Proposed Grounding System for A Solar-Powered Building Design at A State University in Pampanga

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Abstract: - As PV systems age, grounding concerns arise, posing a risk to system safety, among these hazards include incorrect electrical connections, improper design and installation of grounding systems, and the resulting from non-system installations. A grounding system provides the necessary safety for the user and the equipment of the solar PV system. This research is intended to propose a solar PV grounding system for the Admin Building at DHVSU Main Campus by determining the appropriate size of wires, breakers, and electrodes through manual computation; and providing a Single Line Diagram for a PV System that is focused on the integration of a grounding system. The proponents collected the Electrical System data of the Admin Building from DHVSU and the Solar PV System data from the existing feasibility study by Edgardo Santos in 2019. The study displayed the components comprising the on-grid solar system, but a grounding system was not included. Subsequently, the sizing of the DC Overcurrent Protective Device and Inverter AC Circuit Breaker were manually computed. DC and AC Equipment Grounding Conductor were sized, and Grounding Electrode System was determined under Philippine Electrical Code (PEC). For the canvassing of the price of significant components, bill of materials for consumables, grounding (bill of materials specific), manpower cost for installation, operation & maintenance cost, delivery of materials, and net-metering application cost, the researchers consulted a registered electrical engineer working at Transnational Uyeno Solar Corporation (TUSC). The Payback Period was calculated by dividing the total cost by the total savings. In modelling the grounding system, significant standards were used in finding the corresponding DC & AC overcurrent protective device, DC & AC equipment grounding conductor, and grounding electrode conductor. After completing all the information needed, the proponents came up with the following results: OCPD Rating = 20 AMP, PV Cable = 2-6mm^2 90-degree Celsius wire with XLPE Insulation, DC Grounding wire = 1-5.5mm^2 THHN, AC OCPD Rating = 150AT 3P MCCB, main wire of the AC system = 4-60mm^2 THHN/THWN, AC Grounding Conductor Sizing = 1-14mm^2 THHN/THWN. The total estimated contract cost amounted to ₱3,039,120. On the other hand, the total contract cost amounted to ₱3,401,680 since the maintenance cost for a PV system without grounding is more expensive. Consequently, the payback period is extended for the PV system without grounding. A total of 3 years, 2 months and 23 days of payback period was computed considering the integration of the grounding system. The grounding system single-line diagram is presented in the study.

Key Words: — *Grounding System, Solar PV System, safety, State University, General Office Building.*

I. INTRODUCTION

A rooftop solar photovoltaic (PV) installation consists of arrays of PV panels and mounting frames that support the panels to the roof, and secure wiring, inverters, and other components that vary according to the type of installation. All of these components must be able to fit on the roof (Asian Development Bank [ADB], 2014). The structure, the frame of the PV panels, and the bolts and nuts are all metallic components that make up the assembly, and the layout of the entire PV system is determined by the surface on which it is installed (Ayub et al., 2018). That is why proper grounding of a PV energy system is critical for ensuring the public's safety throughout the system's years-long existence. Solar PV panels must be bolted and nutted to a grounded structure. While not

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all PV system components will be fully functional during this period, the fundamental PV module will continue to generate potentially hazardous currents and voltages throughout the system's generation. Practical, code-compliant, and well-maintained grounding contributes to the system's overall safety, even when it is not producing usable energy (Wiles Jr., 2012).

Moreover, it is crucial to remember that the requirements contained in the Institute of Electronics and Electrical Engineers (IEEE) codes or any other codes that serve as standards for electrical system design constitute minimum electrical installation requirements. These bare-bones requirements cannot guarantee that the equipment will function satisfactorily. Electrical practitioners frequently require additional grounding components as a result of this. One of these is a copper conductor that is directly connected to the earth and installed around the building's perimeter. To complete the grounding system; the steel building columns and some non-current carrying metallic frames of electrical equipment or some electrical components of the system are connected to this copper conductor (Surbrook & Althouse, 2008).

Unexpected ground faults can occur in PV power systems, just as they can in other types of electrical systems. PV systems that have been installed permanently include elements that are not visible on the electrical schematics of the structures. Stray inductance, capacitance, and resistance are distributed throughout the system. The leakage currents generated by the PV modules, the interconnected array, the cables, surge protection devices, and conduit accumulate to the point where a ground fault occurs (Bower & Wiles, 2000). Grounding all PV systems is a good idea, as it helps protect humans from unintended shocks and possible death. In addition, it can assist in preventing post-installation fires within the system. Furthermore, there's a report in the United States indicating that when an undiscovered or unrepaired ground fault occurs on ungrounded DC electrical systems (non-PV) used by electrical utilities, a second ground fault frequently occurs for the same reason within two weeks. Double ground faults cause problems because they may go undetected by overcurrent devices and thus provide no protection. In their ungrounded direct current electrical systems, utilities always rely on extensive electronic ground-fault detectors (Wiles, 2010).

Generally, PV arrays are installed outdoors to maximize sun exposure (Böhm et al., 2016). Due to the fact that PV panels are always installed on the roofs of houses and buildings, they take up a lot of space, making them more susceptible to lightning strikes during thunderstorms (Haider et al., 2012; Metwally, 2011). Typically, lightning strikes result in overvoltage and overcurrent, which can result in damage to rooftop PV panels (Mohamed et al., 2019). Unless otherwise specified in the electrical code, all equipment's grounding wires must be connected together and directed to a single service grounding point. Surge protectors or lightning arresters, as well as special grounding, will guard against lightning damage. They provide a direct path to the ground, ensuring that the solar PV system's components are not struck by lightning (Gevorkian, 2008). Additionally, to minimize personal and property damage, lightning surge currents must be drained to the earth via low resistance paths (Moongilan, 2013). Lightning that strikes equipment will also strike the wiring. Lightning exposes equipment to extremely high voltages and currents, which can deteriorate the insulation between circuit elements and cause significant damage to system components. As a result, lightning protection is necessary, even more so in tropical areas like Manila (ADB, 2014).

Recent research studies and scientific discussions have contributed to the contemporary analysis of fire risk and safety issues in PV systems, resulting in heightened safety in the PV industry (Chouder & Silvestre, 2010). In a case study conducted by Falvo & Capparella (2015), in terms of safety design, it's important to consider that a PV plant constitutes a grounding system of generation, where the Direct Current (DC) presence results in changes to the technical rules. Moreover, if certain electrical faults occur, the plant is a possible source of fire. Grounding systems are able to provide the necessary safety for electrical equipment under lightning. In order to prevent negative effects on the system created by high voltage leaking, grounding resistance must be checked periodically (Colak et al., 2014). In addition, proper grounding enhances safety for both user and equipment, improves performance, and may even reduce costs (Wiles, 2012). After all, grounding can't prevent a lightning strike but can prevent damage to the solar PV system.

Don Honorio Ventura State University (DHVSU) Main Campus is found at Bacolor, Pampanga, which has enough sunlight and can generate an average of 4.5 kWh per square meter every day, based on its geographical location in the northern part of the country [Renewable Energy Developers Centre (REDC), 2013]. Similar to the Lyceum of the Philippines University – Laguna (LPU-L), LPU-L also consists of high voltage apparatus, switchgear equipment, and other electrical equipment (Dimayuga et al., 2015). One of the prime objectives of the said study is to understand the importance of a grounding system and how it affects the electrical system of an institutional building. In fact, the University is popularly known for its extremely warm temperature. The University will contribute to conserving energy for future generations and help reduce the production of greenhouse emissions once clean energy sources become its primary electricity provider (Krauter & Rüther, 2004).

Moreover, an assessment of the influence of realistic protection devices and grounding methods on the total system performance becomes critical when deploying a protection system in a real-world environment. Up to this point, the protection of PV systems was designed based on technologies and strategies taken over from existing matured solutions developed for auxiliary DC systems in big power plants and traction power systems (Tang & Ooi, 2007). Recently, however, coordinated protection strategies have been proposed (Fletcher et al., 2012; Emhemed & Burt, 2014). Apart from protection systems, standardization of future DC systems regarding installation design and instrumentation is currently the most crucial barrier to wide-scale adoption.

Concerns about grounding arise as existing PV systems age, posing a hazard to system safety. These issues include faulty electrical connections, improper grounding device design and installation, and the implications of non-code-compliant system installations (Wiles, 2012). The obligatory ground-fault detection systems in use today do not identify all possible ground faults (Marrero, 2000). In some instances, fires and equipment damage have occurred due to misdiagnosed ground faults. Proper care is essential to ensure complete grounding and avoid overloading the inverter as a result of a power outage or other external reasons (Ball et al., 2013).

Ayub et al. (2018) compared side grounding with different soil resistivities, it is found that voltage drops at the grounded point of an assembly varied significantly. On the other hand, mid-section grounding arrangements with different soil resistivities have apparently shown that midsection grounding may not be advisable because it does not offer any noticeable advantage. Therefore, for a single assembly, side grounding may be the best grounding strategy to be adopted. Further work will be conducted on different points of lightning attachment for a single solar PV assembly and for groups of solar PV assembly. In terms of the applicability, according to Santos (2019), the installation of solar panels with net metering is applicable for DHVSU's main campus; the said program will help the university to lessen the; carbon footprint produced, and dependency on distribution utility. The analysis process has been facilitated in the identification and estimation of total quantities of solar panels, inverters, and load demand of the system, once installed.

Specifically, there are 32 buildings in DHVSU that are feasible for solar PV installation in the previous study (Santos, 2019). The preceding study only focused on how many panels are to be used to supply the demand of the building and reduce the cost of energy consumption of DHVSU. Considering the load the solar PV system can produce and its capacity, a grounding system design and an overcurrent protective device are not mentioned. In addition, the cost of labor and material for the grounding system is not included in the total cost of the system. This gave the researchers the idea to design a grounding system from the previous study and make further inquiries.

This paper is intended to propose a solar PV grounding system at Don Honorio Ventura State University, taking into account the standards of PEC 2017 and NEC 2017 by; 1.) Determine the appropriate size of accompanying PV system wire, grounding wires, breakers, and electrodes through manual computation, and 2.) Provide a Single-Line Diagram for a Solar PV System focusing on integrating a grounding system towards improving its safety.

The General Office Building (Administration Building) is the building selected for the representation of all the feasible buildings grounding system designs, and also to accomplish the study on time.

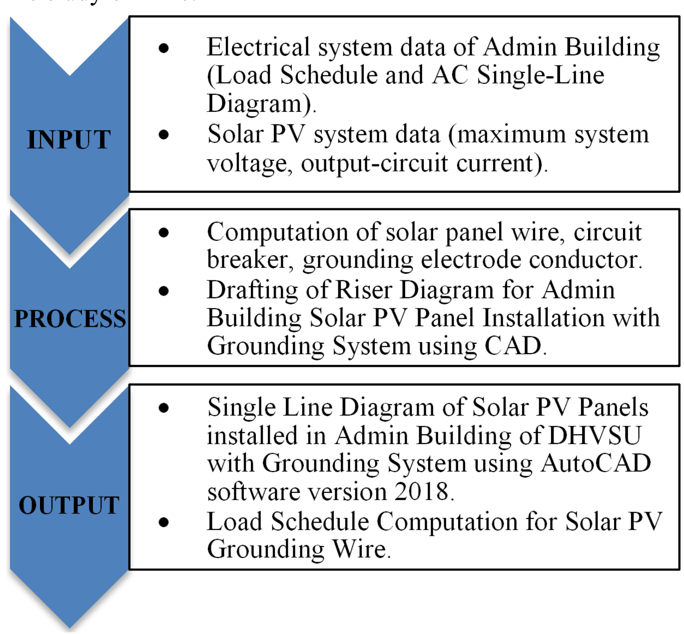

Fig.1. Framework of the Study

Figure 1 shows the input, process, and output of the study. The input contains the existing data used to generate the results of this study which are the electrical system data of the Admin Building consisting of the Load Schedule and AC Single-Line Diagram, and the Solar PV System data collected from the published feasibility study (Santos, 2019) consists of maximum system voltage and output-circuit current. The process that was undertaken by the proponents to come up with the output was: computation of solar panel wire, circuit breaker, grounding electrode conductor; and drafting of single-line diagram for Admin Building Solar PV Panel Installation with Grounding System. Finally, the output of the study comprises the Single Line Diagram of Solar PV Panels installed in the Admin Building of DHVSU with Grounding System and Load Schedule Computation for Solar PV Grounding Wire.

II. METHODS

The proponents described the stages to undertake in developing the study as seen in Figure 2,

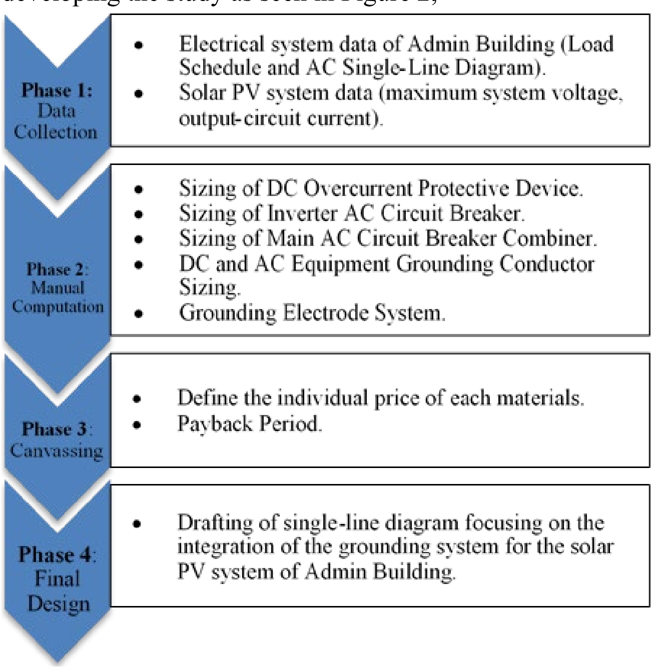

Fig.2. Process flow of the study

Figure 2 presents the four (4) phases to undertake in designing the proposed solar PV grounding system.

2.1 Phase 1: Data Collection

There are two (2) different types of data from the Admin Building of DHVSU that were gathered by the researchers. First is the data that consists of the electrical loads/load schedule, and AC single-line diagram. Lastly, the solar PV system data from the previous study (Santos, 2019) consists of maximum system voltage, output-circuit current, and the number of panels.

Only the load schedule, AC single-line diagram, maximum system voltage, and output-circuit current were used from the data in order to compute the solar panel grounding wire, circuit breaker size, and arrive at the overall draft of the single-line diagram design focusing on the integration of grounding system for the said solar PV system.

2.2 Phase 2: Manual Computation

2.2.1 Sizing of DC Overcurrent Protective Device

According to PEC 2017, Section 6.90.2.2(a), the maximum current is the total of the parallel module rated short-circuit currents multiplied by 125 percent. Given as:

$$Max.Current\ (I_{max}) = I_{mpp} \times (1.25) \qquad \textbf{eq.1}$$

where:

I_{max} = Maximum current

I_{mpp} = Max. Power Current (sum of the short-circuit current ratings of the PV modules connected in parallel)

1.25 = Safety Factor of Potential Irradiance

Then, according to PEC 2017 Section 6.90.2.2(b)(1), circuit conductors and overcurrent devices must be sized to carry at least 125 percent of the maximum currents calculated in 6.90.2.2. (a). Given as:

$$I_{ocpd} = I_{max} \times (1.25) \qquad \textbf{eq.2}$$

where:

I_{ocpd} = DC Overcurrent Protective Device current rating

I_{max} = Maximum current

1.25 = Maximum demand

Then, the computed maximum current is multiplied to the safety factor of continuous duty to determine the Overcurrent Protection Device (OCPD) rating.

Note: Overcurrent devices must be rated or adjusted in accordance with PEC 2017 table 2.40.1.6.

2.2.2 Sizing of Inverter AC Circuit Breaker

According to the ohm's law, taking the √3 due to the derivation of the three-phase power formula.

$$I_{inverter} = \frac{p}{v(\sqrt{3})} \qquad \textbf{eq. 3}$$

where:

$I_{inverter}$ = inverter's maximum continuous output current p = inverter's rated power

v = line to line voltage

Then, according to Section 6.90.2.2(b) and 6.90.2.3(b) of PEC 2017, in sizing the circuit breaker PV circuit currents shall be considered as Continuous. The maximum OCPD rating is 125% of the maximum current. The current rating for CB or fuse depends on the ampacity of the wire used in the circuit. Given as:

$$Continuous\ Current\ (I_{max}) = I_{Inverter}(1.25) \quad \textbf{eq. 4}$$

where:

$Continuous\ Current\ (I_{max}) = I_{ocpd}$ = Max. Continuous Output Current (per Phase)

$I_{Inverter}$ = inverter's maximum continuous output current

1.25 = Demand factor (D.F.)

The load current of the inverter is multiplied to the safety factor of continuous load in order to obtain the continuous current.

Note: Overcurrent devices must be rated or adjusted in accordance with PEC 2017 table 2.40.1.6.

2.2.3 *Sizing of Main AC Circuit Breaker Combiner*.

Using eq. 3 to compute the inverter load current, the sum of the capacity of the two inverters was divided by the line voltage. Then using eq. 4 to compute the continuous current for the Main AC Circuit Breaker Combiner.

2.2.4 DC and AC Equipment Grounding Conductor Sizing

Section 6.90.5.5 of PEC 2017 requires to multiply 125% of the photovoltaic-originated short-circuit currents in that circuit for sizing if and only if the system is protected by the ground-fault protective equipment required by 6.90.1.5. The researchers considered the DC and AC OCPD as the ground-fault protective equipment of the system. Using the calculated rating or setting of the automatic overcurrent device in equation 2 and equation 4, the size of the DC and AC ground wire were determined using PEC 2017 table 2.50.6.13.

2.2.5 Grounding Electrode System

Admin Building of DHVSU is powered by distribution utility which is why an AC grounding electrode is required as mentioned in Section 6.90.5.7 (a) of the PEC 2009 which requires an AC System to have an AC grounding electrode in accordance with Section 2.50.3.1 through Section 2.50.3.11. The grounding electrode conductor shall be installed in accordance with Section 2.50.3.15.

Since the output of a solar PV system is DC, a DC grounding electrode is required to install, Section 6.90.5.7 (b) suggests that a grounding electrode system shall be provided in accordance with Section 2.50.8.7 for grounded systems or Article 250.169 for ungrounded systems. The grounding electrode conductor shall be installed in accordance with Section 2.50.3.15.

2.3 Phase 3: Canvassing

For the canvassing, the researchers consulted with a licensed electrical engineer working at Transnational Uyeno Solar Corporation (TUSC). TUSC specializes in the installation of solar PV systems. The canvassed data consists of the price of major components, bill of materials for consumables, grounding (bill of materials specific), manpower cost for installation, operation & maintenance cost, delivery of materials, and net-metering application cost. The overall canvassed price of all the equipment considered for the integration of solar PV grounding system is equal to the total cost of the system, which is used for the computation of the payback period.

2.3.1 Payback Period

The Admin Building of DHVSU is connected in Meter 1. According to Santos (2019), the total savings computed for Meter 1 is ₱33,658.2 per month. Since there have been changes in the loads in the present year, the researchers updated the computed total savings for meter 1. The updated total savings is equal to ₱78,415.4 per month based on the latest electrical loads that have been gathered from the admin building. The canvassed total cost of the system was divided to the total savings of Meter 1 per month in order to acquire the payback period of the system in years considering the grounding system.

$$Payback\ Period = \frac{Total\ Cost\ of\ the\ System}{Total\ Savings} \quad \textbf{eq. 5}$$

where:

Payback period = length of time it takes to recover the cost of the investment, in years.

The total cost of the system = Total contract price (major components, bill of materials for consumables, grounding, manpower cost for installation, operation & maintenance cost, delivery of materials, net-metering application cost)

Total savings = Total savings per month.

2.4 Phase 4: Grounding System Modelling

Essential standards were utilized in determining the DC & AC overcurrent protective device, DC & AC equipment grounding conductor, and grounding electrode conductor. After the computation, the Single-Line Diagram was modelled focusing on the integration of the grounding system for the solar PV system of the Admin Building. It comprises the actual size of wires to be used and where the additional safety equipment is installed in the system. In addition, it shows the grounding system positioned from the panel to the grounding electrode.

III. Results and Discussion

This section presents the major findings of the study.

As a representation of all the feasible buildings for the conduct of a grid-tied solar PV system, the ADMIN building of DHVSU was used. The given data employed for the design of the grounding system is as follows:

3.1 Interpretation of the manual computation results

The computed Overcurrent Protective Device (OCPD) Rating on Eq. 2 is 21.88 A, which is approximately equal to 25 A; therefore, for the DC side of inverter 1 and inverter 2 use 25 AMP Fuse as per PEC 2017 2.40.1.6 & 6.90.2.2(B)(1). As per PEC 2017 3.10.1.16, assuming PV cables 90-degree Celsius wire with XLPE Insulation, a 3.5mm^2 wire can be used, but as advised by an engineer working at TUSC, in actual practices, one size higher than the rated wire size is much efficient to use. This is because solar systems perform continuous duty. For the safety of the system a 6mm^2 PV cable shall be used. For the DC Grounding Conductor Sizing, the researchers considered actual practice. The DC ground wire used is 1-5.5mm^2 THHN wire, one size higher than the 25 Ampere Fuse as per PEC 2017 table 2.50.6.13.

The computed Continuous Current on Eq. 4 is 125.5 A, and this current will be utilized to determine the AC OCPD Rating of the two inverters, which is about 150 AT 3P, as per PEC 2017 2.40.1.6 & 6.90.2.2(B) (1). After identifying AC OCPD, a 4-60mm^2 THHN/THWN copper cable is used as the main wire per inverter in the AC part of the PV system. For the Grounding Conductor of the AC output of the inverter, the proponents used 14mm^2 THHN/THWN cable wire as per PEC 2017 table 2.50.6.13.

The estimated Continuous Current on the Main AC Circuit Breaker Combiner is 251.025 A, which is almost equivalent to 300 AT, 400 AF 3P MCCB according to PEC 2017 2.40.1.6 & 6.90.2.2(B) (1). Once AC OCPD has been determined, a 4-150mm^2 THHN/THWN copper wire is used as the main conductor of the AC side of the PV system that is connected in the main panel board of the admin building. For the AC Grounding Conductor Sizing, the proponents used 1-22mm^2 THHN/THWN cable wire as per PEC 2017 Table 2.50.6.13.

3.2 Cost of the PV system (with grounding)

The total contract cost of the whole system with grounding, considering both solar PV and grounding system, and the total installation cost of the entire system amounted to ₱3,039,120 (TUSC, 2022).

According to TUSC, customers who consulted with them usually encountered maintenance issues. For instance, when DC ground-fault occurs, some panels are damaged since there is no grounding system that could dissipate the leaked current. For the AC side of the PV system, when grounding does not exist, inverter parts are prone to damage as a result of ground fault. TUSC also added that parts of the inverter are hard to acquire, since the manufacturers are from foreign countries. Thus, inverter repair by replacing its components becomes impracticable, and replacing the entire inverter turns into the only suitable option. The maintenance of ungrounded solar PV systems, including ground-fault and operational costs, was applied for the study, adding to the system's total expenditure without grounding.

In this manner, the total expenses of the system without a grounding system amounted to ₱3,401,680, much higher than the total contract price with a grounding system at ₱3039120 since the maintenance cost for a PV system without grounding is much more expensive.

These costs were estimated by a skilled engineer currently working at TUSC since the researchers do not have prior experience in putting up and maintaining a PV system. The total prices were used in the manual computation of the payback period required.

3.3 Payback period

The total cost of significant components was lesser since the grounding system cost was not included in the calculation. Power inverter parts are replaced multiple times for a solar PV system without grounding as compared to PV systems' power inverter parts with a grounding system (Wiles, 2012).

In comparison, considering the maintenance cost of the ground-fault and maintenance cost of the PV system, the payback period in years of the solar PV system without grounding system installed was approximately much higher (3 years, 7 months and 12 days) due to a higher maintenance cost as compared to the payback period with grounding system installed (approximately 3 years, 2 months and 23 days).

Note: payback period results may vary depending on what equipment will be damaged in the system.

3.4 Drafting of the Grounding System Single-Line Diagram:

The grounding system single-line diagram is presented in figure 3.

There are a total of 8 strings of panels that are connected with two inverters, with each string containing 19 panels connected in series. For the DC part of the PV system, each panel is bonded to a grounding wire with a 5.5mm^2 THHN; each panel is bonded to the grounding wire using Grounding terminal lugs (crimp type). When each panel is connected to the grounding wire, the grounding conductors of strings 1 to 4 will be bonded, same as string 5 to string 8. Then, from the roof, a single grounding wire of the same size of 5.5mm2 THHN for string 1 to string 4 and a single grounding wire with also the same size of 5.5mm^2 THHN for string 5 to string 8. It runs in the raceway down to the wall, where the grounding electrode conductor is bolted into the rapid shutdown system transmitter's casing and the DC side of the inverter.

For the grounding electrode conductor of the AC output of the two inverters, each inverter has a 14.0mm^2 THHN wire, which is bolted to the AC ground per inverter. These two grounding conductors are screwed at the busbar of the AC Enclosed Circuit Breaker (ECB) combiner. Then, from the busbar of AC ECB a 1-22mm^2 THHN/THWN cable wire will be connected to the existing admin building grounding system since the admin building operates in AC.

Additionally, according to NEC (2017), PV circuits installed on the building must include a rapid shutdown function. Even when the inverter is turned off, a high voltage is retained in the panel. In the model, the researchers included a rapid shutdown system. The additional system consists of a rapid shutdown module installed to all panels, a transmitter installed on the DC side of the PV system, and a PV system disconnect installed at the inverter's AC output.

Furthermore, the researchers incorporated a Surge Protection Device (SPD) in the model, which diverts any excess voltage to guarantee that the equipment receives consistent power levels. This SPD contains a 5.5mm^2 THHN grounding wire that is bonded to the AC grounding electrode conductor.

This model was evaluated by a licensed Electrical Engineer currently working at TUSC and validated the efficacy of the model.

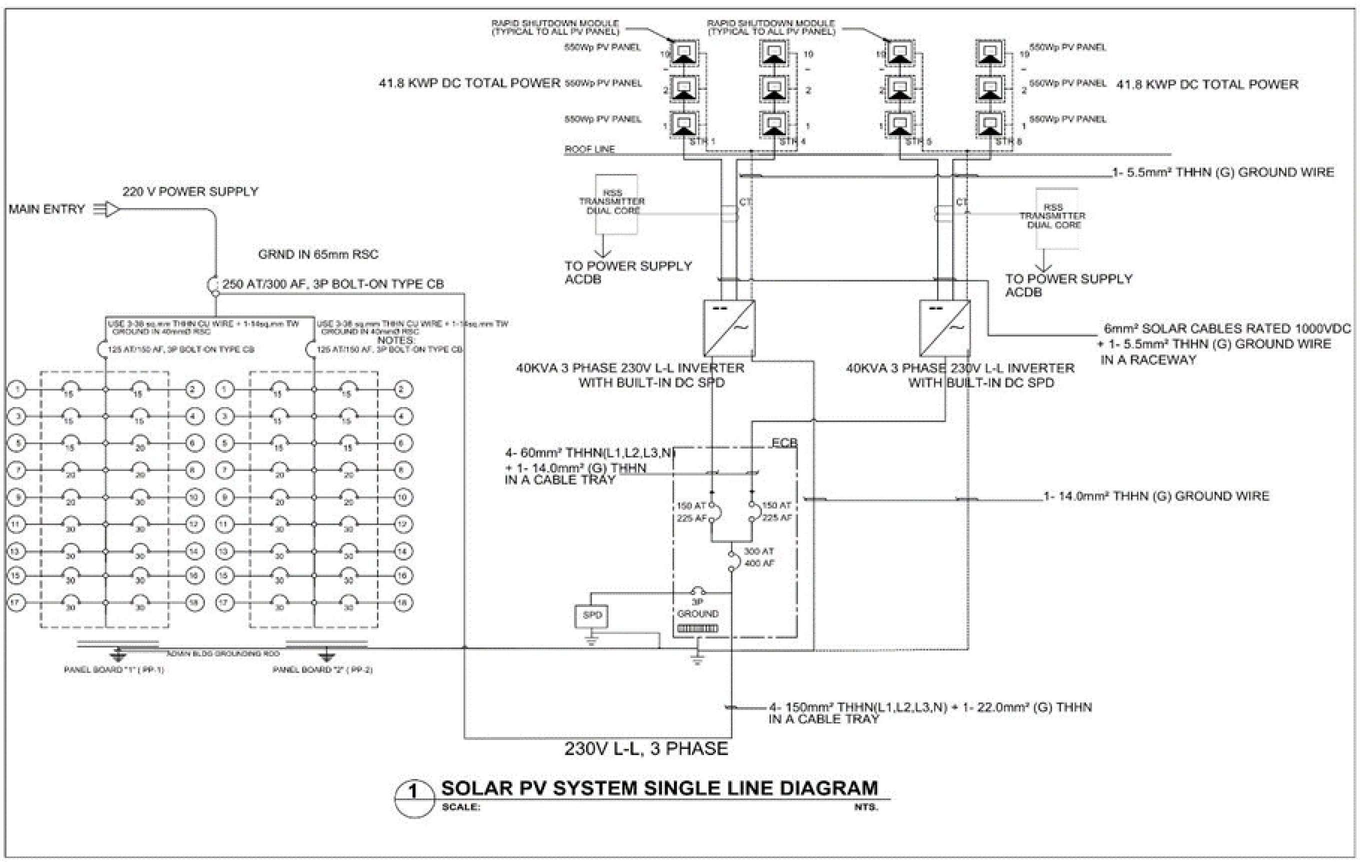

Fig.3. Single-Line Diagram

IV. CONCLUSION

This study discussed the relevance of grounding in a solar PV system. It provided a grounding system design for the Administration Building of DHVSU to constitute the viability of the other buildings in the university. The study additionally comprises an economic analysis of the grounding-equipped solar system. Grounding the solar system prevents possible damage to the solar panels and other components from stray currents caused by lightning surges or short circuits. As explained comprehensively in the Results and Discussion segment, it also makes the system cost-efficient. It was found that the payback period of a PV system incorporated with grounding occurred in lesser time as compared to a PV system without grounding.

V. RECOMMENDATION

This research has proven the advantages of grounding a solar PV system regarding safety and economy. However, the proponents utilized only one building to demonstrate the results. The proponents recommend to regard the following for further research:

The proponents recommend performing a similar calculation process and designing a grounding system, including the economic analysis for all the other feasible buildings in DHVSU. This will allow the future proponents to also compare the payback period of the existing solar system design to the payback period when grounding is added in all the buildings.
Future proponents may consider conducting a separate study for off-grid solar PV systems with grounding to determine the distinction in lifespan and savings.

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