ISSN 2683-345X
journal homepage: http://ijiemjournal.uns.ac.rs/
International Journal of Industrial Engineering and Management
Volume 14 / No 2 / June 2023 / 105 - 121

Original research article

Risk Assessment and Mitigation Strategy of Large-Scale Solar Photovoltaic Systems in Pakistan

S. M. Inayat[a,*], S. M. R. Zaidi[a], H. Ahmed[a], D. Ahmed[a], M. K. Azam[a], Z. A. Arfeen[b]

[a] *Institute of Business Management, Industrial Management, Karachi, Pakistan;*
[b] *Electrical Engineering Department, Islamia University of Bahawalpur, Bahawalpur, Pakistan*

ABSTRACT

Solar photovoltaic (PV) systems and their installation are essential to determine a general practice for specialized risk assessment, which reduces the danger linked and the solutions to avoid those hazards, which call mitigation strategies. This paper aims to present the risk assessment and mitigation strategies for large-scale Solar PV systems in developing countries. To achieve this, complaints-related data has been collected from well-known companies providing Solar PV to industrial and residential consumers. This paper presents insights on the repetitive complaints, potential risks identified, and their severity along with probability. Further, risk mitigation strategies to resolve these complaints timely and significantly are listed by industry experts. Overall, the study briefed each risk, its detail, and classified the complaints in three different companies.

ARTICLE INFO

Article history:
Received December 21, 2022
Revised March 28, 2023
Accepted April 7, 2023
Published online April 18, 2023

Keywords:
Solar PV plant;
Risk register;
Risk prioritization;
Risk matrix;
Risk assessment;
Complaint response;
Delphi

*Corresponding author:
Syeda Misbah Inayat
std_26870@iobm.edu.pk

1. Introduction

Energy is an essential factor for the growth of any country. The economy of country, whether it is developing or developed, is highly based on the energy resources of that particular region. Every human activity is linked directly or indirectly with the energy for proper execution. Those activities could be related to the industrial, education, agriculture, health, or residential sectors. The importance of energy resources becomes more significant for the countries, which are in the developing phase and are underdeveloped [1]. Pakistan is a developing country in south Asian countries. There have been several developments in recent times to make the country's economy relatively sustainable. In addition, the population of the country is also increasing with time. Therefore, for these developments and a big population, a clean energy system and alternate energy resources are required to deal with the country's energy demand [2, 3]. Unfortunately, Pakistan is facing a shortage of energy, and it is unable to meet the present energy demand of the people [4]. Due to this shortage, load shedding is increased for all sectors, including residential, commercial, and industrial zone. Due to the imbalance between generation and usage of electricity, developing countries like Pakistan have more frequent power breakdowns which may last for 6–8 hours per day

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

http://doi.org/10.24867/IJIEM-2023-2-327

in urban areas and 10-12 hours in rural areas during summer seasons [5-8].

Due to the energy shortage and prolonged power outages, many industries are shifting to alternative energy resources, like solar, wind, tidal and biofuels, to make their operations smooth [9]. The dependency on fossil fuels has resulted in various environmental hazards like carbon emissions, the greenhouse effect, global warming, and climate changes that ultimately affect the standard of living and create health issues all over the country [10]. In addition, due to the over usage of fossil fuels and natural resources, the country faces depletion of natural gas. As a result, the residential sector mainly faces gas load shortage, and the situation worsens more in winter. The solution is to decreasing fossil fuel usage whilst using more renewable energy, that is, solar, wind, tidal and biofuels resources. These could help lower fossil fuel consumption in the country and save the environment from impulsive climate changes [10].

For Pakistan, the requirement for clean energy resources has been increasing by 9% annually. According to the study [11], the energy demand is expected to increase 8-fold by 2030 and around 20-fold by the year 2050. To fulfill this energy crisis in Pakistan, renewable energy could play a vital role by reducing the energy demand and supply gap. Renewable energy only contributes around 4 percent of the total power generation capacity of the country as per National Electric Power Regulatory Authority (NEPRA) 2020 annual report [12]. Among all these renewable energy resources (RER), solar energy has the higher potential to resolve the energy crisis in Pakistan to a higher extent because, geographically, Pakistan is located on the Sunbelt and receives a substantial amount of sunlight every year [13].

In the last few years, the solar energy market in Pakistan has seen phenomenal growth from 2011 to 2020. Figure 1 portrays the increasing trend of solar photovoltaic (PV) energy installed capacity in Pakistan (Irena renewable energy statistics 2021) [14].

Based on these statistics, different analysts and studies have forecasted a compound annual growth rate of more than 2.5% between 2022 and 2027. In this forecasting period, the most dominating segment for the Pakistani solar market is the utility sector due to the lower prices of solar modules and many ongoing projects. The Government of Pakistan has set up a target of achieving a 30 percent contribution through renewable energy by the end of 2030 by ARE (Alternative and Renewable Energy) policy in 2019. For this purpose, many solar power projects have been initiated and are in progress. By the end of December 2021, six solar power plants with a capacity of 430 MW were in operation for the utility sector. In contrast, other projects providing 460 MW are in the planning stage. This shows the clear intent of the Pakistani government to improve and increase the solar energy market in the country [14].

Along with the increasing trend of the solar energy market, the risks associated with solar technology should also be considered. Risk management related to solar power technology is essential for any owner or industrialist to make the operations well functional. Various risks associated with the PV system must be identified and analyzed early so that the project can succeed and reduce unexpected events like unconditioned power failure and sudden breakdowns.

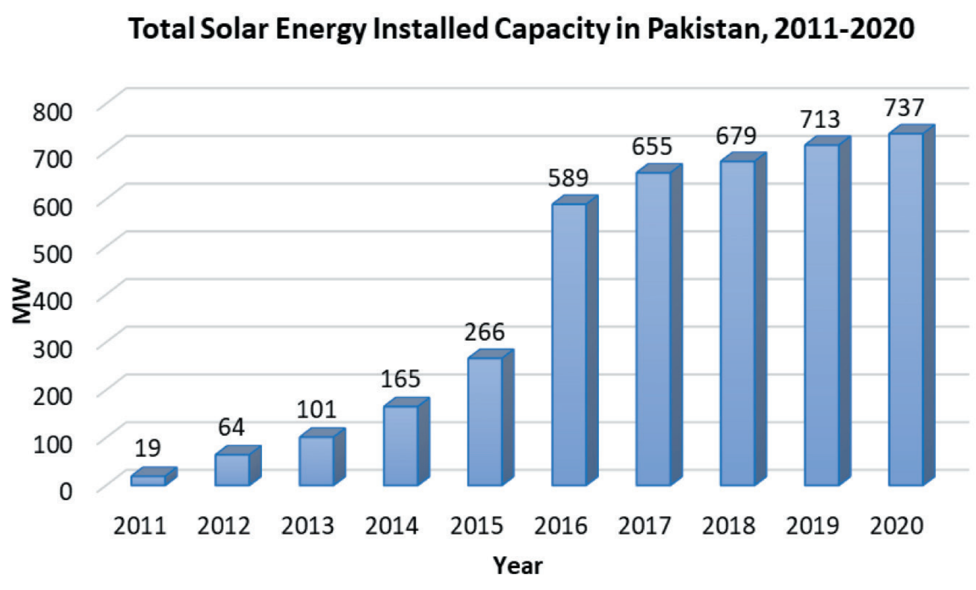

Figure 1. Total Solar Energy Installed Capacity in MW, Pakistan, 2011-2020 [14]

If risks are not appropriately considered, there is a higher possibility that the project will collapse, or the company will face a financial setback due to the lack of adequate risk management and mitigation strategies [15].

2. Literature Review

Despite the solar industry's rapid growth, a number of certain and uncertain risk factors related to utility, technical sophistication, and improper maintenance throughout a large solar PV project's entire life cycle could compromise its quality and impede further growth. Due to the fact that risks are a part of every project's life cycle, risk assessment is crucial to EPC solar projects. Wu et al. [16] assert that three factors—inadequate equipment selection, unfavorable weather, and a lack of qualified technicians—are the main causes of the risks connected to the maintenance and operation of solar PV plants [17]. They recommended enhancing design requirements, acceptance standards, and an effective monitoring system with qualified professionals to mitigate these problems [16]. The main cause of the deficiencies is a result of poor risk-mitigating strategies. It is well within the control of Pakistani contractors to successfully mitigate the risks associated with projects, which is a crucial component to finishing the projects on schedule [18].

2.1 Risk Management

Risk can be defined or analyzed as an event or any situation which can occur in the future. Depending on the risk nature, it could result in a threat or an opportunity. It is crucial to identify the risk through the combination of its probability of occurring and the impact of that particular risk. Risk management involves the identification of the risk, the complete evaluation of that risk, and the selection of the method or mitigation strategy against that risk [19]. At the same time, some researchers believe that risk management is the planning of the resources to tackle and reduce the possibility of the occurrence of the risk through monitoring its consequences and conditions related to the particular risk. The risk can be measured by using activities that include estimating the probability of risk and the impact of that risk on the system. The equation can be written as the following:

$$R = P \times I \tag{1}$$

Where R represents the risk score, P represents the probability of the risk occurrence, and I represent the impact of the risk. The risk score is attained by multiplying the probability of risk occurrence and the impact. Through this risk score, risks are then classified and prioritized.

2.2 Risk Register

The term risk register is a type of record that serves as a tool to find out the possible risks involved in performing any project to consider it for better completion of that particular project. A risk register involves proper analysis, identification, and risk solving before they convert to problems for the staff and management of any company. This register helps the management to take the appropriate step against any potential setback involved in the project to reduce the risk and complexity of the problem.

A Risk Register contains several partitions, including the risk name or the risk identification number, risk description, risk category, risk analysis, risk mitigation, risk priority, and risk status. These items in the risk register help the firm to cope with the possible risks and reduce them up to a certain amount. The risk name or the risk identification number is the title or name given to that particular risk. The risk category helps assign the risk to its appropriate team for resolving whether it is related to the operations, budget, technology, information, etc. Risk analysis tells about the severity of that risk and its impact on the project. Risk mitigation tells about the appropriate solution against that risk in order to solve it. It includes an action plan for solving the risk. Risk priority helps us to identify whether the risk is on the higher or lower priority based on its impact. Whilst Risk status tells about the current status of that risk, whether it is sorted out or not through the employed mitigation strategy [20].

2.3 Risk Prioritization

As electric consumers know, photovoltaic energy is rapidly expanding, and researchers have identified numerous risks to adopting renewable energies. Managing the risks associated with their operation, these solar power plants requires prioritizing and educating them with online lectures. A new framework for risk management and risk prioritization of these solar power plants is proposed in this study.

After compiling a risk register of certain hazards and issues that have primarily affected grid-enabled solar PV systems, first prioritize the risks into various categories. Risk prioritization is known as the method of evaluating and analyzing a vulnerability and its consequences by determining the probability and severity of the hazard. Nonetheless, operating these Solar PV plants to meet load requirements involves several risks that must be recognized and standardized [21]. A review of the literature and expert interviews assists in the identification of these risks. Expert opinions are also used to assess, prioritize, analyze, and mitigate these risks.

Increasing the likelihood and impact of favorable events while reducing the likelihood and impact of unfavorable events is the goal of risk prioritization for the project [22]. The likelihood or frequency of an event occurring, which may have a safety effect or result in a possible outcome, is referred to as risk probability [23]. The severity of the risk refers to the amount of harm that could reasonably occur as a result or consequence of the hazard.

2.4 Complaint Behavior

Consumer needs and beliefs differ, making it difficult for any organization to reasonably satisfy its consumer. Errors and disasters are unavoidable and expected in any industry. Complaints are proof of a customer's dissatisfaction with a product, service, or government action. A dissatisfied person's action includes communicating about something unwanted or unacceptable about a product or service.

Several studies show that customer complaint behavior, complaint handling, and post-complaint behavior are interlinked, and the following table gives an overview of previous research studies on these factors.

In this one of a kind research, several risks related to the solar system are listed. The complaints and their frequency is recorded and a risk prioritization matrix is also created. Experts views on resolving the complaints in the most optimal manner are also listed and this could benefit the solar panel companies. Their particular mitigation strategies, along with their response time, are provided to lessen the risks more efficiently, which can benefit future investors and owners of solar system businesses as solar system consumers. Figure 2 depicts the occurrence of a risk or fault in the PV plant, which was corrected in a very short amount of time by using the correct measures. After the fault is rectified, the PV plant begins to operate and supplies power to the load.

Table 1. Dimension wise distribution of article [24]

Dimension	Study	Total
Customer Complaint Behavior	Singh & Pandya(1991), Hamzelu et al.(2006), Fernandes & Santos(2008), Kim et al.(2010), Park et al.(2014), Preko & Samual(2015), Bergel & Brock(2018), Berry et al.(2014), Defranco et al.(2005), Gursoy et al.(2007), Jones et al.(2002), Keng et al.(1995), Kim et al.(2014), Kitapci & Dortyol(2009), Lau & Ng(2001), Liu & Mcclure(2001), Mattila & Wirtz(2004), Mccoll-kennedy et al.(2003), Ngai et al.(2007), Phau & Baird(2008), Sharma et al.(2010), Singh(1991), Soares et al.(2017), Stephens & Gwinner(1998), Tronvoll(2007), Yuksel et al.(2006)	26
Complaint handling	Cook & Macaulay(1997), Lam & Dale(1999), Davidow(2003), McCole(2004), Huitema & Ros(2008), Orsingher et al.(2010), Hansen et al.(2010), Abosag et al.(2011), Bell & Luddington(2006) , Clark et al.(1992), Anthony(2008), Gruber et al.(2006), Gruber et al.(2009), Huppertz(2007), Johnston(2001), Mattila et al.(2013), Miller(1995), Ogbeide et al.(2015), Simon(2013), Zairi(2000)	20
Post complaint Behavior	Badawi(2012), Neira et al.(2010), Conlon & Murray(1996), Davidow(2000), Estelami(2000), Gursoy et al.(2007), Halstead et al.(1993), Karatepe(2006), Maxham & Netemeyer(2002), Maxham & Netemeyer(2003), Rothenberger et al.(2008), Tax et al.(1998), Wirtz & Mattila(2004), Au et al.(2001), Blodgett et al.(1997), Gelbrich & Roschk(2011), Hui & Au(2001), Schoefer & Diamantopoulos(2008)	18

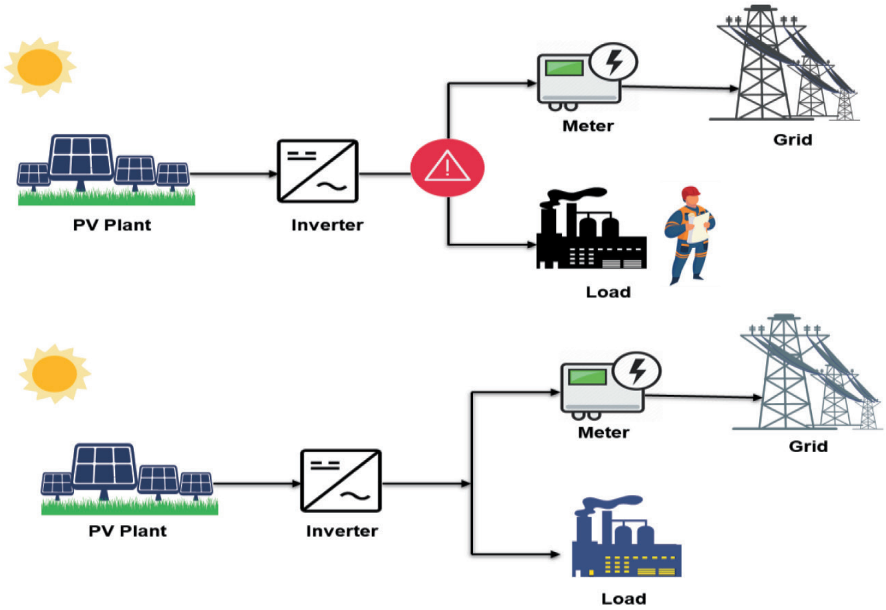

Figure 2. Theoretical Framework

3. Methodology

The methodology portrayed in this research provides a pragmatic approach to Solar PV system complaint mitigation strategies and their implementations. Pragmatist research incorporates positivism and interpretivism into the scope of a study. In order to conduct research in relatively new and dynamic ways to find solutions to research problems, pragmatic researchers must incorporate operational decisions into their research designs. This methodology is deductive reasoning, which includes one or more descriptions, analysis logic, and conclusions from inductive reasoning [25]. This research gathered information from existing literature and conducted interviews and discussions with critical stakeholders and experts. A literature review was performed to identify possible risks in the most recent research on risk assessment of solar PV systems [26]. Secondly, do structured interviews with solar market pioneers to identify all potential risks associated with solar PV systems in Pakistan. The information acquired about potential risks was then used in risk assessment and prioritization using a risk matrix method.

Because pragmatist research is used, we can use complex or mixed methods. Mixed methods research allows for using both qualitative and quantitative data collection and analysis tools. Rather than focusing on research philosophies. Pragmatic research enables a researcher to choose the best strategy for achieving the study's objective. As a result, the said paper focusing using action research, which is commonly based on diurnal issues and is concerned with developing practical solutions to these problems.

The research opinion's second innermost layer addresses the data time horizon. We use cross-sectional data in this layer to collect data from multiple samples simultaneously. In contrast to longitudinal data. The merit of cross-sectional data that collects information from multiple samples at a single point in time.

The Delphi technique analyzes the risk involved in solar PV plants. It is a method of gathering individual opinions on issues with no or little predefined evidence and where opinion is significant [27]. In Delphi studies, this is typically accomplished with the use of successive questionnaires. The respondents are asked for information and their opinions [28]. During the course of this study, we had a meeting with the top experts of the industry who helped us in listing the mitigation strategies for resolving multiple types of complaints.

3.1 Risk Register for Solar System

The focus of this research is to prepare the risk register involving firm risks and problems faced by industries after installing the solar power system as their energy resource. Many industries face similar and dissimilar problems related to the PV system during operations. Those issues or complaints and their particular mitigation strategy are gathered through the inline survey and meetings to maintain the risk register related to the solar source. Different industries use more than one mitigation strategy for complaints of similar nature; therefore, a well-developed risk register is significant in order to provide a set of solutions against these complaints for the industries using solar power systems and for those who are willing to install the PV system in future as well. This register could provide them with several recorded problems or complaints along with their solutions to reduce their maintenance cost as well as helps them in their troubleshooting. Figure 3 depicts the flowchart for the methodology for the risk assessment.

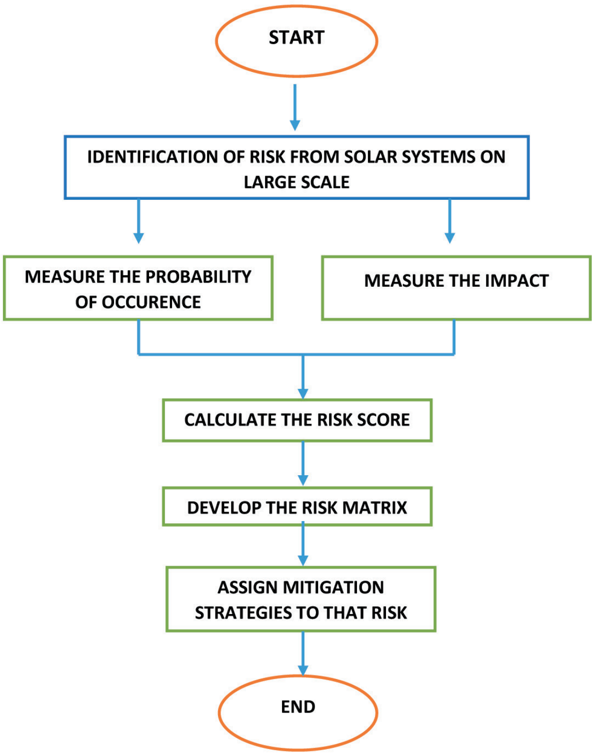

Figure 3. Flow chart for the methodology for risk assessment

3.2 Risk Assessment

Identifying risks and their effects is the process of conducting a risk assessment. In this regard, the likelihood and seriousness of the hazard are assessed. A hazardous situation can lead to property damage (including equipment damage), injuries (possibly fatalities), and financial loss [29]. Information on accidents and related events makes it easier to identify the circumstances that create dangerous situations. The expected likelihood and magnitude of an event brought on by a hazardous event are combined to form risk. The two elements of risk are risk severity and risk probability. It is essential to look into every potential result of an unsafe situation, including the worst case (slightest chance situation).

3.3 Risk Probability

Risk probability is the term used to describe the likelihood of an event [30]. As tabulated in Table 2, it is classified into the following categories in decreasing order of frequency. Risk is classified as "Most likely" if it is anticipated to happen in most situations. It is highly significant because it happens frequently. Similarly, to this, rare risks are categorized as "Likely" risks. The risk is categorized as "Occasional" and only happens occasionally if it arises due to another event. Risks that occur infrequently or under exceptional conditions are given the lowest rank.

Table 2. Risk Probability

Likelihood	Description	Value
Frequent	Most likely to occur (has occurred frequently)	5
Likely	Likely to occur sometimes (has occurred infrequently)	4
Occasional	Unlikely to occur but possible (has occurred rarely)	3
Unlikely	Very unlikely to occur (not known to have occurred)	2
Extremely unlikely	Almost inconceivable that the event will occur	1

3.4 Risk Severity

The impact of a risk event is measured in terms of risk severity. Catastrophic, Major, Moderate, Minor, or Insignificant are all potential consequences. Risk severity, also known as risk impact, is the anticipated harm or unfavorable outcome due to exposure to the risk. In other words, it evaluates how serious a situation might be if a specific Risk materializes in the future. The severity of the outcomes provides a rating based on the impact of the risk that has been identified, as marked in Table 3.

Table 3. Risk Severity

Severity	Consequences	Value
Minor	Minor failure or degradation, hardly noticeable, has no impact on system performance.	A
Major	Failure/degradation will result in non-operation of the system	B
Hazardous	Major equipment damage and reduction in safety margins	C
Catastrophic	Equipment destroyed	D

3.5 Risk Matrix

The risk of a solar PV system is quantified in this paper using the risk matrix approach. A risk matrix, also known as a probability and severity risk matrix, is used to depict the possible system risks. The two intersecting elements that form the foundation of the risk matrix are the likelihood that a risk event will occur and its potential effects on the system. Based on the likelihood and severity of a risk, it is categorized as critical, high, moderate, or low. Solar companies can use risk matrices to prioritize various risks and create a suitable mitigation strategy as part of the risk management process [31-33].

In Figure 4, risk is described as the product of the probability (or likelihood) of an asset failure and the impact of severity of the failure outcome. A risk matrix, as opposed to sophisticated risk calculations, provides a measure of risk using simple scoring systems. By evaluating the risk's severity ranking by multiplying its probability rank by its impact rank in a Probability/Impact matrix, one can often determine how severe a risk is. The higher the risk rating, the greater the system's overall risk. This strategy assists in balancing the importance of severity and probability.

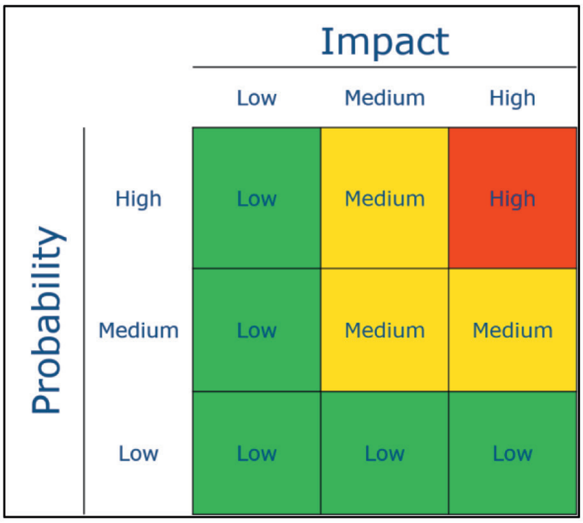

Figure 4. Risk Matrix

3.6 Response in Risk Management

There are three dimensions, i.e., customer complaint behavior, complaint handling by firms, and post-complaint behavior of customers, which broadly cover the complaint management fact.

1) Customer Complaint Behavior

Whenever customers' expectations are not fulfilled by their experience, their behavior changes from complaints to dissatisfaction. Noncomplaining behavior happens because dissatisfied customers analyze the cost-benefit trade-off before registering the complaint. Suppose the product price is high, consumers complain openly. Nonetheless, if the product price is low, customers should refrain from using it without complaining. So companies must focus on each issue about products and services, especially to avoid losing customers.

2) Complaint Handling

Complaints handling is the primary process that retains a customer and makes him loyal to the product or services. Currently, most companies rely on complaints, which also irritates consumers. Individual complaints handling process should be managed to avoid such loss and consumer priorities.

Essential factors that need to be the focus are:

- Timeliness
- Facilitation
- Apology
- Credibility
- Attentiveness

3) Post - Complaint Behavior

Feedback is the best process to ask the consumer about the experience. Like different companies call their consumer to check their satisfaction level. Customer experience regarding complaint handling is to be judged and discussed. Together all the justice dimensions are essential to post-complaining behavior.

4. Results

Based on the past literature and data gathered from semi-structured interviews with the three leading companies of solar PV systems in Pakistan, potential risks of solar PV systems are identified. A total of 29 potential risks were identified and classified according to the risk's severity and probability. We categorized the 29 potential risks into four broad categories, as shown in Figure 5. The bar chart in figure 4, depicts each risk, its severity, and the possibility of its occurrence in any system.

The risks, their descriptions, and the frequency of complaints in the PV plants of three different solar installers are also shown in Table 4 below. Table 4, shows that despite the three different installers using three different solar installation techniques, each risk may or may not occur more frequently. Moreover, Figure 6 indicates the occurrence of the risks of solar PV plants in three different solar firms, as mentioned

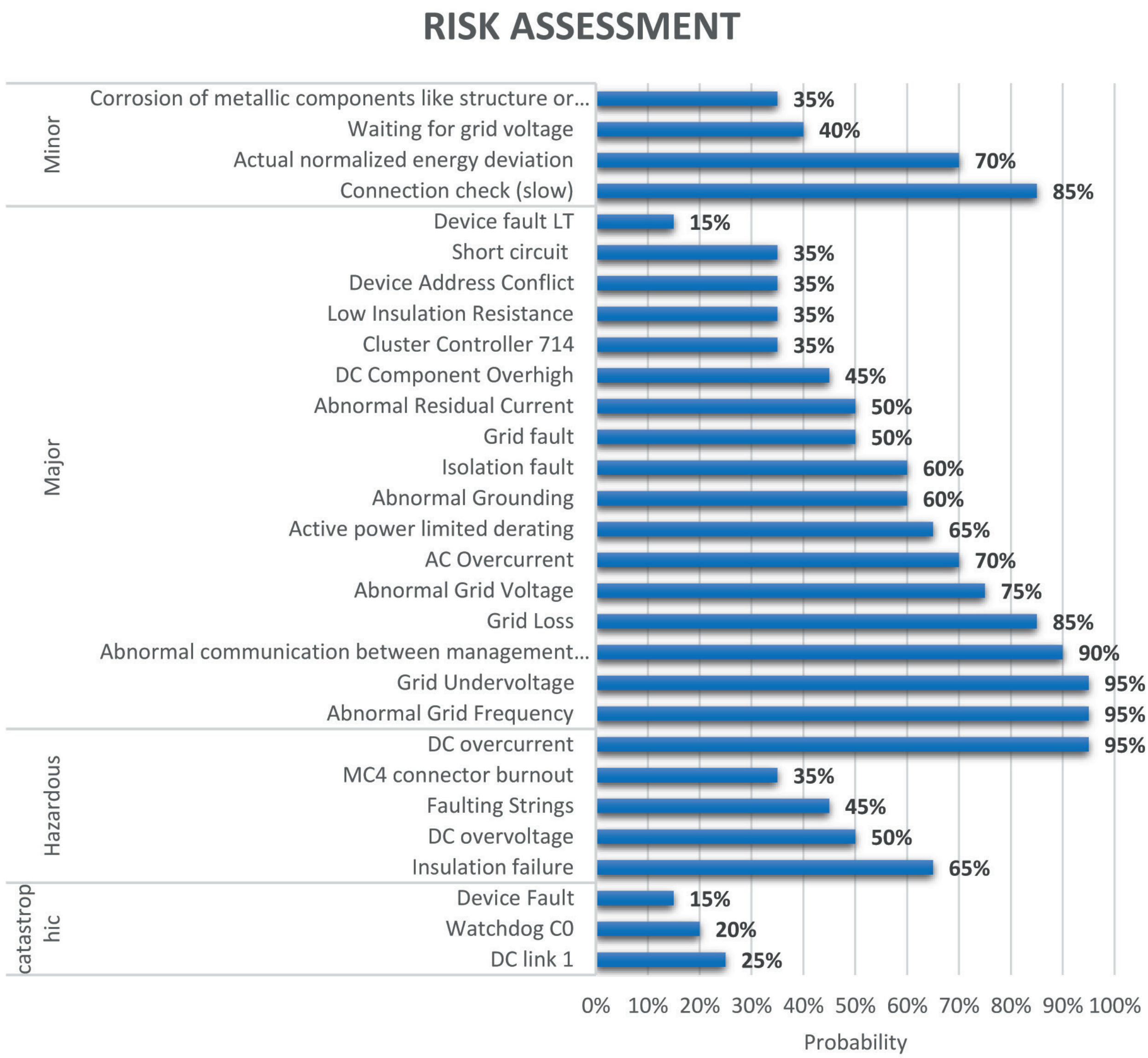

Figure 5. Risk Assessment

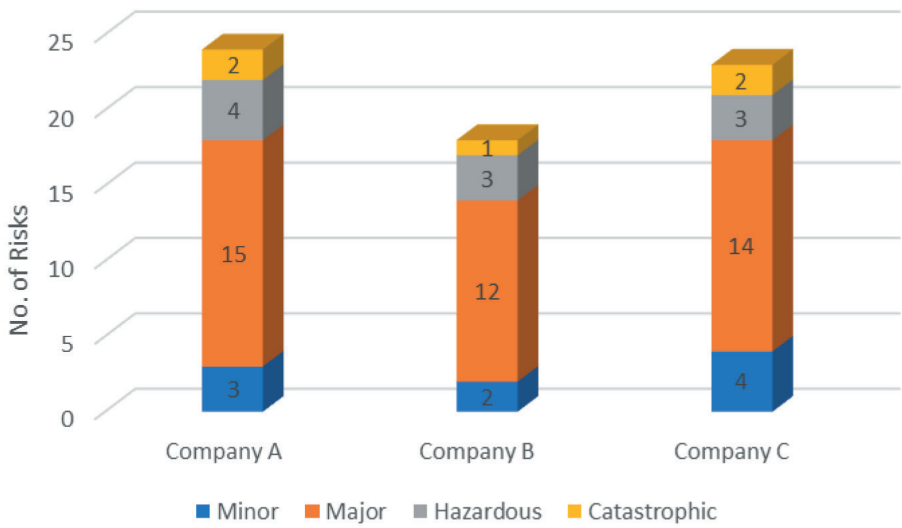

Figure 6. Level of Risk Occurrence

Table 4. Risks occurrence in three different solar installer's PV plants

S.No.	RISK TITLE	DESCRIPTION	A	B	C
1	Abnormal communication between management system and equipment	Communication malfunction between power section and control and regulation unit	✓	✓	✓
2	Connection check (slow)	The inverter has not sent data for a longer time.	✓	✓	x
3	Cluster Controller 714	Fault in the communication with the device persists	x	x	✓
4	Abnormal Grid Frequency	The actual grid frequency is lower/higher than the requirement of the local power grid standard.	✓	✓	✓
5	Abnormal Grid Voltage	The phase phase voltage exceeds the configured limit value for the configured duration.	✓	✓	✓
6	Grid Undervoltage	The grid voltage is below the lower threshold or the low voltage duration has lasted for more than the value specified by LVRT.	✓	✓	✓
7	Waiting for grid voltage	The AC cable is not correctly connected or the country data set is not correctly configured.	x	x	✓
8	DC overvoltage	Overvoltage at the DC input.	x	✓	✓
9	Grid fault	The grid voltage or grid impedance at the connection point of the inverter is too high. The inverter has disconnected from the utility grid.	✓	✓	✓
10	Grid Loss	There is a permanent AC grid failure.	✓	✓	✓
11	MC4 connector burnout	Burning of MC4 connector due water ingression causing short circuit arc.	✓	x	x
12	Abnormal Residual Current	Residual current measured from the LT exceeded the limits. residual current > Limit values of 20 mA, 130mA, 280mA respectively	✓	x	✓
13	Low Insulation Resistance	The PV array is short-circuited to ground.	✓	✓	x
14	Abnormal Grounding	The neutral wire or PE cable of the device is not connected.	✓	✓	✓
15	Insulation failure	The inverter has detected a ground fault in the PV array.	✓	✓	✓
16	Faulting Strings	DC Wire bured due to short circuit.	✓	x	✓
17	AC Overcurrent	over current at the grid side.	✓	✓	✓
18	DC overcurrent	Overcurrent at the DC input. The inverter briefly interrupts feed-in operation.	✓	✓	x
19	DC Component Overhigh	Interior overtemperature	✓	x	✓
20	Device Address Conflict	IP address conflict.	✓	x	x
21	Device Fault	An unrecoverable fault has occurred in the internal circuit of the device.	✓	✓	✓
22	Actual normalized energy deviation	The normalized energy was below the accepted deviation from the highest normalized energy of the best performing inverter in the defined check period.	✓	✓	✓
23	DC link 1	The device has disconnected from the grid due to an imbalance in the internal DC voltage and is switched on again briefly.	x	✓	✓
24	Device fault LT	Power section hardware shutdown	x	x	✓
25	Isolation fault	An isolation fault was detected.	✓	✓	✓
26	Watchdog C0	The internal firmware protection function has been triggered.	✓	x	x
27	Active power limited derating	The inverter has reduced its power output for more than ten minutes due to excessive temperature.	✓	✓	✓
28	Corrosion of metallic components like structure or cable tray	Corrosion due to salty air or water ingress.	✓	x	✓
29	Short circuit	Short circuit of buring of wires due to high voltages.	✓	✓	x

earlier. Figure 7 illustrates that significant risks related to the grid and solar PV system inverters happened in all three firms' PV plants.

We analyze the risk severity and probability of different PV plants located in different areas and installed by different companies. Each pie chart defines the number of complaints received by the specific company regarding categorized risk in this research.

According to Risk Assessment, significant risks were the recurring events that companies identified as having the highest level of encountering during their work operations. Figure 8 depicts a significant risk that solar industries frequently face in Pakistan because of the unstable grid, voltage fluctuations, and problematic connectivity. Since the last few decades, Pakistan's power distribution system has been plagued by line faults, imbalanced conditions, instability, and forced interruptions. The reasons for this are a poor protective system, an unbalanced load, aged and inadequate infrastructure, and a shortfall in power generation compared to demand.

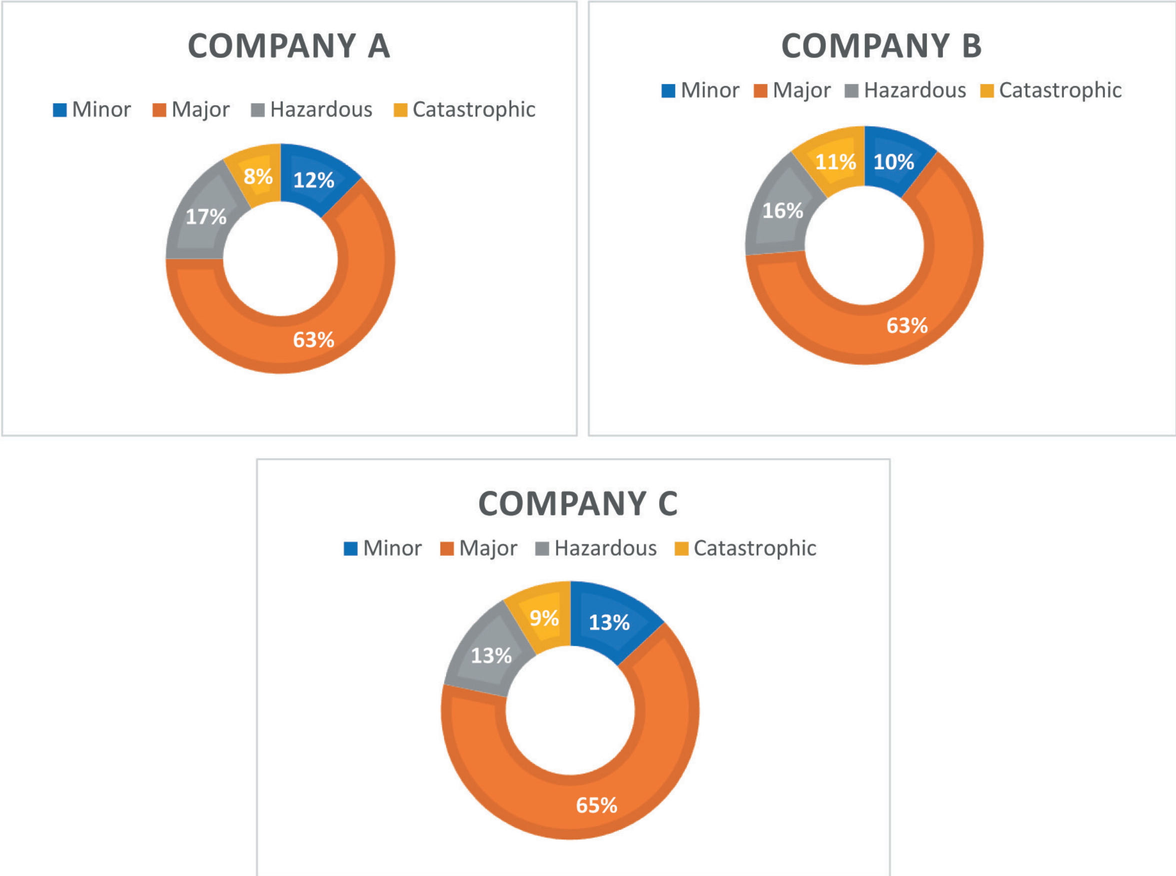

Figure 7. Type of risk occurrence in each company

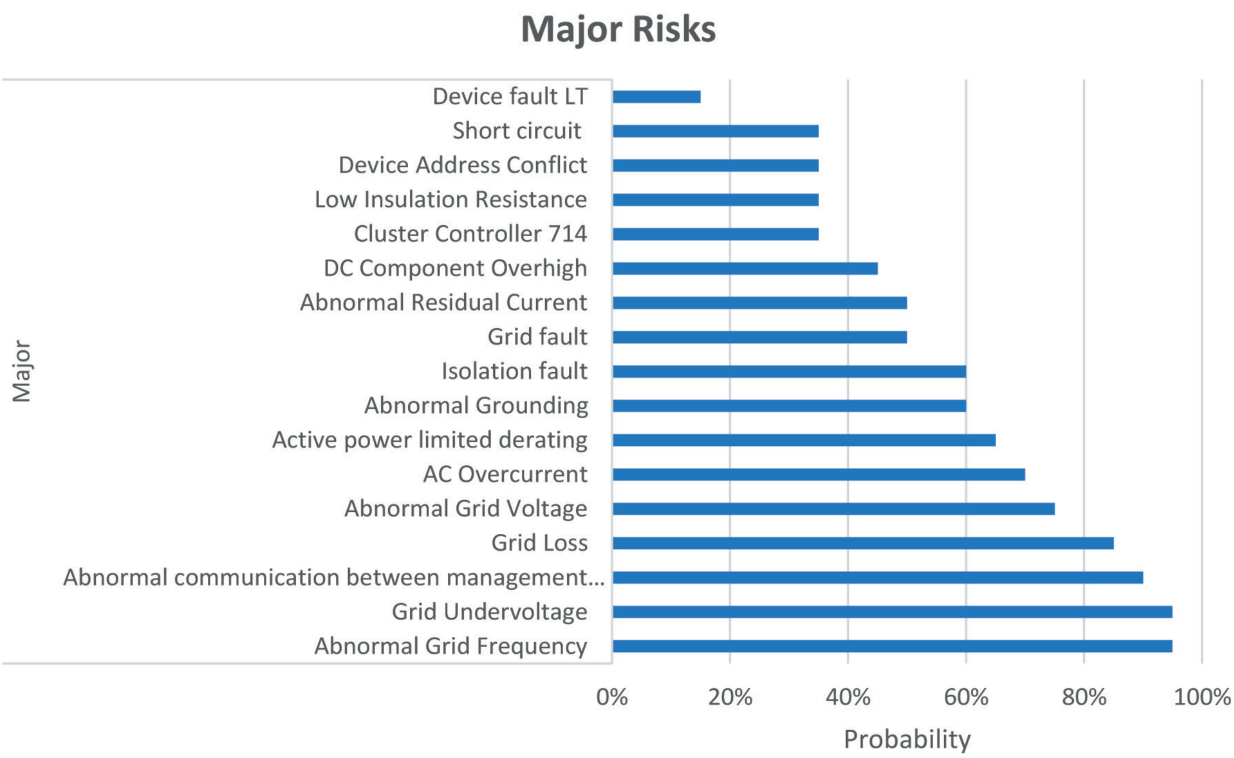

Figure 8. Probability of Major Risks

Due to these grid issues, the failure and non-operation of the system frequently occurred in all three companies' solar PV plants. Voltage fluctuations and an inferior voltage profile are seen in many parts of Pakistan, in addition to other technical problems. In the summer and peak hours, the customer end voltages typically fluctuate between 20 and 220 volts, interrupting the operation of grid-connected PV systems.

Risk is determined by the probability of an event occurring and its subsequent impact with severity. The likelihood of the event occurring is the probability. Severity is defined as the amount of damage and negative consequences resulting from the event. Without considering the impact of mitigation measures, a risk index is assigned for each risk event based on the likelihood and severity of each risk.

The risk matrix created and coded in the aforementioned Table 5 is based on the impact or probability. To make risk elimination easier for solar companies, the risk indexing has also been color-coded according to region of severity as shown in Table 6.

5. Discussion

5.1 Risk Mitigation

The best practices implemented by solar industry professionals to eliminate the potential risks which are described in Tables 7 -10. These directives will aid in hindering problems at earlier stages of solar operations. As we can see, catastrophic risks are those that, despite having the lowest likelihood of occurring, have the most significant potential for harm [1].

5.2 Customer Complaints

Customer complaints should be classified according to their criticality, and the resolution time to those complaints should be determined accordingly. To reduce the significant damage, establish a customer complaint response and resolution time based on risk severity and consequences. If the risk causes damage to the system, it must be rectified immediately, and the response time should be within an hour.

Table 5. Risk Matrix

PROBABILITY ↕ / IMPACT ↔	Minor	Major	Hazardous	Catastrophic
Most Likely	5A	5B	5C	5D
Likely	4A	4B	4C	4D
Occasional	34	3B	3C	3D
Unlikely	2A	2B	2C	2D
Exceptional	1A	1B	1C	1D

Table 6. Risk Tolerance

Region	Indexes	Criterion
Critical	5B, 5C, 5D, 4C, 4D, 3D	Potential harm that pose the highest risk in terms of strategic significance considering their likelihood of occurring and consequences.
High	4B, 3B, 3C, 2C, 2D, 1D	Severe events can result in equipment loss, but the consequences are minor in comparison to a risk rated as critical.
Moderate	5A, 4A, 2B, 1B, 1C	A moderate risk event is one that results in risks that can have an impact but are not severe.
Low	3A, 2A, 1A	A low-rated event has little or no impact on the system's operational activities and performance.

Table 7. Risk Mitigation of Catastrophic risks

Level of Risk	Risk	Probability of Occurrence	Region	Mitigation
Catastrophic	DC link 1	25%	2D	If this error occurs more than once, turn off the inverter and restart it after a few minutes. If this still needs to be rectified, contact a technical person.
	Watchdog C0	20%	2D	This critical error can be resolved by performing an AC reset or firmware update. Turn the ac power circuit breaker on and off. If the code persists, use the inverter's software tool to update the firmware.
	Device Fault	15%	1D	Turn off the AC switch and DC switch, wait for 5 minutes, and then turn on the AC switch and DC switch. If the fault persists, contact your dealer or technical support.

Table 8. Risk Mitigation of Hazardous risks

Level of Risk	Risk	Probability of Occurrence	Region	Mitigation
Hazardous	Insulation failure	65%	4C	Check for ground faults in the PV system by measuring the voltage. If the voltage measurement was unsuccessful, inspect the PV system for ground faults using insulation resistance measurements.
	DC overvoltage	50%	3C	Check the series connection of each string; it should be within the inverter's maximum range. Change string configuration if the number of panels exceeds an array of the system.
	Faulting Strings	45%	3C	1. Check whether the current in the PV string is significantly lower than in other PV strings. If yes, check whether the PV string is shaded. 2. If PV modules in the PV string are clean and not shaded, check whether the PV string is damaged.
	MC4 connector burnout	35%	3C	First, turn off the inverter and remove that MC4. Then change the MC4 connector with the new piece. Fix all the connections and check all the lost connections.
	DC overcurrent	95%	3C	In real-time, the solar inverter detects its external working conditions. The solar inverter automatically recovers after the fault is restored. If the alarm occurs frequently and affects the PV plant's energy yield, check whether the DC output is short-circuited. Contact your dealer or technical support if the problem cannot be resolved.

Table 9. Risk Mitigation of Major risks

Level of Risk	Risk	Probability of Occurrence	Region	Mitigation
Major	Abnormal Grid Frequency	95%	5B	Check the configured frequency limit and the configured nominal frequency. Either grid frequency fluctuates due to instability at the grid, or configured frequency needs to be appropriately set.
	Grid Under voltage	95%	5B	1. If the alarm occurs occasionally, the power grid may be temporarily abnormal. The device automatically recovers after detecting that the power grid becomes normal. 2. If the alarm frequently occurs, check whether the power grid voltage is within the allowed range. If not, contact the local power operator. If yes, modify the power grid under the voltage protection threshold after obtaining the consent of the local power operator. 3. If the fault persists for a long, check the connection between the AC switch and the power cable.
	Abnormal communication	90%	5B	Check that the device is connected through a network cable. Check whether the router network can access the public network.

Level of Risk	Risk	Probability of Occurrence	Region	Mitigation
Major	Grid Loss	85%	5B	Check that AC grid and power cable are connected and that the AC switch is ON.
	Abnormal Grid Voltage	75%	4B	If grid conditions stabilize, the inverter automatically recovers. Check that the grid voltage is within a safe range. If it still needs to be, get in touch with the power company.
	AC Overcurrent	70%	4B	If the alarm occurs frequently and affects the operation of the power plant, check whether AC short circuit exists. If the fault persists, contact your dealer or technical support.
	Active power limited de-rating	65%	4B	When the inverter reduces its power to protect internal components from overheating, this is called temperature de-rating. Examine the heat dissipation and whether the fans are operational or not contaminated.
	Abnormal Grounding	60%	4B	Power off the device (turn off the AC switch and DC switch, and wait for a period specified on the device safety warning label), and then perform the following operations: 1. Check that the PE cable of the device is connected correctly. 2. If the device is connected to a TN power grid, check whether the neutral wire is connected correctly and whether the voltage to the ground is abnormal. 3. After powering the device, check whether the output mode set on the device matches the actual cable connection.
	Isolation fault	60%	4B	1. Turn off the AC connection. 2. Measure the open-circuit voltage of each string. 3. Disconnect the PE (AC earth) and other earthing from the inverter. Maintain the DC connection. – A red LED illuminates to indicate an error. – The isolation fault message is no longer displayed because the inverter can no longer distinguish between DC and AC voltages. 4. Disconnect all DC wiring but keep the DC+ and DC- from each string together. 5. Record the voltage between (AC) PE and DC (+) as well as the voltage between (AC) PE and DC (-). 6. Notice that one or more readings do not show 0 Volt; these strings have an isolation fault.
	Grid fault	50%	3B	If the error frequently occurs because of the high grid voltage, your inverter can no longer overcome it and shuts down. Check the inverter grid code or country code is selected correctly or not. If it still needs to be, get in touch with the power company.
	Abnormal Residual Current	50%	3B	If the alarm occurs frequently or persists, check whether the DC-to-ground impedance is too low.
	DC Component Over high	45%	3B	If the alarm occurs frequently and impacts the PV plant's energy yield, check whether the DC output is short-circuited. Contact your dealer or technical support if the problem cannot be resolved.
	Cluster Controller 714	35%	3B	Check the Ethernet cable and connector. If the error does not remove, change the cable and configure the IP setting.
	Low Insulation Resistance	35%	3B	Check that the PE cable of the device is correctly connected. Check the output-to-ground impedance of the PV array. If a short circuit or inadequate insulation exists, rectify it.
	Device Address Conflict	35%	3B	Change the RS485 address or connector of the data logger.
	Short circuit	35%	3B	Check all possible reasons for short circuits. All loose connections should be removed. MC4 connectors are correctly connected or not.
	Device fault LT	15%	1B	Check the inverter status and shut down the device; if the error occurs again, check the internal hardware or contact the service center.

Table 10. Risk Mitigation of Minor risks

Level of Risk	Risk	Probability of Occurrence	Region	Mitigation
Minor	Connection check (slow)	85%	5A	Check the internet connectivity of your plant.
	Actual normalized energy deviation	70%	4A	Check that PV module are not in the shade and are properly cleaned. All the strings are working correctly and generating the expected power.
	Waiting for grid voltage	40%	3A	Examine the input voltage of the inverter. Check the PV generator configuration if it is close to the input OV threshold.
	Corrosion of metallic components like structure or cable tray	35%	3A	However, if grid voltage fluctuations cause the error, the inverter will automatically rectify it when grid conditions stabilize. If the error persists, check the grid configuration and country code.

The magnitude of the system damage dictates how these complaints should be handled. For example, if there is a short circuit in the system or the inverter or breaker catches fire, the solar service provider must immediately resolve the problem. Furthermore, issues such as a grid malfunction, abnormal grounding, or other issues that render the system inoperable rather than causing severe harm can be resolved in a matter of days without needing immediate action. Whereas, issues in which the system is operational but minor faults, such as non-availability of steady internet, or deviation in output generation due to dirt on PV modules, do not warrant any physical visit by the service provider, and the customer can rectify the risk. However, consumer behavior should be taken into account while dealing with such complaints, as it directly impacts clientele relations and business. A poor customer service experience can significantly damage your reputation. As it is imperative to timely address these issues, any communication gap between the customer and service provider adversely affects the business's reputation. Figure 9 depicts the response time depend upon the complaint severity.

Four broad categories, the intervention of risk origination, its likelihood of occurrence and time to cater is tabulated in Table 11.

6. Conclusion

The use of solar energy has increased significantly in our modern world, but it also carries some risks that must be addressed in order of priority. This paper uses the Delphi technique to evaluate and identify potential risks associated with solar photovoltaic systems. Through deep research by the team members and interviews with the solar experts, we have classified the risks and hazards according to their severity. This has allowed us to determine which risks need to be addressed first.

The research by the team was carried out in four phases. Firstly, interviews with experts facilitated the identification of risks through their experiences. After the interviews, in-depth research into determining how those risks are to be mitigated gave us a framework for managing them. Thirdly, by analyzation of

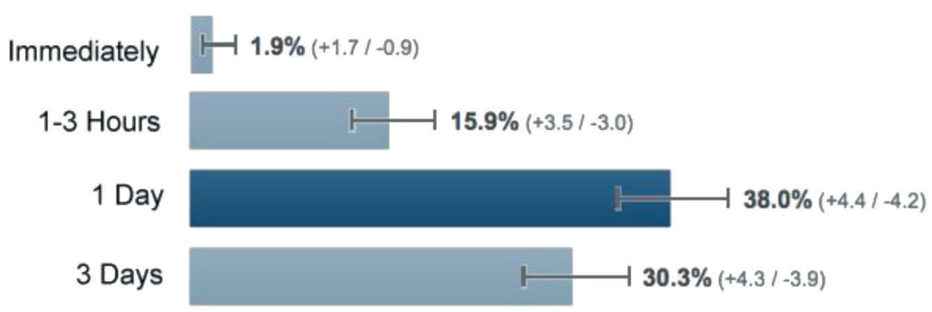

Figure 9. Response Time

Table 11. Complaint Response Time

Level of Risk	Risk	Probability of Occurrence	Response time
Catastrophic	DC link 1	25%	Immediately
	Watchdog C0	20%	within a day
	Device Fault	15%	within a day
Hazardous	Insulation failure	65%	within hours
	DC overvoltage	50%	within a day
	Faulting Strings	45%	within a day
	MC4 connector burnout	35%	Immediately
	DC overcurrent	95%	within a day
	Short circuit	35%	Immediately
Major	Abnormal Grid Frequency	95%	No Physical visit required
	Grid Under voltage	95%	No Physical visit required
	Abnormal communication between management system and equipment	90%	within 1 or 2 days
	Grid Loss	85%	No Physical visit required
	Abnormal Grid Voltage	75%	No Physical visit required
	AC Overcurrent	70%	within 1 or 2 days
	Active power limited de-rating	65%	within 1 or 2 days
	Abnormal Grounding	60%	within a day
	Isolation fault	60%	within a day
	Grid fault	50%	within 1 or 2 days
	Abnormal Residual Current	50%	within a day
	DC Component Over high	45%	within a day
	Cluster Controller 714	35%	within 1 or 2 days
	Low Insulation Resistance	35%	within a day
	Device Address Conflict	35%	within 1 or 2 days
	Device fault LT	15%	within a day
Minor	Connection check (slow)	85%	No Physical visit required
	Actual normalized energy deviation	70%	No Physical visit required
	Waiting for grid voltage	40%	No Physical visit required
	Corrosion of metallic components like structure or cable tray	35%	within 1 or 2 days

the criticality of risks, we were able to comprehend how they have to be resolved depending on the likelihood of their occurrence and the severity of the resulting damage. Moreover, conclusively, the timeframe for rectifying risks identified in the research was also made evident.

As a result of this extensive research, experts could strategize for the potential future risks beforehand in the rapidly expanding solar market. This research could significantly aid in risk management and prioritization, as it has categorized the risks and their management meticulously by classifying each risk and providing mitigation strategies for them. Further describing how hazardous those risks are and how they need to be addressed according to the gravity of the consequences of those risks. The proposed risk management framework in this study can benefit the solar industry, and managers will be able to understand risk management steps and implement them in any region.

Future research may include risks related to governmental policies affecting solar PV systems operations and installation in developing countries. Moreover, the risk of the supply chain cycle of the solar PV system from procurement to installation can be identified using various techniques. Besides technical risk, financial risk can also be incorporated that can affect the implementation of solar PV plants. Financial risks such as return on investment (ROI) may deviate from projected years due to technical risks that may affect the unit generation solar PV plant.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] I. Naseem and J. Khan, “Impact of energy crisis on economic growth of Pakistan,” Int. J. Afr. Asian Stud., vol. 7, pp. 33–43, 2015.

[2] K. Fatai, L. Oxley, and F. G. Scrimgeour, “Modelling the causal relationship between energy consumption and GDP in New Zealand, Australia, India, Indonesia, The Philippines and Thailand,” Math. Comput. Simul., vol. 64, no. 3, pp. 431–445, 2004, doi: 10.1016/S0378-4754(03)00109-5.

[3] T. Muneer, S. Maubleu, and M. Asif, “Prospects of solar water heating for textile industry in Pakistan,” Renew. Sustain. Energy Rev., vol. 10, no. 1, pp. 1–23, 2006, doi: 10.1016/j.rser.2004.07.003.

[4] “State of Industry Report 2016,” National Electric Power Regulatory Authority (NEPRA), Islamabad, Pakistan, 2016. Accessed: September 10, 2022. [Online] Available: https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202016.pdf

[5] M. Farooq and A. Shakoor, “Severe energy crises and solar thermal energy as a viable option for Pakistan,” J. Renew. Sustain. Energy, vol. 5, no. 1, p. 13104, Jan. 2013, doi: 10.1063/1.4772637.

[6] A. Ghafoor and A. Munir, “Design and economics analysis of an off-grid PV system for household electrification,” Renew. Sustain. Energy Rev., vol. 42, pp. 496–502, 2015, doi: 10.1016/j.rser.2014.10.012.

[7] A. Ghafoor, T. ur Rehman, A. Munir, M. Ahmad, and M. Iqbal, “Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability,” Renew. Sustain. Energy Rev., vol. 60, pp. 1332–1342, 2016, doi: 10.1016/j.rser.2016.03.020.

[8] A. Pavlović, A. Frank, A. Ivanišević, and I. Katić, “The Impact of Climate Change on Sustainable Development: The Case of Vojvodina,” Int. J. Ind. Eng. Manag., vol. 12, no. 2, pp. 141–150, 2021, doi: 10.24867/IJIEM-2021-2-283.

[9] S. Ahmed, A. Mahmood, A. Hasan, G. A. S. Sidhu, and M. F. U. Butt, “A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities,” Renew. Sustain. Energy Rev., vol. 57, pp. 216–225, 2016, doi: 10.1016/j.rser.2015.12.191.

[10] A. Sharma, J. Srivastava, S. K. Kar, and A. Kumar, “Wind energy status in India: A short review,” Renew. Sustain. Energy Rev., vol. 16, no. 2, pp. 1157–1164, 2012, doi: 10.1016/j.rser.2011.11.018.

[11] N. Hameed, “Solutions for Energy Crises in Pakistan,” Islamabad Policy Research Institute, Islamabad, Pakistan, Volume II, 2015. Accessed: March 15, 2023. [Online]. Available: http://www.ipripak.org/wp-content/uploads/2016/01/sfecpii.pdf

[12] “Pakistan - Country Commercial Guide,” International Trade Administration U.S. Department of Commerce, Washington, DC, USA, 2022. Accessed: March 15, 2023. [Online]. Available: https://www.trade.gov/country-commercial-guides/pakistan-renewable-energy

[13] F. Bakhtiar and A. Ahmed, “A Review of Solar Energy in Pakistan: Current Status and Future Prospects,” Sci. Technol. Dev., vol. 36, no. 3, pp. 189–195, 2017, doi: 10.3923/std.2017.189.195.

[14] “Pakistan Solar energy market – growth, trends, covid-19 impact, and forecasts (2023-2028),” Mordor Intelligence, Hyderabad, Telangana, India, 2022. Accessed: March 15, 2023. [Online]. Available: https://www.mordorintelligence.com/industry-reports/pakistan-solar-energy-market

[15] H. L. Wang, Q. X. Hu, Y. Yang, and C. Wang, “Performance differences of electrical submersible pump under variable speed schemes,” Int. J. Simul. Model., vol. 20, no. 1, pp. 76–86, 2021, doi: 10.2507/IJSIMM20-1-544.

[16] Y. Wu, J. Zhou, Y. Hu, L. Li, and X. Sun, “A TODIM-Based Investment Decision Framework for Commercial Distributed PV Projects under the Energy Performance Contracting (EPC) Business Model: A Case in East-Central China,” Energies, vol. 11, no. 5, p. 1210, May 2018, doi: 10.3390/en11051210.

[17] A. Kumar and A. Kaur, “Complaint Management-Review and Additional Insights,” Int. J. Sci. Technol. Res., vol. 9, pp. 1501–1509, Feb. 2020.

[18] S. Eti and B. Çelebi, “Defining the Main Risk Factors for Solar Energy Companies with Fuzzy Entropy BT - Financial Strategies in Competitive Markets: Multidimensional Approaches to Financial Policies for Local Companies,” in Financial Strategies in Competitive Markets, H. Dinçer and S. Yüksel, Eds. Cham: Springer International Publishing, 2021, pp. 355–367, doi: 10.1007/978-3-030-68612-3_25.

[19] S. Sreenath, K. Sudhakar, and A. F. Yusop, “Solar photovoltaics in airport: Risk assessment and mitigation strategies,” Environ. Impact Assess. Rev., vol. 84, p. 106418, 2020, doi: 10.1016/j.eiar.2020.106418.

[20] Asana. “What is a risk register: a project manager’s guide (and example).” Asana.com. https://asana.com/resources/risk-register (accessed Mar. 15, 2023).

[21] S. Shojaeimehr and D. Rahmani, “Risk management of photovoltaic power plants using a novel fuzzy multi-criteria decision-making method based on prospect theory: A sustainable development approach,” Energy Convers. Manag. X, vol. 16, p. 100293, 2022, doi: 10.1016/j.ecmx.2022.100293.

[22] G. Guerrero-Liquet, J. Sánchez-Lozano, M. García-Cascales, M. Lamata, and J. Verdegay, “Decision-Making for Risk Management in Sustainable Renewable Energy Facilities: A Case Study in the Dominican Republic,” Sustainability, vol. 8, no. 5, p. 455, May 2016, doi: 10.3390/su8050455.

[23] M. F. A. Mostafa, S. H. E. Abdel Aleem and A. F. Zobaa, "Risk assessment and possible mitigation solutions for using solar photovoltaic at airports," 2016 Eighteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2016, pp. 81-88, doi: 10.1109/MEPCON.2016.7836875.

[24] K. Otieno, Complaint and response mechanisms: A resource guide. Monrovia, CA, USA: World Vision International, 2009.
[25] A.J. Beltis. "How to Respond to Customer Complaints." Hubspot.com. https://blog.hubspot.com/service/respond-to-customer-complaints (accessed Mar. 15, 2023).
[26] S. Thangaratinam and C. W. E. Redman, "The Delphi technique," Obstet. Gynaecol., vol. 7, no. 2, pp. 120–125, Apr. 2005, doi: 10.1576/toag.7.2.120.27071.
[27] C. M. Goodman, "The Delphi technique: a critique," J. Adv. Nurs., vol. 12, no. 6, pp. 729–734, Nov. 1987, doi: 10.1111/j.1365-2648.1987.tb01376.x.
[28] P. Liu and M. Cai, "Complaint Response Strategies in Interpersonally Sensitive Phone Interactions in Chinese Service," Advances in Social Sciences Research Journal, vol. 7, no. 12, pp. 153-180, 2020, doi: 10.14738/assrj.712.9440.
[29] A. Melnikovas, "Towards an explicit research methodology: Adapting research onion model for futures studies," Journal of Futures Studies, vol. 23, no. 2, pp. 29-44, 2018, doi: 10.6531/JFS.201812_23(2).0003.
[30] D. R. Marlow, D. J. Beale, and J. S. Mashford, "Risk-based prioritization and its application to inspection of valves in the water sector," Reliab. Eng. Syst. Saf., vol. 100, pp. 67–74, 2012, doi: 10.1016/j.ress.2011.12.014.
[31] "Risk Rating & Assessment." Institute.acs.org. https://institute.acs.org/lab-safety/hazard-assessment/fundamentals/risk-assessment.html (accessed Mar. 15, 2023).
[32] C. M. Affonso, Q. Yan and M. Kezunovic, "Risk Assessment of Transformer Loss-of-Life due to PEV Charging in a Parking Garage with PV Generation," 2018 IEEE Power & Energy Society General Meeting (PESGM), Portland, OR, USA, 2018, pp. 1-5, doi: 10.1109/PESGM.2018.8586581.
[33] Y. Wu and J. Zhou, "Risk assessment of urban rooftop distributed PV in energy performance contracting (EPC) projects: An extended HFLTS-DEMATEL fuzzy synthetic evaluation analysis," Sustain. Cities Soc., vol. 47, p. 101524, 2019, doi: 10.1016/j.scs.2019.101524.