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Research Article

Evaluation of Various PV Module Cable Connectors and Analysis of their Compatibility

Satish Pandey*

Analytics Department, Mahindra Susten Pvt. Ltd., Mumbai, India

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Abstract

The growth of the PV industry in India is reaching an exponential rate. To maintain the quality of this sector, we have to be confident that each element going in the infrastructure of the PV installation is made in accordance with its application. We have seen a lot of failure in the connectors which often lead to a safety hazard. Here we have characterized different aspects of photovoltaic connector's over a population by measuring various combinations. This helps us to select the right connector as per our application after selection of right connector, the crimping of PV module connectors should also be assessed. Since loose or improper crimping also contributes in increased contact resistance & hence results in increased power losses.

Keywords: *Contact resistance, Crimping, PV module connector.*

1. Introduction

PV connectors are used to connect two or more number of PV modules in series & parallel to make a string. Along with the PV modules, these connectors also sustain in the field for about 25 years. A PV connector has to withstand harsh weather conditions like extreme heat, cold, rain etc. So noble quality is the main concern for any manufacturer or customer.

When these connectors are exposed in the field to face different weather conditions at different loading, the resistance of contact pin increases by some fraction over a period [Benjamin B. Yang, N. Robert Sorensen, Patrick D. Burton, Jason M. Taylor, Alice C. Kilgo, David G. Robinson and Jennifer E. Granata], which is irreversible. According to a survey, due to increased contact pin resistance of a connector, the annual energy loss was observed 140 Watt-hour per string. (Photon International, January, 2010) These losses can become enormous as the number of strings increases. The contact pin resistance of two different connectors may not be same due to manufacturing constraints. If the contact pin resistance is high, power losses will also be high. With higher current and temperature, dilapidation of connectors is rapid and the factors that contribute to the dilapidation and failures of PV connectors are (A. S. Bahaj, P. A. B. James, and J. W. McBride, 2003):

- Fretting due to relative movement of the contact interfaces. The relative movement can be caused by multiple cycles of temperature expansion and contraction or by environmental factors.
- If the temperature rise is more for any connector, with a period of time the connector dimension may change due to expansion & contraction of connectors and the connectors might get dilapidated fast.
- Corrosion can happen through the ingress of contamination at the contact interface.
- Gradual age-related changes also change the stiffness and morphology of the connector material.

2. Experimental Analysis

2.1 Sampling

Here, we have evaluated the quality of various Connectors present in the market. Ten sets of Connector from popular manufacturers were examined in this study. Details of these connectors are shown in Table 1.

2.2 Tests

For electrical compatibility, the contact resistance was measured as per IEC 60512 / Test [2b] & temperature rise was measured as per EN 50521:2008. In addition, the mechanical compatibility was tested by Insertion-Retention force, conducting water proof test, Insulation resistance test, and wet leakage current test as per EN 50529. The purpose of these tests is to provide insight into weather harshness, on field test analysis & rank the connector manufacturers. The various tests are as below: -

*Corresponding author's ORCID ID: 0000-0002-7047-2818

Table 1: Connector Details

Sr No.	Manufacturer	Model No.		Degree of protection	Sample Year	Related Voltage(v)	Related Current(A)
		Male	Female				
1	Multi-Contact	MC4(PV-KST4)	MC4(PV-KBT4)	IP 67	2015	1000	30
2	Bizlink	S418-F2	S418-F1	IP 67	2015	1500	40
3	Amphenol	Helios H4R,H4CMC4D	Helios H4R,H4CFC4D	IP 68	2015	1000	42
4	Jkoom(Jinko)	PV-JK00M	PV-JK00M	IP 68	2014	1000	25
5	Sunter	PV-C202-CZ010	PV-C202-CK010	IP 67	2015	1000	30
6	Lumberg	LC4-CP 30	LC4-CP 31	IP 68	2015	1000	30
7	COYO	CN4A-A001	CN4A-A002	IP 67	2015	1000	33
8	Elmex	EMPV4-1	EMPV4-2	IP 67	2016	1000	30
9	Hosiden	HSC2014	HSC2013	IP 67	2015	1000	30
10	QC4	QC4.10	QC4.10	IP 67	2015	1000	35

2.2.1Wet leakage current test

The material which is used for insulation body of these connectors are m-PC, PC+PA66 and PPO and these materials have distinct capability of water sipping & heat resistivity, which is tested by the wet leakage current test. The contact pin of Table-1 connectors is made up of tin plated copper alloy, however, the earlier silver copper alloy was used by most manufacturers.

2.2.2 Mechanical Compatibility test

In addition, mechanical compatibility of connectors is assessed by measuring insertion and retention forces. If insertion force is too large, there may be loose connection between contact pins and if the retention force is too low, it may open even if low tensile force is applied to it. A good quality PV connector should have high withdrawal force and medium insertion force. The range of these forces is defined in standard IEC 60512 / Test [15a](John H. Wohlgemuth, 2012).The connectors with locking device or with snap-in device shall withstand a load of at least 80N & compliance shall be tested according to clause 6.3.14 of IEC 60512 [15f].

2.2.3 Water proof test

This was conducted so that sipping of water into the connectors can be detected. The water proof test was executed for IPX7 condition as defined in EN 50529. The connectors were kept in 1 m depth of water for 30 min & voltage was applied across the connector then leakage current was measured.

3. Measurement setup and approach

3.1 Electrical Tests

Fig.1 Measurement setup for micro-ohmmeter

3.1.1 Measurement of Contact Resistance

The contact resistance of PV connectors was measured using micro-ohmmeter with accuracy of ±0.05%, which is based on four wire measurement concept & hence provides maximum accuracy. For the test, contact pins were taken out from the connector and resistance of bared pins (as shown in Fig.1) was taken. The measurement setup is shown above in Fig 1. It allows maintaining a constant current of 1A through the contact pins for 60 seconds. Micro-ohmmeter was used to measure the resistance values. The contact resistance was measured as per IEC 60512/ Test [2b] & temperature rise was measured as per EN 50521:2008.

3.1.2 Measurement of Temperature rise

The temperature rise test was carried out by High Current Tester/Oven/Digital Thermometer. For this test, temperature was kept at 90°C and the current was set to 30A.

Table 2: Results of contact pin resistance test

Male/ Female	Multi-contact	Bizlink	Amphenol	Jkoom (Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	0.22	1.468	0.4	0.624	0.318	-	0.78	0.19	-	0.54
Bizlink	1.425	0.67	0.66	0.67	0.702	-	0.286	0.23	0.78	0.56
Amphenol	0.38	0.29	0.32	0.706	0.246	-	0.412	0.241	-	
Jkoom(Jinko)	0.269	0.24	0.348	0.26	0.402	-	0.501	0.371	-	
Sunter	0.248	0.674	0.261	0.705	0.37	-	0.385	0.3	-	
Lumberg	-	-	-	-	-	0.42	-		-	
COYO	1.08	0.347	0.317	0.701	0.292	-	0.62	0.215	-	
Elmex	0.25	0.369	0.443	0.771	0.36	-	0.357	0.89	-	
Hosiden	-	0.68	-	-	-	-	-	-	0.82	
QC4	0.55	0.775								0.465

All values are in mΩ

Table 3: Results of temperature rise test

Male/Female	Multi-contact	Bizlink	Amphenol	Jkoom(Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	-	-	-	-	-	-	6.4	-	-	
Bizlink	-	-	-	7.5	-	-	-	-	-	
Amphenol	-	-	-	-	-	-	-	-	-	
Jkoom(Jinko)	-	10.2	-	-	-	-	-	-	-	
Sunter	-	-	-	-	-	-	-	-	-	
Lumberg	-	-	-	-	-	-	-	-	-	
COYO	6.4	-	-	-	-	-	-	-	-	
Elmex	5.3	-	-	-	6.9	-	-	10.8	-	
Hosiden	-	-	-	-	-	-	-	-	-	
QC4										

All values are in degree Celsius

4. Test Results

It was observed that all the connectors followed IEC 60512 standard but there was a difference in various parameters of connectors of different manufacturers. To assess the quality of connectors, contact pin resistance & temperature rise was mainly considered. Five samples of each manufacturer were selected & the results of various tests are shown below:

4.1 Contact pin resistance test

As per IEC 60512 the resistance of contact pins should be less than 5 mΩ. It was observed that all the contact pins have resistance less than 5mΩ. The minimum self-resistance was 0.22 mΩ for Multi-contact connector sample and the maximum self-resistance was 0.89 mΩ for Elmex connector. Minimum resistance between contact pins of two different manufacturers was 0.24 for Jinko (male) & Bizlink (female). Similarly, Maximum resistance between contact pins of two different manufacturers was 1.468 mΩ for multi-contact (male) & Bizlink (female). The detailed results are shown in Table 2. The values listed in Table 2 are average of contact resistance for male to female & female to male of different makes and - symbol signifies that the test was not conducted for these combinations and this may be compatible

Fig.2 Samples of various make of connectors

4.2 Temperature rise test

As per IEC60512 the temperature rise of connectors should be less than or equal to 45°C. It was observed that connectors have temperature rise less than 45°C. The maximum temperature rise in different manufacture case was 18.8°C between Jinko & Bizlink whereas within the same make it was 10.8°C in Elmex. The detailed results are shown in Table 3.

It was observed that all the connectors are mechanically compatible with each other and the all the connectors possess temperature rise within specified operating temperature range i.e. -40°C to 85°C as per standard.

Table 4: Results of Insertion force test

Male/Female	Multi-contact	Bizlink	Amphenol	Jkoom (Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	-	-	-	-	-	-	41.97	-	-	
Bizlink	-	-	-	22.94	-	-	-	-	51.48	25.25
Amphenol	-	-	-	-	-	-	-	-	-	
Jkoom(Jinko)	-	21.08	-	-	-	-	-	-	-	
Sunter	-	-	-	-	-	-	-	60	-	
Lumberg	-	-	-	-	-	<_20[7]	-	-	-	
COYO	67.86	-	-	-	-	-	<_50[8]	-	-	
Elmex	-	-	-	-	60	-	-	<_50[9]	-	
Hosiden	-	-	-	-	-	-	41.97	-	-	
QC4		27.5								

All values are in Newton (N

Table 5: Results of Retention force test

Male/Female	Multi-contact	Bizlink	Amphenol	Jkoom (Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	-	-	-	-	-	-	411.56	-	-	
Bizlink	-	-	-	260.64	-	-	-	-	176.9	241.76
Amphenol	-	-	-	-	786	-	-	-	-	
Jkoom(Jinko)	-	240.84	-	-	-	-	-	-	-	
Sunter	-	-	242	-	-	-	-	60	-	
Lumberg	-	-	-	-	-	>_10[7]	-	-	-	
COYO	665.43	-	-	-	-	-	>_50[8]	-	-	
Elmex	-	-	-	-	60	-	-	>_50[9]	-	
Hosiden	-	248.48	-	-	-	-	-	-	-	
QC4		243.25								

All values are in Newton (N)

Table 6: Results of water proof test

Male/Female	Multi-contact	Bizlink	Amphenol	Jkoom (Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	✓	✓	✓	-	-	-	✓	-	-	✓
Bizlink	✓	✓	-	✓	-	-	-	-	✓	✓
Amphenol	✓	-	✓	-	-	-	-	-	-	
Jkoom(Jinko)	-	✓	-	✓		-	-	-	-	
Sunter	-	-	-	-	✓	-	-	-	-	
Lumberg	-	-	-	-	-	✓	-	-	-	
COYO	✓	-	-	-	-	-	✓	-	-	
Elmex	-	-	-	-		-	-	✓	-	
Hosiden	-	✓	-	-	-	-	-	-	✓	
QC4	✓	✓								✓

Water proof test at 1m depth for 30 minutes (pass/no)

4.3 Insertion force test (Mechanical test)

As per IEC60512-13-2 the Insertion force required for the connectors should not be more than 98.06N. It was noted that connectors have insertion force less than 98.06N. The least force was noted to be 21.08N between Jinko (male) & Bizlink (female). The detailed results are shown in Table 4.

4.4 Retention (Withdrawal) force test

As per IEC60512-13-2 the retention force required for the connectors should be greater than or equal to 78.45N. It was observed that all connectors have retention force greater than 78.45N. The maximum force that was recorded was 786N between Amphenol (male) and Sunter (female). The detailed results are shown in Table 5.

4.5 Water proof test

The insertion & retention forces were measured using metal gauge & tensile tester. As per IEC60529 14.1 (degrees of protection provided by enclosures), there should be no sipping of water into connectors and the connector should pass current leakage test. The leakage current should not be more than 2 mA. It was observed that connectors pass this criterion as well. The detailed results are shown in Table 6

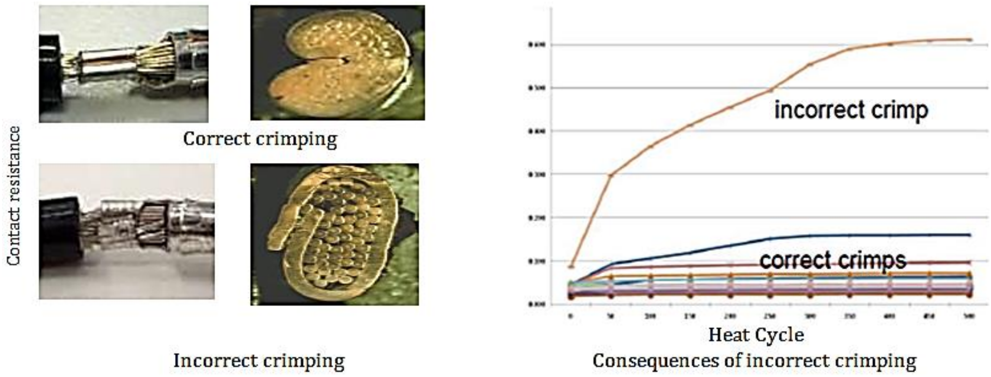


Fig. 3 Consequences of incorrect crimping

5. On-field analysis

5.1 Introduction on crimping of connectors

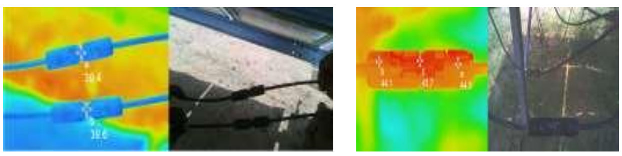
In PV connector, crimping is a key part of its assembly, since it also affects the contact resistance. If the crimping is not proper the contact resistance increases and the temperature rise at the contact is more, in some cases the connector may burn out. Fig 3 shows that due to incorrect crimping the contact resistance increases about 3 times (*Contact Technology for Safe Connectors*, November 12, 2013). PV-Plants failures which are related PV connectors -

a) Risk of fire may result to a danger for life Service hours resulted which can result in higher expenses

b) Increased electrical resistance which results in reduction of the PV plants efficiency and less income

c) Insulation fault may result in danger of electrical shock

The consequences of incorrect crimping can also be seen by Infra-red thermography inspection of connectors. Infra-red thermography inspection was also carried out to investigate the temperature rise during loaded condition. The figure below shows the Infra-red thermography images of PV connectors. It was observed that the connectors which are loosely crimped have higher temperature at contacts and crimping point by approximately 6°C



Correctly crimped PV Connector | incorrectly crimped PV connector

Fig.4 Thermographic Inspection of PV connectors

The above observations show that PV connectors play an important role in good operation of a PV plant. If PV connectors are loosely crimped, it may lead to burning or fire. If it happens at large scale, it may affect the generation of plant and can also lead to loss of wealth. An investigation has proven that after five to seven years, the failure rate of PV connector significantly increases. The figure below shows that the error due to module connectors is 29% of total errors occurred in last ten years (*Contact Technology for Safe Connectors*, November 12, 2013)

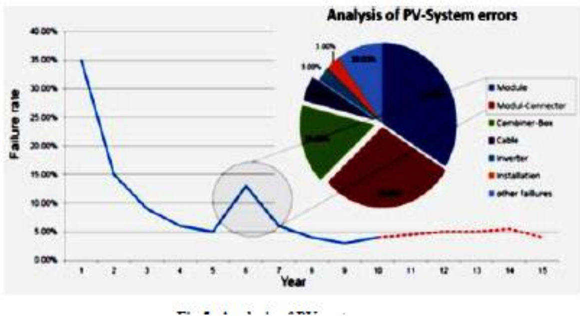


Fig.5 Analysis of PV system errors

5.2 Experimental Analysis

5.2.1 Resistance analysis over a long time period

In this analysis the contact pin resistance of four different manufacturers of connectors i.e. Multi-contact, Bizlink, Jkoom & Lumberg was measured. Initially, the contact pin resistance of the connectors was measured before assembling it, after that these connectors were assembled to form a string with PV modules at the site to study the effect of the field condition. After one year of exposure, same connectors were measured for contact pin resistance and the obtained results are shown in Fig 6. The major change was observed in Bizlink and Lumberg connectors where the resistance of contact pin was increased by 19.70% & 14.29% respectively while for Jinko connectors it was increased only 3.85%. However, the performance of multi-contact connector is close to Jinko connectors. The variation of the resistance is shown in Fig 6.

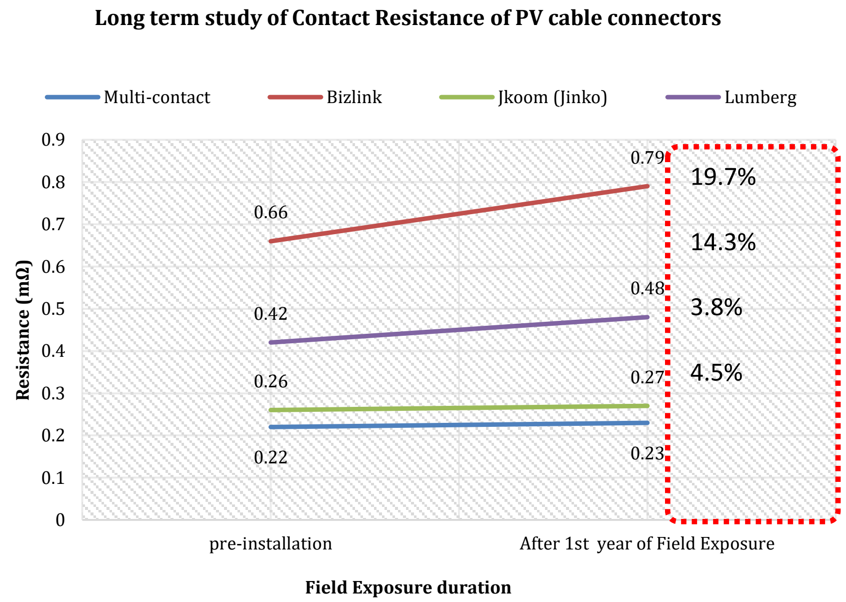


Fig.6 Change in contact resistance while field exposure over a period of time

The standard connectors for photovoltaic system – safety requirement and test DIN EN 50521 (VDE 0126-3) requires that the resistance may increase to no more than 50% of the resistance value or ≤5 mΩ.

Table 7: Compatibility between various types of PV connectors

Male/Female	Multi -contact	Bizlink	Amphenol	Jkoom (Jinko)	Sunter	Lumberg	COYO	Elmex	Hosiden	QC4
Multi-contact	√	-	√	-	-	-	√	√	-	√
Bizlink	-	√	-	√	-	-	-	-	√	√
Amphenol	√	-	√	-	-	-	-	-	-	
Jkoom(Jinko)	-	√	-	√		-	-	-	-	
Sunter	-	-	-	-	√	-	-	√	-	
Lumberg	-	-	-	-	-	√	-	-	-	
COYO	√	-	-	-	-	-	√	-	-	
Elmex	√	-	-	-	√	-	-	√	-	
Hosiden	-	√	-	-	-	-	-	-	√	
QC4	√	√								√

6. Recommendation

This paper suggests that a good quality of connectors should be used for a PV plant so that the plant can perform well for its designed life span. A good quality connector should have proper crimping, less contact resistance, IP67 rated, high withdrawal force & less insertion force. Table 7 shows the compatibility of various types of PV modules connectors. Here, we have evaluated different makes of connectors & ranked based on contact resistance, quality & price.

		Contact				
Product	Average	Resistance	Quality	Price	Final	Rank
	Contact	Index	Rating (Q)	(P)	Rating	
	Resistance (R)					
Bizlink	0.66	0.8	4	5	37.6	**1**
QC4	0.6	0.89	4	4	33.8	**2**
Jkoom (Jinko)	0.37	1.44	4	3	30.9	**3**
Amphenol	0.4	1.32	5	2	30.6	**4**
Sunter	0.42	1.26	4	3	30.5	**5**
Elmex	0.49	1.08	3	4	30.2	**6**
COYO	0.51	1.04	4	3	30.1	**7**
Hosiden	0.75	0.71	4	3	29.4	**8**
Lumberg	0.53	1	4	2	26	**9**
Multi-contact	0.58	0.91	5	1	25.8	**10**
Relative						
weightage	**0.53**	**2**	**4**	**4**		

Conclusion

1) This paper describes the results of an effort to examine connector's compatibility under various test conditions. The comparison shows the difference in contact pin resistance of different cable connectors of different manufacturers.
2) Over a period of time, change in contact pin resistance of PV cable connectors is observed. As connectors are exposed to field condition, the contact resistance increases, which results in higher power loss in DC field of the solar plant.
3) Initially, the connectors were characterized to measure the expected contact pin resistance and variability that installers and system designers should expect.
4) The findings estimate a typical contact resistance of the manufacturers in this study to be5mΩ between connectors.
5) These values are well within the expected and acceptable range for photovoltaic connectors. In addition, the results of an ongoing experiment were reported to identify the change in resistance over a period of time in field condition and it was observed that as long as the PV connector spends time on field, its contact resistance increases linearly.
6) Moreover, the temperature rise of connectors is in the expected range.
7) This paper presents only a study of electrical & mechanical compatibility of various connectors as received by Mahindra Susten (five sample per make), whereas it doesn't certify the inter-compatibilities of the connectors.

Note: Brand/companies referred in the Research Paper are properties of respective owners and no rights are claimed in the same. Views expressed by the author are personal views based on individual research and study and any third party references are merely for academic, research, educational and non-commercial purpose

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