Forensic Analysis of Fire in a Substation of a Commercial Center

G. Ala, *Senior Member, IEEE,* S. Favuzza, *Senior Member, IEEE,* M. Mitolo, *Fellow, IEEE*
R. Musca, G. Zizzo, *Senior Member, IEEE*

***Abstract*—In this paper, the authors discuss the legal liabilities of the professional engineer as both the engineer of record of a project and the construction site manager. In particular, this paper analyzes the case of a fire at the end-user Medium Voltage-Low Voltage (MV-LV) substation of a shopping center in Italy, which occurred a few years after the maintenance works on the electrical installation. The professional engineer who had designed and overseen the construction of the substation was accused of professional negligence. The authors through the examination of applicable technical standards, as well as of safety regulations, demonstrate that the professional engineer had acted diligently and that there was no ground for the negligence charges. The analysis of the substation fire is provided, and the importance of the chain of custody, the chronological documentation, and the secure storing of all the artifacts and fire-damaged evidence is discussed. The authors believe that this paper can be a useful reference for electrical forensics engineers, investigating similar accidents.**

***Index Terms*— Forensic Engineering; Professional Engineer; Electric Fire; Substations; Legal liability; Safety.**

I. INTRODUCTION

In late 2018 a fire occurred at the end-user Medium Voltage-Low Voltage (MV-LV) substation supplying a shopping center in Italy. The fire destroyed the MV switchgear and cables and the LV switchboards inside the substation and caused the tripping of the protective device of the electrical utility located at the upstream High Voltage-Medium Voltage (HV-MV) station. The operation of this protective device caused a black-out in the area where the shopping center was located (Figure 1). The loss of revenue, and the consequently hazardous conditions, prompted the electrical utility to take legal action against the owners of the shopping center, which were sued for damages.

The destruction of major electric equipment of the substation caused the shopping center to be closed to the public for two weeks, which also caused economic losses for the concessions.

As a consequence, the shopping center owner filed a civil suit for negligence against the professional engineer who, years before, had designed and supervised the maintenance of the electrical equipment of the substation.

During the trial, an expert witness demonstrated that the professional engineer, recipient of the lawsuit, had acted according to best practices and that no technical errors had been made during maintenance. This paper, based on [1], discusses the legal case, and the errors made in the custody of the physical evidence.

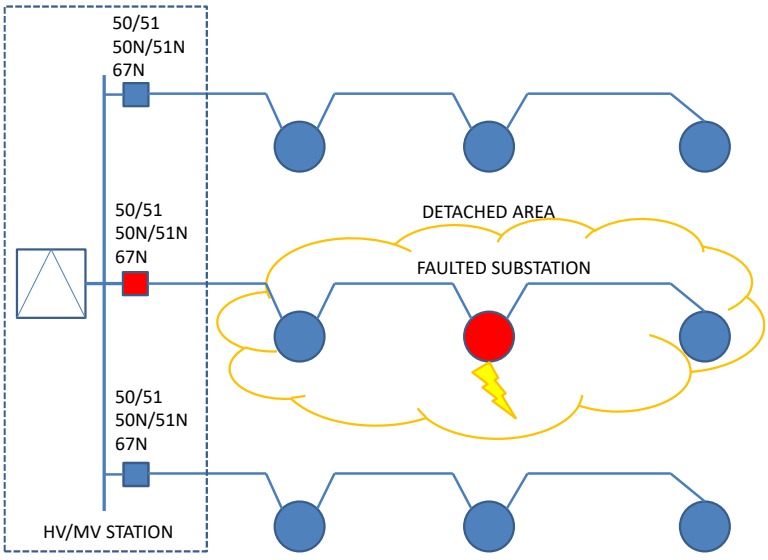

Fig. 1. Black-out caused by the fire in the faulted substation.

II. The legal claim

After the fire occurred, the owners of the shopping center suffered economic losses and hired a consultant to investigate the causes of the fire.

The consultant examined the MV-LV substation, the damaged equipment and examined the contract drawings documenting the project of the substation. He also examined the technical documentation detailing the electrical maintenance that was performed at the substation, three years earlier. The maintenance work consisted of the replacement of all the MV switchgears and connection and termination of MV cables. Through the examination of the project files, this consultant also noted that the professional engineer (P.E.), who had originally designed and then supervised the substation renovation:

- had not performed the lightning risk assessment per the international standard IEC 62305;
- had not prescribed the installation of MV fire propagation resistant cables, necessary when cables are bunched;
- had not prescribed the installation of temperature sensors for the three MV-LV transformers of the substation.

Based on the above, the shopping center owners filed a claim against the professional engineer of record for professional negligence, that is, the *failure to exercise the care and skill that are ordinarily exercised by other professional engineers in performing engineering services under similar circumstances.* The negligence is conduct that falls within the legal standard established to protect others against harm.

The plaintiff, who brought the civil suit to the court, stated that:

- the defendant (i.e., the professional engineer of record) had to perform the lightning risk assessment of the substation. The failure to provide this assessment before construction indicated that the engineer had not duly completed the project;
- the defendant had to specify the installation of MV fire propagation resistant cables. The failure to specify such cables contributed to the fire propagation;
- the defendant had to prescribe the installation of temperature sensors at the transformers. The failure to specify such sensors contributed to the fire ignition and its propagation.

III. Applicable Legal Framework and Technical Standards

For the protection against fires in shopping centers in Italy, the following documents are relevant:

- Presidential Decree 151/2011, that provides a list of the activities under the control of the National Fire Brigade [2].
- Minister Decree 07/08/2012, describing the requirements for the fire safety of projects [3].
- Minister Decree 03/08/2015, that is the national Fire protection code [4];
- Legislative Decree 81/08, Safety in the workplace [5].
- Minister Decree 27/07/10, that is the national mandatory technical rule for the protection against fires in shopping centers [6].
- CEI Standard 64-8-part VII section 751, that provides indications for the design and the realization of electrical installations in places with a high risk of fire [7].
- CEI Standard 11-17, on the installation and the choice of the cables to be installed in buildings [8].
- CEI Guide 64-50, that provides practical instructions for the installation of electrical components and devices in buildings [9].

With reference to the MV-LV substation, the following documents must also be considered:

- The Minister Decree 15/07/2014, that is the national mandatory technical rule for the protection against fires of electrical machines [10].
- The IEC Standard 61936-1, on power installations exceeding 1 kV a.c. [11].
- The CEI Guide 20-89, on the installation of MV cables [12].
- The CEI Guide 99-5, on the construction of private MV-LV substations [13].

IV. The Defendant's Rebuttal

A. Premise

The Minister Decree 27/07/10 is not applicable to the case under examination because the substation is separated by the shopping center's building and is more than 10 m far from it (Fig. 2).

The Minister Decree 15/07/2014 is not applicable because the transformers inside the substation are not oil-insulated transformers.

As a consequence, being the above two technical rules not applicable to the case under examination, the substation could not be considered an activity under the control of the national fire brigade, thus the Presidential Decree 151/2011, the Minister Decree 07/08/2012 and the Minister Decree 03/08/2015 were inapplicable. This rationale allowed the legal de-escalation of the case.

Fig. 2. Position of the substation and of the shopping center.

B. *On the failure to provide the lightning risk assessment of the substation*

According to the Legislative Decree 81/08, the lightning risk assessment falls on the building owner and it is not a professional obligation of the engineer who designs the installation. Since the substation had been in service for many years prior to the maintenance in question, the above risk assessment had to be performed by others and could have not been the responsibility of the defendant.

In addition, the design contract stipulated between the defendant and the commercial center ownership did not include any lightning risk assessment.

Lastly, the absence of the lightning risk assessment cannot necessarily imply that a fire has to be caused by a lightning strike. It was in fact verified that the day of the fire, no storms occurred in the area where the shopping center was located, or in the area of the MV line supplying the substation.

C. *On the MV cables*

According to section 751 of the CEI Standard 64-8, cables with resistance to flames propagation must be specified when bunched only in buildings with a higher risk of fire, as synthetized in Table I [14]. The MV-LV substation was not to be deemed at higher risk of fire, because:

- it was not a commercial enterprise under the periodical inspection of the national fire brigade (e.g., unlike storage facilities of compressed flammable gases);
- it was not to be considered a place with a high density of crowding, and with a limited capacity of outflow (art. 751.03.2 CEI 64-8);
- the supporting structures were not combustible (art. 751.03.3 CEI 64-8);
- no flammable or combustible materials were present (art. 751.03.4 CEI 64-8).

The CEI Guide 99-5 confirms that MV-LV end-user substations are ordinary places and not at higher risk of fire (art. 8.1), and identifies the CEI Standards 11-17 and 64-8 as the technical standards to be used to specify the proper type of cables.

TABLE I. CABLES CLASSIFICATION WITH REFERENCE TO FIRES AND THEIR UTILIZATION, ACCORDING TO CEI 64-8.

Category	Standard compliance	Application
cables without particular fire performance characteristics		Ordinary places
cables (single) with resistance to flame propagation	IEC 60332 series	Higher risk of fire places
cables (bunched) with resistance to flame propagation	IEC 60332 series	
cables with low emission of smoke (LSZH)	IEC 61034-1	Higher risk of fire places - places with a high density of crowding, with a limited capacity of outflow (art. 751.03.2 CEI 64-8);
cables with low emission of acidic and corrosive gases	IEC 60754-1 IEC 60754-2	
cables with fire-resisting characteristics	IEC 60331-21 IEC 60331-1	Higher risk of fire places - Safety circuits

According to the above standards and the CEI Guide 64-50, cables with minimum fire rating may be used in ordinary locations. In the case under examination, the MV cables installed in the substation were *flame propagation resistant* (single-core), therefore, with a remarkable better fire performance than those with minimum fire ratings prescribed by the applicable standards.

In addition, the term “flame propagation” referred to cables, implies that the fire propagation occurs from a higher fire risk location to an ordinary location, but not within the same location. Technical standards, therefore, recommend the use of fire barriers between rooms.

As an example, the CEI Guide 20-89 on the installations of MV cables, indicates (art. 8.2.1) that for cables without particular fire ratings, fire barriers may be installed where cables leave the fire compartment.

Therefore, it appears that when the fire spreads inside a room or compartment, e.g., within the same substation, fire protection barriers must protect the adjacent rooms against the fire spread, and not necessarily the location where the fire has started.

In addition, the CEI Standard 11-17 recommends the evaluation of the risk of fire propagation by electrical cables and ducts only for locations at higher fire risk. The Standard does not prescribe the preliminary installation of devices to avoid this risk, but only the risk evaluation. In the case in question, the evaluation of the risk of fire propagation was not required, being the substation an ordinary place.

Still, cables with a specified fire rating (according to the Italian fire protection code) are only needed for electrical systems installed after the 1st of July 2017; the substation under examination was installed several years before this date, thus, cables did not need any particular fire rating.

Finally, by examining the project files and the protective device coordination studies, it was found that the MV cables were protected against ground-faults by the 50N/51N relay. According to Standard CEI 64-8, this relay can lower the risk of fire [6], [13].

In conclusion, the presence of MV cables rated with resistance to fire propagation within the substation exceeded the minimum fire rating requirements and added safety to the installation.

D. On the failure to prescribe the installation of temperature sensors at the transformers

The fire did not involve the transformers. Therefore, the absence of the temperature sensors was not relevant to the case at issue. In addition, the examination of the project documentation indicated that the transformers were protected against over-currents by circuit breakers installed at both the MV and LV sides of the transformer; the circuit breakers were effectively coordinated with the damage curve of the transformers.

E. Conclusion

In conclusion, the statements of the plaintiff's consultant that errors and omissions were made by the defendant were baseless and erroneous and based on requirements that were not directly pertinent to the fire in the substation.

V. Examination of the Fire-Damaged Artifacts

To establish the cause(s) of the accident, the equipment involved in the fire (i.e., physical evidence) needed to be examined. However, after the event, the shopping center owners removed from the substation the damaged equipment, and installed the new, so that to allow the reconnection of the substation to the power grid; the substation's walls and roof were cleaned up and painted. This occurred without a prior inspection with all parties involved, which would have documented the fire scene.

Fire patterns are the visual and measurable effects that remain after the fire, thus they are essentially artifact evidence; such artifacts were lost.

In addition, the damaged equipment was transported from the fire site to the storage area without positive identification of parts or a documented chain of custody. The physical evidence was stored in an outdoor area, exposed to weather, which compromised its integrity. The artifacts remained in the outdoor area for months before their inspection was scheduled. During the multi-party examination, large metal areas of the switchgears were covered in rust (Fig. 3) and several electrical components were missing.

The artifacts were neither marked for proper identification at the accident site, nor properly stored in the storage area. Thus, during the inspection was not possible to find evidence to determine possible ignition points within the artifacts, where the fire may have started.

The preservation of the fire scene and of the damaged artifacts (or buildings) is a crucial aspect of every legal claim because it provides elements for the identification of fire origin [15]. The importance of this activity is discussed, for example in [16], where the author describes several electrical phenomena that occur at the fire scene and the activities that the consultant must perform to identify fire patterns and fire origin. Also in [17], the authors present some case studies of electrical fires that show the importance of examining the artifacts and debris at the fire scene. NFPA 921 provides fundamental guidelines for fire investigations [18].

VI. Importance of the Fire Risk Assessment

The case under examination demonstrated how important is the correct fire risk evaluation for a place, installation or working activity. The electrical designer must always classify the place/activity with regards to fire events at the very beginning of the project. This classification must be based on the fire risk assessment provided by the client or, if a specific assignment from the client exists, by the designer itself.

The fire risk assessment may indicate that the building is an ordinary location (i.e., lower risk of fire) or a higher-risk of fire location. The fire risk assessment must consider both the CEI Standard 64-8 part VII, which classifies the locations with a higher risk of fire into three typologies, and the Presidential Decree n. 151/2011, which provides a list of locations and activities under the periodical control of the national fire brigade. The risk assessment may also include specific situations where the electrical equipment can cause a fire [19]-[20]. Results of the risk evaluation are summarized in Table II, where the applicable standards for the electrical design are also listed.

VII. Conclusions

Based on the elements provided by the plaintiff's consultant, herein discussed, the lawsuit for professional negligence was dismissed by the court. Physical evidence should always be protected from loss, contamination, and degradation [15]-[17]. The improper storage and the restoration work at the substation compromised the integrity of such evidence; this caused a true challenge for the determination of possible ignition points within the fire damaged equipment, as well as for the analysis of fire patterns in the substation. It was also apparent that no efforts were made to maintain the security and integrity of the physical evidence from the time of the initial discovery and

collection to the date of the multi-party examination. The chain of custody was undocumented.

This case clearly shows that in the case of an alleged electrical fire, a consultant must:

- categorize the locations (i.e. ordinary, higher fire risk, etc.);
- identify the applicable technical and legal framework;
- identify the required protective measures for the specific installation;
- examine the project documentation for completeness and correctness;
- identify the proper ratings for fire protection and fire-resistant equipment/components, as required by applicable standards;
- examine the contract between the professional engineer and the owner to identify the technical responsibilities and obligations of the engineer;
- examine inspection reports;
- inspect the fire location to possibly determine the point of origin of the fire, the specific causes of the fire, the contributing factors to a fire's spread;
- examine the artifacts to determine ignition points.
- do not move the artifacts from the fire scene prior to inspection and proper documentation of evidence: conductors compromised by fire may break.
- if artifacts must be removed for restoring the service, detailed photos must be taken.
- collect and pack debris according to their location on the fire scene.

A correct assessment of the accident from a legal and engineering point of view is essential for a good representation of the case in court.

TABLE II. PLACES/ACTIVITIES CLASSIFICATION WITH REGARDS TO THE RISK OF FIRE

Code	Classification	Applicable standards
O11	Ordinary place (low risk of fire)	General parts of CEI Standard 64-8 and CEI Standard 61936-1
M11	Place not under the periodical inspection of the national fire brigade but with a high risk of fire for high density of crowding or limited capacity of outflow (art. 751.03.2 CEI 64-8).	General parts of CEI Standard 64-8 and CEI Standard 61936-1 Part VII of CEI Standard 64-8
M12	Place not under the periodical inspection of the national fire brigade but with a high risk of fire for the presence of combustible supporting structures (art. 751.03.3 CEI 64-8).	
M13	Place not under the periodical inspection of the national fire brigade but with a high risk of fire for the presence of flammable or combustible material (art. 751.03.4 CEI 64-8).	
H11	Place under the periodical inspection of the national fire brigade but not with a high risk of fire according to CEI Standard 64-8 part VII classification.	General parts of CEI Standard 64-8 and CEI Standard 61936-1 DPR 151/2011 DM 07/08/2012 Fire protection code or, as an alternative, Minister Decree containing the technical specifications for protection against fire for the specific place/activity if existing.
VH11	Place under the periodical inspection of the national fire brigade and with a high risk of fire for high density of crowding or limited capacity of outflow (art. 751.03.2 CEI 64-8).	General parts of CEI Standard 64-8 and CEI Standard 61936-1 Part VII of CEI Standard 64-8 DPR 151/2011 DM 07/08/2012 Fire protection code or, as an alternative, Minister Decree containing the technical specifications for protection against fire for the specific place/activity if existing.
VH12	Place under the periodical inspection of the national fire brigade and with a high risk of fire for the presence of combustible supporting structures (art. 751.03.3 CEI 64-8).	
VH13	Place under the periodical inspection of the national fire brigade and with a high risk of fire for the presence of flammable or combustible material (art. 751.03.4 CEI 64-8).	
VH14	Place under the periodical inspection of the national fire brigade and with a high risk of fire for two or more of the conditions reported by CEI Standard 64-8 part VII.	

Particular 1. 1st Switchgear

Particular 2. Presence of rust

Particular 3. 2nd Switchgear

Fig. 3. Pictures of a fire-damaged MV switchgear.

ACKNOWLEDGEMENT

This work has been carried out within the framework of the International Research Agreement titled "*Innovative Solutions for Safety in Power Systems*", between the University of Palermo (Italy) and the Irvine Valley College (USA).

REFERENCES

[1] G. Ala, S. Favuzza, R. Musca, G. Zizzo, M. Mitolo, "Legal Liability of Professional Engineers: the Case of a Fire at a Shopping Center", 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Genoa, Italy, 11-14 June 2019.

[2] Presidential Decree n. 151/2011. Regolamento recante semplificazione della disciplina dei procedimenti relativi alla prevenzione degli incendi, a norma dell'articolo 49, comma 4-quater, del decreto-legge 31 maggio 2010, n. 78, convertito, con modificazioni, dalla legge 30 luglio 2010, n. 122.

[3] Minister Decree 07/08/12. Disposizioni relative alle modalita' di presentazione delle istanze concernenti i procedimenti di prevenzione incendi e alla documentazione da allegare, ai sensi dell'articolo 2, comma 7, del decreto del Presidente della Repubblica 1° agosto 2011, n. 151.

[4] Minister Decree 03/08/15. Codice di prevenzione incendi (Fire protection code).

[5] Legislative Decree n. 81/2008. Testo unico sulla salute e sicurezza sul lavoro.

[6] Minister Decree 27/07/10. Approvazione della regola tecnica di prevenzione incendi per la progettazione, costruzione ed esercizio delle attivita' commerciali con superficie superiore a 400 mq.

[7] CEI Standard 64-8. Electrical installations of buildings.

[8] CEI Standard 11-17. Generation, transmission and public distribution systems of electric power - Cable lines.

[9] CEI Guide 64-50. Residential building - Electrical, telephonic and data transmission installations. In situ general installation criteria.

[10] Minister Decree 15/07/2014. Approvazione della regola tecnica di prevenzione incendi per la progettazione, l'installazione e l'esercizio delle macchine elettriche fisse con presenza di liquidi isolanti combustibili in quantità superiore ad 1 m³.

[11] IEC Standard 61936-1. Power installations exceeding 1 kv a.c - Part 1: common rules.

[12] CEI Standard 20-89. Selection and erection of medium voltage electric cables and accessories - application criteria.

[13] CEI Guide 99-5. Guidelines for the execution of earthing systems of active and passive consumers connected to distribution systems with voltage exceeding 1 kV AC.

[14] M. Mitolo, S. Favuzza, G. Zizzo, "Fire risk assessment and cable selection for end-user substations", 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2017, Milan, Italy, 6-9 June 2017.

[15] K. Clemente, E. Hesla, "Two Electrical Forensic Engineering Case Studies", IEEE Transactions on Industry Applications, Vol. 50, No. 6, 2014, pp. 4197-4201.

[16] D. P. Utt, "Electrical evidence at fire scenes", 2010 IEEE Symposium on Product Compliance Engineering Proceedings, 18-20 October 2010.

[17] J. Swart, J. Loud, D. Slee, "Arcing and fires - case studies", 2009 IEEE Symposium on Product Compliance Engineering, 26-28 October 2009.

[18] NFPA 921: "Guide for Fire and Explosion Investigations". 2014

[19] M. Mitolo, T. J. Bajzek, "Safety Against Burns from Hot Touchable Parts of Electrical Equipment", IEEE Transactions on Industry Applications, Vol. 52, No. 5, 2016, pp. 3699-3704.

[20] G. Parise, E. Hesla, C. S. Mardegan, L. Parise, E. Bragagni Capaccini, "Measures to Minimize Series Faults in Electrical Cords and Extension Cords", IEEE Transactions on Industry Applications, Vol. 55, No. 5, 2019, pp. 4551-4556.