PV MODULE TRANSPORTATION IN TRUCKS WITH TWO DIFFERENT FLOOR DESIGNS

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ABSTRACT: This work aims to understand the nature of the vibration experienced by the PV modules during transportation over 800 kms on two different types of containers. The methodology used for the analysis of transportation vibration data generated during PV module transportation is reviewed. Transportation vibration data was collected from 5 PV module pallets placed in two containers, one with a metal floor and another one with a wooden floor. It is shown that signal-triggered data sampling result in less loss of information compared to time-triggered data sampling. It was found that the PV modules placed in the container with wooden floor showed lower amount of damage as compared to the PV modules in the container with metal floor. The vibration along the axis perpendicular to the PV module plane was severe in the 10-20 Hz range.
Keywords: PV Module, Transportation, Vibration, Micro-cracks

1 INTRODUCTION

PV industry uses different types of trucks or containers for transporting PV modules to power plants in large volume. Previous studies analyzed the transportation vibration data from PV modules inside standard pallet of 20 modules and cassette type packing of 2 modules [1]. The work reported that the vertical vibration profile obtained for the PV module transportation on Indian roads were not fitting with the ASTM D4169 Assurance Level II [2], the main reference of IEC 62759-1:2015 [3]. Another study focused on the lateral vibrations experienced by the PV modules placed vertically in a 25 PV module pallet [4]. Lateral vibrations generated during the transportation of vertically placed PV module pallets were immoderate. The study also recommended to incorporate the laboratory simulation of the lateral vibration for the PV module pallet in the IEC62759 standard. The analysis methodology used in previous studies [1],[4] were adopted from Singh et al. [5].

This study attempts to review the analysis methodology and update it with the required modifications. IEC 62759-1: 2015 standard recommends to conduct same series of tests for the PV module transportation for all type of trucks [2]. This study also focuses on finding the dependence of the truck type on the vibration experienced by the PV modules over a longer distance. PV module transportation vibration data collected from containers with 2 different floor types were analyzed. One container had wooden floor and the other container had metal floor. The experiment was conducted on two fully packed containers which covered around 800 kms.

2 EXPERIMENTAL DETAILS

2.1 PV Module, Pallet and Container

Crystalline silicon PV Modules of size 1.95 m X 0.99 m with 72 cells and a maximum power of 320 W were used in this study. Two containers were used for transporting 35 PV module pallets. One container had wooden floor and the other container had metal floor. The transportation started from the PV module manufacturing unit and ended at the installation site covering around 800 kms. Fig. 1 shows the arrangement of PV module pallets inside the two containers. The circle at the top right corner of the figures of both containers indicates the driver's side. Each box represents the top view of the pallets. 5 PV module pallets which were under observation are marked in red. The pallets were handled using forklift, electric pallet truck or hand pallet truck.

25 PV modules were kept under observation. These 25 PV modules were distributed in 5 pallets, P1, P2, P3, P4 and P5. 5 PV modules were distributed in each pallet, as two PV modules at both the ends and one PV module at the middle. Fig. 2 shows the arrangement of PV modules inside the pallet. One PV module in each pallet was attached with an accelerometer to collect vibration data. The PV modules which were under observation are marked in yellow.

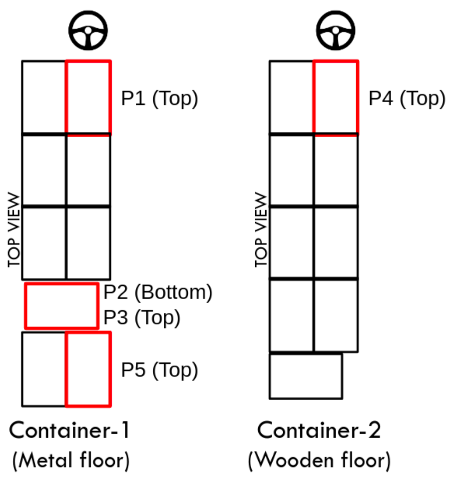

Figure 1: Top view of the pallets arranged over 2 containers; red boxes indicates the PV module pallets under observation.

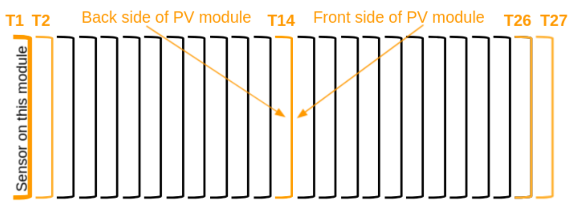

Figure 2: Arrangement of PV modules inside the pallets; yellow color indicates the PV modules kept under observation.

2.2 Instrumentation

Five GCDC X16-4 accelerometers [6] with extended battery backup were used for this study. The accelerometers were attached to the center of the backsheet with 3M 950 double sided adhesive tape. The sensors were set to record continuous 3-axes vibration data at 800 Hz sampling rate. From this data, vibration data events were sampled in two ways: (i) time-triggered events where a vibration data event of 2 seconds duration was sampled once in every 10 minutes, and (ii) signal-triggered events where a vibration data sample of 2 seconds was sampled when the magnitude of the vibration data exceeds 1.5 g (15 m/s2). A pre-sampling of 1 sec was used. Hence, the signal-triggered samples would consist of 1 second vibration data before triggering and 1 second after triggering. This would make sure that the threshold crossing point of the peak would be in the middle of the data sample.

3 RESULTS AND DISCUSSIONS

Transportation vibration data were analyzed using Power Spectral Density (PSD) profiles. Electroluminescence (EL) images taken before and after transportation were compared to detect micro-crack generation or propagation due to transportation and handling.

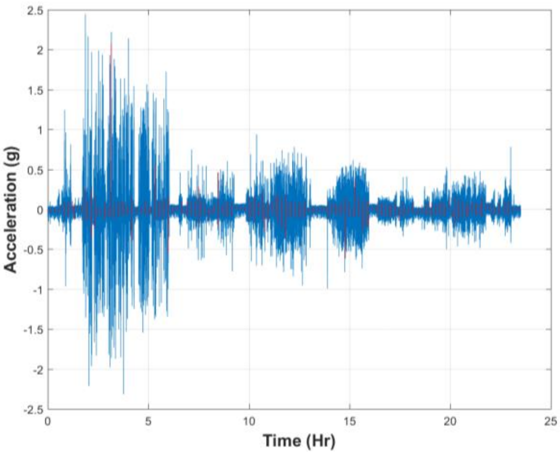

Figure 3: Vibration data representing time-triggered samples of 10 minutes interval; The blue color data indicates continuous acceleration data and the sampled events are marked in red.

PSD profiles were generated for the individual signal-triggered and time-triggered events. Linear averages of these PSD profiles were taken to find the final PSD profile. It was then benchmarked with ASTM D4169 Assurance Level II, which is the main reference of IEC 62759-1:2015 standard.

PSD profiles generated using this methodology resulted in PSD profiles which were not severe as compared to the PSD profiles obtained from previous studies [1],[4]. This led to a detailed analysis of the time-triggered and signal-triggered data. It was carried out by comparing PSD profile generated from the signal-triggered and time-triggered data separately. Fig. 3 shows vibration data representing time-triggered samples of 10 minutes interval. Fig. 4 shows vibration data representing signal-triggered events at 1.5 g threshold. In both the figures, the blue color data indicates continuous acceleration data recorded by the accelerometers and the sampled events are marked in red.

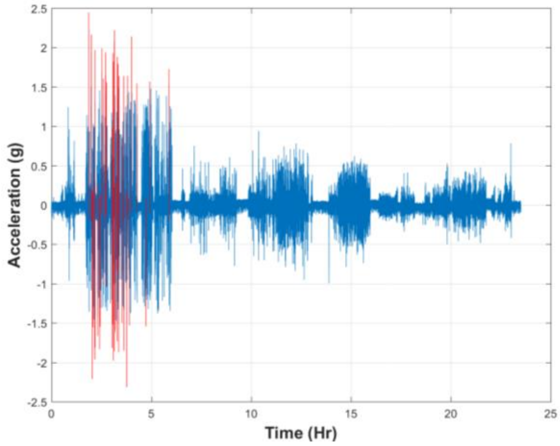

Figure 4: Vibration data representing signal-triggered events at 1.5 g threshold; The blue color data indicates continuous acceleration data and the sampled events are marked in red.

From Figures 3 and 4, it may be observed that there were more number of time-triggered events sampled than signal-triggered events. The severity of time-triggered events was less as compared to the signal-triggered events. Time-triggered events were sampled even when the container was stationery. In order to understand the impacts of this analysis scheme, the PSD profiles of these data were plotted separately. Figures 5 and 6 shows the PSD profiles generated from the time-triggered events alone and signal-triggered events alone, respectively. From these figures, it may be observed that the severity of the PSD profile generated from time-triggered samples was less as compared to the PSD profile generated from signal-triggered events. Hence, signal-triggered samples should be used for the PSD profile analysis. In the remainder of this work, PSD profiles were generated from signal-triggered events alone.

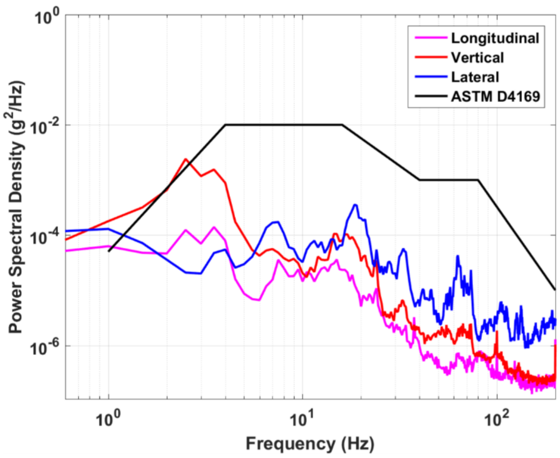

Figure 5: PSD profile generated from time-triggered events alone.

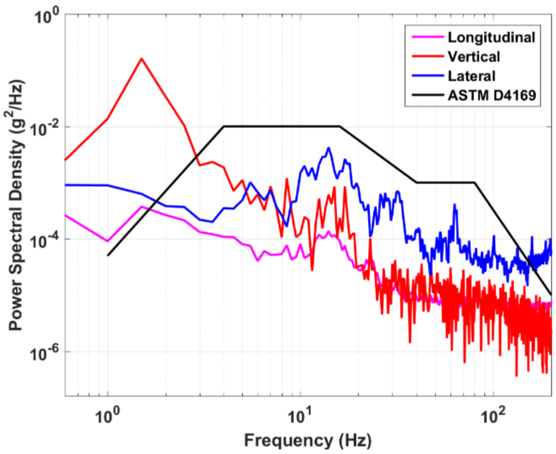

Figure 6: PSD profile generated from signal-triggered events alone.

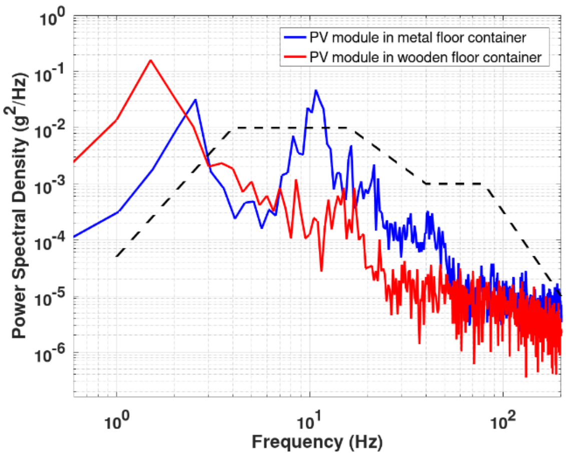

Figure 7: A comparison between the PSD profiles of vertical vibration data from PV modules placed inside the pallet P4 (placed in container with wooden floor) and pallet P1 (placed in container with metal floor).

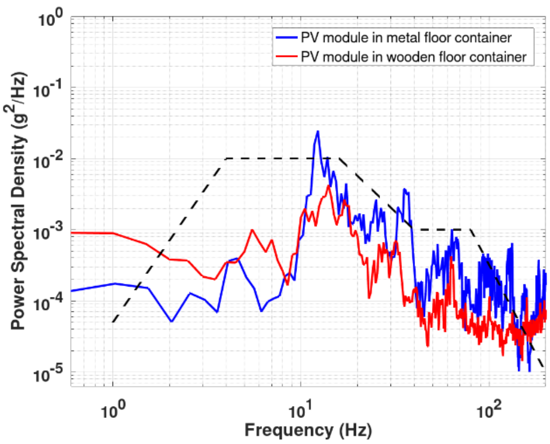

Figure 8: A comparison between the PSD profiles of lateral vibration data collected from PV modules placed inside the pallet P4 (placed in container with wooden floor) and pallet P1 (placed in container with metal floor).

Fig. 7 shows the comparison between PSD profiles of the vertical vibration data collected from the PV modules placed inside pallet P1 (placed in container with metal floor) and inside pallet P4 (placed in container with wooden floor). At lower frequency (1-3 Hz), vertical vibration magnitude was severe for the PV module placed in container with wooden floor. But a peak in the vertical vibration data was observed at 11 Hz for the vibration data from the PV module placed in container with metal floor. But it was absent in case of the PV module placed in container with wooden floor. Similar peak was observed from the lateral axis of the truck (along perpendicular to the PV module plane), in the previous studies [1],[4].

Fig. 8 shows the comparison between PSD profiles of the lateral vibration data from the PV modules placed inside pallet P1 (placed in container with metal floor) and inside pallet P4 (placed in container with wooden floor). From 10 Hz onwards, lateral vibrations from the PV module placed in container with metal floor were more severe than the vibrations from the PV module placed in container with wooden floor.

Table I: Crack statistics of 5 PV modules each from pallets P1 (placed in container with metal floor) and P4 (placed in container with wooden floor)

Type of micro-cracks generated or propagated	**Number of cracks from PV modules in P1 (metal floor)**	**Number of cracks from PV modules in P4 (wooden floor)**
New mode A cracks generated	19	0
New mode B cracks generated	0	0
New mode C cracks generated	1	0
Mode A transformed to mode B	1	5
Mode A transformed to mode C	1	0
Mode B transformed to mode C	0	1
Number of existing damaged cells before transportation (out of 5 PV modules)	53	151
Number of damaged cells during transportation (out of 5 PV modules)	22	6

Table I shows the crack statistics of 5 PV modules each from pallets P1 (placed in container with metal floor) and P4 (placed in container with wooden floor). Among the 5 PV modules placed in the container with wooden floor only 6 cells were damaged out of 5 modules during transportation and handling. In case of container with metal floor, 22 cells out of 5 modules were damaged during transportation and handling. Hence, it may be concluded that the wooden floor dampened the vibrations more effectively compared to metal floor. Influence of other parameters like the condition of the containers, skills of the drivers, etc. different between two containers could have also played a role in influencing this observation.

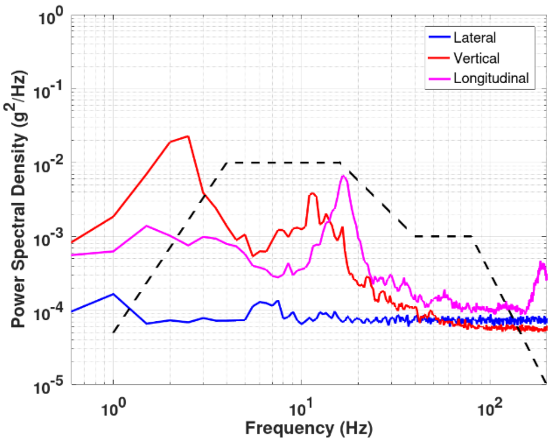

Figure 9: PSD profiles of 3-axes vibration data collected from the PV module inside pallet P3. The axis perpendicular to the PV module plane was oriented towards longitudinal direction of the container.

Fig. 9 shows the 3-axes PSD profiles of the vibration data collected from the PV module inside pallet P3. The axis perpendicular to the PV module plane was oriented towards longitudinal direction of the container. In the PSD profile, a peak in the longitudinal vibration data was observed in 10-20 Hz range. Previous study reported similar peak in the lateral direction when the axis perpendicular to the PV module plane was along lateral direction of the truck [4]. Hence, it may be concluded that, irrespective of the relative orientation of the module surface vis-à-vis the direction of travel of the truck, vibrations along the axis perpendicular to the module plane is quite significant and should be used for laboratory simulations.

4 CONCLUSIONS

This work investigated the vibration generated on PV modules during transportation in two types of trucks with different floor designs. This work also reviewed the analysis methodology used for the PSD analysis. For the PSD profile analysis of the vibration data generated during PV module transportation, only signal-triggered events should be used. From the comparison between PV modules placed in two type of containers, the PV modules placed in the container with wooden floor showed lower amount of damage as compared to the PV modules placed in the container with metal floor. A peak in the vertical vibration data was observed at 11 Hz for the data from the PV module placed in container with metal floor. But it was absent in case of the PV module placed in container with wooden floor. Irrespective of the direction of travel of the truck, vertically placed PV module experiences severe vibrations in 10-20 Hz range along the axis perpendicular to the module plane. Hence, the vibration along the axis perpendicular to the PV module plane aligned over lateral/longitudinal direction of the truck may be included for the laboratory simulation of the transportation of vertically placed PV module pallets.

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REFERENCES

[1] D. P. Vasudevan, P. Bhatt, and A. Kottantharayil. "Impact of Transportation on Indian Roads, on PV Modules." In 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), pp. 1529-1532. IEEE, 2019.

[2] ASTM D4169-16: Standard Practice for Performance Testing of Shipping Containers and Systems, 2016.

[3] IEC 62759-1:2015: Photovoltaic (PV) modules-Transportation testing- Part 1: Transportation and shipping of module package units, 2015.

[4] D. P. Vasudevan, P. Bhatt, and A. Kottantharayil. "Lateral vibrations experienced by vertically placed PV modules in the pallet during transportation." In 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), pp. 1323-1325. IEEE, 2020.

[5] S. P. Singh *et al.*, "Measurement and Analysis of Truck and Rail Shipping Environment in India," in Packaging Technology and Science, vol. 20, pp. 381-392, 2007.

[6] GCDC X16-4 USB Accelerometer Data Logger User Manual, www.gcdataconcepts.com.