Case Study of Solar Photovoltaic System Cable Connectors Failures

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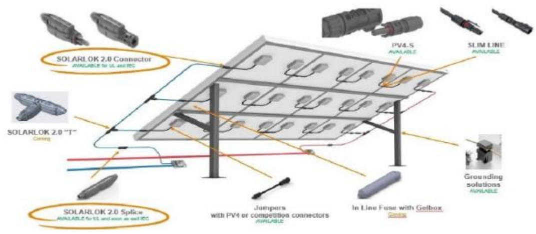
1. Background

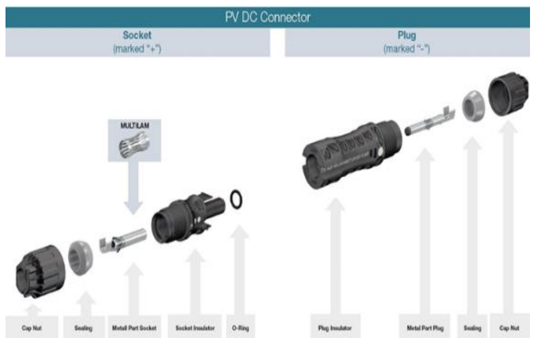
In 2016, a fire accident occurred at the Taipei Gongguan Water Treatment Plant due to a solar power system, marking it the first case in Taiwan. After months of investigation, forensic analysis indicated that the cause of the fire was not external factors such as smoking or dry leaves but poor contact in the quick disconnect connectors of the photovoltaic system [1]. Subsequently, domestic photovoltaic industry stakeholders began to emphasize quality control and awareness of quick disconnect connectors.

Quick disconnect connectors (Hereinafter referred to as Connectors) are widely used in photovoltaic systems [2][3][4] (Fig. 1). Fig. 2 illustrates their detailed exploded view, distinguishing between socket and plug. Each assembly includes a nut cover, gripping structure, metal terminal, and insulated terminal, with the connection between the socket and plug requiring an O-ring washer. For outdoor installation, connectors must meet weather resistance requirements (UV, temperature, humidity, etc.) and be waterproof and dustproof (IP 65 or higher) to ensure the long-term safety of connections. International standards such as UL 6703 and IEC 62852 have been established for connectors, providing equipment quality benchmarks for industry players.



Source: [5]

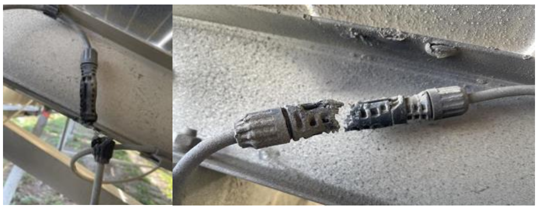
Fig 1 Types of Connectors used on photovoltaic



Source: [6]

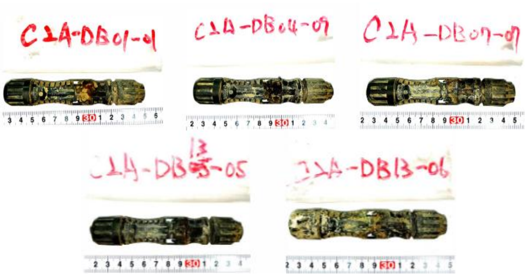
Fig 2 Exploded diagram of Connectors

Since January 2023, a significant number of failures have occurred in the photovoltaic module connectors at a domestic solar power station, resulting in nearly 3,100 series strings failing (statistics until January 2024). Most failures have occurred at the junctions where the positive and negative poles of the series strings connect to the DC lines, causing severe loss in electricity generation. This study analyzes five sets of connectors used in the station to clarify the reasons for these failures and improve the operational reliability of the solar power station. The on-site burn damage appearance and samples of the five sets of connectors are shown in Fig. 3 and Fig.4, respectively.



Source: Pictured by Renewable Energy Department

Fig 3 Appearance of burned-out Connectors



Source: Pictured by TPRI

Fig 4 Five sets of on-line Connectors

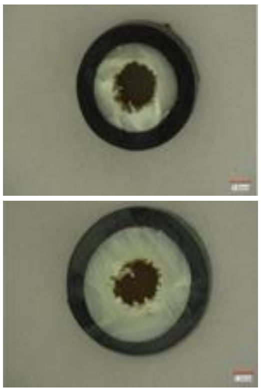
2. Research Contents

Upon observing the connectors used in 5 sets of lines, it was found that the brand and model of the socket side differed from those of the plug side. There was no significant gap between the two ends when joined. Still, the gap between the socket and the nut cover was noticeably larger than that between the plug and the nut cover, as shown in Fig. 5. Upon actual disassembly, it was discovered that the gripping structures used at both sides were different, confirming that they were from different brands (different design structures).

Source: Pictured by TPRI

Fig 5 The condition of the connector junction

After measuring the dimensions of the conductors at both sides of the connector, it was found that while the conductor (stranded copper wires) diameters were the same, there was a significant difference in the outer diameter of the conductor insulation. The outer diameter of the insulation at the socket side was noticeably larger than that at the plug side. This dimensional difference is hypothesized to be the primary reason for the different gaps observed on both sides, as shown in Fig. 6.



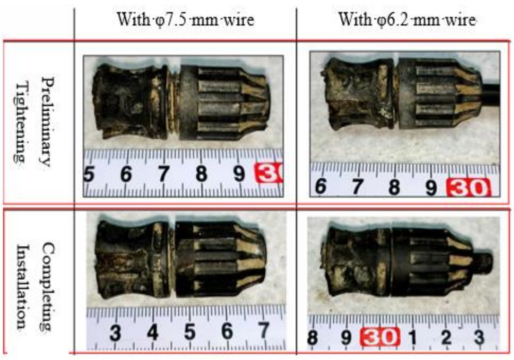
Source: Pictured by TPRI

Fig 6 Cross-sectional diagram of the conductor connections at both sides

(Up: Plug conductor φ6.2 mm; Down: Socket conductor φ7.5 mm)

A recommended torque tightening table can be found in the product catalog and installation manual. This table indicates that different tightening torques are suggested for different conductor diameters. Some connector manufacturers recommend using a handheld accessory wrench for preliminary tightening, followed by applying the specified torque to complete the installation process [7][8].

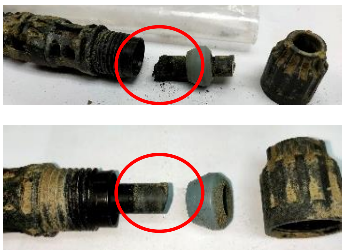
Following the above steps, we conducted a practical simulation of the connector locking process. When only the handheld wrench was used for preliminary tightening, the observed gap distance matched that found in the connectors used on-site. Subsequently, applying the recommended torque using a torque wrench (4 N-m suggested for AWG #12 wire diameter) visibly reduced the gap distance, as shown in Fig. 7. Therefore, it was deduced that the installer only performed preliminary tightening without completing the installation.



Source: Pictured by TPRI

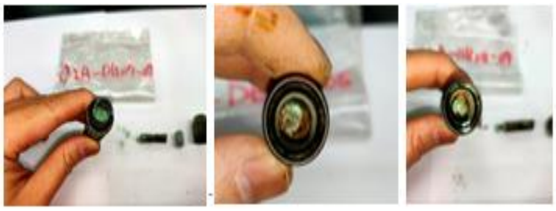
Fig 7 Comparison of gaps between preliminary tightening and complete installation

An incomplete connector assembly due to inadequate tightening could not prevent moisture and dust from entering (Fig. 8), leading to the formation of corrosion products and oxides (Fig. 9). This incomplete assembly contributed to subsequent overheating and burning at the connector junctions.



Source: Pictured by TPRI

Fig 8 Dust (red circle) ingress into the connectors



Source: Pictured by TPRI

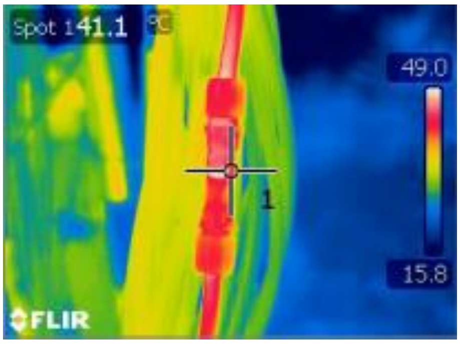
Fig 9 Corrosion products and oxides on the connectors

Based on the results of SEM-EDS analysis, it is inferred that the bright green areas inside the junction are corrosion products of copper alloys formed due to humid and salty environments (such as basic copper carbonate (Patina) and copper chloride). The black areas inside the junction are copper oxides formed due to high-temperature oxidation. Both are consequences of inadequate connector assembly.

3. Conclusions

Common causes of connector failures include six main factors: 1. Improper installation leading to incomplete contact points and increased electrical resistance, 2. Incorrect installation tools causing non-compliance with product specifications or component damage, 3. Lack of trained personnel following standard installation procedures resulting in poor sealing, 4. Interconnecting different brands which may compromise sealing and waterproof (or dustproof) properties due to design differences, 5. Use of uncertified connectors lacking international standards and certifications, raising concerns about equipment reliability, and 6. Incorrect material selection where connector materials do not consider environmental aging factors, leading to degradation from contact with oil or sunlight and subsequent failure of characteristics[9]. The above factors can result in power loss, ground short-circuit accidents, fires, economic losses, injuries, and legal liabilities.

This study's case involves frequent connector failures due to factors 3, 4, and 5 mentioned above. Specific improvement suggestions include reviewing and controlling field design and equipment selection, strengthening standardized operating procedures for on-site construction personnel, conducting effective education and training for installation personnel, and subsequently verifying installation effectiveness through visual inspections and infrared temperature checks (Fig. 10). These measures are essential to ensure the long-term reliability of connectors in the field.



Source: [9]

Fig 10 Abnormal connector temperatures (Infrared Thermal imaging)

4. References

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