Development of energy conversion and lightning strike protection simulation for photovoltaic-wind turbine on grid

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ABSTRACT

Photovoltaic (PV) installations and wind turbines that are installed on the rooftops of buildings need to be protected because the layout is in a high position and there is a risk of being struck by lightning. Therefore, a more effective protection system is designed to anticipate electronic damage and fire on all materials in the distribution network, especially the addition of PV and wind turbine installations on building roofs. The purpose of this study is to simulate a lightning protection system on the distribution network and the results of on-grid PV energy conversion using electrical transient analyzer program (ETAP) software. Feeder relay delay times and cascade coordination patterns between outgoing and incoming relays do not overlap. the delay time of the relay working on the feeder is 0.31 s and the coordination pattern of the outgoing relay and incoming relay does not touch each other, so the delay time for the incoming relay is 2.73 s. Then testing the results of PV energy conversion connected to the grid using MATLAB Simulink monitoring obtained data reaching 1.600 Wp at peak power with sun conditions parallel to the PV installation layout.

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1. INTRODUCTION

Utilization of renewable energy sources, especially photovoltaic (PV) and wind turbines has the potential to be used, especially in areas with tropical climates, including North Sumatra. The installation of renewable energy development is very important because it can reduce the use of electrical energy [1]–[3]. However, expensive investment costs and suboptimal energy conversion will greatly affect the installation of PV and wind turbine [4]. Renewable energy sources, especially PV, have several installation techniques to make it more optimal, namely by installing PV horizontally, tilted and centered on the sun with the aim of all installation techniques to obtain increased energy conversion [5]–[7]. Then the optimization of other PV energy conversions is installed on the roof or known as rooftop PV with the aim of being free from shadow effects around the panels [8], [9]. Actually, the model of applying PV on the roof is very suitable to be developed in various climate zones, especially countries with tropical climates, especially the North Sumatra region [10]. Therefore, the review of photovoltaic and wind turbine installations in the North Sumatra region continues to be encouraged because it is an area with the most potential for PV and wind turbine installations. Another thing is also supported by this region has a fairly high intensity of sunlight and promising wind potential [11], [12]. However, the complex problem of irregular weather fluctuations makes the percentage of Sumatran areas that receive rain quite high, including the Medan city area which is entering the rainy season based on the number of seasonal zones (ZOM) with monitored data that the condition of the island of Sumatra has sufficient rainfall tall [13], [14]. The occurrence of the rainy season will also have the potential for lightning, both direct lightning strikes which occur when lightning strikes the phase wire directly and also multiple strokes, namely with the characteristics of several strikes at the same point in the region which of course will be more at risk of material damage if PV is installed and wind turbine on the roof of the building [15]–[17]. This will later become a problem in installing PV and wind turbine on the roof with the installation position always at a height with the risk of being hit by a lightning strike which will later affect electrical disturbances in the form of disconnections and also fire of panel materials causing fatal damage in used electrical power [18]–[20]. The next impact will occur in the disturbance of the stability of electric power which is very influential also in the use of electrical energy [21]–[24]. To anticipate problems and support the potential for PV installation, a safer installation model is built so that power stability and electrical energy reserves are maintained by installing PV and wind turbines directly connected to the power grid and adding technology that can reduce damage to electrical equipment components around PV installations and wind turbine. The next strategy to anticipate lightning disturbances and short circuits is to install the PV component layout on the roof of the building, even though it is very at risk of lightning strikes, but a relay protection coordination system will be designed and supported by a reliable protection. Technology with PV and wind turbine installation techniques on a connected roof directly on the power grid using early streamer emission (ESE) technology in reducing the occurrence of lightning strikes. Therefore, before carrying out the installation, a more optimal relay coordination accuracy test is carried out with simulations and scenarios on the distribution network using electrical transient analyzer program (ETAP) software and also MATLAB software to see PV energy conversion [25]–[27]. The reliability of the installation of this technology will certainly increase consumer confidence in the installation of renewable energy, this is of course considering that the material and operational costs of the installation are very high so that it must be protected [28]–[30]. The design that will be discussed in this case is a simulation using the ETAP software development and is used to make improvements to the stability of PV power, coordination of PV systems and wind turbine connected to the grid, PV energy conversion and also the installation of the layout for the installation of protection systems in the PV and wind installation zones turbine.

2. METHOD

The development in this research was carried out by means of a problem-solving approach, namely, developing a lightning protection system design using early streamer emission (ESE) technology. Then, carry out the layout of the installation of lightning protection components in strategic areas such as the use of Evo Franklin Ef 150 technology on towers that have the potential to be struck by multiple stroke lightning to protect the rooftop PV area. The next strategy is to carry out a simulation of the ETAP software by simulating an increase in the integration of lightning protection system technology in the rooftop PV zone and energy conversion in PV installed on the roof of a building. PV construction will be carried out in the North Sumatra area using weather radar to see predictions of weather conditions in Figure 1.

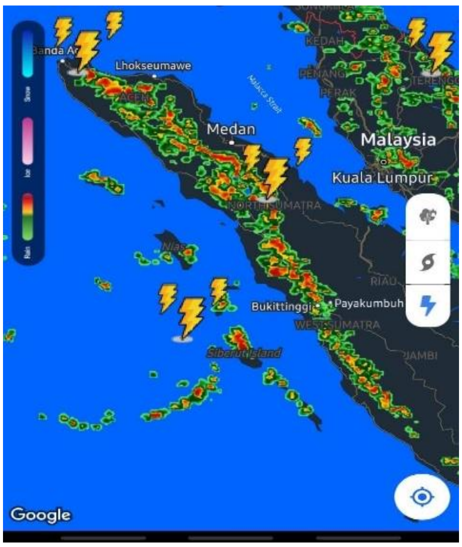

Figure 1. Conditions of areas with lightning in North Sumatra based on weather radar

The mechanism of lightning strikes is caused by the transfer of electric charges between clouds and the ground as negative from cloud to earth, positive from cloud to earth, negative from earth to cloud and positive from earth to cloud [31], [32]. The striking distance or return stroke of the lightning is determined by the current magnitude of the lightning striking the ball rolling in (1).

$$i(0,t) = \frac{i_0}{\eta} \times \frac{\left(\frac{t}{t_1}\right)^n}{1+\left(\frac{t}{t_1}\right)^n} exp\left(\frac{t}{t_2}\right) \quad (1)$$

where i_0 is the current magnitude of the lightning strike, t_1 is lightning strike's future time, t_2 is the lightning strike decay time and η is the exponential value with (2).

$$\eta = \exp\left[-\left(\frac{t_1}{t_2}\right) \times \left(n \times \frac{t_2}{t_1}\right)^{\frac{1}{n}}\right] \quad (2)$$

Seeing the condition of the North Sumatra region using weather radar software, there will be the potential for natural disturbances such as lightning strikes if PV and wind turbines are installed. However, on the contrary, if it is exploited properly, the sun's potential, especially the intensity of sunlight, is very high and also the potential for wind is very good. Therefore, a protection system design was carried out with the first step being a trial using the ETAP software simulation which was conditioned on the distribution network. This will later become a feasibility test in order to be able to minimize structural damage, equipment damage, fire on the components to be used. The PV used to generate electricity from solar energy uses the polycrystalline type with an installed power capacity of more than 2 kW. The data collection technique for energy conversion used is an observation technique, which is a technique for direct observation of what is happening in the field, variables for the data to be analyzed using weather fluctuations and specifically for lightning protection systems, namely during rainy weather conditions in the North Sumatra region. Figure 2 shows the installation of a roof PV and a grid-connected wind turbine with a simulation of a direct lightning strike.

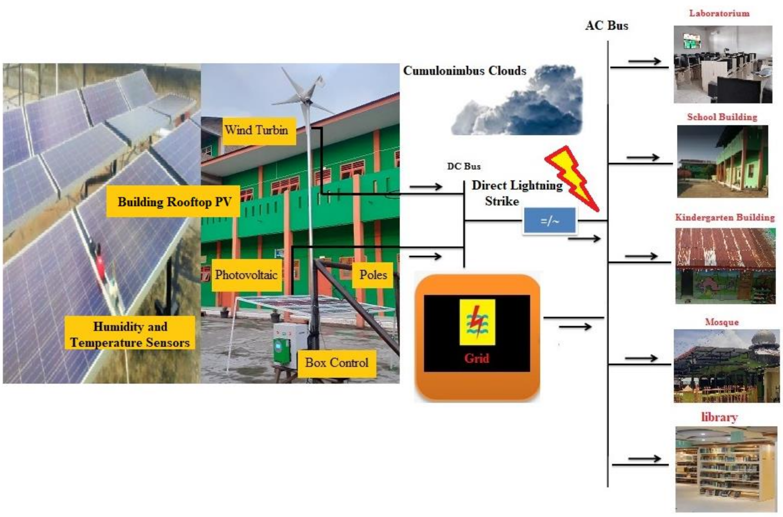

Figure 2. Grid-connected roof PV and wind turbine installation systems [33]

3. RESULTS AND DISCUSSION

The integration of PV installations and wind turbines connected to the grid network was previously carried out by simulating using the ETAP software. The design of the single line diagram that has been designed is then carried out short circuit simulations on the electricity distribution network. Single distribution network diagram with scenarios on 5 loads that are overall connected to the grid network. Lightning protection support technology in the PV installation zone uses air terminal ESE technology which is integrated into the PV rooftop on grid. Typically, this ESE model has an active element at the end of the air terminal. The main claim of the ESE technology is functioning on the payload of the array space preventing lightning discharge into the protected facility i.e., the photovoltaic installation zone. Then in addition to evaluating the system reliability of installing the lightning protection system, monitoring the energy conversion produced by the rooftop PV will also be monitored with the aim of seeing the output power of the rooftop PV system on grid in supplying power to the load based on different weather fluctuation parameters.

3.1. Protection coordination simulation using ETAP software

The scenario in the ETAP software will be carried out using 5 loads, namely laboratories, school buildings, kindergartens, mosques and libraries. The simulation results on the lightning signal found on the 20 kV bus bar are 3-phase fault currents, when a fault current occurs, the relay detects a fault current and then the relay gives instructions to circuit breaker (CB) 23 to isolate the fault current which is marked with an X on CB 23. Then if CB 23 fails to work, the incoming CB will be coordinated to work to isolate the disturbance flow which can be seen by an X also on the incoming CB. Figure 3 shows the power flow of the distribution network using 5 loads.

After the CB is active and working, then the cascade coordination pattern is applied to the ETAP software simulation by making a case of disturbance due to lightning on CB 23, then CB 22 will immediately protect it systemically. The simulation can be seen working with the coordination of 2 CBs that are used on the outgoing side first with the first CB then if the disturbance cannot be overcome then the incoming relay will be coordinated to give instructions to the second CB so that it can open, which means breaking the electricity network. Figure 4 shows relay coordination on the CB in protecting against disturbances, especially in lightning strikes.

Based on Figure 4, the lightning sign on the 20 kV bus bar on the feeder is a 3-phase fault current. When a fault current occurs, the relay detects a fault current, then gives instructions to CB23 to isolate the fault current which is marked with an X on CB23. Furthermore, if CB23 fails to work, the incoming CB22 will be coordinated so that it can work in isolating the disturbance flow marked with an X on the incoming CB22. The circuit breaker that is successfully instructed by the overcurrent relay when it is detected if there is a short fault current is shown based on the curve in Figure 5.

In the curve of Figure 5 it can be seen that the delay time of the relay working on the feeder is 0.31 s and the cascade coordination pattern can be seen that the curve lines of the outgoing relay and incoming relay do not touch each other, and on the incoming relay the delay time of relay work is 2.73 s. The results of the curve also experience coordination of the overcurrent relay found in the feeder works after relay 23 gives a trip instruction to relay 22.

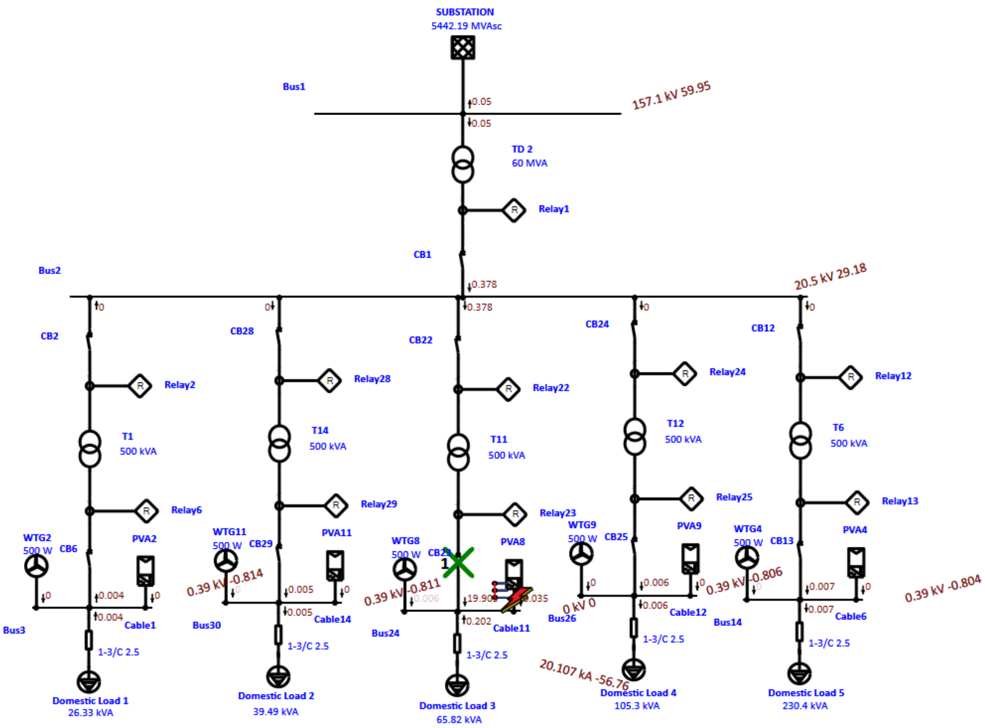

Figure 3. Power flow single line distribution network diagram using PV and wind turbine on 3 phase short circuit in distribution network with 5 loads

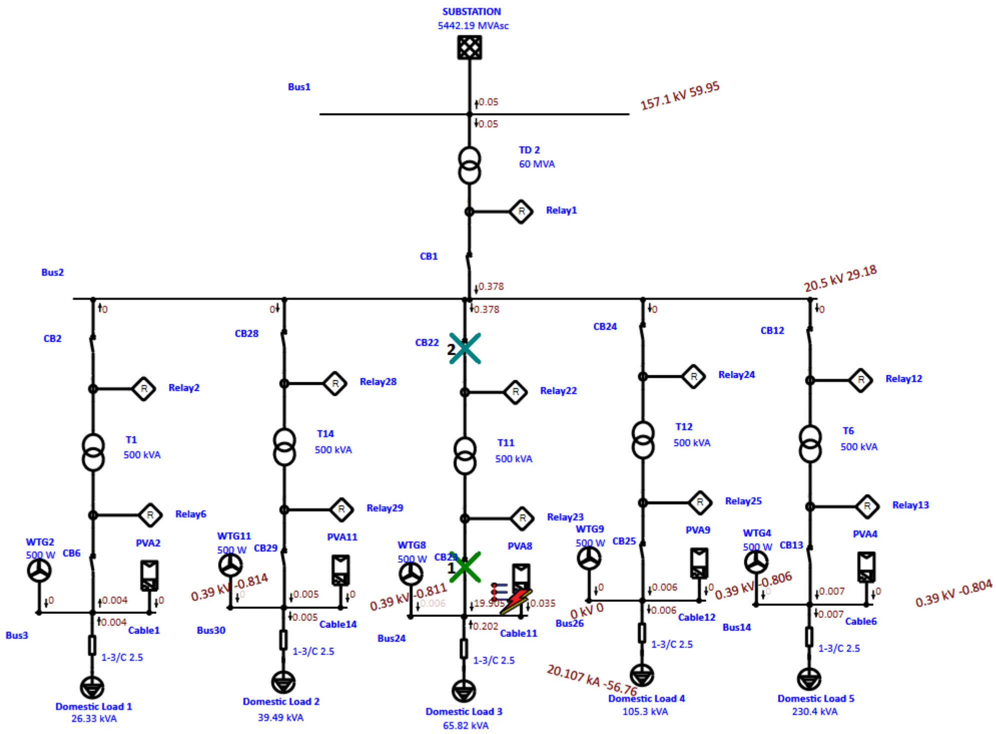

Figure 4. Simulation results of coordination of lightning strike protection on a distribution network using PV and wind turbine on a 3-phase short circuit in a distribution network with 5 loads

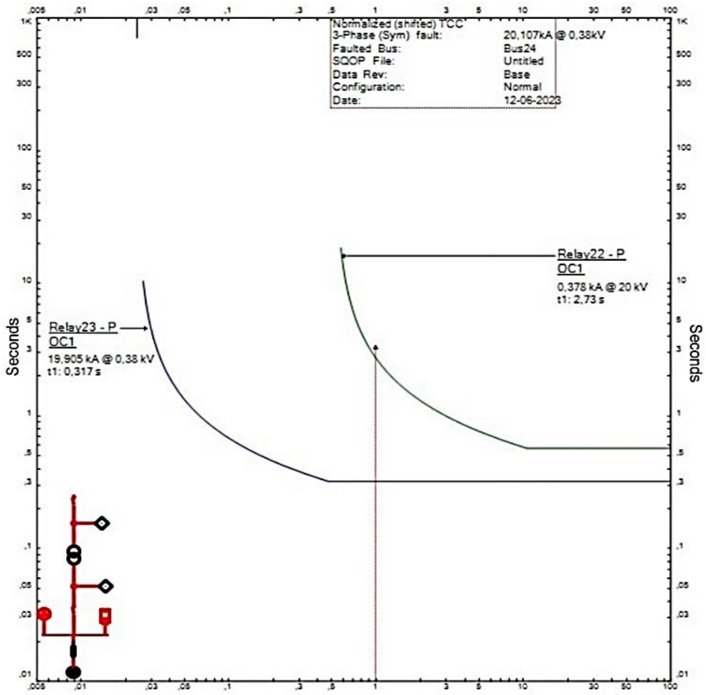

Figure 5. Coordination curve of overcurrent relay protection on 3-phase short circuit in STR distribution network with 5 loads

3.2. PV installation design in lightning strike protection zones

Development in minimizing the danger of lightning strikes on PV, it is necessary to design an effective lightning protection system so that later it is useful for protecting equipment such as installing PV on the roof of a building. The use of applications for rooftop PV monitoring using MATLAB software is very helpful in real time monitoring of load usage, especially energy conversion. Therefore, this system is designed to be integrated using ESE terminal technology which is specifically designed to conduct electricity when a lightning strike occurs on grounding, then bentonite cement is also installed to support reducing electrical conduction due to direct lightning strikes. Furthermore, the installation of a solar power system connected to the grid network using a grid tie inverter is installed on the roof of the building with the additional integration of grounding installation with the formation of bentonite cement. Figure 6 shows the layout for installing PV on grid and using ESE technology to protect against lightning strikes in the PV installation area.

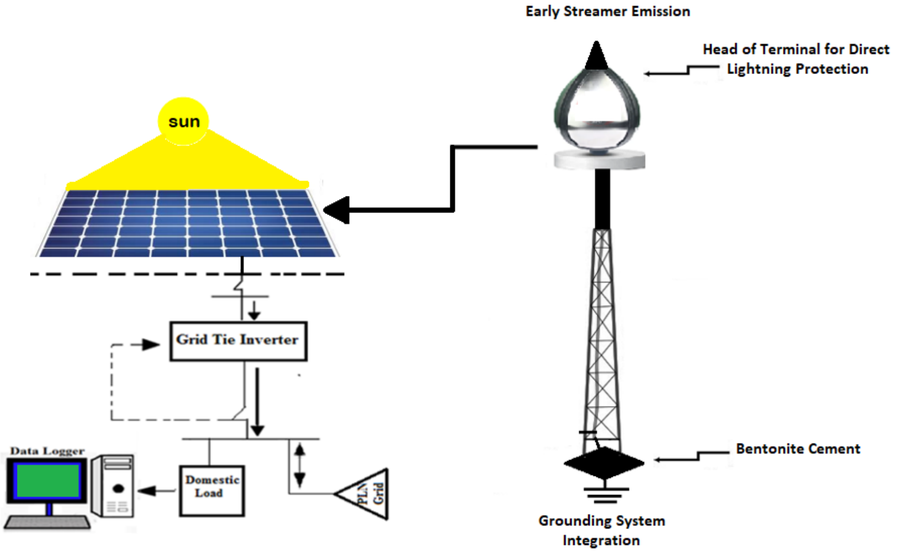

Figure 6. Design for completion of PV protection system when direct lightning strikes occur

3.2. Performance of energy conversion on rooftop PV with Simulink MATLAB software

The data collection process for power energy conversion uses 1hour intervals starting from 7:00 pm to 6:00 am. Retrieval of data on energy conversion values of polycrystalline solar panels with a capacity of more than 2 kW. Data is taken using a Visual Basic design by recording data in the form of values and displaying DC power data. Then the recorded data is displayed in MATLAB Simulink to display the DC power output as shown in Figure 7.

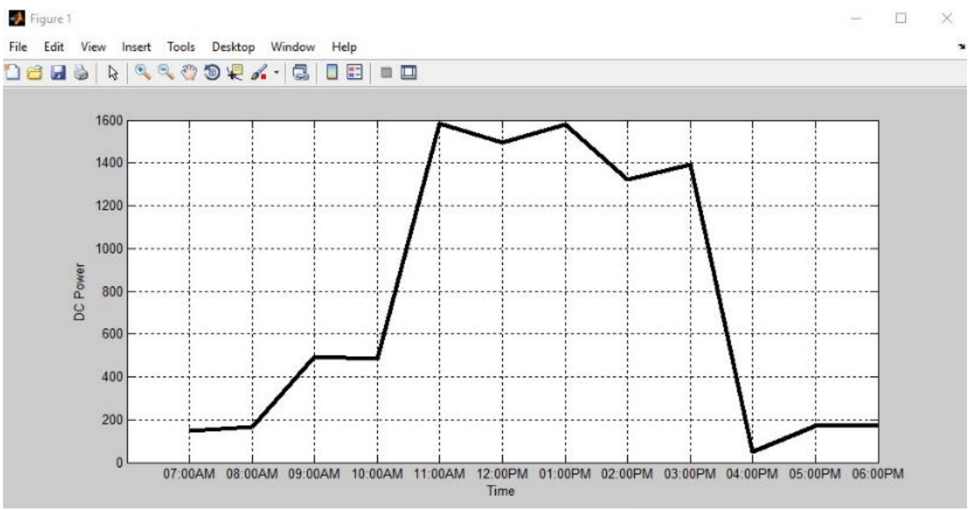

Figure 7. The results of DC power measurements use MATLAB Simulink

Based on the output data collection from PV in a flat position which during sunny conditions the peak power is 1.600 Wp, namely at 11:00 pm. This condition is still not optimal due to fluctuations in the weather, especially in the North Sumatra region where clouds occasionally cover the PV so that the DC power graph looks irregular.

4. CONCLUSION

Based on the use of the ETAP software to coordinate relay settings when a direct lightning strike occurs, the overcurrent on the incoming side is set to the primary setting with a time dial. The delay time for the relay is 0.31 s for the feeder and the cascading coordination pattern between the outgoing relay and the incoming relay does not overlap. Then on the incoming relay, the relay delay time is 2.73 s. The results of the curve also experience coordination of the overcurrent relay found in the feeder, namely the relay works after relay 23 gives a trip instruction to relay 22. This calculation proves that the outgoing overcurrent relay works faster than the incoming overcurrent relay. The implementation of the cascade coordination pattern in the simulation was successfully carried out, which can be seen from the performance of the CB on the outgoing side first, then if the disturbance cannot be resolved, it will be coordinated on the incoming relay to give instructions to the CB to open, which means breaking the electricity network. Then the PV installation and wind turbine connected to the grid network work well but the wind is not optimal due to the low wind speed in the North Sumatra region during the day. For energy conversion produced by PV using MATLAB Simulink, data obtained reached 1.600 Wp at peak power with sun conditions parallel to the PV installation layout.

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