Journal of Interdisciplinary Innovational Letters
Vol 2 No 1 (2025): 32-41

Ensuring Quality in Photovoltaic (PV) Plant Construction: A Case Study from the Alhanakiyah 2 GW Haden Solar PV IPP Project, KSA

Muhammad Haseeb Khalid[*1]
[1]QAQC Manager China Energy CEEC, KSA
Corresponding author: haseeb_kd@hdec.com

Abstract

With particular reference to the Alhanakiyah 2 GW Haden Solar PV IPP Project in Saudi Arabia, this study offers a thorough analysis of quality assurance and quality control (QAQC) approaches in photovoltaic (PV) plant construction. Drawing on 12 years of professional experience and guided by industry standards and documentation procedures, the study examines important elements of equipment and material approval, quality documentation, and efficient site operations. PV infrastructure is focused on enhancing performance reliability, reducing environmental damage, and guaranteeing long-term sustainability. The study highlights how robust QAQC implementation not only improves performance reliability and system efficiency but also minimizes potential risks during construction and post-commissioning phases. It also underscores the importance of environmental stewardship by mitigating ecological impact through quality-driven practices. Overall, the findings contribute practical insights for engineering professionals, project managers, and quality practitioners aiming to optimize construction outcomes and ensure high standards in utility-scale PV power generation projects.

Keywords: Photovoltaic Systems, Solar Power Projects, Quality Assurance (QA), Quality Control (QC), Inspection and Testing Plan (ITP), Material Approval Request (MAR), Site Inspection Report (SIR), Non-Conformance Report (NCR), Renewable Energy Infrastructure, EPC Project Management

1- Introduction

With photovoltaic (PV) systems serving as a center of sustainable development, the worldwide move toward renewable energy has placed solar power as a foundation in satisfying energy needs while lowering carbon emissions. As utility-scale solar projects grow as seen in Saudi Arabia's daring Alhanakiyah

1. 2 GW Solar Project

The need for strong quality assurance and quality control (QAQC) systems becomes rather important to guarantee operating efficiency, longevity, and environmental sustainability (Alange, 2025; Caldeira, n.d.). A flagship project developed by ACWA Power under Saudi Arabia's National Renewable Energy Program (NREP), the Alhanakiyah solar project fits the country's Vision 2030 objectives of generating 50% of its electricity from renewables by 2030 (Alange, 2025). To reduce dangers linked to equipment failure, poor performance, and safety concerns that may result in expensive rework, warranty claims, or even systemic failures (Caldeira, n.d.; Alange, 2025), such big projects need rigorous QAQC procedures. Common QAQC problems in PV plants include micro-fractures in solar cells, poor insulation resistance, and water entry problems that, if not corrected during construction (Caldeira, n.d.), can greatly lower output.

PV plant construction quality assurance and control (QAQC) covers many phases: pre-production (design and material validation), production (installation and component testing), and post-production (commissioning and audits) (Caldeira, n.d.). While on-site QAQC checks installation correctness, electrical safety, and structural integrity, pre-production inspections guarantee conformance with global standards (e. g. , IEC 61215 for modules) and confirm material requirements (Nieto-Morone et al., 2024). Like other gigawatt-scale projects, the Alhanakiyah initiative profits from sophisticated QAQC technologies including real-time digital monitoring systems (e. g. , FTQ360's software for automated punch lists and inspection checklists), which improve traceability and corrective action effectiveness (Alange, 2025; Caldeira, n.d.). QAQC procedures beyond technical execution should fit with more general sustainability goals. Under systems like the IEA-PVPS Task 12, which stress circular economy concepts and life cycle assessment (LCA) to reduce ecological effects ("PV Sustainability," n.d.), the environmental footprint of the PV sector from resource extraction to end-of-life recycling is increasingly under investigation. A concern highlighted by Saudi Arabia's commitments under the Paris Agreement (Alange, 2025) is that the scope of the Alhanakiyah project calls for sustainable material sourcing and waste management techniques to lower its carbon footprint.

Using industry standards, this paper analyzes QAQC techniques used in the Alhanakiyah project. Important points of concentration include:

- Materials and equipment Approval: Rigorous PV modules, inverters, and balance-of-system elements are tested to ensure that they meet performance and lifespan requirements.
- Digital tools for tracking audit trails, guaranteeing compliance, and enabling troubleshooting comprise documentation procedures.
- Best installation, commissioning, and safety procedures to avoid issues such cell misalignment or cable faults

Through examination of these components, the study seeks to provide practical recommendations for improving QAQC in mega-scale PV projects, thereby guaranteeing that they deliver on their promise of clean, dependable energy while supporting global climate goals. For areas like the Middle East, where solar energy is crucial for economic diversification and energy security 24, the results are especially pertinent. With empirical data from the Alhanakiyah case study as a baseline for future projects in comparable high-capacity, high-stakes situations, the following parts will explore QAQC techniques, problems, and innovations.

2. Literature Review

2.1 Urgency of Quality in PV Systems

According to studies, the quality of materials and construction techniques immediately affects the dependability and effectiveness of PV systems (Jordan & Kurtz, 2013). Emphasizing the need of strong inspection procedures (IEC, 2016), the International Electrotechnical Commission (IEC) offers standards (e. g. , IEC 61215 and 61730) for PV module testing and approval (Sinha et al., 2021).

2.2 Common Quality Issues in PV

Projects Typical quality issues in solar plants include inadequate material handling, missing inspection documentation, and incorrect installation, according to research by (Kut et al., 2024). These promote moisture ingress, delamination, and system underperformance.

2. 3 QA/QC Strategies in Renewable Projects

Best practices for quality assurance and control in infrastructure projects include organized documents such Inspection and Testing Plans (ITPs), Non-Conformance Reports (NCRs), and regular calibration registers (2008; DataCalculus, n.d.). To improve compliance, more and more digital instruments and real-time monitoring systems are used.

2. 4 Integration of International Standards

Foundational in organizing QAQC systems worldwide are international frameworks like ISO 9001 and IEC standards. Projects combining these requirements show better traceability and uniformity in quality assurance procedures (Mahmood et al., 2022).

2. 5 Human Elements' Role in QAQC

Maintaining standards depends much on the QAQC staff's skill and training. Research show that frequent professional development and knowledge-sharing among QAQC engineers greatly lower project risks and improve compliance (Alam, 2023).

3. Methodology

Utilizing a case study approach, this study thoroughly examines the execution of quality assurance and control strategies in the Alhanakiyah 1. 2 GW Solar Power Project. Supported by field experience and document analysis, the approach targets four major pillars of good practice:

- Excellent document types (e. g., MARs, MIRs, SIRs): These tools—Material Acceptance Request (MAR), Material Inspection Request (MIR), and Site Inspection Report (SIR) are essential for guaranteeing transparency and traceability. The study examined how these papers are approved, finalized, and filed as well as how they relate to inspection procedures.

- Approvals for equipment and materials: Approvals and certifications of incoming tools and equipment were carefully reviewed. This covers testing records, manufacturer certifications (TUV, IEC), and the internal quality assurance measures needed prior to on-site implementation.
- Procedures for handling and storage: To evaluate how materials (especially PV modules and inverters) are stored, protected, and handled, on-site inspections and photographic recording were employed. Factors like shade, waterproofing, safe stacking, and temperature exposure were taken into account.
- Tracking of nonconformance and corrective measures: The study looked at how quality variations are noticed, classified (major, minor, observation), and treated. Particular emphasis was placed on the use of Non-Conformance Reports (NCRs), root cause analysis techniques, documentation of corrective measures, and evidence-based closure of quality problems.

Field observations, real-time project documentation, QAQC staff interviews, and register and log analysis kept by the quality control team were among the primary data sources used to assess these four dimensions.

4. Results and Discussion

Applying a thorough QAQC system in the Alhanakiyah Solar Power Project revealed a number of important lessons on the execution of quality standards throughout the PV plant lifespan. Every important focus area in the approach showed possibilities for development and strengths.

4. 1 Quality Document Practices Across all Phases of the Project

All documentation types MARs, MIRs, SIRs—were always utilized. Maintaining traceability, guaranteeing prompt inspections, and providing accountability for approval processes depended on these records. With checklists linked directly to these documentation templates, the ITP (Inspection and Testing Plan) served as the basis for quality control scheduling. Structured documentation, approval tracking, and inspection reporting used specific formats including the ITP Format, MAR Format, SIR Format, and the SIR Register.

- ITP Format provides a matrix of inspection responsibilities (Hold, Witness, Surveillance) across stakeholders as shown in figure-1.

Figure No1: ITP Format Document

H	Hold
W	Witness
S	Surveillance
R	Review
P	Performed

S No	Description of Inspection & Test	Acceptance Criteria	Verifying and Control Data, Forms	EPC Frequency	Sub-Con /EPC Construction	OEM	EPC QA/QC	PC Engineer
1	DOCUMENT APPROVAL							
1.1	Approved Drawing , MDS & Technical specifications	Latest Revision of Drawings & MDS	IFC Stamp on Drawings Approved MDS	100%	-	-	H	H
1.2	Materials Approval request (MAR)	Approved Drawing/Approved Specification	PQ Documents/FAT Reports/Specification Data sheet	100%	-	-	H	H
1.3	Instrumentation tools and caliberation	Calibration Certificate	3rd Party Reports	100%	-	-	H	S
2	Material Inspection Request							
2.1	Material Quality Inspection	Visual Inspection/Approved Drawings/Approved TDS-Specifications/IEC Standards/Test Report	Material Inward Register Packing List/Delivery Note/FAT reports/OEM Installation Manual	100%	-	-	H	W
3	Solar Cable & MC4 installation							
3.1	Solar Cable laying and Dressing MC4 - Connections	Approved Drawing/Approved Specification	MP0228-HDEC-PV-ELE-DRA-0010-02 MP0228-HDEC-PV-ELE-DRA-0009	100%	P	-	H	W/100%
4	Testing							
4.1	Continuity Test - For string identification (From one String to another string) Polarity Test	MOS	Approved Equipment/Method of Statement	100%	P	-	H	R
5	NON CONFORMANCE REPORT & FIELD QUALITY ALERT							
5.1	If Non Conformance is Observed at Site, NCR/SQO Will be Raised	NCR Closeout Report	MP0228-HDEC-GE-QA-ICT-0012-02 MP0228-HDEC-GE-QA-ICT-0013-01	100%	-	-	H	R

- MAR Format is used to submit and track material approval requests prior to use, as shown in figure 2.

Figure No 2: MRA Format Document

Reference Drawing No	Reference Code / Standard	Reference Spec:
MP0228-HDEC-PV-ELE-DRA-0003-03 MP0228-HDEC-PV-ELE-DRA-0002-02		

Discipline:		CIVIL		ARCHITECTURAL		ELECTRICAL		MECHANICAL		OTHERS

Material Description:
HDPE DWC - 40sqmm & connectors
Manufacturer / Supplier:
Crown Pipes
Attached Reference Documents:
1. Product Catalogue 2- UV Test Report
CODE-1 No Objection
CODE-2 No Objection with Comments
CODE-3 Revise & Resubmit
CODE-4 Rejected

MAR Format

- SIR Format captures details of inspections conducted on-site, including observations and compliance status as shown in figure 3.

Figure No 3: SIR Format Document

Location	PV Area	Submission Date	12/3/2024
Sub Location	Block 129 - West	Inspection Date	12/4/2024
Inspection Title	Solar Cable Laying	Time	3:00 PM

	Witness	Hold	Review	Surveillence	Perform
Subcontractor Engineer	□	□	□	□	■
EPC Engineer	□	■	□	□	□
Company/Consult Engineer	■	□	□	□	□

Discipline:-
- □ Civil
- □ Architectural
- □ Mechanical
- ■ Electrical
- □ Others

ITP S.No	Description Of Inspection	Reference Drawing/Report
4.1	**Sand Bedding, Cables laying, dressing and Conduits installation, FO Cables, Earthing cable laying- Layer by Layer (All type of cables)** (Sand Covering and Solar Cable Laying with in conduit)	MP0228-HDEC-PV-ELE-DRA-0003-04

- □ CODE-1 No Objection
- □ CODE-2 No Objection with Comments
- □ CODE-3 Revise & Resubmit
- □ CODE-4 Rejected

- SIR Register maintains a log of all site inspection reports for traceability and audit readiness as shown in figure 4.

Figure No 4: SIR Register Maintains Document

Block NO.	Region	Subcontractor Name	Escavation+ Earthing			
			Date	SIR Number	SIR Status	Remarks
1	East	Man Energy				
	West					
2	East	Man Energy	04-02-2025	MP0228-HDEC-PV-QA-SIR-2749	Code-2	Near MVPS excavation not done.
	West		04-02-2025	MP0228-HDEC-PV-QA-SIR-2750	Code-2	SCB 31 and 21 Excavation not done.
3	East	Man Energy				
	West					
4	East	CCS				
	West					
5	East	Man Energy	04-02-2025	MP0228-HDEC-PV-QA-SIR-2751	Code-2	Near MVPS excavation not done.
	West		04-02-2025	MP0228-HDEC-PV-QA-SIR-2752	Code-2	Near MVPS excavation not done.
6	East	Man Energy	02-02-2025	MP0228-HDEC-PV-QA-SIR-2662	Code-1	
	West		02-02-2025	MP0228-HDEC-PV-QA-SIR-2663	Code-2	SCB 9 and 27 are not included in inspection due to MVPS work.

- Document archiving was found to be well-organized, supporting both internal reviews and third-party audits.

4. 2 Materials and Equipment Approval

The equipment approval processes guaranteed that only certified, high-quality components were used. PV modules, inverters, and structural elements were inspected against international standards such as IEC 61215 and 61730. Approved procedure required certification from recognized organizations like TÜV Rheinland. Manufacturer audits and batch-wise testing improved faith in supply chain quality, and rejection of bad materials was well documented.

4. 3 Notes on Storage and Handling

Visual inspections of the storage facilities verified that products were stored in temperature-protected locations with enough ventilation and organization. To stop micro-cracks, PV modules were arranged vertically with padding. Direct sunshine, dust, and moisture were shielded from every delicate piece of equipment. Under manufacturer recommendations, mechanical handling equipment like cranes and forklifts were used to lessen physical strain on the materials during installation and transportation. This structured approach to material handling mirrors the principles of adaptive task execution found in computing systems, such as the dual-layer, multi-queue adaptive priority scheduling model (Iqbal et al. 2024), which enhances efficiency by prioritizing tasks based on urgency and resource availability ensuring that critical operations are managed with minimal risk and maximum responsiveness."

4. 4 Recognition and Resolution of Non-Conformance

Clearly, a methodical approach to finding and correcting non-conformances was being used. Based on the possible influence on safety or performance, NCRs were appropriately classified as significant, minor, or notes. Every NCR comprised thorough descriptions, accountable staff, suggested fixes, deadlines, and closure evidence. Root cause investigations were finished within the specified time, and the quality team followed up to confirm execution. Regular updates of registers for NCRs, SQOs, and calibration records showed a mature and proactive QAQC system.

4. 5 General Effectiveness of QAQC

Process Project dependability and reduced rework were enhanced by the combination of documentation, approval procedures, appropriate material handling, and organized non-conformance management. Along with guaranteeing compliance, the QAQC process was instrumental in meeting schedule adherence and lowering lifecycle costs. Furthering the QAQC system's effectiveness were team communication and cross-departmental cooperation.

These findings emphasize how important it is to incorporate good methods into the fundamental operational plan of big-scale PV projects. Especially in difficult settings like the Middle East, lessons from this project offer a duplicable pattern for other solar energy infrastructure projects.

5. Conclusion

The results of the Alhanakiyah 1. 2 GW Solar Power Project emphasize the vital part quality assurance and control play in the effective completion of large-scale photovoltaic projects.

Standardized documentation formats, strict material approval processes, prudent handling techniques, and systematic non-conformance management guaranteed both compliance and effectiveness over all project phases. The research emphasizes that a well-designed QAQC system not only protects technical performance and safety but also maximizes resource efficiency and long-run dependability. Integrating world-renowned standards and involving cross-functional teams, the project met operational excellence and established a benchmark for next solar projects in comparable environmental and regulatory settings. Looking forward, use of predictive analytics and digital QAQC tools may help to improve monitoring, traceability, and proactive quality measures even further. Advocating for ongoing QAQC process improvement, this study advises reproducing such models to guarantee the viability and efficacy of renewable energy projects all around.

References

Alam, A. M. ul. (2023). *Mitigating Risks And Ensuring Compliance: Human Factors In Pharmaceutical Quality Management System* (S. Shilpi, Ed.). ACSCIP. https://doi.org/10.5281/ZENODO.10221214

Alange. (2025, April 10). *Al Hanakiyeh Solar Project: 1.1GW Connection by 2025 is Essential - PVknowhow.com*. https://www.pvknowhow.com/news/al-hanakiyeh-solar-project-grid-2025-2/

Ammad Hassan Khan, Salman Azhar, & Arshad Mahmood. (2008, August). *Quality Assurance and Control in the Construction of Infrastructure Services in Developing Countries – A Case Study of Pakistan*. Conference: First International Conference on Construction In Developing Countries (ICCIDC–I) "Advancing and Integrating Construction Education, Research & Practice, Karachi, Pakistan.
https://www.researchgate.net/publication/339899436_Quality_Assurance_and_Control_in_the_Construction_of_Infrastructure_Services_in_Developing_Countries_-_A_Case_Study_of_Pakistan?utm_source=chatgpt.com

Caldeira, E. (n.d.). *The Important Role of QAQC in Large-Scale Solar Energy Projects*. Retrieved July 4, 2025, from https://blog.ftq360.com/blog/qaqc-for-large-solar-energy-projects

DataCalculus. (n.d.). *Quality Assurance in Renewable Energy Projects*. DataCalculus. Retrieved July 4, 2025, from https://datacalculus.com/en/blog/renewable-energy-power-generation/renewable-energy-project-manager/=

Iqbal, M., Shafiq, M. U., Khan, S., Alahmari, S., & Ullah, Z. (2024). Enhancing task execution: a dual-layer approach with multi-queue adaptive priority scheduling. *PeerJ Computer Science*, 10, e2531.

Jordan, D. C., & Kurtz, S. R. (2013). Photovoltaic Degradation Rates—An Analytical Review. *Progress in Photovoltaics: Research and Applications*, *21*(1), 12–29. https://doi.org/10.1002/pip.1182

Kut, P., Pietrucha-Urbanik, K., & Kurek, P. (2024). Comprehensive Analysis of Failures in Photovoltaic Installations—A Survey-Based Study. *Energies*, *17*(23), 5986. https://doi.org/10.3390/en17235986

Mahmood, N., Ajmi, A., Sarip, S., Kaidi, H., Jamaludin, K., & Talib, H. (2022). Modeling the Sustainable Integration of Quality and Energy Management in Power Plants. *Sustainability*, *14*(4), 2460. https://doi.org/10.3390/su14042460

Nieto-Morone, M. B., Rosillo, F. G., Muñoz-García, M. A., & Alonso-García, M. C. (2024). Enhancing photovoltaic module sustainability: Defect analysis on partially repaired modules from Spanish PV plants. *Journal of Cleaner Production*, *461*, 142575. https://doi.org/10.1016/j.jclepro.2024.142575

PV Sustainability. (n.d.). *IEA-PVPS*. Retrieved July 4, 2025, from https://iea-pvps.org/research-tasks/pv-sustainability/

Sinha, A., Sulas-Kern, D. B., Owen-Bellini, M., Spinella, L., Uličná, S., Ayala Pelaez, S., Johnston, S., & Schelhas, L. T. (2021). Glass/glass photovoltaic module reliability and degradation: A review. *Journal of Physics D: Applied Physics*, *54*(41), 413002. https://doi.org/10.1088/1361-6463/ac1462