More Electric Aircraft Fault Current Protection: A Review

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***Abstract*— By development of more electric aircraft (MEA), it is essential to have an overview of recently presented methods to protect MEA against fault current. This paper gives an overview of possible faults that may be occurs in the electric power system of more electric aircraft. Various functionalities and fault limiting solutions are also covered. Besides, the paper focuses on the main challenges for improving the reliability of the distribution system in MEA based on protection functions such as fuses, circuit breakers, and fault current limiters. Finally, the suggestions are surveyed to enhance electric power system performance of MEA.**

Keywords—more electric aircraft, fault current, circuit breaker

I. Introduction

Over recent decades, there has been tremendous progress in the efforts to move toward more electric aircraft [1]. Many subsystems that previously employed mechanical, hydraulic, and pneumatic power have been fully or partially replaced with electrical systems [2, 3]. Moreover, Civil-aircraft manufacturers have identified that these 'More-Electric' technologies can help reduce overall life-cycle cost and weight for the aircraft operator, as well as optimize performance [4]. To achieve a progressive structure, the aircraft industry is developing required mechanical, electrical, and electronic components, and looking at new concepts to protect and monitor them throughout their operating life [5].

Considering MEA, electrical power system (EPS), the actuators, landing gears, pumps, engine starters, the environment control systems (ECSs) and the deicing systems are all powered by the electric energy [6, 7]. Whether, it is well assumed that the safety is the main issue for the MEAs development beside, there is a major need to quickly identify and locate electrical faults [8, 9]. One of the most significant requirements of MEA technologies is the fault management (FM) devices which especially provides safety of the aircraft [10]. Indeed, the protection of a fault in the MEA electric system is facing some technical challenges [11].

To increase aircraft safety and protection enhancement, this paper firstly provides an overview of MEA's possible faults and challenges. Next, protection methods in MEA electrical system are reviewed and an evaluation report has been checked.

The Rest of the paper is organized as follows: section II gives an overview of more electric aircraft and also shows a diagram of it. In section III analyze possible short-circuit faults in MEA. Protection mechanisms that can be used for MEA are reviewed in section IV, protection system location in MEA is discussed in section V and finally, conclusion is given.

II. An Overview of MEA

To reduce the weight and size of the aircraft, the secondary power system of the more electric aircraft, high voltage direct current (HVDC) system which recognized as the ideal power supply system of MEA is suggested to supply power of MEA [12]. However, the higher voltage level (±270 V) increases the risk of current faults, easily leading to overheating accidents, even as high as thousands of Celsius, and the high temperature can damage the structure of the aircraft within a short period of time [13].

Accordingly, the frequency and voltage level for the electrical grid need to be considered, as they directly relate to the system topology and overall weight. This system is still adopted in modern aircrafts, because of the overall good performance. An energy supply system for MEA, consisted of DC/DC converters, wiring harness, circuit breakers, FCLs and power flow controller [14, 15].

Fig. 1 depicted power system distribution structure of the MEA which is contain the DC power distribution center that supply power of MEA and feed starter generators by rectifiers, the existing engine in both side that feeds with starter generator (S/G) also a convertor within them which raise the power of S/G, a gas turbine that introduced auxiliary power unit (APU), instrumentation system and power electronic system that operate functions in aircraft (Table 1).

III. Short-circuit occurrence in MEA's electric system

A mixture of faults can always contribute to system failure, thus, the possible faults must be solved or controlled to achieve the system with both predictable and reliable characteristic, which can be improved by regular maintenance service [16]. Faults are usually due to the malfunction of components, such as defective devices and sensor failures, which can distort measurements or cause missed sampling. Also, broken or poor connections, weak communication, hardware, or software malfunctions are the common causes of faults [17].

Developing uncontrolled faults which are depicted in Fig. 2 can be contained power distribution center faults, fault on power electronic unit, battery management system fault, starter generator fault, APU generator fault, both AC and DC converters fault, existing motor fault, cabin electric system fault and other possible faults that all of them are shown in Fig. 2, will endanger any safety of MEA electric system and the response to them can be classified into following sections of protection methods [18].

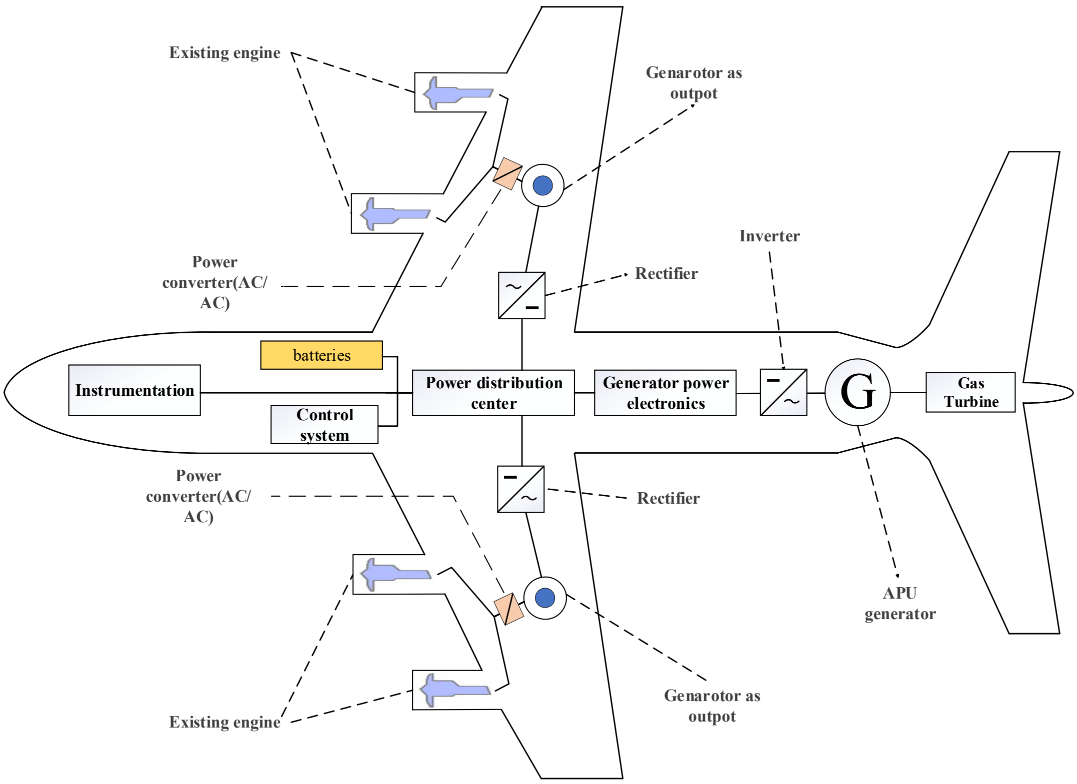


Fig. 1. Electrical system diagram of MEA

TABLE I. DIFFERENT SUBSYSTEMS IN MEA'S ELECTRIC SYSTEM

Subsystem	Function	Type
Power distr. center	Supply MEA power	Solid wire
APU generator	Auxiliary power	Electric machine
Power electronic system	Implementation functions automatically	Solid-state
Starter generator	Flotation existing motor	
Existing engine	Turn fan of MEA	
Power convertor	Increase AC power level	

IV. PROTECTION METHODES

In all architectures in aircraft, overcurrent protection devices play a rather important role in the electrical system by limiting current levels in the wires and protecting the electrical and electronic equipment in aircraft applications [19]. Protection methods in electric system circuits of MEAs is a challengeable issue in their design schemes. In this part, various protection methods are presented as follows: Fuse [20], FCL [21], Circuit breaker [22] and power flow controller [23].

1. fuse

Fuse is a general safety device in electrical systems which protect the circuit in face of overcurrent. An essential component that interrupted a large current flow [24]. Actually, it can be used in MEA to protect equipment.

1.1. Ultra-fast programming of silicide polysilicon fuses

By the importance of protection in electrical systems, devices with a fast operation have been required. Silicide polysilicon fuses (SPF) which rapidly replaced laser fuses, because of electrical programming which reduces programming costs and increases their flexibility. To the increasing the performance of the MEA electric system, these sensitive fuses can be used in low power loads in MEA such as communication load, lighting load, sound load, and others because of their quick action [25]. The structure and place where located are shown in Fig. 3.

2. Circuit breaker

A circuit breaker is an electrical switch that works automatically and is designed to protect circuits of MEA electrical circuit from the damage of overcurrent due to overload or short-circuit [26].

2.1 Solid-state fast breaker

The solid-state fast circuit breaker (SSCB) [27] shows significant benefits (Fig.7. (b)) in response, which usually shuts off the fault current in a few microseconds [28].

2.1.1 Solid-state AC fast breaker

Short-circuit detection in less possible time is extremely important. However, because of fault speed, to prevent damage, a device by fast action to break the circuit is needed. Circuit breakers plays an important role in this concept. Accordingly, a solid-state AC fast circuit breaker design with two anti-parallel IGBT that paralleled with a series RC and a parallel diode is presented in this section as Fig. 4 [29].

According to Fig. 2, generators are faced with fault risk. hence, a solid-state AC fast breaker is purposed to protect and security this component from accidental overcurrent or overvoltage.

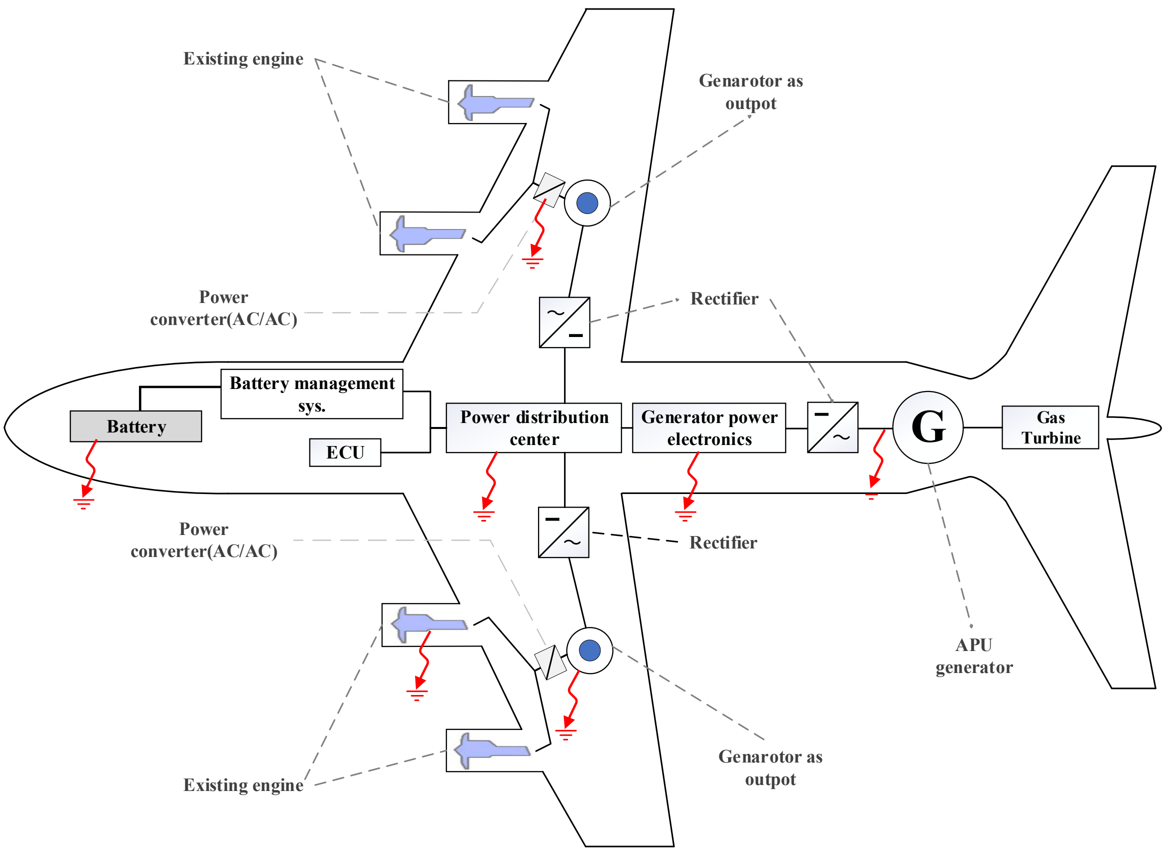


Fig. 2. Fault current that may occur in MEA system

2.1.2 *Solid-state DC fast breaker*

The design of dc circuit breakers is more complex than ac circuit breakers because there is no natural zero current that can cut off the current [30]. This can not only cause the rapid failure of the fault current, but also the operational tasks of re-closing and re-fragility. This type of circuit breakers can be used in the DC part of the MEA system as well as Fig. 5 [31].

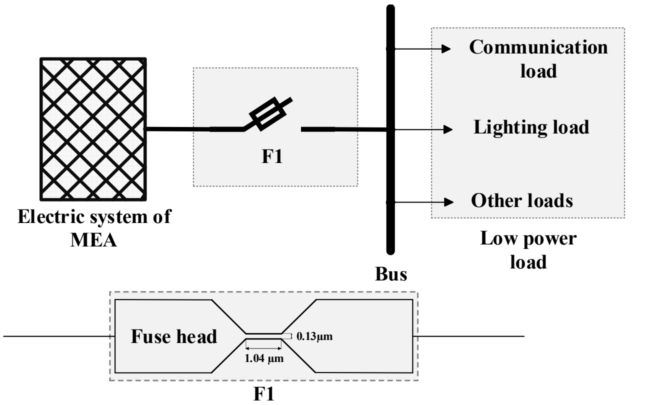


Fig. 3. Load protection by Ultra-fast programming of silicided polysilicon fuse

2.2 *Mechanical breaker*

Mechanical circuit breaker (MCB) is modeled by active current injection for a system surface, which provides a convenient representation of circuit breaker for MEA use [32].

2.2.1 *Medium-speed MB*

A considerable number of circuit breakers that are used in the electric systems is in medium speed MB's subsystem. Their action duration time is between 100ms to 500ms. These classes of MBs are useful in MEA's electric system which is not need high-speed action to break.

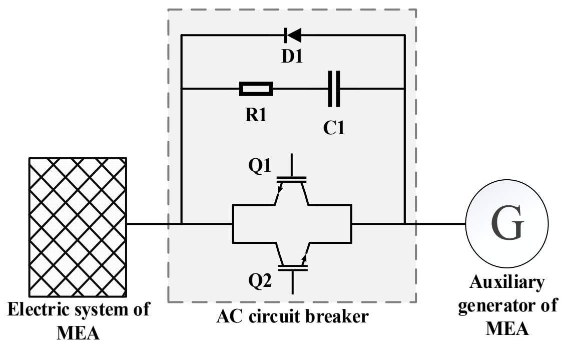


Fig. 4. Solid-state AC fast breaker which is used in MEA to protecting the auxiliary generator

2.2.2 *Fast MB*

The breaker mentioned above, there are other kinds of breaker which are faster than medium speed class such as ABB's is limiter Fig.7. (a) that work under 100ms [33].

3 *Fault current limiter (FCL)*

Another solution to MEA electrical system protection is to use technologies such as fault current limiters (FCLs). FCL is one of the protective devices used to limit the fault current [34, 35]. Power electronic units and power distribution center are an extremely sensitive mechanisms that a small fault can affect the whole the aircraft. Therefore, they must not be exposed to any fault [36].

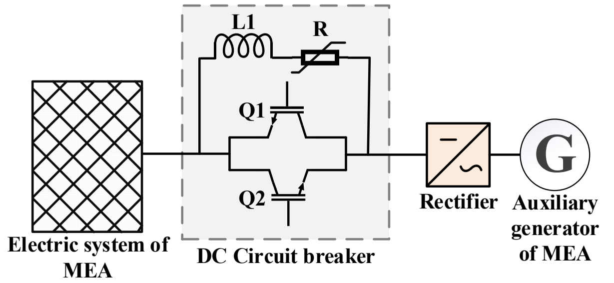


Fig. 5. solid-state DC fast breaker connected to DC part of a rectifier in MEA electrical system

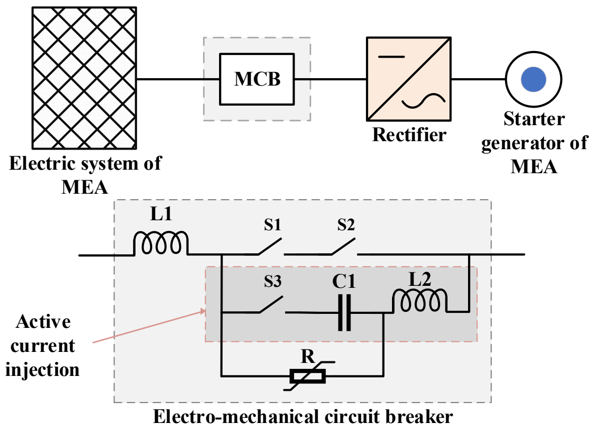
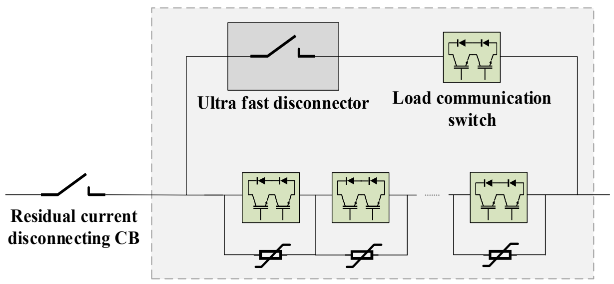
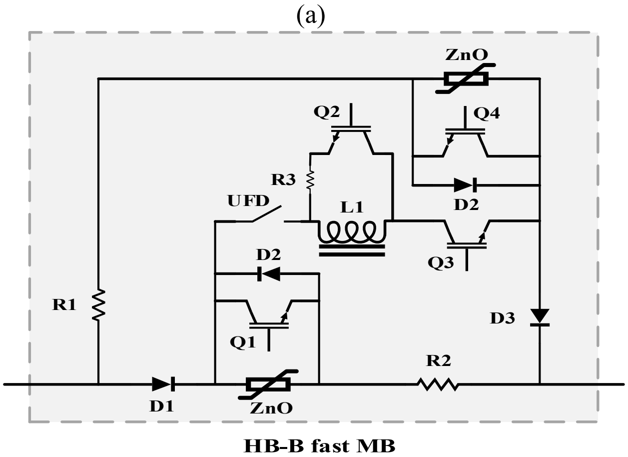


Fig. 6. An EMCB based on active current injection



(a)



(b)

Fig. 7. (a) ABB fast CB, (b) solid-state CB

3.1 Resistive superconductive fault current limiter (SFCL)

Short circuit current level is reduced by SFCL which passes under defective conditions. Also, SFCL should be installed near important equipment for protection aim. Therefore, the resistive and position of the SFCL help to reduce weak currents and increase transient stability in the system [37].

3.1.1 Resistive AC SFCL

This type of SFCLs in the normal operation of AC systems have no resistance but in faulty condition imposes a resistance by superconducting to prevent overcurrent [38].

3.1.2 Resistive DC SFCL

The DC resistive SFCL includes a superconducting coil which is placed in a diode bridge [39]. Its operation is based on the synergistic use of the concepts of resistance limiter and rectifier. Under normal operating conditions, the protected circuit current circulates through the diodes and bypasses the superconductor [40]. Fig. 8 shows a topology of R-DC SFCL.

3.2 Inductive SFCL

Inductive SFCL, which is installed in the circuit as a reactor, usually includes a core, a primary copper coil, and a superconducting secondary short coil with a magnetic connection placed in a crystal. The absence of uninterrupted current and circuit wires due to superconducting failure is one of the important benefits of inductive SFCL [41].

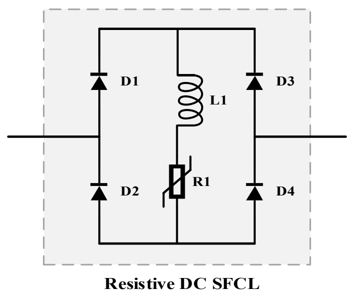


Fig. 8. A resistive DC SFCL

3.2.1 Inductive AC SFCL

Inductive SFCL operates on the basis that, as the saturation device goes in or out of saturation, its impedance changes significantly. To achieve the current limit in both half-cycles, two arc induction devices (inductors) are required in each phase. These are saturated by a DC bias field supplied by a superconducting coil. The AC line to be protected is wrapped around two inductor cores [42].

3.2.2 Inductive DC SFCL

One of the advantages of the SFCL based on the DC reactor is that there is no surge current during fault occurrence because the DC reactor prevents a sudden increase in current. Therefore, the fault current steadily increases during the fault. It takes more than 5 cycles to troubleshoot an existing electrical system that has installed conventional circuit breakers (CBs) [43].

3.3 Inductive FCL

This section purpose inductive FCL [44] to limit overcurrent in the convertors, batteries, power electronic units, and power distribution center which is shown in Fig. 7.

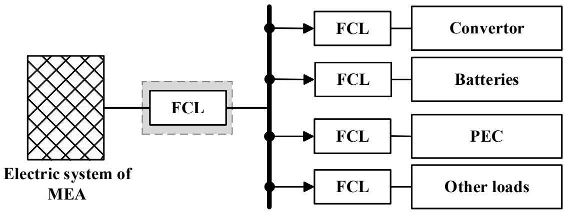


Fig. 9. Location of FCL in MEA DC system

3.3.1 Inductive DC FCL

Due to the lack of zero value, a fast-acting structure compared to the above structure is required to protect DC components and sections [45]. Fig. 10 (a) shows a topology of inductive DC FCL.

3.3.2 Inductive AC FCL

All AC equipment such as AC buses is faulty [46]. Therefore, to reduce fault current and protect them in the electrical system security an AC FCL must be placed in these busbars and components. Fig. 10 (b) shows an AC FCL that sets the constraint in less time [47].

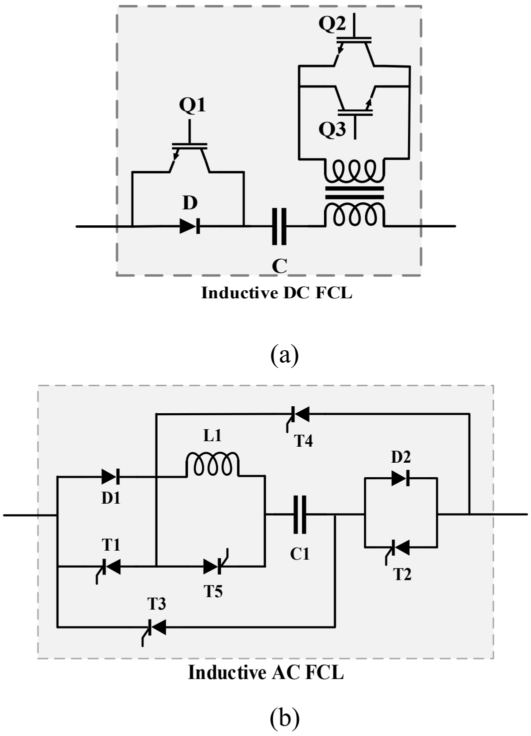


Fig. 10. Proposed inductive AC FCL

4 Power flow controller

In this section, a structure of power flow control is proposed. The PFC controls current flow and sequence it can control fault current with the DC reactor to prevent increasing current amplitude. Thus, it is suggested to use in busbars and wires [48.49].

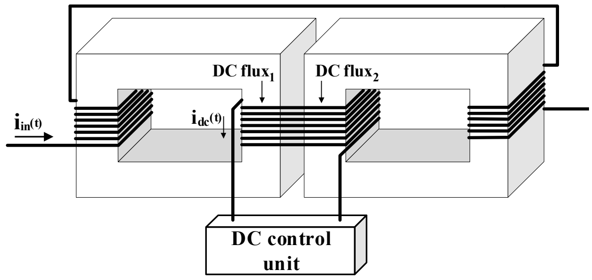


Fig. 11. Protectiev Power flow controller

V. Protection System Location in MEA

In this section, a brief comparison of the reviewed protection structure is given. This presentation is considered based on each protection component operation and placement in MEA electrical system, while the possibility of short circuit faults is regarded for all MEA components as shown in Fig. 2. This classification is illustrated in Table II.

TABLE II. MEA Protection System Comparison and Classification

Structure type	*operation*	*Delay*	*Functional placement in MEA*
SPF [23]	Current breaker	0.5 ms	Low power loads
SS-AC fast CB [29]	Current breaker	3 ms	AC lines and busbars
SS-DC fast CB [31]	Current breaker	3.7 ms	DC lines and busbars
EMCB [33]	Current breaker	5 ms	Rectifiers
ABB fast CB [33]	Limit current and breaker	5 ms	Power distribution center
SSCB [28]	Limite current and breaker	3 ms	Starter generator
R-DC SFCL [40]	Current limiter	10 ms	DC low power load
Inductive DC FCL [45]	Current limiter	3.2 ms	DC power loads
Inductive AC FCL [47]	Current limiter	7 ms	Converters and motors

I. Conclusion

Short circuit fault occurrence is a far more harmful event in vulnerable power electronic-based MEA than other electrical systems. In this paper, first of all, an overview of MEA is presented and then possible faults are debated to demonstrate influents of fault in each part of the MEA. In addition, a comprehensive review of the well-known fault current protection structure obviously shows the appropriate operation of them to enhance fault protection in MEA. Finally, the results are prepared by the table to depict the location and features of each protection devices. This review result can be extensively enriched future researches in the field of MEA protection.

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