Solar defect

Problem statement

The solar industry is becoming increasingly anxious due to the repeated failures of solar cells due to the presence of defective panels. Solar cells have been found to be malfunctioning within one to two years from the day of their installation. The industry is becoming highly skeptic about such failures as world leaders and academic scholars have regarded such incident as quality issues that the $77 billion industry is facing currently. The increasing failures of solar cells have become a disturbing issue just as the solar cells are coming to verge of being adopted globally in almost majority of the households. However, due to lack of data regarding the defective cells and vital statistics related to such failures have limited the option of researchers around the world to learn about the possible reasons behind such failures. It is with regards to this fact that the researcher is attempting to conduct an in-depth research to explain the reasons behind the failure of solar cell panels and recommend certain actions that could be directed towards preventing further failure of solar cells.

Abstract

The purpose of this report is to identify the problems associated with solar cell failures that are being faced by the solar cell industry. The researcher attempts to explain the reasons behind the defective solar cell panels that are being identified in a number of cases related to a solar cell panel. The research will have both quantitative and qualitative elements whereby the researcher will seek to conduct a questionnaire survey with eight quality control officers from 3 leading solar cell manufacturing companies in the world. Given the fact that not much statically data is available regarding the major reasons behind the failure of solar cells, the information gathered from the survey will allow the researcher to shed some light on the possible reasons. Thereafter appropriate solutions can be recommended in order to reduce defects in solar cells.

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Company overview

Dissigno is a San Francisco based Solar Cell manufacturing company which has an established track record in power projects. The company is primarily engaged in the development and operation of solar power (over 60 MW), LED (over 100 MW) (Dissigno, 2014). Regardless of being a renowned manufacturer of solar cells over the past decade, the company has recently reported major failures in solar cells in many of their projects. The company has blamed its quality centers China primarily where its manufacturing facility is based. The reasons as to why the solar cells fail are still unknown.

Solar City is the largest provider of solar cell in the US. The company makes fresh energy available to businesses, government institutions, homeowners, schools and universities. Solar City is known to provide such services at a cheaper rate compared to the prices that the above mentioned entities pay for electricity generated through natural gas, oil and coal (Solar City, 2014). The company also procures large consignments of solar cell parts from Chinese manufacturers Trina and Yingly solar.

First Solar has installed more than 8 Giga Watts of photovoltaic energy all over the world. Their energy solutions have successfully expanded energy portfolio which in turn has brought down the risk of fluctuation in the price of fuel. The company is known for providing affordable photovoltaic energy solutions which facilities a fully solar energy enabled electricity distribution (First Solar, 2014). According to Woody (2013) of the New York times First Solar had kept a cash reserve of $271.2 million in order to compensate for the cost incurred while replacing the defective panels that were installed in the solar cells in the year 2008 and 2009.

Solar cell manufacturing technologies

Capturing solar energy is the end result of complex physical and chemical procedures. As a first step raw silicon is extracted from sand. In order to be used in the photovoltaic (PV) industry in the semi-metal should be 99.99% pure (Carstensen, et al., 2011). Generation of solar power requires the PV industry to utilize the semi conducting features of silicon. Raw silicon is melted in specially designed in temperatures of over 1400 degree centigrade (Carstensen, et al., 2011). A thin rod referred to as the seed crystal is then submerged in the liquid raw silicon and pulled back

up very slowly. At this step the liquid silicon accumulates on the crystal and solidifies. Over the next four days a silicon rod of upto 2.8 meters takes shape (Carstensen, et al., 2011). The rod (ingot) is then cut into rectangular shape and later on square shaped solar cells can be installed on the surface of the solar modules. The ingots are cut into thin slices with the help of a fine wire saw. The slices are called wafers which forms the foundation of each solar cell. Once the wafers are sliced they are thoroughly washed in a wash tunnel in order remove even a smallest piece of dust.

The wafer surface becomes very flat like a mirror and it reflects many rays of light which can no longer be used to generate power. In order to prevent this reflection, the wafer surfaces are then etched and roughened in a chemical bath. If the cells are seen under a microscope, one can see the resulting pyramid structure. With this fine pyramid structure, light is refracted multiple times allowing incoming light to be used far more effectively. The next step in solar cell contraction is diffusion. Here a negative charged phosphorus layer is added to each wafer's positively charged layer. In an oven with a temperature of over 900 degree centigrade phosphorous atoms are injected with the help of nitrogen. The gaseous phosphorus nitrogen mix is put on the wafer. At the interface of positive and negative charged layers the free charge carriers created by the light are released. This generates an electric current.

Problems & Defects associated with manufacturing process

The major defects in solar cell panels are identified in various developmental cycle of the modules. A considerable number of solar cell malfunctioning can be attributed to defective modules as a result of natural catastrophes. Many businesses, governmental institutions and homeowners who previously thought presence of manufacturing defects were the major reasons behind the malfunctioning of their solar cells refuted their comments when investigation highlighted a completely different issue. A majority of those solar cell modules were found to be malfunctioning largely because of damage caused to the panels due to hail storm or snow load. The defects proved to be major which in turn damaged the cell modules that are responsible for storing the energy received from solar rays. Moreover snow load over the solar cell modules due to heavy snow fall has also been reported as one of the major reasons behind solar panel defects. Figure 1 given below shows how hail storm leads to cracks in PV modules. The figures also show shattered glass of PV modules largely due to heavy hail storm.

Figure 1: Error pattern in PV modules due to hail storm

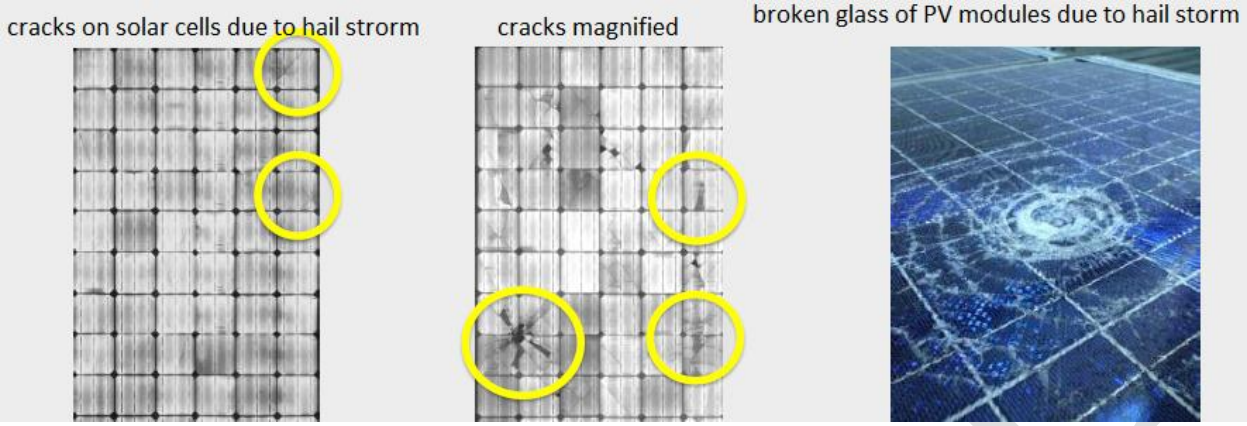


Figure 2 and figure 3 given below on the other hand show how snow loading over PV panels lead to solar cell defects.

Figure 2: Error patterns in PV module due to snow loading

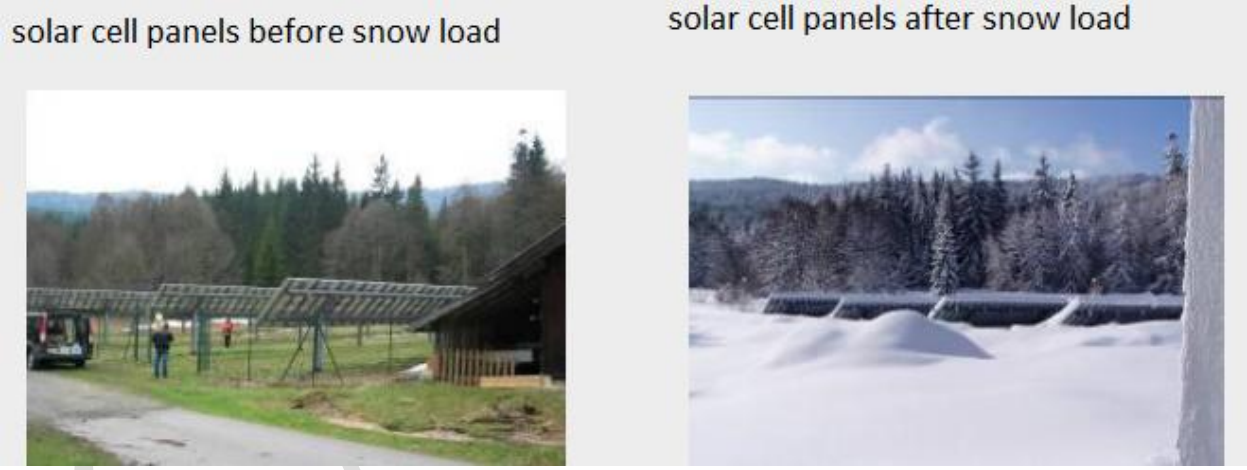
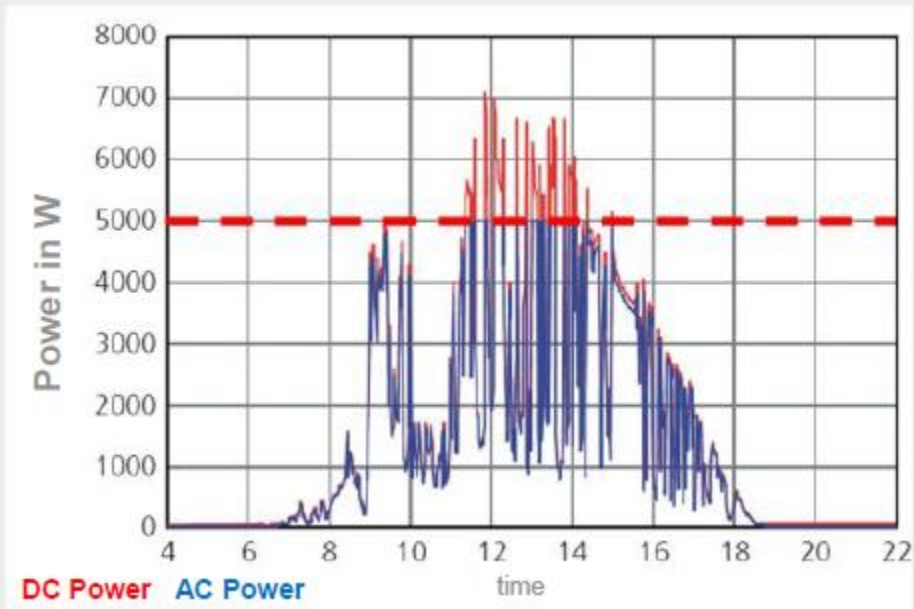


Figure 3: Defective frames due to snow loading

A considerable number of solar cell defects have also been attributed to wrong system design. Improper selection of photovoltaic components and inappropriate photo voltaic module connection leads to flow of power beyond limitation. The major reason behind such overflow of power is largely due to the flow of high voltage as a result of wrong choice of PV components. The yield loss due to power restriction results quickened aging of inverter components in the solar cells. Therefore, due to such high power flow the solar cell starts malfunctioning. Figure 4 given below shows how the flow of power crosses the threshold limit due to inappropriate manufacturing process. The red dotted line in the figure denotes the power limitation.

Figure 4: Flow of power in inappropriately designed solar cells



Another problem associated with malfunction solar cell panels can be witnessed in overvoltage and poor lighting protection design employed in solar cells. It has often been reported that grounding connection in solar cells are done with inappropriate materials. This exposes the solar cells to high degree of risk when it comes to absorb the power generated lighting strikes. Solar cell manufacturing companies are often found using degraded quality and inexpensive materials for establishing ground connections with the devices in order to save he overhead expenses of making connections using expensive materials. Figure 6 given below shows ground connections established in devices with inappropriate materials.

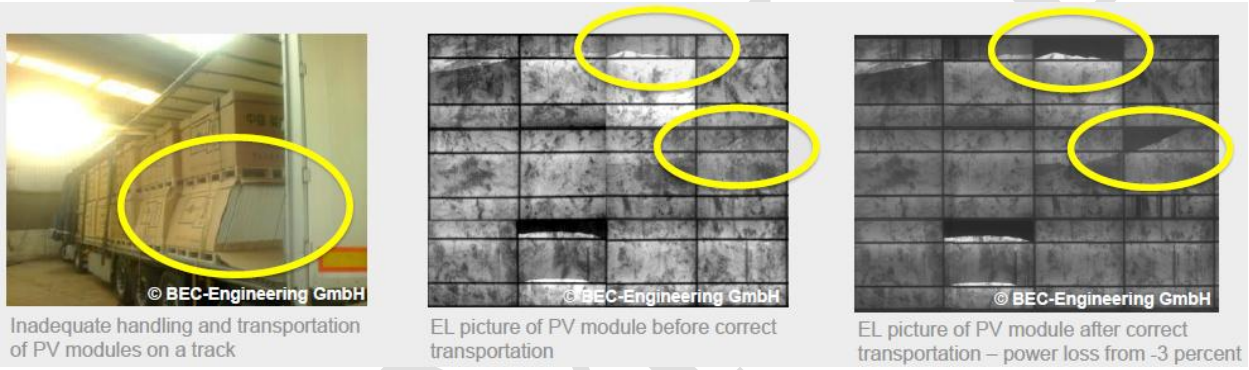
Figure 5: Ground connection with incorrect object

Implementation of bad engineering techniques sometimes results in incorrect installation of lighting protection. Such engineering defects lead to shading of PV generator and as a consequence the photovoltaic cell starts malfunctioning. Due to these engineering errors photovoltaic cells often get damaged due to minor incidents of lighting and fire. Figure 6 and 7 given below shows how lighting protection mechanisms are incorrectly installed and how they lead to shading of photovoltaic generator.

Figure 6: Incorrect installation of lighting protection mechanism

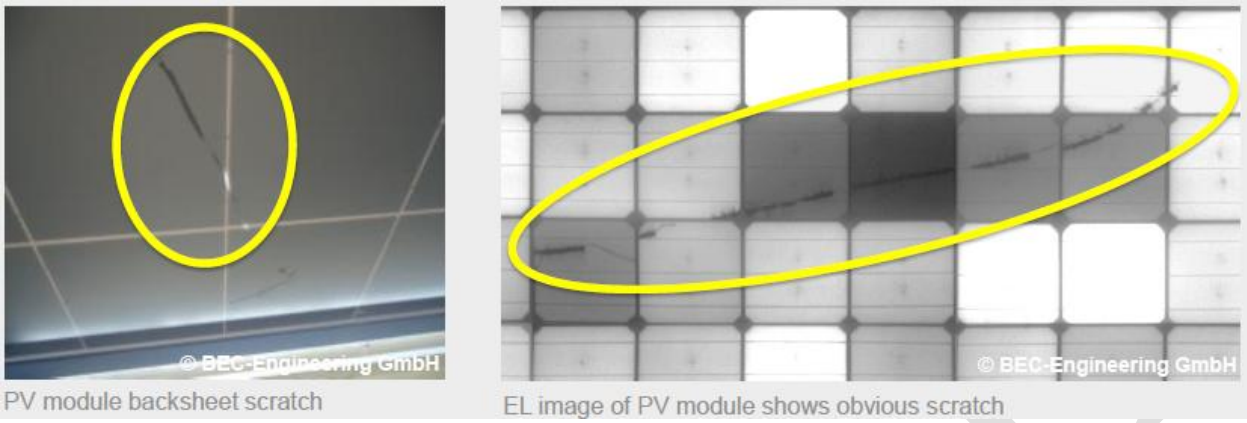
Transport damage is another major reason behind malfunction solar cells. The damaged caused while procurement of PV modules are sometimes so small that they are virtually undetectable. However, such damages may often prove reduce the device's functionality as well as its operational age. Improper transportation facilities may result in loss of power of up to 3%. According to proper risk assessment, transportation damages may result in short as well as long term yield loss. This damage has the propensity of increasing in upcoming years thereby resulting in greater amount of power loss. The figures given below suggest how solar cells are inappropriately handled while transporting and the resultant damages.

Figure 7: Damages in solar cells due to inappropriate transportation



Defective photovoltaic panel due to handling damage is another grave issue that the solar industry is facing in the contemporary business environment. This is precisely because of the fact that inappropriate handling often results in scratches or deep spots on the back sheet of solar cells. Inappropriate handling of PV panels occurs especially in factories which have inexperienced professionals and manufacturing team. Risk assessment conducted by solar cell manufacturing teams have revealed that such scratches and deep spots that occur on PV panels result in the deterioration of the PV modules which in turn accumulates a lot of humidity. Such humidity can degrade the functionality of the solar panels. In addition to that such handling errors may also lead to insulation problems which may heighten the risk of electrical shock. Figure 8 given below explains the damages that occur on PV modules as a result of inappropriate handling.

Figure 8: Error pattern in PV cells due to inappropriate handling



PV module backsheet scratch

EL image of PV module shows obvious scratch

Improper DC cabling can also lead to defective solar cell panels. An inappropriately connected DC plug may cause the solar cell to burn due to overheating. Moreover, there is always a risk of electrical arc, yield loss and sometimes may result in component failure. Figure 9 given below shows error pattern in solar cells due to improper DC cabling.

Figure 9: Error pattern in PV cells due to improper DC enabling

In addition to that installation error on mounting system is another reason behind defects in solar cells. Installation errors happen because of several reasons such as using a wrong combination of installation materials on the post where the system is mounted. Inadequate torque provided on the mounting screws fails to provide adequate support to heavy wait PV cells installed on the panels. Sometimes erroneous assumption may lead to the construction of short posts following which they have to be mounted using different materials which may not provide adequate support to the panels. Such lack of stability may lead to damages in the PV modules.

Figure 10: Installation errors

Encapsulation error and use of poor solar cells are also amongst the major reasons that lead to defects in PV modules. While encapsulation errors lead to degradation in power in the solar panels, use of poor solar cells lead to PV module breakdown. Installation of poor solar cells leads to less power output. Figure 11 given below shows power degradation due to encapsulation errors as well as less power output due to installation of poor solar cells.

Figure 11: Encapsulation errors

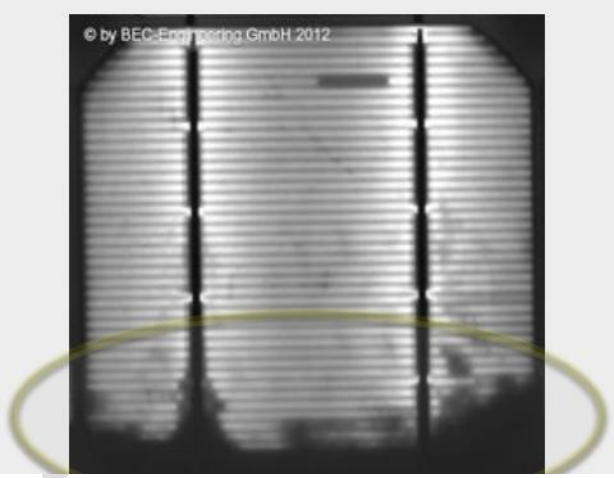
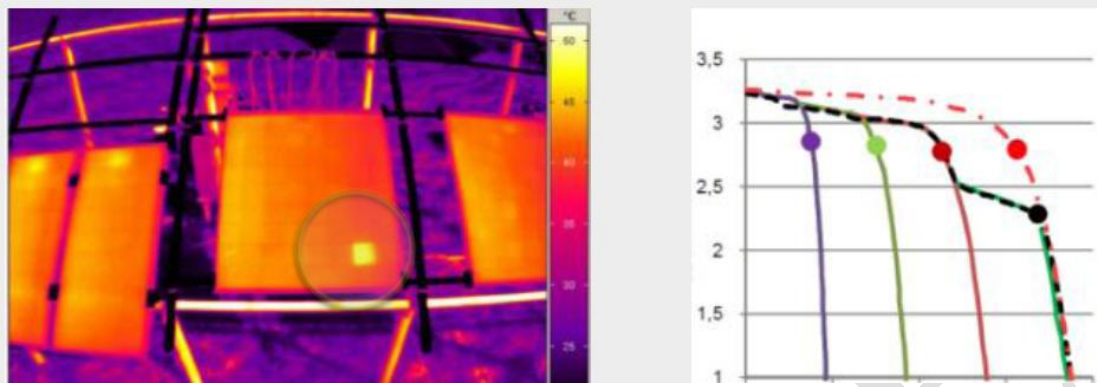


Figure 12: Error pattern due to poor solar cells



Overview of proposed solutions

In order to evaluate the solutions for fixing solar cell defects, one needs to understand the reasons why solar cells malfunction. One way of understanding the reasons is to carry out a 5 why analysis on the basis of which solutions will be proposed.

5 why is an analytical procedure that is used to explore a cause effect relationship of an underlying problem. The fundamental reason behind the implementation of this technique is to identify the origin of a particular problem.

In this particular case the major issue is the presence of defects in solar cells. Therefore the proposed solution has to be in complete alignment with the probable reasons behind the defects in solar cells.

Issue: Defective solar cell panels

Why? Improper selection of photovoltaic components and inappropriate photo voltaic module connection

Why? Inappropriate protection design against lighting and over voltage

Why? Transport damage and handling errors

Why? Improper DC cabling, encapsulation errors and use of poor quality solar cells

Therefore, the four reasons which have been identified above points out to one major reason stated below.

Why? Inadequate operations management and deteriorated quality of manufacturing process.

In order to make sure that manufacturing operations are effectively managed, managers of solar companies should implement lean manufacturing technique. Implementation of this technique will also allow managers to ensure that the quality of operations, right from the design of solar cells to their subsequent transport and installation, is superior. Lean manufacturing technique is implemented in majority of companies throughout the world (Panizzolo, et al., 2012). Toyota and General Motors are notable examples of corporations who have successfully implemented the lean manufacturing technique (Hodge, Goforth and Thoney, 2011).

The major reason behind use of poor quality cells, improper PV components, and encapsulation error and transport damages is deteriorated management quality. In such cases managers fail to makes sure that the accurate materials are being delivered in the right quantity, at the right place and at the right time (Furlan, Vinelli and Dal Pont, 2011). Therefore such mismanagement combined with time limits of delivery compels manufacturers to design and install solar cells in hurry. In such cases either they choose the wrong component in a hurry or intentionally think of doing so as the right materials is not available at their disposal (Taj and Morosan, 2011). As a consequence defects are found in PV modules of solar cells. Therefore, implementation of lean management technique will allow managers to make sure that the right components are being delivered at the right place, at the right time and the right quantity (Gurumurthy and Kodali, 2011).

Consequently managers will be able to manage time effectively which in turn will allow them to monitor that the right components are being used to design the solar cells. Given the fact that a considerable number of defects in solar cells are found due to transport damage, handling damage, encapsulation error and installation damage, the appropriate solutions for each of this issue will be explained in the following sections. However, it is essential to take in consideration that lean manufacturing is not devoid of flaws and there are seven manufacturing defects which can significantly impair the production process.

These deadly defects are overproduction, waiting, over-processing, transport, motion, inventory and defects. Overproduction is caused when firms produce products solely based on anticipation of future demand instead of present demand. Overproduction is considered as waste because it leads to unnecessary consumption of inventory. Waiting or halt in work-in-progress is considered as a critical defect as it result in zero value addition. Similarly, transport is considered as a waste in lean manufacturing because it adds no value to the product from practical perspective. Besides, no consumer pays an additional amount for transportation (Lean Manufacturing Tools, 2014).

Unnecessary motion is considered as a waste in lean Manufacturing. The reason is that excess movement of manpower, machinery and other resources result in consumption of time resulting to increase in idle time and production loss. Over-processing is considered as a waste because it involves use of superfluous techniques, clumsy processes and oversize equipments, resulting to increase in cost and handling time. Mass scale inventory is considered as a flaw in lean production because it blocks investment, requires storage space and appropriate handling. Ironically, defects in products are also a crucial defect in lean production. The reason is that minor defects or quality errors often slow down the production process due to replacement and rework thereof (Lean Manufacturing Tools, 2014). The wastes that can be recognized in solar defects are overproduction and defect (Woody, 2013; Wang, 2012).

Another solution that can be included in this regard for developing holistic approach is cross functional team review. Cross functional teams are essential for product development but often tend to deviate from their primary aim resulting to development of discrepancies in the process. Periodic review of such teams ensures that the members are focused on their goal (Bamber, et al., 2003).

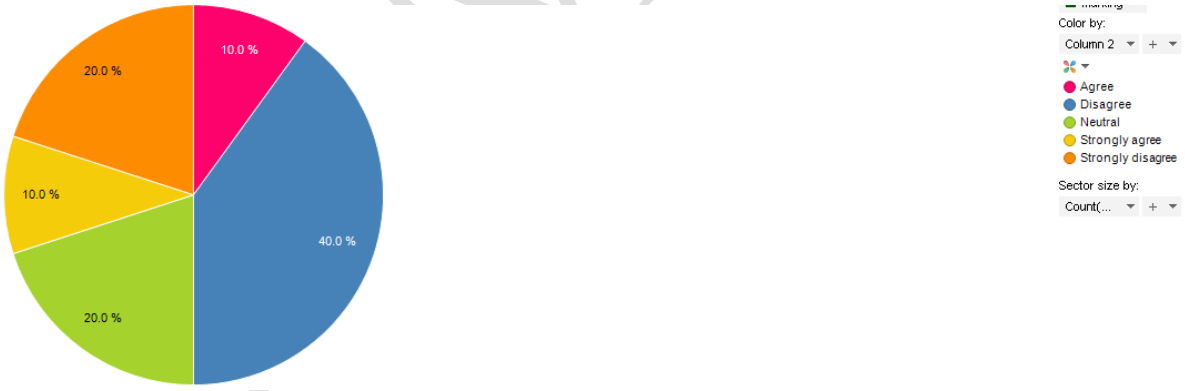
Data Analysis through questionnaire survey

This section involves a descriptive analysis of the major reasons behind solar cells defects as perceived by 10 quality control officers belonging from three reputed solar energy providers.

The following incidents have been considered as the major reason behind defects in solar cell panels. To what extent do you agree or disagree

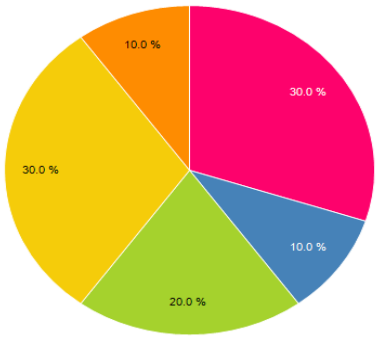
Statement	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Natural catastrophes such as hailstorm and snow load	1	1	2	4	2
Wrong system design, improper selection of PV components	3	3	2	1	1
Encapsulation errors	2	3	1	2	2
Improper DC cabling	1	2	3	2	2
Inadequate protection against lighting and over voltage	2	3	1	2	2
Installation errors	2	2	1	3	2

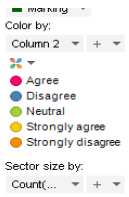
Statement 1



Most of the quality control officers who participated in this survey expressed their disagreement over role of Natural catastrophes in developing defects in solar cells.

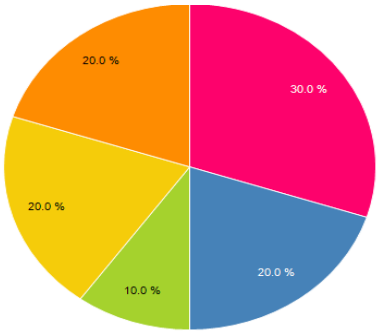
Statement 2

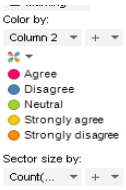




Wrong system design and improper selection of PV components has been criticized and held responsible for the defects by more than 75% respondents.

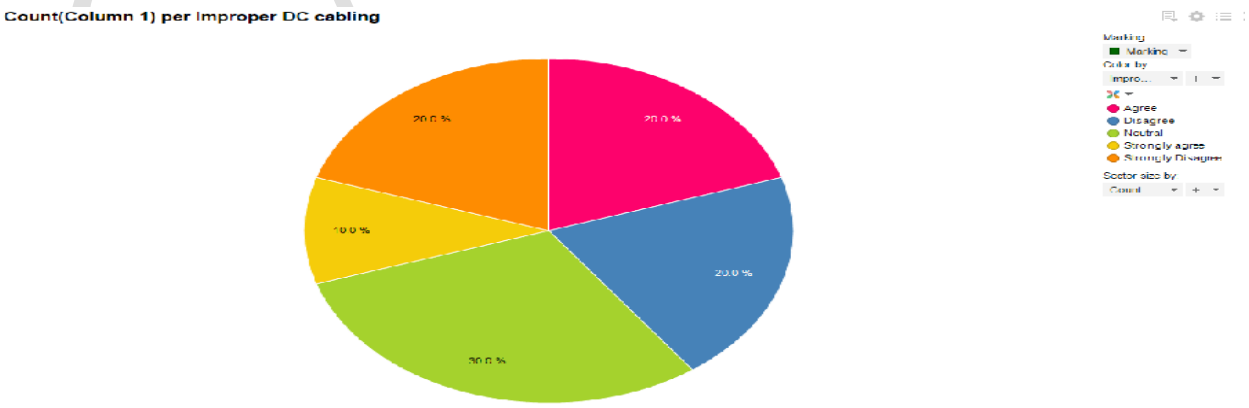
Statement 3





Encapsulation errors were held responsible by 5 respondents while 4 of them disagreed in this regard.

Statement 4



The above analysis suggest that only few participants (30%) considered improper DC cabling responsible for defects in solar cell while most individuals either disagreed or remained neutral.

Statement 5

50% of the participating quality officers indicated that inadequate protection against lighting and over voltage is responsible defects in solar cell. However, the notion was negated by 40% of participants while 10% chose to remain neutral.

Statement 6

Installation errors as a cause of defect in solar cells got mixed feedback from the participating quality officers. Except one officer who remained neutral, four were in favor of installation errors as a cause while others disagreed on this point.

A thoroughly descriptive analysis of the survey feedbacks provided by the managers have revealed wrong system design, inadequate protection used against lighting and over voltage and installation errors as the major reasons behind the defects that are found in modern solar cells.

The following sections involve a brief analysis of the solutions that can be implemented in order to make sure that such defects do not occur further.

Implementation of Proposed Solution or Actions

The major reason behind inaccurate system design is the use of improper PV components. This is precisely because managers often fail to make sure that the right components are delivered at the right quantity and time. This compels engineers to use wrong components or deteriorated quality components while designing solar cells (Sopori, 1999). This makes it necessary for the managers to implement lean manufacturing technique which in turn will allow them procure accurate materials at the right quantity at a precise time. In that way managers will be able to prevent design errors which occur mainly due to unavailability of adequate materials. Moreover, managers also need to ensure that ground connections are established properly with the solar cell panels (Yang, Hong and Modi, 2011). Superior quality materials needs to be used in order to make sure that ground connections are properly made which in turn will prevent any form of damage on the solar cells as a result of lighting or flow of high voltage (Carstensen, et al., 2011). Engineers will have to be extremely careful while installing the solar cells. They will have to mount the screws strongly over the mounting post by providing adequate torque. This will enable them to make sure that the mounting posts provide adequate support to the solar cells thereby preventing further damage (Fullerton, Kennedy and Widener, 2013).

A comprehensive assessment of 5-why analysis suggests that solar defects occur due to inefficient operations management and deteriorating manufacturing quality. The quality of operational management and manufacturing quality in solar industry can be improved by means of total productive maintenance (TPM). According to Jeong and Phillips (2001), TPM is manpower intensive process that primarily focuses on preventive maintenance and ensures maximum equipment effectiveness. Thereby, it enhances overall performance and quality.

In context of lean manufacturing, two wastes have been recognized namely, waste of overproduction and waste of defects. The problem associated with overproduction can be managed using just-in-time production technique. JIT technique will minimize unnecessary piling of finished stock (Ōno, 1978). The author appended that waste of overproduction and

defect can be eliminated by Kanban system as the system follows certain strict guidelines which deliver 100% defect free products (Ōno, 1978).

The solar industry can deploy periodic (quarterly or half yearly) review of various cross functional teams working for product development. The review should particularly emphasize on elimination of various wastes that have been discussed with respect to lean manufacturing and operational efficiency in the teams.

Conclusion

Dissigno, Solar City and First solar are regarded amongst the most reputed solar energy service providers in the world. However, recently the three companies discovered a considerable number of defects in solar cells. The researcher in this report conducted a survey with ten quality control officers from the survey regarding their perceptions about the reasons behind these defects. It was learnt that system error design error, installation error, inadequate lighting protection are the major reasons behind these defects.

In order to reduce such defects in solar cells managers need to implement lean manufacturing process so as to ensure that proper materials are being procured at the right quantity and right time. The managers also have to ensure that the materials are being properly used to design the solar cells. Installation of these solar cells has to be done carefully with proper focus on the torque that is being provided to mount the screw. Other suggestions in this regard include elimination of waste of overproduction and defect and cross functional team review. Review of cross functional teams was referred as a solution because it was determined continuous review will ensure goal orientation among team members.

Reference List

A. Furlan, A. Vinelli, and G. Dal Pont. Complementarity and lean manufacturing bundles: an empirical analysis. *International Journal of Operations & Production Management*, vol. 31, pp. 835-850. (2011).

A. Gurumurthy, and R. Kodali. Design of lean manufacturing systems using value stream mapping with simulation: a case study. *Journal of Manufacturing Technology Management*, vol. 22, pp. 444-473. (2011).

B. Sopori. (1999, December 13). *Impurities and Defects in Photovoltaic Si Devices: A Review*. [online] Available: http://www.nrel.gov/docs/fy00osti/27524.pdf

C. J. Bamber, P. Castka, J. M. Sharp, and Y. Motara. Cross-functional team working for overall equipment effectiveness (OEE). *Journal of Quality in Maintenance Engineering*, vol. 9, pp. 223-238. (2003).

Carstensen, A. Schütt, G. Popkirov, and H. Föll. CELLO measurement technique for local identification and characterization of various types of solar cell defects. *physica status solidi*, vol. 8, pp. 1342-1346. (2011).

Dissigno. (2014). *Dissigno*. [online] Available: http://dissigno.com/?page_id=1669

First Solar. (2014). *First Solar is the global leader in photovoltaic (PV) solar energy solutions*. [online] Available: http://www.firstsolar.com/en/about-us

G. L. Hodge, R. Goforth, J. A. Joines and K. Thoney. Adapting lean manufacturing principles to the textile industry. *Production Planning & Control*, vol. 22, pp. 237-247. (2011).

K. Y. Jeong, and D. T. Phillips. Operational efficiency and effectiveness measurement. *International Journal of Operations & Production Management*, vol. 21, pp. 1404-1416. (2001).

Lean Manufacturing Tools. (2014). *7 Wastes of Lean Manufacturing*. [online] Available: http://leanmanufacturingtools.org/77/the-seven-wastes-7-mudas/

M. G. M. Yang, P. Hong, and S. B Modi. Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *International Journal of Production Economics*, vol. 129, pp. 251-261. (2011).

Ōno, T. (1978). *Toyota production system: beyond large-scale production*. [online] Available: http://www.kellogg.northwestern.edu/course/opns430/modules/lean_operations/ohno-tps.pdf

R. Panizzolo, P. Garengo, M. K. Sharma, and A. Gore. Lean manufacturing in developing countries: evidence from Indian SMEs. *Production Planning & Control*, vol. 23, pp. 769-788. (2012).

R.R.Fullerton, F.A. Kennedy and S. K. Widener. Management accounting and control practices in a lean manufacturing environment. *Accounting, Organizations and Society*, vol. 38, pp. 50-71. (2013).

S. Taj, and C. Morosan. The impact of lean operations on the Chinese manufacturing performance. *Journal of manufacturing technology management*, vol. 22, pp. 223-240. (2011).

Solar City. (2014). *SolarCity delivers better energy*. [online] Available: http://www.solarcity.com/company/about

T. Woody. (2013, May 28). *Solar Industry Anxious Over Defective Panels*. [online] Available: http://www.nytimes.com/2013/05/29/business/energy-environment/solar-powers-dark-side.html?pagewanted=all&_r=2&

U. Wang. (2012, October 16). *Report: 180 Solar Panel Makers Will Disappear By 2015*. [online] Available: http://www.forbes.com/sites/uciliawang/2012/10/16/report-180-solar-panel-makers-will-disappear-by-2015/