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REVIEW OF THE BUILDING STANDARD SHNK 2.04.15-23 "PHOTOELECTRIC STATIONS" AND RECOMMENDATIONS FOR ITS EXPANSION

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Abstract

The presented review analyzes real incidents and typical negative factors associated with the operation of solar photovoltaic stations (PV stations) in Uzbekistan. Cases of mechanical damage to solar panels due to extreme weather events (hurricane winds, dust storms), including cases where parts of the modules were torn off and destroyed, were noted. Problems associated with operational and design shortcomings are considered, ranging from improper equipment connections and the use of inappropriate components to the lack of proper technical supervision. Examples of emergencies that occurred at facilities with solar installations - such as fires and power outages - are provided along with their presumed causes. Special attention is paid to the influence of the republic's hot, arid climate on the efficiency and reliability of PV stations. Dust accumulation and extreme temperatures reduce energy output and accelerate the wear of photovoltaic modules. Based on the identified facts, typical risks for solar power plants in Uzbekistan are summarized, and it is shown that a combination of errors (both natural and anthropogenic) can lead to accidents, economic losses, and a decrease in confidence in solar energy. It is concluded that it is necessary to develop unified standards and strengthen technical supervision in the implementation of PV stations. The presented conclusions and recommendations are aimed at improving the safety, durability, and operational efficiency of solar power plants in the dry, hot climate conditions of Uzbekistan and Central Asia as a whole.

Keywords: Photovoltaic systems, solar energy, construction standards, SHNK, operation, reliability, climate, Uzbekistan, technical, supervision.

1. Introduction

Uzbekistan is actively increasing the use of solar photovoltaic stations (PS), however, their operational practices reveal several incidents and problematic situations. On January 28, 2024, a strong wind damaged 91 solar panels at a solar power plant under construction in the Sherobod district - the modules were torn off and destroyed, although they were not yet fully operational. In another case, in September 2024, a fire in one of the buildings on the territory of Tashkent State Agrarian University [1] caused rumors about the possible involvement of solar panels (≈40 kW) installed on the roof of the building. Representatives of the institution denied the version of the fire due to the FES, emphasizing that the fire was located in a neighboring building. Nevertheless, the mere presence of a large solar installation at the damaged site has drawn attention to the fire safety issues of such systems.

2. Materials and Methods

The extreme natural and climatic conditions of Uzbekistan create additional risks for the reliable operation of solar power plants [2]. The region is characterized by a hot, arid climate and frequent dust storms. Sand dust settling on the surfaces of photomodules can significantly reduce their output power and requires regular cleaning of the equipment. In addition, prolonged periods of abnormal heat (for example, over 60 days of extremely high temperatures in summer exceeding 40°C) lead to the degradation of the efficiency of photoelectric modules. In combination, heat and dust can cause overheating of panel elements (hot-spot

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effects) and accelerated material aging, increasing the likelihood of failures [3].

In addition to the influence of the external environment, the human factor and organizational shortcomings play a significant role. It should be noted that a significant portion of new solar power plants with a capacity of more than $10\,kW$ in Uzbekistan were installed with violations, about $20-30\%$ of the inspected installations were assembled and installed with critical errors or were incomplete due to the lack of appropriate standards. It should also be noted that such systems do not meet design requirements, and moreover, often a part of the equipment is missing or incorrect connection to the network is performed. Due to this, the operation of such stations is fraught with accidents and losses - without refinement, they remain only 40% safe and do not yield the calculated capacity (less than 40% or more). In practice, cases of using unsuitable components have already been noted: for example, the use of conventional power cables instead of specialized solar cables can lead to short circuits and irreversible consequences, as the standard wire is not designed to transmit the required parameters of direct current. The lack of qualified supervision and quality control, coupled with the rapid growth of the industry, exacerbates the problem. In particular, government documents stipulate the urgent need to improve the qualifications of specialists in the installation and maintenance of solar panels in the regions, which is intended to reduce the number of errors in the installation and operation of solar power plants [4].

The integration of solar power plants into the energy system remains a separate challenge. Even the commissioning of large new SESs does not guarantee the improvement of local power supply without considering the network's capabilities [5]. For example, after the launch of the $100\,MW$ Total Eren solar station in the Tutli neighborhood (Samarkand region) [6], residents of nearby settlements continued to experience power outages, as it turned out that the station releases energy to the general grid and does not directly supply local lines. This case showed that the power outage of plots can persist due to infrastructure limitations, despite the presence of renewable energy generation.

Thus, the typical risks of FES operation in Uzbekistan's conditions include: exogenous factors - wind loads, extreme heat, high dust levels (and associated abrasive and thermal effects); as well as anthropogenic factors - design and installation errors, insufficient technical supervision, and service regulations violations. While official statistics on solar power plant accidents are currently limited, the provided real examples and expert reviews demonstrate vulnerabilities that can lead to equipment damage, station parts failure, fires, and other negative consequences. Taking these factors into account at the design and operation stage, developing standards for the resilience of solar power plants to local climatic conditions, and a system of regular technical control are necessary measures to ensure the safe and efficient operation of solar energy in the region.

In this regard, ensuring safety during the design and operation of large photovoltaic power plants in the equipment of roof network stations remains a serious challenge. It should be noted that currently, the only specialized regulatory document in the republic is the construction standard SHNK 2.04.15-23 "Photoelectric Power Plants," which came into force in 2023 [7]. The validity of this standard is limited to small installations - up to 10 kW, and the conducted critical analysis showed that this SHNK does not sufficiently fully cover the issues of safe placement and operation of solar panels installed in buildings.

It should also be noted that the text lacks a number of key requirements, without which it is impossible to reliably use high-capacity FES. In particular, SHNK 2.04.15-23 does not regulate or address the following aspects that hinder the scale-up of FES in the republic for small farms, social and domestic facilities, and industrial facilities.

The analysis revealed several significant shortcomings and gaps, which are listed below:

No requirements for load-bearing structures and loads. Calculations of wind and snow loads on solar panels and their fastening are not regulated in the norm. The additional static load from the equipment on the roof is not taken into account. This means that designers are not obligated to check the strength of the roof or facade under the weight of panels and the influence of local climatic factors (wind, snowfall, etc.), which is fraught with damage to structures during extreme weather events. Additionally, the seismic loads on building panels have not been disclosed, despite the region's high seismicity.

Fire safety aspects were not taken into account. The SHNK lacks clear fire safety requirements for FESs: measures to prevent fire and spread of fire on the roof with solar panels are not specified. There are no requirements for the use of cable and conductor products with appropriate insulation and resistance to UV radiation, protective disconnectors in case of an accident, arc breakdown detection systems, etc. The

minimum fire safety margins between panel groups and flammable roof elements are also not regulated. As a result, the risk of fire at FES facilities increases, especially when installation organizations lack experience.

Disregarding labor protection requirements. The regulation does not contain special provisions on occupational safety during the installation and maintenance of solar installations at height. There are no instructions on the mandatory enclosure of workplaces on the roof, the use of safety systems, safe approaches to panels for cleaning and repair. Installation workers and maintenance personnel are at risk of injury without proper safety regulations at the facility.

No electrical safety and network connection requirements. The SHNK does not provide details about the safe connection of the photovoltaic station to the building's internal power grid and external power system. Emergency protection measures (for example, anti-island devices, automatic shutdown during overload), electricity quality requirements (voltage, frequency, harmonics) when power is supplied to the network, and the procedure for accounting for two-way energy exchange (within net metering or other schemes) are not described. The absence of these norms makes it difficult to integrate the FES into the existing power system and can lead to emergency regimes.



Figure 1. Damage to photoelectric modules due to incorrect installation

The procedure for acceptance and servicing has not been developed. In the current version, there is no section on acceptance tests and commissioning of the FES after installation. It is not specified what checks the contractors and customers must perform before connecting the station (for example, testing the insulation, grounding, and the operability of the protections). Also, the requirements for periodic maintenance and technical supervision of photovoltaic stations during operation are not regulated. Without these provisions, it is difficult to ensure the long-term reliability and safety of installations, especially large ones.

No expiration clauses. SHNK 2.04.15-23 does not consider modernization or decommissioning of solar panels. There are no requirements for the safe disposal of worn-out modules, batteries, and inverters, or for assessing the possibility of extending their service life. This leaves a gap in the regulatory framework for the future, when the first generations of installed FES reach the end of their life cycle.

There are no methods for economic evaluation of projects. The document does not provide methods for assessing the efficiency of solar power plants - calculating the cost of solar power generation, saving traditional energy resources, and project payback periods. For example, there are no references to the Regulation No. 3180 (09.09.2019) of the Ministry of Justice of the Republic of Uzbekistan on determining the cost of design and survey work and methods for calculating fuel savings and reducing greenhouse gas emissions [8]. Thus, investors and engineers lack a unified approach to the technical and economic justification of large installations.

The listed gaps lead to the fact that SHNK 2.04.15-23 is practically inapplicable for photovoltaic power plants with a capacity exceeding $10-100\ kW$, which require stricter engineering measures. The practice of recent years has already revealed cases where, due to the lack of standards, errors were made: the use of unsuitable cables led to breakage of the insulation after 2-3 years of operation (short circuit and fire risk), panels were fastened to the roof with breaks and were torn off by the wind, fires occurred on roofs with solar installations. All this emphasizes the need to refine the standard, taking into account the experience of operating large FES.

In connection with the above, the main purpose of this report is a critical analysis of SHNK 2.04.15-23 "Photoelectric Power Plants" for its further strengthening, as well as the possibility of its application for photovoltaic power plants with a capacity exceeding $10-100\ kW$.

Main part. Comparison with international standards and missing provisions. To eliminate these shortcomings, it is necessary to refer to the experience of international standards and norms in the relevant part, as well as to existing authoritative documents (IEC, NFPA, etc.), which comprehensively cover the safety of FES. The comparison results showed that the national SHNK lacks key provisions found in the following international standards:

IEC 62548:2016 (Photovoltaic (PV) arrays - Design requirements) [9]. This standard sets the technical requirements for designing photomodular arrays and DC circuits. In particular, IEC 62548 regulates the

selection and laying of DC conductors, the installation of protective devices (safeguards, circuit breakers), disconnectors, and grounding for PV modules. The standard focuses on ensuring electrical safety, taking into account the specifics of PV systems - for example, DC circuits are capable of generating and maintaining an arc even at relatively small currents, posing a fire hazard. In the national SHNK, such detailed requirements are absent: there are no instructions on the mandatory presence of DC disconnectors and fuses for each panel row, on the minimum cross-sections and insulation of cables, on the calculation of short-circuit currents in PV arrays, etc. As a result, designers may not consider special measures for DC, which are standard according to IEC 62548.

IEC 60364-7-712:2017 (Low voltage electrical installations - Part 7-712: Solar PV power supply systems) [10]. The International Electrical Installation Code IEC 60364 includes a special section 712 for photovoltaic installations. It extends to electrical wiring and PV system equipment in buildings, requiring the correct selection and application of devices in the installation. The standard contains rules for protection against overvoltages and overvoltages (for example, thunderstorms): section 712.534 requires the installation of impulse overvoltage protection devices in PV systems. Additionally, requirements for disconnection and switching have been introduced: section 712.536 prescribes the availability of PV module isolation means from the network for safe maintenance. In addition, IEC 60364-7-712 establishes limiting cable lengths and current limits, requirements for marking system elements (warning signs about the presence of PV at the facility), permissible grounding schemes, etc. The national document does not contain such detailed instructions. In particular, the SHNK does not require protective disconnection devices in case of ground closure in PV circuits, does not regulate the presence of disconnectors under load between photomodules and the inverter, does not stipulate the procedure for marking DC cables (which remain under voltage even when the network is disconnected). These elements, which are mandatory according to IEC 60364, are currently out of our sight.

IEC 62938:2020 (PV modules - Non-uniform snow load testing) [11]. This standard introduces a methodology for testing photomodules for uneven snow load. It simulates real conditions when snow is unevenly distributed on the panel surface (for example, a snowdrift at the bottom edge of the panel). The IEC 62938 test checks the mechanical strength of the module under such uneven load and determines the critical value of the snow pressure that leads to damage. The tested modules demonstrate the magnitude of the permissible load and the change in output power under the limiting load. In foreign practice, this standard is especially important for roof installations in snowy regions - it ensures that the panel and its fastening withstand snowdrifts without destruction. In SHNK 2.04.15-23, there is no mention of uneven snow load: neither the requirement to use modules tested according to IEC 62938, nor the methodology for calculating snow load on inclined panels. Thus, the national document lags behind global snow risk accounting standards, which is critical even for certain regions of Uzbekistan (in the north and mountains where snow is possible).

IEC 61730 (PV module safety qualification). IEC 61730 series standards (last edition 2023). [12] establishes minimum structural safety requirements for photomodules and their testing procedures. Essentially, IEC 61730-1/2 guarantees that certified PV panels have sufficient electrical insulation, fire resistance of materials, protection from electric shock, and overall failure. In many countries, the rules require the use of only modules that have passed IEC 61730 certification (or UL equivalent). The national standard does not contain a direct requirement for panel certificates according to international safety standards. This means that theoretically, any panels can be used, even those that have not passed full certification tests, which increases the risk of using low-quality products (with insufficient fire resistance of the back film, weak frame, etc.). The absence of a link to IEC 61730 or similar module standards is a clear gap that reduces the overall security level of systems.

NFPA 70 (National Electrical Code, USA) [13]. The US National Electrotechnical Code (NFPA 70) contains a 690th chapter specifically dedicated to solar photovoltaic systems. NFPA 70 is extremely detailed: it provides, for example, a system for rapidly shutting off PV modules in buildings (Rapid Shutdown) to protect firefighters and personnel during a fire. According to clause 690.12 of the NEC, all PV circuits in the building must have the function of emergency disconnection to safe low voltage within 30 seconds after the disconnection is activated. Additionally, NEC requires mandatory grounding of photomodules and structures, installation of fuses on each panel branch, application of specific type cables (PV Wire), and arc fault protection (ARC-fault protection) for systems above certain power. The SHNK does not contain such provisions: there is no concept of a rapid shutdown system for roof FES, there are no

requirements for arc protection, and the section on FES electrical installations is much less detailed. Also, NFPA 70/NEC and related norms (for example, NFPA 1 Fire Code) contain requirements for ensuring firefighters' access to the roof with panels (passages, disconnected sections) and equipment marking. These aspects - fire tactics and interaction with emergency services - have not yet been reflected in the national standard.

Thus, international standards cover the entire spectrum of PV installation safety: from structural strength to electrical safety and operation. In the Republic of Uzbekistan, however, none of the listed standards have yet been harmonized or officially implemented. SHNK 2.04.15-23 was developed independently and omits many critical provisions present in the IEC and NFPA. This creates a regulatory vacuum for large solar power plant projects: there are no mandatory technical guidelines that are followed worldwide during the construction and connection of solar power plants. For the reliable development of the industry, it is necessary to close this gap by absorbing the best practices from international documents.

3. Results

Recommendations for expanding the SHNK to installations with a capacity of more than 100 kW. To ensure safe and efficient operation of large photovoltaic stations (with a capacity of more than 100 kW) in Uzbekistan's conditions, it is necessary to revise SHNK 2.04.15 taking into account the specifics of such installations. Below are scientific and technical recommendations aimed at expanding the scope of the standard, in which the correct calculation and installation of fasteners, taking into account wind loads, are critically important for preventing such accidents, as shown in Figure 2.



Figure 2. Damage to flat roof solar panels after a hurricane

1. Location specifics: roofs, facades, and ground installations.

In the new version, it is necessary to differentiate the requirements depending on the place of installation of the FES:

Roofing stations: introduce norms for calculating the additional load on the roof structure. Require that before installing a large FES, the load-bearing capacity of the roofs and rafters of the building be checked, taking into account the weight of the equipment and the maximum wind force (see below). It is necessary to provide for the requirements for fastening modules to the main load-bearing elements of the building (beams, trusses) using anchor bolts passing through the roofing pin. It is necessary to ensure the preservation of the roof's tightness when installing fasteners (special sealants, seals). It is also advisable to regulate the placement of panels: for example, retreats from the edge of the roof to reduce sailing in the corners of the building, and the presence of technological passages for maintenance and access.

Facade (integrated) panels: develop separate requirements for photovoltaic modules installed on building facades. Considering that facade panels are subjected to direct wind pressure, it is necessary to normalize the strength of the fastening systems according to the loads on the building height. Requirements for the anti-vandal and fire-safe installation of facade FES should be provided: fasteners should prevent the panel from falling down during any single failure of the element, and the structure should prevent fire from spreading over the suspended PV panels (for example, using non-combustible substructures). In addition, it is important to consider the thermal impact on the walls: recommend designs that allow for the ventilation of the space behind the panels to prevent overheating of the facade.

Ground installations: for large ground-based solar parks, requirements for site selection and soil preparation should be added. Frame structures for modules should be designed according to local wind regions (for example, according to the wind map of Uzbekistan), with a sufficient safety margin. It is necessary to consider the possibility of dust storms - provide filters or screens that protect against direct abrasive effects of dust on the moving parts of trackers (if used). To prevent panels from being flooded by heavy rains, it is advisable to recommend modules installed at a minimum height above ground level and drainage measures. Environmental protection norms are also necessary: for example, enclosing the territory to prevent people and animals from entering electrical installations, measures to combat soil erosion under panel arrays, etc.

2. Consideration of climatic conditions (wind, heat, dust, snow).

The design of a FES with a capacity of $> 100\ kW$ should be based on the details of the local climate:

Wind loads: The standard should require consideration of wind speed specific to the area and installation height. Climatic data (wind rose, maximum gusts) should be used with adjustment to the building's roof height (wind pressure increases in tall structures). It is required to include the methodology for calculating the lifting force acting on the panel during wind and to indicate the safety factors for fasteners. For example, it is possible to introduce a requirement to withstand a wind speed not lower than X m/s (according to the district's climate) with a safety factor of 1.5, similar to international approaches. In practice, this means increasing the number of fastening points for each module and using large-diameter anchor bolts that can withstand wind forces. It is also advisable to regulate the need for an aerodynamic gap between a series of panels and the roof (for example, minimal clearance) to prevent the formation of lifting force under the module block.

Temperature and solar radiation: In Uzbekistan's hot climate, the FES equipment is heated to extreme temperatures. It is recommended to supplement the SHNK with an indication of the choice of components designed for ambient temperature not lower than $+50\ldots+60\ °C$ (panels, inverters, cables must have the corresponding temperature class). For panels, the decrease in their power at high temperatures should be considered - it is advisable to require designers to calculate productivity with a correction to the temperature coefficient of the modules. It is also advisable to indicate measures to reduce overheating: natural ventilation of the rear of the modules, sufficient distance between the rows of panels for free air circulation, etc. In the climate section, one can note the need to consider ultraviolet radiation - all plastic and rubber fastening elements, cable insulation must be UV-resistant, otherwise they will break down after several years.

Dust and sandstorms: Dustiness is characteristic of many regions of the republic. The SHNK should be supplemented with recommendations for protecting equipment from dust. For example, inverter stations and distribution boxes must have a casing protection level not lower than IP65 (dust-proof). It is worth considering the requirement for the presence of filters or screens in the invertors' ventilation openings, as well as the possibility of regularly cleaning the panels. Dust not only reduces generation by settling on modules but can also cause abrasive wear of surfaces during wind. Therefore, it might make sense to indicate that in especially dusty areas, panels with special coating that reduces dust adhesion should be used, or automatic dry cleaning systems should be planned. Thus, the standard will encourage consideration of the dust deposition factor when evaluating production and selecting equipment (e.g., more powerful cooling fans with dust reserves).

Snow loads: Although most of Uzbekistan's territory has low-snow winters, some areas (mountainous regions, the north of the country) may experience significant snow loads. The SHNK should be supplemented with norms for calculating uneven snow load on panels, similar to IEC 62938. It is recommended to use panels tested for strength under uneven pressure (have a load test certificate equivalent to, for example, X Pa unevenly). In addition, in the standard itself, it can be indicated that the panel mounting structures on the roof must withstand an asymmetrical load - when the panel base is covered with snow, and the upper part is relatively free. In numerical terms, the required calculated snow mass can be taken from the SNIP data for snow areas (for example, Y kg/m^2 for the region) with an increasing coefficient of 1.2 to account for unevenness. It is also worth adding practical instructions: for example, to provide fences (snow traps) on the roof above the panels to prevent large masses of snow from accumulating directly onto the modules. And, as part of the maintenance, prescribe the need to clear the panels of excess snow to prevent overload.

3. Electrical safety and network connection.

For stations with a capacity of over $100\ kW$, compliance with electrical safety requirements is especially important, therefore, the new version of the SHNK needs to be brought into line with the best world practices:

DC circuits and equipment: Introduce a requirement that all DC components (cables, connectors, fuses) be designed for the maximum voltage of the open solar module circuit at low temperatures. DC cables must have double insulation and UV resistance (type PV1-F or equivalent). All positive and negative conductors from panel arrays should be protected by circuit breakers or melting inserts for current exceeding the calculated short-circuit current by no more than 25%. The project also needs to include DC load disconnectors - devices that can be used to disconnect photo modules from inverters during maintenance or fire. These disconnectors should also be available outside the building (on the facade or in the inverter room) so that emergency services can disconnect the PV system if necessary. This measure is actually dictated by

international practice (IEC 60364-7-712, NEC 690), which requires visible breaks in the PV circuit.

Grounding and Lightning Protection: The standard must include mandatory grounding of metal structures and solar module frames. The minimum cross-section of the grounding conductor (for example, at least 6 mm2 of copper) and the connection method (bolted connection with anti-corrosion treatment) must be specified. It is necessary to consider the integration of FES into the building's lightning protection: if the building is equipped with lightning rods, panels and structures must be connected to the potential equalization system. Otherwise, it is recommended to install a separate lightning receiver above the panel plane with ground branches so that a direct lightning strike does not destroy the panel. In addition, on DC circuits, it is desirable to require devices for protection against impulse over voltages (UZIP), since long cables on the roof are vulnerable to lightning strikes. DC UZIPs must be installed in distribution boxes (combiner box) when cables enter the building.

Inverters and network: In the new version, it is necessary to detail the requirements for inverters and their connection. Inverters must comply with network standards (for example, GOST, harmonized with IEC 62116, IEEE 1547) - have built-in protection against island conditions, voltage and frequency overvoltage/decrease, and current overload. When designing a station with a capacity of >100 kW, it is necessary to calculate the impact on the network: determine whether the short-term power output exceeds the capacity of the local network. It is recommended to introduce a requirement to coordinate the project with the energy supplying organization if the power of the FES exceeds a certain threshold (for example, 50% of the power of the transformer supplying the facility). This will allow, in advance, to provide for the modernization of the network (strengthening of transformers, installation of relay protection) when implementing large FES. It is also necessary to indicate the necessity of installing a two-way type electricity meter (meters that account for both the released and consumed energy) at the station's connection node. Without this, it is impossible to correctly implement "energy exchange" schemes with the network.

Electrical Energy Quality: The standard may require that the inverters of large photovoltaic power plants comply with the electrical energy quality parameters of GOST or IEC. In particular, the level of higher current harmonics generated by the inverter should not exceed the established norms (e.g., IEC 61000-3-15). The power factor when working for the network should be kept close to one (unless otherwise agreed upon). To smooth down potential voltage fluctuations during variable generation (e.g., cloud passage), it is recommended to use an automatic reactive power regulator or other voltage-sustaining systems. These measures will improve the compatibility of large FESs with electrical networks and prevent the deterioration of consumer power supply quality.

Safety and Marking: An important addition will be the requirement to mark all elements of the PV system. Inverter cabinets, network connection points, and building distribution boards must have warning signs about the presence of a generating unit nearby. For example, the inscription "Careful, solar power plant - circuits under voltage even when the network is off" indicates to personnel and firefighters the potential voltage from the panels. The disconnection diagram can also be indicated (the location of the same DC disconnectors and AC switches). In addition, the emergency shutdown system should be considered in the electrical safety section. It is possible to adopt from the NEC the requirement that buildings with photovoltaic power plants must have the ability to quickly disconnect PV modules in an emergency situation - whether it be a special switch or an automatic system when a fire alarm is triggered. Such solutions are not yet widely used, but for large installations, they are justified to minimize damage during emergencies.

4. Reliability of fasteners and structures.

Large FESs must be operated for decades, therefore the standard must ensure long-term structural reliability:

Materials and anti-corrosion protection: The requirements should include instructions on using fasteners and supporting structures made of corrosion-resistant materials (stainless steel, aluminum, zinc-plated steel with the corresponding class of zinc coating). The climate of Uzbekistan (heat in summer, dust, in some areas soil salinity) can lead to accelerated corrosion; therefore, ordinary black metal without protection is unacceptable. It is also necessary to stipulate the need for protective coatings for bolts and anchors, contact of heterogeneous metals (to avoid galvanic corrosion between, for example, the aluminum frame of the panel and the steel support, insulating gaskets must be used).

Strength and Structure Tests: It is recommended to require manufacturers or installers to confirm the strength of the selected assembly system. For example, the design documentation for a FES with a

capacity of $> 100\,kW$ must contain calculations or certificates of loading tests for fasteners (wind, snow) at a given panel configuration. The norm for conducting acceptance tests of the assembled structure can be included: selective verification of the bolt tightening torque, inspection of welds on supports, load testing of one module (for example, suspending a load imitating wind). Such inspections, although selective, would increase confidence in the safety of the structure before commissioning.

Legality and maintenance: It is advisable to reflect in the standard that fasteners must retain their properties throughout their entire service life (at least 20-25 years). For this purpose, scheduled inspections and maintenance can be ordered: for example, every 5 years, the fasteners are reviewed - loosened bolts are tightened, rusted elements are replaced. It is also worth mentioning that the designs should provide for easy replacement of individual modules or parts without disassembling the entire array (modularity). This is important for maintaining operability: if one panel breaks or the fastener is damaged, it must be replaced promptly.

Ballast systems: If ballast fasteners are used on flat roofs (without through-to-plate fastening), the standard must establish special conditions for their application. For example, only allow when calculating wind for a specific roof and with windshields along the perimeter. Ballast (walkway slabs, concrete blocks) must provide a sufficient mass, and this should also be considered according to the loads. In this case, it is necessary to consider the load distribution across the roof to avoid local overloads of the floor slabs. Probably, ballast systems are not optimal for photovoltaic power plants with a capacity of $> 100\,kW$, therefore, mechanical fastening to the building structure can still be recommended as a more reliable option.

Vibrations and mechanical impacts: In the standard, it can be mentioned that fasteners must withstand not only static but also dynamic loads. In addition to wind and seismic effects, modules can experience equipment vibration or wind resonance. The structure should not enter into resonance during normal wind gusts. This requires the analysis of the "panel-mount" system's own frequencies and, if necessary, the use of damping elements. For example, add washers with nylon inserts to damp vibration in the fastening joints. These details are usually not mentioned in the standards, but for large installations (with long rows of panels), a well-thought-out fastening design helps prevent fatigue damage to the metal over time.

5. Evaluation of efficiency, payback, and replacement coefficient.

In addition to purely technical requirements, economic justification and energy efficiency are important for large projects:

Technical and economic evaluation methodology: It is proposed to include an appendix to the SHNK with a methodology for calculating the efficiency of the FES. It should describe the principles for determining the annual electricity production of the solar power plant (based on climatic data on solar radiation), calculating the savings of primary energy resources (how much conditional fuel is replaced by solar generation), and calculating the project payback period. For example, specify the formulas for the net reduced effect, the internal rate of return (IRR), taking into account the investment in the station, and the expected savings on electricity or fuel for generators. It is also necessary to consider different types of systems: on-grid, off-grid, and hybrid. For on-grid (network) systems, savings are calculated as the cost of energy not taken from the network minus possible maintenance costs; for off-grid systems - as the cost of substituted diesel fuel or other source; for hybrid systems - the combined effect. A unified methodology will allow for more objective comparison of projects, preventing situations where each calculation is carried out based on different assumptions.

Using current climate data: To accurately assess electricity production, it is necessary to rely on the latest data on solar radiation. It is recommended to provide reference information on solar potential for the regions of Uzbekistan - average annual total radiation ($kWh/m^2 \cdot year$) per horizontal surface, as well as recalculation coefficients for the optimal angle of inclination, in the appendix. These data should be obtained based on both long-term meteorological stations and modern satellite observations. Considering climate change over the past decades, it's important to note that solar radiation could increase or change seasonally. Including such data in the standard will allow designers to correctly model FES generation and avoid excessive optimism or pessimism. For example, if an average annual radiation increase of 5% has been recorded over a 30-year period, this should be reflected in the forecast of production for the next 20 years of operation of the new station.

Energy replacement coefficient: SHNK should be supplemented with the concept of replacement coefficient, which shows the share of energy needs covered by the FES, or the share of traditional resources that have been successfully replaced by

renewable energy sources. For buildings with solar installations, this coefficient can be calculated as the ratio of PV production to the building's total energy consumption per year. The standard can recommend target benchmarks: for example, if state policy is aimed at generating 20% of RES, then for new large facilities, it is advisable to design FESs that replace at least 20-30% of annual consumption. In addition, it is worth noting the safe maximum of integration - the same methodology for determining the maximum power of the FES for connection to the network. If a local network or facility is unable to receive a larger portion of solar power without compromising reliability, it is necessary to either modernize the infrastructure or limit the capacity. In the standard, criteria can be given: for example, without special network measures, the power of the distributed generation should not exceed 50% of the transformer load or cause a return flow to the higher network beyond a certain level. This calculation allows for determining the upper limit for implementing solar power plants at a specific node and avoiding overloading the grid with solar energy at noon. If it is necessary to connect a large capacity, energy storage systems or intelligent generation management should be provided.

Environmental and social impact: As part of the performance evaluation, it is also beneficial to consider the reduction of CO_2 emissions and other pollutants due to FES. It is recommended that the justification for the large-scale plant project include the expected emission reduction (in tons of CO_2 equivalent per year) based on the replacement volume of electricity from the network mixture. This highlights the project's contribution to environmental goals. In addition, the standard could mention social effects - for example, improving the energy supply of remote settlements, creating jobs while producing components locally. Although these aspects are not technical, their presence in the regulatory clarification would encourage more responsible and comprehensive project planning.

6. Harmonization with international standards.

It is crucial that the updated SHNK does not contradict global technical norms, but rather complements them, taking into account national specifics. For this, it is recommended:

Revising the document's structure: It might be worthwhile to divide the standard into several parts or applications dedicated to different aspects (construction part, electrical part, economic assessment). In this case, the electrical part should be developed based on IEC 62548 and IEC 60364-7-712, translating and adapting the main requirements. This will accelerate harmonization - in fact, the provisions of international standards verified by practice will be implemented into national rules. For example, directly borrowing wiring, protection, and testing requirements from the IEC will facilitate the integration of Uzbek FESs into the global security requirements system.

References to standards: In the text of the SHNK, references to applicable international and interstate standards should be provided. For example: "photomodules must comply with the requirements of IEC 61215 and IEC 61730 for testing and safety," "inverters - IEC 62109 (power electronics safety) and GOST R MEK 61683 (photoconverters efficiency) " and so on. Such references will force equipment suppliers to use certified products. Also, with links to the IEC, it is easier to update national norms as new editions of international norms are released - it is enough to track changes in basic standards.

Considering foreign rules in the national context: Not all foreign requirements can directly apply to Uzbekistan, but they should be analyzed for the feasibility of implementation. For example, the American Rapid Shutdown system can be adapted or simplified if its full implementation is too costly. Nevertheless, the basic principles (presence of external PV system shutdown during a fire) are quite applicable to us as well. Another example is that European fire safety standards for roofs with solar panels recommend leaving paths with a width of at least 1 m without panels for firefighters to access. Perhaps such a requirement should be introduced in the SHNK for public and residential buildings. Harmonization does not mean a literal copying of all IEC/ISO/EN clauses, but it implies bringing our rules to a comparable level of strictness and completeness.

Interaction with standardization bodies: For full implementation of harmonization, it is necessary to parallelly develop or revise GOSTs (O'z DSt) for photoelectric systems. The SHNK as a construction standard can refer to them. For example, to develop the Uzbek State Standard "Photoelectric Systems. Design and Installation Rules" based on IEC 62548/60364, Uz DSt "Photoelectric Modules. General Security Requirements" based on IEC 61730 and others. The introduced GOSTs will become mandatory when referencing the SHNK, which will ensure their application. Such comprehensive standardization work will raise the quality level of projects to a new level and facilitate the integration of the Uzbek RES market with the global market (certification, equipment import-export).Theorem-

type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

Theorem 1. Example text of a theorem. Theorems, propositions, lemmas, etc. should be numbered sequentially (i.e., Proposition 2 follows Theorem 1). Examples or Remarks use the same formatting, but should be numbered separately, so a document may contain Theorem 1, Remark 1 and Example 1.

The text continues here. Proofs must be formatted as follows:

Proof of Theorem 1. Text of the proof. Note that the phrase "of Theorem 1" is optional if it is clear which theorem is being referred to. Always finish a proof with the following symbol.

The text continues here.

4. Discussion

Confirming the above, it should be noted that after updating and strengthening SHNK 2.04.15-23, it is necessary to simultaneously strengthen control over compliance with the norms: state bodies, when certifying or commissioning facilities, must verify that the project takes into account wind loads, fire safety, electrical equipment compliance with standards, etc. Only under the condition of strict adherence to the new rules will the advantages contained in them be realized in practice.

5. Conclusions

Expanding the scope of SHNK 2.04.15-23 "Photoelectric Power Plants" for installations exceeding 100 kW is an urgent measure for the safe development of solar energy in Uzbekistan. The proposed changes fill the gaps in the current edition by introducing requirements for strength, fire and electrical safety, labor protection, and efficiency based on international experience. The implementation of these recommendations will ensure the reliable integration of large FES into buildings and the power grid without a threat to people and infrastructure. In the context of the rapid growth of the renewable energy sector and the course towards increasing energy efficiency, updating the standards for the design and operation of photovoltaic stations will be an important step towards sustainable and safe energy supply. Harmonized with advanced standards, the new document will contribute to achieving national goals for the implementation of "green" capacities, protect the health and property of citizens, and contribute to the development of the modern regulatory framework for "green" construction in the Republic of Uzbekistan.

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