ICESP X – Australia 2006
Paper 5B1

SPARK AND ITS EFFECT ON ELECTROSTATIC PRECIPITATOR

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ABSTRACT

The role of components in an Electrostatic Precipitator (EP) for a spark and both the phenomenon and mechanism of a spark are elaborated and then the type of spark is classified by the condition of shortage between the discharge and collecting electrodes. The secondary voltage and current waveforms of a spark are discussed in order to address the severe effect of the secondary and primary current spikes while a spark occurs. The fundamental difference between a spark and its detection algorithm in a wet EP and a dry one is explained so as to clarify why the spark detection for a wet EP cannot work for a dry one. The problem of frequent sparking in a dry EP is addressed together with the explanation on the disadvantage of the spark detection and control algorithm adopted in most AVC in service today. The effectiveness and significance of the damage caused by sparks on both primary and secondary sides of the electrical circuit of an EP are elaborated with two field cases as respective demonstrations. The investigations' results and solutions developed thereby in these two field cases are given together with the observations after implementing the solutions. Further, an enhanced algorithm of spark control is proposed in order to overcome the problem of frequent sparking in a dry EP.

INTRODUCTION

Electrostatic Precipitator (EP or ESP) is widely used in coal-fired power plant and other industries, like cement mill, steel mill, pulp and paper mill, etc., as the device of particulate pollution control. A transformer/rectifier set (T/R set) is used to convert an input of 50/60 Hz alternative current (AC) at low voltage (typically 220~480V) into an output of direct current (DC) at high voltage (typically 30~100KV) in order to generate the corona effect on the discharge electrode (DE) from which the electrons are emitted to bombard the particles suspended in the flue gas. After certain treatment time the particles carry sufficient negative charges and then are moved toward the grounded collecting electrode (CE) due to the electrical field constituted between DE and CE.

The occurrence of a spark between DE and CE or ground is inevitable due to the limited dielectric strength between them and various conditions during operation. It is known that the particulate collection process will be terminated during sparks resulting in the temporary degradation of collection effectiveness of the EP. Other damages caused by sparks can also be seen from time to time in fields but such damages are easily overlooked or mistaken as being caused by other problems. Therefore, it is essential to understand the nature of a spark and its effect on an EP.

ROLE OF COMPONENTS IN ELECTROSTATIC PRECIPITATOR

1. Discharge and Collecting Electrodes

It is to note that DE at high voltage, grounded CE and flue gas with suspended particles in between constitute a "capacitor-like" structure with the characteristic of both capacitance and resistance depending on the concentration of particles in the flue gas, the resistivity of particles and the thickness of the particle layer deposited on CE.

In other words, the energy fed into DE is unlikely entirely transmitted onto the particles suspended in the flue gas but certain portion of such energy is stored in the capacitor-like precipitator. It is usually understood that the larger the area of CE is connected with one T/R set, the larger the capacitance is constituted thereby.

2. Transformer/rectifier Set

A T/R set provides high voltage DC fed into DE as called the secondary output (voltage and current) that is according to the primary input AC controlled by a thyristor pair. Hence the secondary current from a T/R set will not change when a spark occurs if the T/R set is built with the adequate impedance.

One way to understand this is to perform a "short-circuit-test" in which DE and CE are firmly connected and then the thyristor is fired. It is clearly observed that the secondary current from the T/R set is according to the firing angel of the thyristor adjustable manually up to the rating of the T/R set.

DIRECT-SHORT-CIRCUIT AND NEAR-SHORT-CIRCUIT

The situations causing a spark in an EP can be classified into two categories as follows:

1. Direct-Short-Circuit

A "direct-short-circuit" is a passage established between the DE and CE or ground such as the aforesaid short-circuit-test. When a direct-short-circuit occurs, the secondary current just flows through such passage once the thyristor is fired so as to cause more severe damage on DE and CE than on the electrical circuit depending on the magnitude of the secondary current and the integrity of the direct-short-circuit itself.

A common situation of direct-short-circuit in field is when a DE breaking and contacting CE or ground. A symptom similar to the near-short-circuit usually appears once the DE becomes loosen before it breaks. However, this contact of broken DE is unlikely a firm one.

Hence, the secondary current begins to flow from T/R set to the grounded CE through the contact surface between CE and the broken DE once a thyristor is fired. At the instance the secondary current flows across such contact surface and it might become loosen if the contact force is not adequate so as to result in the erosions on DE and CE usually seen in fields.

2. Near-short-circuit

A "near-short-circuit" is another common situation happened in field such as the particles accumulated on the grounded internal structure, including CE, inside an EP resulting in shorten dielectric clearance between the DE at high voltage and ground. It is to note that the accumulated particles are not an electrical passage of good conductivity but with certain resistance. Hence, an equilibrium circuit of both resistance and capacitance is established in this situation.

When a thyristor is fired, both secondary voltage and current are fed and stored in the capacitor-like EP during the thyristor firing period. The dielectric strength between DE and ground finally breaks down while the secondary voltage reaches a threshold level, usually near the vicinity of peak secondary voltage depending on the dielectric clearance between DE and CE or ground, and then the stored energy is released at this instance in the form of a secondary current spike as illustrated below.

3. Secondary Current Spike

Figure 1 is a schematic diagram of the secondary voltage (Vs) and current (Is) wave forms in an EP during normal operation and a spark. For normal operation, a thyristor is fired at points *a* and *a'* and then Vs begins to rise up to its peak level till the end of the thyristor firing period at point *b* while Is is fed into DE within the duration between points *a'* and *b'*.

Assuming a nearly-short -circuit occurs at point *b1*after a thyristor is fired at point *a1* and then Vs cannot rise up to its peak level but till point *b1* at which Vs suddenly dropping down to a very low level at point *c* and stays at a very low level till the end of the thyristor firing period at point *c1*. In the same period Is begins to flow at point *a1'* till *b1'* at which the spark occurs and right afterwards an "Is spike" suddenly appears at point *c'* due to the discharge of energy stored in the area integration of Vs and Is from *a1* to *b1* and from *a1'* to *b1'* respectively.

The area integration of Vs and Is within period from *a1* to *b1* and from *a1'* to *b1'* is arithmetically equal to the area integration of Vs and Is within period from *b1* to *c1* and from *b1'* to *c1'*. It is obvious that the magnitude of this Is spike at *c'* is much higher than the peak Is during normal operation since the Vs area from *b1* to *c1* is close to zero. Further, this Is spike appears in a very short period of time from *b1* to *c* such that *dIs/dt* during such short period from *b1'* to *c'* becomes significantly large and hence takes a heavy toll on the electrical circuit and components.

An automatic-voltage-controller (AVC) detects the spark occurring at point *b1* and then stops firing the thyristor for certain period of time in the subsequent cycles in order to quench the energized ions near the sparking spot so that the particulate collection process is terminated during this quench period. Afterwards a thyristor is again fired at point *a2* in order to restore the Vs and Is, i.e., the particulate collection process, and eventually reach the normal operation level at point *a3* or *a3'*.

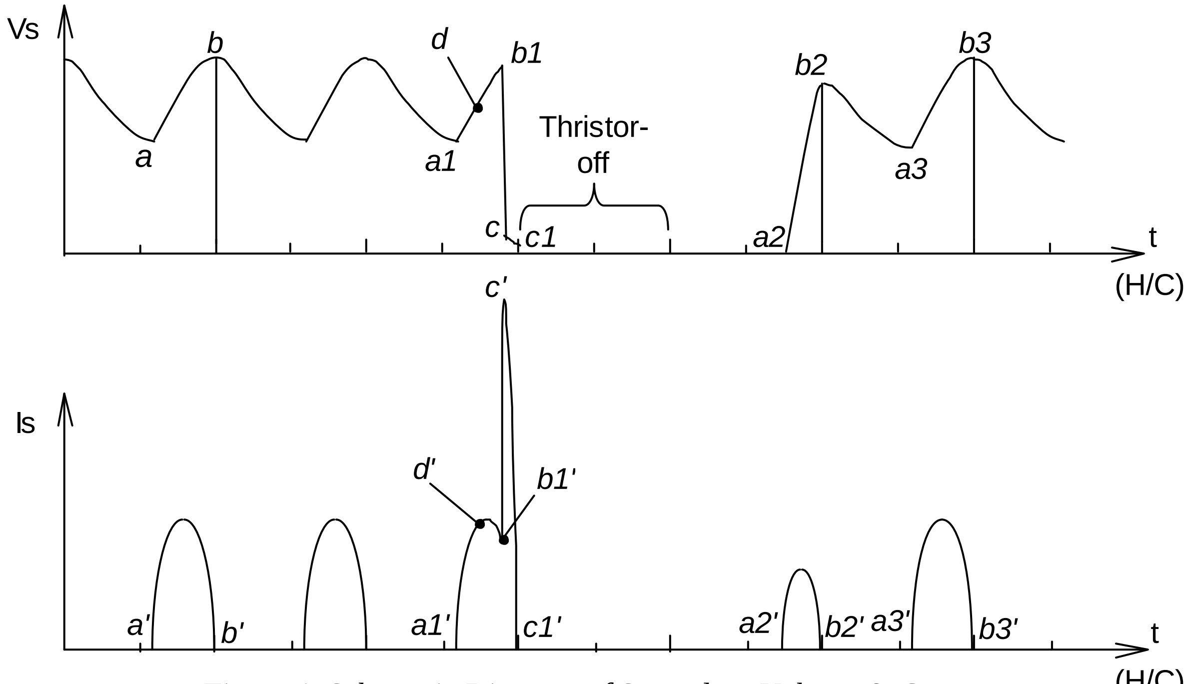

Figure 1. Schematic Diagram of Secondary Voltage & Current

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EFFECT OF A SPARK IN AN ELECTROSTATIC PRECIPITATOR

1. Discharge of Stored Energy

When a spark occurs, not only the output of the T/R set but also the energy stored in the capacitor-like structure, DE and CE, are released and the later one takes a heavy toll on the electrical circuit and components due to the significantly large *dIs/dt*.

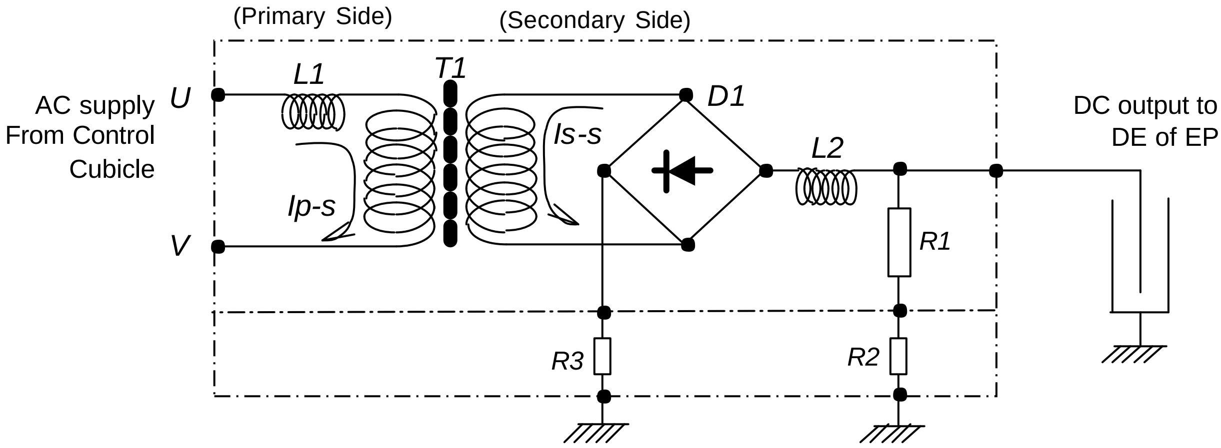

Figure 2. Schematic Circuit Diagram of T/R Set and EP

A schematic circuit diagram of T/R set and EP is shown in figure 2 in which *R1* is the voltage divider for measuring Vs reading along with signal resistor *R2* and *R3* is the signal resistor for measuring Is readings.

A secondary current spike (denoted as "*Is-s*") appears at the instance a spark occurs through the secondary side of the circuit and thus induces a primary current spike (denoted as "*Ip-s*") at the primary side of the circuit [1]. It is to note that the magnitude of this primary current spike is also much greater than the rated primary current (Ip) during normal operation. Hence it explains why an unusually high Ip could be observed on the analogue Ip meter during sparking if the AVC did not take action properly.

Hence, every electrical component in the secondary side shown in figure 2 is subject to the danger due to the significantly large *dIs/dt* if the AVC is not able to eliminate the sparking condition in time. Likewise, the electrical components in the primary side are also subject to the danger due to the primary current spike during sparking. A well-designed primary choke *L1* usually is able to withstand and suppress this primary current spike so that the damage on the primary side is not frequently seen in fields.

2. Detection and Control of a Spark

Various techniques are employed by different AVC makers to detect a spark in order to quench it in time. For example, the comparison of Vs level [2] and the change of slop in Vs waveform [3] are used to detect a spark because the change in Vs waveform is the major character of a spark as shown in figure 1.

Once a spark is detected, the AVC will stop firing the thyristor for a predetermined period of time in the subsequent cycles and then begin to fire the thyristor afterwards as afore-mentioned. The period of not firing thyristor is usually adjustable by the plant people to fulfill the different requirements of the EP in different plant conditions such as startup, loading increase or decrease, shutdown and so on.

3. Problem of Frequent Sparking

A common problem regarding EP operation is the frequent sparking during the transient loading condition because of the process control such as startup, shutdown and change of process material. Further, some applications inherently have the character of frequent sparking such as the soda recovery boiler in a pulp and paper mill because of the properties of the fine soda ash itself.

If the AVC is not able to handle this frequent sparking condition but just keeps on stopping thyristor from firing once detects a spark, the effectiveness of particulate collection of the EP will become lower and lower as the emission form stack will become higher and higher until either fine or complains or perhaps both of them arrive the plant. Therefore, from time to time plant people have to operate the AVC manually when encountering such frequent sparking problem.

4. Spark Detection for Wet EP

The spark detection algorithm for wet EP only considers a spark occurring near the vicinity of peak Vs as a "spark" and then a proper action will be taken accordingly. As for those sparks occurring not near the vicinity of peak Vs are not considered as "sparks" and hence no action will be taken.

Using the aforesaid spark detection algorithm for a wet EP is due to the fundamental difference between a wet EP and a dry one as follows: there exist flue gas, suspended particulate or aerosol matters and water mist at substantially high concentration between DE and CE in a wet EP while in a dry one there exist only flue gas, suspended particulate matter and moisture at substantially lower concentration between DE and CE. The water mist in a wet EP is so dense that it is very easy to induce a spark not near the vicinity of peak Vs, i.e., just like the problem of frequent sparking, so that a wet EP must use a spark detection algorithm other than that is used for a dry EP in order to eliminate the problem of frequent sparking.

Furthermore, when a spark occurs in a wet EP, the aerosol matter and water mist can absorb the energy released from the capacitor-like DE and CE as being vaporized thereby. Thus, a spark occurring not near the vicinity of peak Vs only causes limited damage on DE, CE and the electrical components of a wet EP. However, field experiences indicate that it is not a good practice to use the spark detection for wet EP in a dry one due to the aforesaid fundamental differences between them.

EXPERIENCE OF DAMAGE CAUSED BY SPARKS

1. Case 1: Damage Caused by Primary Current Spike [4]

1.1 Background and Problem

A sludge incineration plant in an oil refinery is equipped with a hot-side EP (operation temperature at 320~350^{O}C) as a particulate control device down stream of the sludge incinerator. This EP was originally equipped with an analogue AVC that was not able to substantially detect a spark but most likely kept firing the thyristor at a constant firing angle, which was determined by plant people.

This plant decided to upgrade the analogue AVC by a modern digital one for better spark control but encountered the problems never happened before after upgrade as follows:
(1) Main circuit breaker of 480V AC primary supply tripped off from time to time.
(2) Occasionally Vs stayed at low level without under-voltage trip but Is stayed at high level.

The former problem was very disturbing for the plant people while the later one would considerably affect the operation of the entire sludge incinerator. Therefore, an investigation was conducted in order to resolve these problems and it was decided to restore the analogue AVC if eventually no solution could be obtained.

1.2 Investigation and Finding

First of all the main circuit breaker was tested to verify its functional capacity that was found acceptable according to the primary current rating of the T/R set. Then the over current datum of the newly installed digital AVC was lowered in order to trip the contactor (by AVC's command) rather than the breaker without any success, namely, the trip of main circuit breaker was faster than the response of the digital AVC.

However, when the open-circuit-test and short-circuit-test were performed during the investigation, it was found that the main circuit breaker also tripped off during the later one. Further investigation found that the T/R set for this EP had very low impedance such that the primary current was already rammed up to 80% of rating while the primary voltage was only up to 13% at which the main circuit breaker tripped off. The investigation by an oscilloscope indicated that the main circuit breaker tripped at the moment when this EP encountered a spark near the vicinity of peak Vs.

Hence, it was concluded that the root cause of the first problem was the relatively low impedance of the T/R set, possible an undersized primary choke, so that the primary current spike due to a spark was likely to trip off the main circuit breaker before the digital AVC could ever response.

As for the second problem, the investigation by an oscilloscope showed that this EP frequently encounter a spark where was far away from the vicinity of peak Vs and then Vs would likely stay at low level as Is would stay at high level for certain period of time. The internal inspection on this EP revealed the severe deformation of its CE so that the dielectric clearance between CE and DE was shortened significantly.

A hypothesis was developed based on these findings as follows:
(1) Some sparks occurred in this EP were due to neither direct-short-circuit nor near-short-circuit but the shortened dielectric clearance between DE and CE or ground.
(2) A passage between CE and DE like a spark could be established relatively easily at a point far away from the vicinity of peak Vs due to both the shortened dielectric clearance and high operation temperature.
(3) Since the cause for the spark-like passage between CE and DE was not the dust accumulation but the shortened dielectric clearance and high operation temperature, the spark occurred in this EP was not like the usual sparks in EP but somehow like the phenomenon of arc-welding.
(4) Hence, Vs would be lowered but above the under-voltage threshold of 5KV while Is would stay at relatively high level when such arc-welding like spark occurred in this EP.

1.3 Solution and Result

For the first problem, it was decided to add an additional primary choke externally to increase the impedance of the T/R set in order to withstand and suppress the primary current spike due to a spark without changing anything else in the existing circuit. This EP performed well after the addition of an external choke between the thyristor and T/R set as shown in figure 3. The main circuit breaker would not trip again when encountering a spark.

This problem is not common in field but in fact a very good example to demonstrate the sparks' effectiveness, particularly the primary current spike, on an EP. Usually a T/R set should be equipped with a primary choke of 40% impedance or so in order to withstand and suppress the primary current spike due to a spark. In this case the T/R set of this EP seemed to be equipped with an undersize primary choke causing such first problem.

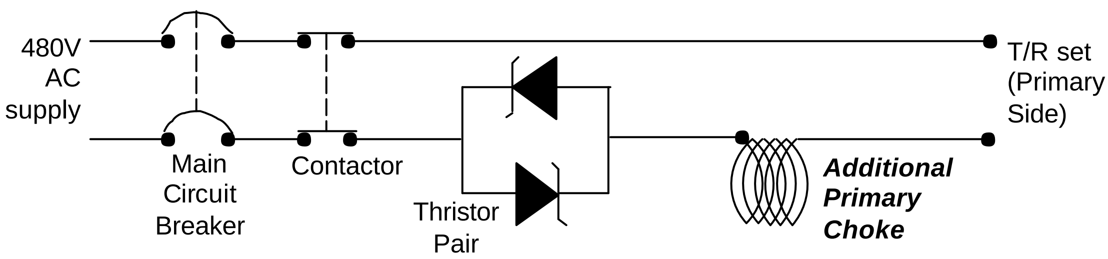

Figure 3. Arrangement of Additional Primary Choke for Case 1

For the second problem, it was decided to increase the under-voltage threshold as well as to change the sensitivity setting of spark detection in order to trip the contactor when encountering the aforesaid arc-welding like sparks. The idea was that the condition of arc-welding like sparks would be eliminated by the under-voltage trip and then the plant people could restore the normal operation of this EP.

It took a substantial time to fine-tune the sensitivity of spark detection because either more or less sensitivity would disable the normal function of the digital AVC due to the variation in the composition of the sludge burnt and loading of incinerator. Nevertheless, the newly installed digital AVC performed well with the unique sensitivity setting for spark detection. Although the plant people have to reset the under-voltage alarm and restore the EP operation from time to time, the occurrence of such second problem was significantly reduced and the effectiveness of particulate collection was maintained.

2. Case 2: Damage Caused by Secondary Current Spike [5]

2.1 Background and Problem

A coal-fired power plant is equipped with weighted wire type EP in which the anti-sway insulator installed on the DE lower frame is subject to the dust falling from the CE while it is rapped. The dust is likely to accumulate on the anti-sway insulator due to its cross section in the round shape, not the inclined plane, in the first field of the EP as shown in figure 4. Therefore, once a while the first field of the EP will be tripped on under-voltage because of the shortened dielectric clearance between DE and ground due to the accumulated dust.

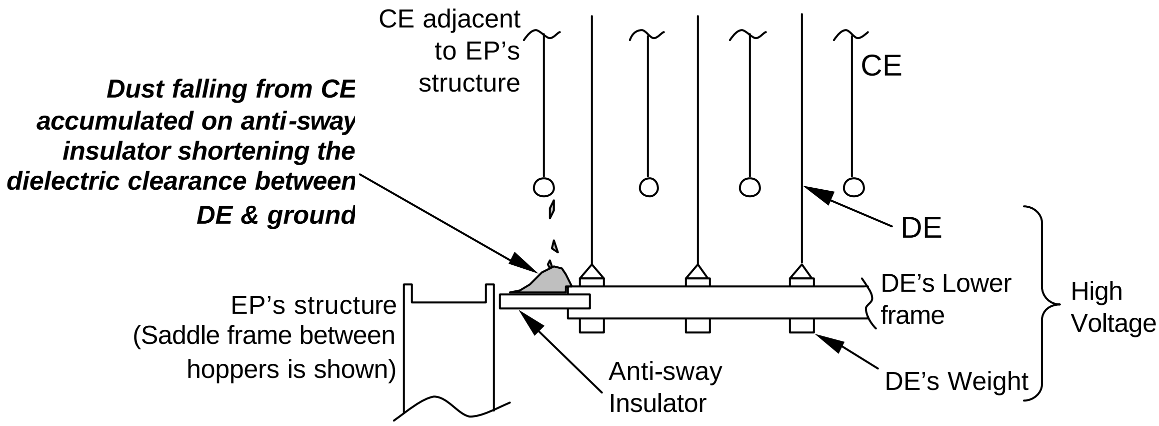

Figure 4. Schematic Diagram of Dust Accumulation of Anti-sway Insulator

Thus, the plant people had developed a procedure called "Current Injection" to overcome the aforesaid problem by firing the thyristor manually (i.e., AVC cannot take action to quench a spark) for using the energy released by sparks to blast away the dust accumulated on the anti-sway insulator. This procedure of current injection had been practiced for more than 10 years with certain success but sometimes the dust accumulated on the anti-sway insulator just stayed as it was and eventually the problem field had to be shutdown.

In an occasion the first field of the EP of No.3 boiler tripped on under-voltage and plant people on duty performed the current injection as usual. However, after several minutes the current injection just could not restore this first field so that the plant people decided to leave the AVC running under manual mode, i.e., kept firing the thyristor at a predetermined firing angle without detecting the sparks and quenching them, for a period of time without the plant people's attendance. During this more than one hour period the secondary side of the electrical circuit of this first field was subject to the very frequent sparking, namely, one secondary current spike for every cycle at which the thyristor was fired.

The secondary side of electrical circuit included a high-tension (HT) cable that comprised outer enclosure and insulation oil within which the core for transmitting the high voltage DC supplied by the T/R set was packed. Further, each EP in this station has twelve half-fields that are divided in two parallel streams, i.e., either left or right stream has six half-fields in serial, but two parallel half-fields in both left and right streams are connected with one T/R set only for the first three half-fields in serial as shown in figure 5. The insulation of the HT cable connecting two parallel half-fields at this first field eventually failed and a fire broke up.

An investigation team was assembled in order to find out what should have caused this fire incident and determine the proper countermeasure accordingly.

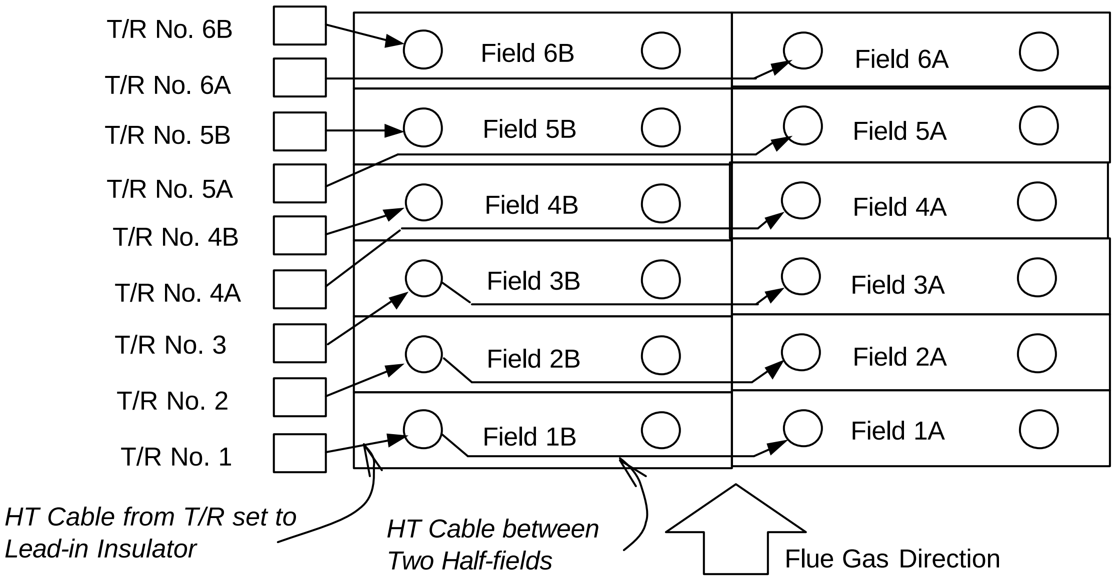

Figure 5. Arrangement Diagram of EP and T/R set

2.2 Investigation and Finding

According to the operational data recorded by a SCADA (System Control and Data Acquisition) system, it was found that the first field of this EP was still running on manual mode to perform the current injection when the fire already occurred. Further, the secondary current spikes at enormous magnitudes were also recorded by the SCADA for more than one hour before the fire occurred.

It was also found that the insulation oil of the aging HT cable between two half-fields at this first field was blown out of its outer enclosure possibly due to the thermal expansion caused by the abnormally high temperature so that the core of HT cable was not insulated afterwards. Then the residual of broken outer enclosure and insulation oil were exposed to both the abnormally high temperature and oxygen in air. Thus, the fire occurred.

It is to note that only secondary output passed through the core of HT cable between two half-fields. How was it to produce the sufficient heat for elevating the temperature of the insulation oil to cause the damage?

Refer figure 5. The energy supplied from T/R No. 1 was stored in both half-field 1A and 1B but the sparks very likely only occurred in one of them, for instance, assuming 1A. Further, the energy stored in field 1B flowed through the HT cable between field 1A and 1B to the former in the form of the secondary current spike at the instance of sparking therein.

Therefore, it was concluded that the root cause for this fire incident was the HT cable between two half-fields in the first field being subject to the secondary current spike resulted from the energy stored in the half-field 1B continuously for more than one hour.

2.3 Solution and Result

This power plant had revised the procedure of performing current injection as follows:
(1) Only the half-field having problem of under-voltage trip is connected with the T/R set and the other half-field in good condition is disconnected.
(2) The plant people must attend the practice and the time for every current injection must not be more than 5 minutes.
(3) If the problem field can not be restored by the current injection for 5 minutes, the plant people must stop the current injection for about 15~30 minutes in order to cool down the HT cable, particularly its the core and insulation oil.
(4) Afterwards the plant people can perform another current injection by the same procedure and time limit until the field is restored or it is decided to abort the practice.
(5) After restoring the problem half-field, the good half-field is re-connected with T/R set.

Moreover, this power plant decided to replace the aging HT cable between two half-fields with improved one that is able to maintain the insulation strength and have the fire retardant capacity since the current injection is inevitable in this plant. Although several old HT cables were found to be leaking the insulation oil after the fire incident, not any fire incident ever occurred again since current injection was performed according to the revised procedure.

This problem is also not common in field but indeed a very good example to illustrate the importance of sparks' effect, particularly the secondary current spike, on EP.

ENHANCED SPARK DETECTION AND CONTROL

1. Basic Hypothesis

Referring figure 1, if a spark occurs at a point not close to the vicinity of peak Vs, for instance, point *d* between point *a1* and *b1* or point *d'* between point *a1'* and *b1'*, the energy stored in the capacitor-like DE and CE is limited. Thus, the magnitudes of both the secondary and primary current spikes due to the spark will not be so significantly large as afore-mentioned and therefore the danger caused by such secondary and primary current spikes will not be so significant.

Hence, it is likely to accept such sparks occurring away from the vicinity of peak Vs without taking any action to quench them. Doing so can avoid the problem of lowering the effectiveness of particulate collection due to frequent sparking at the cost of using little more reliable components in the electrical circuit.

However, if such acceptable sparks keep occurring for a certain period of time, it is an indication for a potential problem in the mechanical aspect or process aspect. Hence, it could be helpful to set a predetermined period of time for such acceptable sparks occurring continuously and an action of quenching sparks will be taken once this predetermined period of time is reached.

2. Practical Aspect

It is known that both Vs and Is of an EP is not constant but variable depending on many factors such as the process condition and compositions of process materials. In addition, the installations of EP in various designs for different applications have different characteristics in the secondary voltage and current. Hence, it is likely to define neither a fixed value nor a relative level acceptable as the threshold of non-sparking in this enhanced spark detection and control algorithm.

According to the above-mentioned, it is reasonable to use the area integration of the Vs and Is waveforms as the indicator for setting the level of the acceptable spark. For example, 25% of the area integration of the Vs and Is waveforms under normal operation can be set as the acceptable level so that the AVC can handle the operational conditions with a broad range of Vs and Is.

3. Procedures of Enhanced Spark Control

(1) Set the area integration of Vs and Is waveforms during the air load or normal operation condition upon the plant personnel's decision as the Upper Datum.
(2) Set a portion of Upper Datum, for example, 25%, as the acceptable spark level.
(3) Set a period of continuous sparks under the acceptable level, for example, five minutes.
(4) AVC calculates the area integration of Vs and Is waveforms at a spark once detects it through either the comparison of Vs level, the change of slop in Vs waveform or other means.
(5) AVC compares the calculated area integration of Vs and Is at the spark against the setting of the acceptable spark level.
(6) If the calculated area integration of Vs and Is at the spark is below the setting of the acceptable spark level, AVC will take no action to quench this spark.
(7) If the calculated area integration of Vs and Is at the spark is above the setting of the acceptable spark level, AVC will quench this spark by stopping firing the thyristor for a predetermined period of time.
(8) If the time for the acceptable sparks occurring continuously is reached, AVC will also quench such acceptable sparks by stopping firing the thyristor for a predetermined period of time.

SUMMARY

Although near one hundred years have passed since Dr. Cottrell designed and built the first EP for the industrial applications, the spark is still a major issue in the engineering and operation of EP. It is known that studying a spark is a considerably difficult task due to both the hazardous nature of EP in operation (high voltage, toxic flue gas at high temperature, etc.) and complicated interactions of mechanical parts and electrical components thereof. Hence, it takes not only the adequate measuring instrument but also the thorough understanding of EP in both electrical and mechanical aspects in order to carry out an effective diagnosis on a problem EP.

Two cases of damages caused by sparks are given in order to emphasis the importance of understanding and handling the sparks properly in an EP rather than address how the sparks can produce the destructive damage thereon. Since every industrial application is different from the other and so are the plants, it is necessary for the plant people to establish the knowledge of the operation and trouble-shooting of own EP in addition to the professional assistance from outside.

Further, the value of a SCADA system is proven not only in helping the plant people to comprehend their equipment but also in conducting a diagnosis on a problem. Field experience has shown that the memory of human being is not reliable for diagnosis but likely misguiding the directions of investigations resulting in the waste of time and effort.

ACKNOWLEDGEMENT
Author wants to give a special thank to *Tai & Chyun Associates Industries Inc.* in Taiwan who gave author the opportunity to acquire the valuable field experience regarding EP in various aspects as being a senior engineer in the company for years.

Author wants to give a special thank to Mr. John Leach, Chief Engineer of *Castlet Ltd.* in United Kingdom, for his kind assistance and patience in many occasions in which author had been involved for dealing with various problems concerning the electrical and control aspects of EP.

Author also wants to address the highest appreciation to Mr. Philip Crommelin who had enlightened author in person regarding the investigation on a problem EP that one must cover as many aspects as possible rather than just focuses on a single factor because usually a problem in an EP is likely a mixture of several individual or correlated factors.

REFERENCES

[1] *PRINCIPLES AND PRACTICES OF ELECTRICAL ENGINEERING*, Alexander Gray, Whit. Sch., M. Sc., G. A. Wallace, M.Sc., Eighth Edition.
[2] *Operation and maintenance manual of MCS-II*; Castlet Ltd., UK.
[3] *Operation and maintenance manual of EPIC-II*; FLAKT-ABB.
[4] *Inspection and Completion Report of Rapping System and AVC Retrofits on EP-B in Sludge Incinerator, Kaohsiung Refinery, CPC, Taiwan*; Tai & Chyun Associates Industries Inc.
[5] *Investigation Report of Fire Incident on Precipitator of Unit 3*, the name of the power plant is not revealed due to the agreement of confidentiality.