the manufacturer's recommended values, the sensor operates in adverse weather conditions, and its detection radius is 20 km around the sensor. Measuring sensitivity is 1 V/m, measuring range - 100 kV/m to + 100 kV/m.

The consoles of the electric field and temperature meters are equipped with HD (Hard Disk) to record their measurements in case of loss of network communication. The measurements are recorded in real time on both the HD of the equipment and the PIMS system. The Network monitoring is performed in real time through the console's Ethernet communication port. A robot was developed using the Mobile application, where the Ethernet port of the electric field meters console are monitored in real time, thus any communication failure between the equipment and the network is recorded. This robot helps us in the corrective maintenance schedules of the consoles. Figure 4.0 shows the message screen registered by the robot.

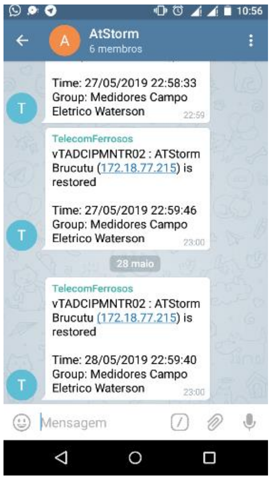

Fig. 4. Message screen for on-line communication monitoring

The times presented by the alert generator are in Universal Time Coordinated (UTC), which is the reference time zone from which all other time zones in the world are calculated. During the analyzes of the data generated by the Climatempo company, it was necessary to subtract 3 hours without summer time and to subtract 2 hours when in summer time.

Figures 5.0 to 9.0 show the electric field and temperature measurements taken by the sensors installed at the company VALE SA, at the Brucutu Mine, located in the municipality of São Gonçalo do Rio Baixo, in the state of Minas Gerais, Brazil.

Correlating information from the company generating alerts and electric field sensor. Figure 5.0 shows that the system of alerts issued by contractor BR_ALERTA_ATM = 2 (Red Alert) was sent before the occurrence of the lightning discharge. This event happened on 04/04/2018. The figure also shows the electric field peaks that prove the occurrence of lightning discharges in those moments. The contracted company sent a report proving that there were 41 cloud-ground (CG) lightning discharges, with current between 15.1 kA and 58.3 kA, with the lowest intensity occurring 6.6 km away from the Brucutu Mine, and the highest intensity occurred 18.2 km away from the mine. The TAG BR_ATS_EIT_BR shows the electric field measurement during the entire measuring period around 20km of radius of the sensor, and the TAG BR_ATS_TIT_BR shows the temperature measurement near the sensor.

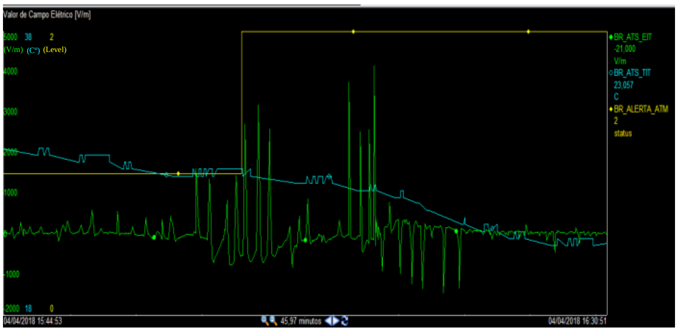

Fig. 5. Electrical field measurement, temperature and red alert. The green color shows the variation of the electric field (V/m); The blue color shows the temperature variation (ºC); The yellow color shows the alert level change (1, 2).

Figure 6.0 shows the electric field evolution over time versus the issuance of green, yellow and red alerts. When the TAG BR_ALERTA_ATM is at 0, it represents green alert, released to work, when it is at 1, this represents yellow alert, which means state of attention. When it is in 2, this means that it is in red alert, maximum risk of occurrence of lightning discharge.

The TAG BR_ATS_EIT shows the variability of the electric field when the occurrence of lightning discharges, be they intra-cloud or cloud-ground. The lightning discharge can be upward or downward, according to the polarity of the electric field and electric current.

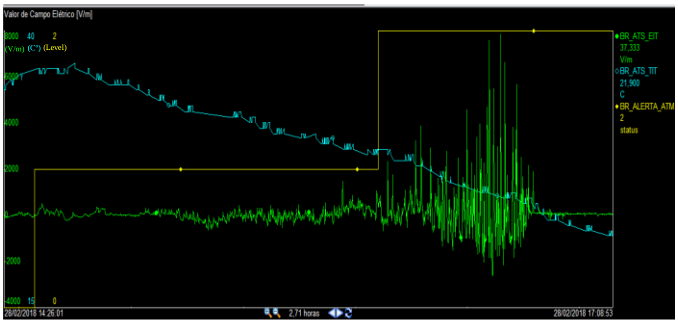

Fig. 6. Red alert, electric field evolution profile and temperature. The green color shows the variation of the electric field (V / m); The blue color shows the temperature variation (ºC); The yellow color shows the alert level change (0, 1, 2).

Figure 7.0 shows the evolution of electric field on March 03, 2018, and their respective alerts issued by the company generating alerts. It is observed that the 19:33 hours had a cloud-ground discharge to 7,9 km of distance of the Brucutu Mine, and this one with current peak of 31,9 kA, this one is represented in Table 2.0. Figure 7.0 shows a very fast evolution of electric field that began at 16:12 hours and with a logarithmic increase until 16:26. At the same time, the electric field reached 30 kV / m. After 16:26, the electric field fell logarithmically. At this same time, there was an lightning discharge with peak current of the order of 31.9 kA, according to Table 2.0. It is noticed that the field sensor saturated during this period, not being able to perceive the other lightning discharges registered according to Table 2.0.

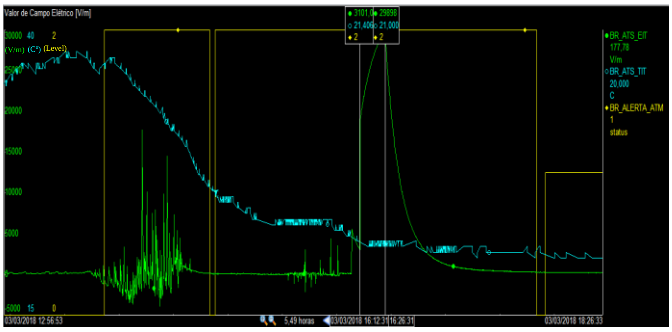

Fig. 7. Electrical field measurement window, temperature and alerts. The green color shows the variation of the electric field (V/m); The blue color shows the temperature variation (ºC); The yellow color shows the alert level change (0, 1, 2).

Information on peak current, geographic coordinates of lightning, distance from observed point (Mine), and type of lightning is provided by the Climatempo company. This information uses the North American network lightning detection Earth Networks (EN). EN's data network uses the triangulation technique to detect the position of lightning strikes. Tables 2.0, 3.0, 4.0 present data from these georeferenced cloud-ground (CG), ground-cloud (GC), cloud-cloud (CC) and intra-cloud (IC) measurements with accuracy above 95% for the southeastern region.

Table 2.0 shows the lightning discharges recorded in March 2018, as well as their respective distance from the Brucutu Mine. The electrical discharges presented refer to cloud-ground discharges. For each lightning discharge, its current peak was presented.

TABLE II. TABLE 2.0 - DETAIL OF THE DISCHARGES, MARCH OF 2018

Date and time	*Type*	*Latitude*	*Longitude*	*Peak Current (A)*	*Distance (km)*
01/03/2018 02:15	CG	-198.231	- 434.351	30437	6.8
03/03/2018 19:33	CG	-1985.059	-4.345.611	31909	7.9
03/03/2018 20:24	CG	-1.986.546	-4.431.496	32065	3.7
04/03/2018 17:22	CG	-1.984.853	-4.347.467	47548	9.7
07/03/2018 23:21	CG	-1.980.605	-43.3	15764	9.5

Date and time	*Type*	*Latitude*	*Longitude*	*Peak Current (A)*	*Distance (km)*
08/03/2018 00:28	CG	-198.558	-434.338	38491	5.6
08/03/2018 01:34	CG	-1.992.724	-4.341.429	53018	7.6
08/03/2018 23:27	CG	-198.088	-4.339.309	36678	5.3
17/03/2018 19:07	CG	-1.982.152	-434.486	35044	8
22/03/2018 08:17	CG	-1.993.224	-4.341.647	50801	8.2

Figure 8.0 shows the electric field peaks of 14,481 and 17,725 V/m, at the same instant of these field peaks, occurred lightning discharges, according to Table 3.0, this lightning discharge were cloud-to-cloud. The difference of 3 hours is based on UTC time base.

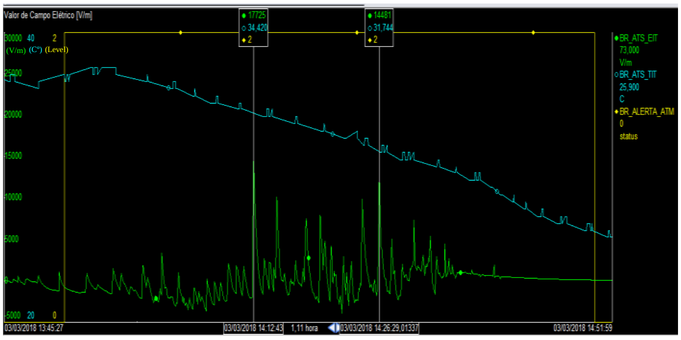

Fig. 8. Electrical field measurement window, temperature and alerts. The green color shows the variation of the electric field (V/m); The blue color shows the temperature variation (ºC); The yellow color shows the alert level change (0, 2).

TABLE III. TABLE 3.0 - DETAIL OF THE DISCHARGES, MARCH OF 2018

Date and time	*Type*	*Latitude*	*Longitude*	*Peak Current (A)*	*Distance (km)*
03/03/2018 17:10	CC	-198.846	- 4.342.053	5151	4.9
03/03/2018 18:16	CC	-198.164	-4.339.806	7127	4.8
03/03/2018 18:22	CC	-1.982.536	-4.338.484	-2978	3.5
03/03/2018 18:58	CC	-1.987.116	-4.341.839	6815	4.2
03/03/2018 18:58	CC	-1.987.363	-4.342.229	2901	4.6

Figure 9.0 show a zoom of Figure 7.0. The electric field measurement at the time of occurrence of various lightning discharges according to Table 4.0, peak current and discharge distance in relation to the Brucutu mine. The Table 4.0 shows the details of each discharge. At this very moment several cloud-cloud, cloud-ground discharges were recorded below 5 km from Brucutu Mine. These lightning discharges were ascending and descending, according to the polarity of the peak discharge current.

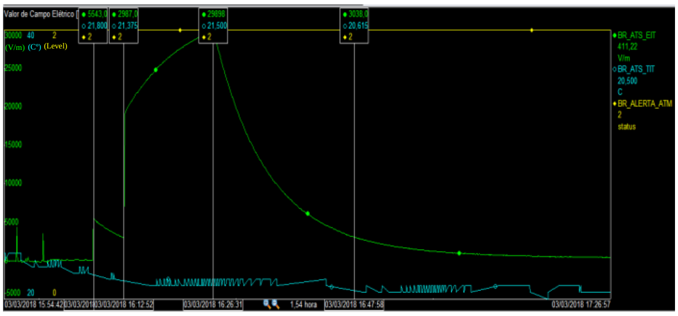

Fig. 9. Zoom window of the measurement of Fig. 7 at the time of saturation of the electric field meter. The green color shows the variation of the electric field (V/m); The blue color shows the temperature variation (ºC); The yellow color shows the alert level.

TABLE IV. TABLE 4.0 - DETAIL OF THE DISCHARGES, MARCH OF 2018

Date and time	*Type*	*Latitude*	*Longitude*	*Peak Current (A)*	*Distance (km)*
03/03/2018 19:00:00	CC	-1.988.452	-4341259	-3357	4.2
03/03/2018 19:00:00	CC	-1.985.983	-4341268	3824	3.5
03/03/2018 19:01:00	CC	-.1985.677	-4341298	-25021	3.5
03/03/2018 19:01:00	CC	-1.986.617	-4341894	7293	4.1
03/03/2018 19:02:00	CG	-1.982.047	-4340273	-3907	4.7
03/03/2018 19:02:00	CC	-1.985.708	-4340901	-8821	3.1
03/03/2018 19:02:00	CG	-1.988.185	-4340146	-4484	3.2
03/03/2018 19:02:00	CG	-1.981.662	-4340209	-6575	5.0
03/03/2018 19:02:00	CC	-1.983.148	-433909	-3195	3.1
03/03/2018 19:04:00	CC	-1.985.697	-4339352	-6100	1.6
03/03/2018 19:04:00	CG	-1.987.763	-4340318	-7638	3.1
03/03/2018 19:06:00	CC	-1.985.896	-4.334.687	-2490	3.1
03/03/2018 19:08:00	CG	-1.985.078	-4339.087	-34634	1.6
03/03/2018 19:11:00	CC	-1.985.265	-4.337.003	-18658	1.1
03/03/2018 19:11:00	CG	-1.985.006	-4.336.453	-18465	1.7
03/03/2018 19:11:00	CG	-1.981.824	-433.509	-8704	5.0
03/03/2018 19:12:00	CG	-1.987.005	-433.833	-47339	1.1
03/03/2018 19:14:00	CG	-198.997	-4335.722	-24037	4.5
03/03/2018 19:14:00	CG	-1.986.613	-4.336.911	-16234	1.1
03/03/2018 19:15:00	CC	-1.981.896	-4.339.167	-2609	4.3
03/03/2018 19:15:00	CG	-1.984.626	-4.338.867	-10961	1.7
03/03/2018 19:17:00	CC	-1.987.332	-4.336.533	-9799	1.8
03/03/2018 19:17:00	CG	-1.985.527	-4.336.883	-7407	1.0
03/03/2018 19:17:00	CG	-1.986.511	-4.334.736	-9867	3.1

Date and time	***Type***	***Latitude***	***Longitude***	***Peak Current (A)***	***Distance (km)***
03/03/2018 19:17:00	CG	-1.984.213	-4.337.418	-9923	1.8
03/03/2018 19:21:00	CG	-1.987.293	-4.334.134	-7303	3.9
03/03/2018 19:22:00	CC	-1.988.683	-433.595	3881	3.3
03/03/2018 19:41:00	CC	-1.985.473	-4.342.033	5849	4.3
03/03/2018 19:42:00	CC	-198.575	-4.341.999	12915	4.2
03/03/2018 19:47:00	CG	-1.987.119	-4.342.335	-11178	4.7
03/03/2018 20:01:00	CG	-198.788	-434.104	-61296	3.8
03/03/2018 20:03:00	CC	-1.990.658	-4.338.446	10054	4.7
03/03/2018 20:04:00	CC	-1.989.117	-4.338.527	9008	3.2
03/03/2018 20:07:00	CC	-1.981.335	-4.338.666	-3705	4.7
03/03/2018 20:13:00	CC	-1.987.402	-4.338.771	14518	1.7
03/03/2018 20:13:00	CC	-1.982.332	-4.336.311	18923	4.0
03/03/2018 20:19:00	CC	-198.287	-4.337.872	-4847	3.1
03/03/2018 20:24:00	CC	-1.982.906	-4.339.068	7321	3.3

V. CONCLUSIONS

With reference to IEC 62793 for the specification of electrical field measuring equipment, I have contracted with a specialized company with a meteorologist working on a 24/7 basis to support the company's needs during all days of the week throughout the year.

In Brazil, major changes will occur in the coming years in relation to the use of standards for care in this area. VALE company is prepared to meet these requirements and is increasingly evolving to be a reference in monitoring and predicting lightning discharges.

For all and any new work within iron ore mining facilities, these are designed using the ESS (Engineering Standardization System), which were elaborated based on national and international regulatory standards and techniques, always taking as a basis whatsoever more restrictive, always aiming at the protection of people and facilities.

The results presented in this paper show that the warning system used by the contracted company is fully correlated with the local electric field monitoring. It is well known that the prediction of lightning discharges through electric field is the state of the art. With that in mind, sensors have been installed for local measurements.

REFERENCES

[1] IEC 62793-5. **Protection Against Lightning, Thunderstorm Warning Systems**. , 2016.

[2] IEC 62305-1. **Protection Against Lightning, Part 1: General Principles**., 2010.

[3] IEC 62305-2. **Protection Against Lightning, Part 2: Risk Management**., 2010.

[4] IEC 62305-3. **Protection Against Lightning, Part 3: Physical damage to structures and life harzard**., 2010.

[5] IEC 62713. **Safety Procedures for reduction of risk outside a structure.** , 2013.

[6] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5419: Proteção contra descargas atmosféricas, Parte 1: Principios Gerais**. Rio de Janeiro, 2015.

[7] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5419: Proteção contra descargas atmosféricas, Parte 2: Gerenciamento de Risco**. Rio de Janeiro, 2015.

[8] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5419: Proteção contra descargas atmosféricas, Parte 3: Danos fisico as estruturas e perigos à vida**. Rio de Janeiro, 2015.

[9] MINISTÉRIO DO TRABALHO E EMPREGO. **NR 10 – Segurança em Instalações e Serviços em Eletricidade**. São Paulo, 2016.