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Study on Effective Technical Audit of Grid Connected Solar PV Project in Nepal

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Abstract
Evidence suggests poor performance of many solar projects especially in low and middle income countries. The technical audit contributes for the increase in the performance, reliability and quality of the project. Therefore, the present investigation aims to identify key indicators required for ensuring effective technical audit and analyze the existing technical audit practice through those indicators. The research found very rare and poor existing technical audit practice, usually audit is based on visual inspection and documentation verification. The further research through questionnaires shows prevailing technical conditions of grid connected solar PV system that can be considered during auditing. The use of AHP for ranking major problems of grid connected solar PV technology concluded module shading and soiling as a most influential challenge. The results obtained from the study can have significant contribution in the technical audit field of grid connected solar PV projects.

Keywords
Grid connected solar PV system, AHP (Analytical Hierarchical Process), NVC (National Vigilance Center)

1. Introduction

Solar photovoltaic (PV) technology is currently penetrating all over the world, with 106 countries having held renewable energy auctions to switch from fossil to renewable energy by the end of 2019 [1]. The PV systems are categorized into standalone and grid connected systems [2] where Standalone systems are isolated from the grid and connected directly to the load. For example, small capacity of solar installed in the house while grid connected systems are usually commercial type where the systems are directly connected to the grid for transferring the power of the solar to the grid. Thus, off grid solar PV systems are applicable for areas without utility grid i.e. isolated sites where power grid is far away such as rural areas or off-shore islands. However, they may also be installed within the city as clean energy or in situation where it is inconvenient or too costly to tap electricity from the utility grid [3].

In Nepal, history of solar power was started with the 1- MW solar PV at Singha Durbar, 680 KW at Sundharighat, 100 KW at Kharipati, 65 KW at Nepal Telecome, 1 KW test project at Institute of Engineering, Pulchowk, Campus. The abundant availability of solar energy throughout the year with the average solar radiation that varies 3.6 to 6.2 KWh/m^2/day and 300 days of sunny weather makes Nepal an ideal country for harnessing solar energy [4]. However, the PV technology still need to gain momentum in commercialized scale [5]. According to DOED, grid connected commercially operated solar PV project is 20.18 MW. Similarly, 22 projects of total capacity 137.56 MW and 35 projects of total capacity 1018.7 MW solar PV projects have taken construction and survey licenses respectively [6].

Though solar power has seen rapid growth and becoming promising renewable energy [7], however, evidence suggests poor performance of many solar projects especially in low and middle income countries reporting 30% of nearly 100 analyzed projects in different countries indicate severe defects [1]. When past results of solar PV projects are analyzed, it reflects the 'bathtub' failure curve. Due to technology infancy failures, failure rates are higher at early stages as are end of life stages, the failure rates again higher due to wear. Quality assurance (QA) is inevitable to reduce electricity costs, since it helps to

ensure stability for investors and other investors ultimately, accelerating future investment in PV technology. QA helps to minimize risk by assuring that a product or service will meet needs or expectation which in turn lower capital cost, increase performance and ultimately, lowers LCOE [8].

ISO 9000 define an audit as a systematic and independent process for obtaining evidence and evaluating this objectively to determine the extent to which needs or expectations are fulfilled [9].
Regular technical and financial auditing ensure investment into the sector is worth as suggested by formula
Technical auditing + Financial information = Total Confidence [10].

1.1 Literature Review

Performance, Reliability and Quality of solar PV systems has become critical area of interest [11]. Parameters that explain energy quantities for the PV system and its components have been established by the IEA photovoltaic power systems programs and described in the IEC standard 61724 that included performance parameters used to define the overall system performance with respect to the energy production, solar resource and overall effect of system losses. Basically, these parameters are the final PV system yield, reference yield and performance ratio [12].

Grid connected solar PV technology is the simplest and most economical solar energy installation available as it does not require batteries. It directly feed their solar energy into the grid. The systems consist of photovoltaic panels connected to the grid through a DC-AC inverter with a maximum power tracker and a permanent controller of the power injected, a bidirectional connection between AC output circuit of the PV system and the grid, the DC and AC loads as well as the control system necessary to ensure the safe operation [13].

From the literature survey, it has been observed that many scholar and practitioners have done research about technical audit. Some of the research relevant to present investigation are summarized below:

- "The need for technical auditing in the Zambian construction industry" research done by Balimu Mwiya [14] has find out the essentiality of technical audit practice in construction projects of Zambia and also proposed the suitable model.

- Another research work done by Anjay Kumar Mishra [15] on "Effectiveness of Technical audit Practice: A case of Parsa District of Nepal" has find out various indicators for the effective technical audit. It has taken two rural road projects Janta Sadak and Atmaram path of Parsa district undertaken by RAIDP, DoLIDAR for the case studies as these two rural road projects depict picture of existing technical audit practice.

- "Technical Audit – A Throughfare of system Perfection" research work of Prof. S.B. Srivastava [16] concluded that technical audit will increase the Customer and owner's delight and gives a new thrust to the organization.

2. Methodology

The research consists of three methodological phases.

First two phases are qualitative type of research while last one is quantitative type of research. The comprehensive literature review and interaction with experts as well as stakeholders of grid connected solar PV technology was done to find out the key indicators to measure the effectiveness of technical audit. As Technical Audit Division (TAD) of National Vigilance Center (NVC) is the authorized institution for performing technical audit of the government invested infrastructure project, the technical audit of Dhulikhel hospital grid connected solar project was taken to analyse the existing technical audit practice of grid connected solar PV project.

Among those indicators, the indicators which are of technical nature are further investigated through questionnaires where solar experts opinion are taken. AHP method is used to prioritize the prevailing problems of grid connected solar PV system. The problems depicted in the Table 1 categorized the problems of grid connected solar PV system on the basis of components where these problems arise.

For the close ended questionnaires, the option getting more than 50% response was selected concluding the definite verdict. If any questionnaire can't obtained more than 50% to any option, then mixed type of verdict.

Table 1: Summary of Major Problems of grid connected solar PV system

Solar Components	Problems	Literature Reference
Solar Panel	Module shading	[17, 18]
	Broken, Bubbles or delamination in the layer of panel	
	Hot spotting	
	Potential Induced Degradation and Light Induced Degradation	
	Loss of Mechanical Integrity of PV panel frame	
Inverter	Overheating	[19]
	Grid Fault	
	Faulty Installation	
	Isolation Fault	
Cables, Connectors and Protection devices	Lightning	[20, 17]
	Poor Connection	
	Short circuit Fault	

2.1 Using AHP to Prioritize

AHP is a decision making model where pairwise comparison is done between criteria/sub criteria as shown in Figure 1 from an expert survey or from actual measurements using nine point scale. It is used to estimate subjective judgment while making decisions or ranking factors [21]. The necessary steps used in AHP is shown in Figure 2.

The key feature of AHP process is consistency check of the judgment of decision makers. There is a possibility that the participants may make poor judgment. Consistency Ratio (CR) calculation can minimize this problem. Saaty [21] suggested inconsistencies upto 10% as tolerable. Deviation from consistency can be calculated using the formula, $CR = CI/RCI$
where $CI = \frac{\lambda_{max}-n}{n-1}$, λ_{max} is the largest principal eigen value, n is the number of elements being compared, CI is consistency Index and RCI is Random Consistency Index whose values are given in Table 2.

3. Survey and Data

For the analyzing of existing technical audit practice, technical audit report of Dhulikhel hospital grid connected solar project was taken. The audit was done by TAD of NVC, authorized government agency for technical audit.

For the analyzing of prevailing technical conditions of grid connected solar PV system, responses of the questionnaires were collected from the solar experts. Since, the main government institution involving in solar projects is Alternative Energy Promotion Center (AEPC) while non-government institution is Solar Electric Manufacturers Association Nepal (SEMAN). So, the target population for getting response for our questionnaires are engineers of AEPC, listed companies in AEPC for doing solar projects and members of SEMAN.

Overall, our total population (N) is 180. More than 60 experts wear requested for the pairwise comparison survey. The total 57 complete and consistent datasets for the estimation were received.

However, Probability type of sampling called simple random sampling technique [24] is used to find out the sample size for getting response of closed ended type of questionnaires.

So, sample size $(n) = \frac{\frac{z^2 * p(1-p)}{e^2}}{1+\frac{z^2 * p(1-p)}{e^2 * N}}$

For 95% confidence interval, sample size (n) = 122.

4. Results and Discussion

The effectiveness of technical audit conduction and prevailing practice were studied on the basis of the following six indicators.

- Provision of budget for technical audit
- Expertise and Experience of Technical Auditing team
- Institutional Arrangement for conduction, monitoring and evaluation of audit
- Availability of Guideline, Manual, Norms and Terms of Reference (TOR)
- Uses of Laboratory Equipment

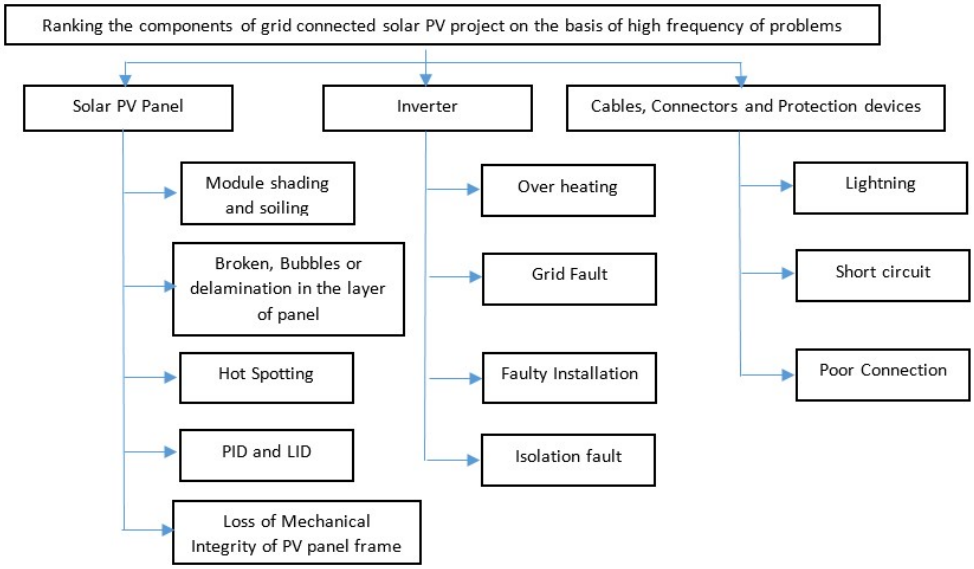

Figure 1: Hierarchical tree for ranking the problems of grid connected solar PV system

Table 2: Random Consistency Index values[23]

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RCI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57

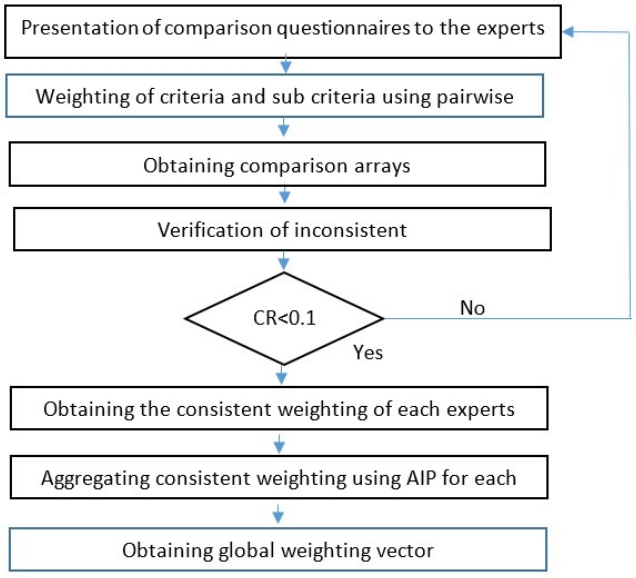

Figure 2: Flowchart of AHP methodology [22]

- Perspective and Participatory approach on technical audit

4.1 A Case Study

Till to date, NVC has done total technical audit of 887 projects [25]. Among them, only one solar project "Combination of grid interactive and off-grid, Dhulikhel hospital (KU Phase II)" was audited which is analyzed base on above mention indicators.

- The engineer's estimation for technical audit depends upon the scope and TOR of the technical audit. For the technical audit of the stated project, the estimated amount was Rs. 2,20,000.
- Technical audit team consists of two members and they are independent technical auditor and renewable energy engineer. The required qualification of the auditor is given as:
  Minimum academic qualification: Bachelor in Electrical/Mechanical Engineering
  Minimum general experience: 10 years
  Minimum Specific experience: 5 years
  The specific experience means the experience in solar PV project.
  Required training: Technical Auditor training

given by NVC.

- The conduction, monitoring and evaluation of audit is done by the Technical Audit Division (TAD) of NVC. Field visit was done by the staffs of TAD to examine and monitor the works of auditor. Before the approval of audit report, final presentation in the presence of Secretary and other staffs was done.

- The audit was accomplished according to the TOR provided to the auditor. There is not definite guideline and manual for the technical audit of solar PV project. Only Nepal Photovoltaic Quality Assurance (NEPQA) is available and testing is done by Renewable Energy Test Station (RETS) if required. The conformance of the product is done through third party test certificate provided by the corresponding manufacturing company.
  The TOR of the technical audit for the stated project has following scope and objective:
  - Scope for technical audit: Process compliance auditing and Auditing of non-compliances.
  - Objective: Quality of the works together with the time and cost aspect of the project.
- Only visual inspection and no use of laboratory equipment. Conformance of the project are decided based on third party test certificate provided for the corresponding product.

- All the required documents, checklists and questionnaires were collected. Starting and closing meetings along with field visits were done in the participants of client and contractor.

Presently, technical audit practice of the grid connected solar PV project is found very rare and poor when analyzed based on the derived six indicators. The budget allocated for the technical audit is less compare to the massive scale of infrastructure projects that has been launch by GON [26]. The engineer's cost estimate for the audit is also less. It needs to be updated based on TOR. As TOR used by NVC for technical audit is same for the all types of infrastructure projects [27], it needs to be made project specific. General types of technical auditor training is given by NVC which is same for all faculties [25]. Additional, separate specific technical auditor training to the concerned faculties and quality management training need to be provided. Only visual inspection, checking documents and manufacture test certificates are not enough. Uses of laboratory equipment need to be promoted in the technical audit. The laboratory arrangement and necessary guidelines/manuals for checking the components of solar PV project need to be expanded.

4.2 Analyzing technical conditions

4.2.1 Ranking of Components

The table 3 depicted major components of solar PV project ranked in terms of degree of occurrence of problems on it. These results, derived from expert opinion; Cables, connectors and protection devices rank in the first position with weight of 30.47%, solar panel (26.22%) in the second and inverter (24.26%) in the third position, in terms of degree of occurrence of problems on it.

4.2.2 Ranking of problems within Components

The table 4 shows that Module shading and soiling (56.18%), hot spotting (12.38%) and broken, bubbles or delamination in the layer of panel (11.23%) as the top three problems in solar PV panel.

Similarly, overheating (29.58%), grid fault (21.75%) and Isolation fault (18.75%) are the top three problems, in terms of degree of occurrence within solar Inverter of grid connected PV system.

Further, poor connection (28.15%) , short circuit (26.9%) and lightning (21.39%) as first, second and third rank in terms of degree of occurrence of problems in cables, connectors and protection devices of grid connected solar PV system.

4.2.3 Overall Ranking

The global weight of each major problems of solar PV project in terms of degree of occurrence shown in Figure 3 was calculated by multiplying the priority weight of each component with the relevant priority weight of the problems within that component. Module shading and soiling (Dust and Dirt) was ranked first with (14.7%) weight followed by poor connection (8.6%) and short circuit (8.2%) in second

Table 3: Solar PV components rank on the basis of frequency of problems arise on it

Components	Priority weight	Priority weight (%)	Rank
Solar Panel	0.2622	26.22%	second
Inverter	0.2462	24.62%	Third
Cables, connectors and Protection devices	0.3047	30.47%	First

Table 4: Ranking of problems of solar PV systems in terms of degree of occurrence

Component: Solar PV panel			
Problems	Priority weight	Priority weight (%)	Rank
Module shading and soiling	0.5618	56.18%	First
Broken, Bubbles or delamination in the layer of panel	0.1123	11.23%	Third
Hot spotting	0.1238	12.38%	Second
PID and LID	0.0392	3.92%	Fifth
Loss of Mechanical Integrity of PV panel frame	0.1021	10.21%	Fourth
Component: Inverter			
Problems	Priority weight	Priority weight (%)	Rank
Over heating	0.2958	29.58%	First
Grid Fault	0.2175	21.75%	Second
Faulty Installation	0.0908	9.08%	Fourth
Isolation Fault	0.1875	18.75%	Third
Component: Cables, connectors and Protection devices			
Problems	Priority weight	Priority weight (%)	Rank
Lightning	0.2131	21.31%	Third
Short circuit	0.2690	26.9%	Second
Poor Connection	0.2815	28.15%	First

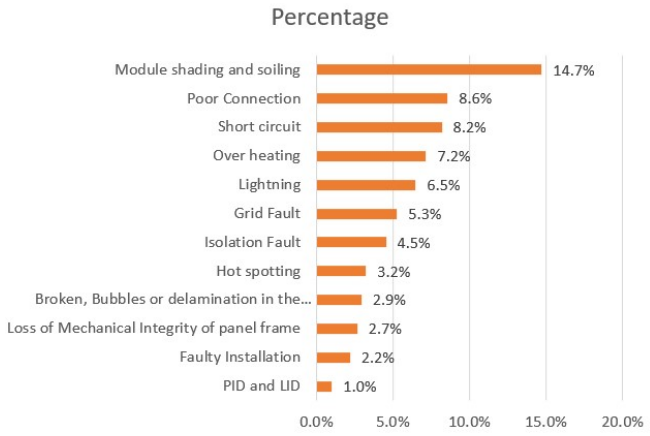

Figure 3: Overall ranking of the problems in terms of degree of occurrence

and third rank respectively. The other ranks after first rank has, not so much difference. Though, module shading and soiling remains in first rank, other problems related solar panel are ranked to the end.

4.2.4 Other Technical Conditions

The table 5 gives prevailing technical conditions related to grid connected solar PV system that helps in technical audit of the project.

5. Conclusions

The existing technical audit practice of the grid connected solar PV project is found rare and very miserable suffering from very low budget. Further research on the technical indicator through questionnaires survey demonstrated several technical problems of grid connected solar PV project and also concluded several tests of the solar components that need to be incorporated during technical audit.The use of AHP for ranking major problems of grid connected solar PV technology concluded module shading and soiling as a most influential challenge.The results obtained from the study can help technical auditing team and other stakeholders of technical audit to take several decisions during the auditing as well as preparation of manual, guideline and TOR related to technical audit of grid connected solar PV project.

6. Policy Implication

As solar PV technology is in nascent phase and large number of grid connected solar PV projects are in

Table 5: Responses of closed ended questionnaires related to grid connected solar PV system

S.N.	Questions	Response	Conclusion
1	Power rate degradation of Solar PV project is very high in the context of Nepal.	33% respondents' remains neutral while 30% disagree, 22% respondents agree, 8% strongly disagree and 7% strongly agree on it.	No majority. Mixed type of verdict.
2	Phase of the project in which technical audit is most fruitful	34% selected commissioning phase, 27% selected design phase, 20% selected operation phase, 10% selected construction phase and 9% selected installation phase.	No majority. Mixed type of verdict.
3	There is adequate lab policy for testing, standardization and certification for solar PV energy sector in Nepal.	48% respondents selected 'No', 38% selected 'Yes' and 14% are not sure.	No majority. Mixed type of verdict.
4	The SCADA system is very much essential in commercialized Nepal's solar PV project.	53% agree, 22% strongly agree, 10% neutral, 8% disagree and 7% strongly disagree.	The SCADA system is essential .
5	Solar anti-islanding feature need to be audited during technical auditing of Solar PV project.	51% agree, 15% strongly agree, 25% remains neutral, 7% disagree and 3% strongly disagree.	Solar anti-islanding feature need to be audited.
6	During technical auditing of any commercialized solar PV project in Nepal, technical auditor need to collaborate with Renewable Energy Test Stations (RETS).	57% agree, 12% strongly agree, 14% remains neutral, 10% disagree and 7% strongly disagree.	Technical auditor need to collaborate with RETS
7	E-waste management of Solar PV project is very much difficult.	54% agree, 14% strongly agree,18% remains neutral, 8% disagree and 6% strongly disagree.	E-waste management is very much difficult.
8	Better interval for technical auditing of solar PV project.	42% selected 1 to 3 years whereas 37% selected 3 to 5 years and only 21% selected more than 5 years..	No majority to any option. Mixed type of verdict.
9	Minimum required conditions to assure quality of grid connected solar PV project during technical auditing.	75% selected test certificates of each components, 66% selected compliance with catalog and technical specification, 66% proper installation with electrical guidelines , 59% selected design verification, 51% selected warranty period of the components, 47% selected using testing equipment, and 23% selected proper protection mechanism for each of the components.	Test certificates; Compliance with catalogue and technical specification; Proper installation with electrical guidelines; Design verification; and Warranty period
10	Minimum tests during technical auditing of solar PV panel must include following tests.	89% selected I-V measurement of modules/strings, 81% selected electrical safety tests, 76% selected panel efficiency, 37% selected PID tests, 43% selected LID test, 34% selected fill factor of module, 32% selected Electroluminescence imaging/infrared thermography	I-V measurement of modules/strings; Electrical safety tests and Panel efficiency.
11	Minimum tests during technical auditing of grid connected Inverter must include following tests.	86% selected efficiency, 78% selected Frequency stability, 76% selected total harmonic distortion , 69% selected output voltage stability, 61% selected anti-islanding and 22% selected self-consumption.	Efficiency; Frequency stability; total harmonic distortion; output voltage stability and anti-islanding.

pipeline, the technical auditing of the project need to be adopted widely from design phase. However, the most fruitful phase for technical audit is the commissioning phase. Further, drastic improvement in the auditing process need to be done in a sustainable way. Module shading and soiling (Dust and Dirt) is the major problem in solar project, thus, robust cleaning mechanism of the panels and clearing of bushes around panels is highly recommended.

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