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Mitigation of Impulsive Transient Effect in Solar Photovoltaic System Caused by Lightning

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Abstract: Solar photovoltaic (PV) system is a form of renewable energy that is constantly utilized to generate electricity. Due to their openness to the outside environment, PV systems are at significant risk of being struck by lightning. Lightning may cause serious damage to solar panels; thus, lightning protection should be considered early in the design process. This project includes the study of the power quality (PQ) problem create by lightning with calculation to produce impulsive transient using an RC circuit. Without the use of a surge protector, The PV system poses a risk of electrical device damage, as well as the risk of fire. A surge protection device (SPD) is a protective device for electrical equipment that protects them against impulsive transients. This project will use Type 2 SPD to prevent the spread of overvoltage in electrical networks and to protect equipment connected to them. It has a 1./50µs voltage wave and is frequently constructed using metal oxide varistor (MOV) technology. MATLAB Simulink is used to simulate the test case for the project. The project's results show steady-state output waveforms, a distorted wave of power quality problems caused by lightning, and mitigated results when the mitigation method was applied.

Keywords: PV System, Power Quality, Impulsive Transient

1. Introduction

Solar photovoltaic (PV) systems have arisen of community and industrial knowledge of renewable energy sources that can be used to generate electricity instead of fossil fuels. Malaysia is privileged in that it is one of the countries with significant PV power production potential. This country is frequently exposed to high amounts of radiation and has a large number of direct sunlight [1]. The nation has a tropical climate with much sunshine, with an annual irradiance average of1642 kWh/m^2 [2]. Malaysia is particularly susceptible to lightning and thunderstorms, with an average of 180–260 days of thunder annually [3]. As a result, when it comes to the requirement for lightning protection systems, the design of installation for such systems, which are outside locations where there is a significant risk of being hit by lightning, particularly those in lightning-prone zones, generates a lot of challenges.

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When a PV farm is struck by lightning, the electronic components are damaged and can melt or crack. Furthermore, lightning surges cause short circuit occurs in the device because the energy of a lightning strike is much greater than the maximum energy that the equipment can withstand [2]. Due to the extraordinarily large transient current and voltage induced by the lightning hit, PV systems and other electrical components, such as inverters, are at risk of serious damage. Damaged electronic components are extremely costly to repair or replace.

Therefore, the purpose of this study is to investigate suitable techniques or components to mitigate lightning strikes on PV systems. To protect the PV system from a lightning strike, a lightning protection system (LPS) need to be installed as stated in IEC 62305 [3]. There are a few types of LPS such as the Franklin rod concept and the Faraday cage concept [4]. Another way to protect electronic components from lightning is SPD with Malaysian standard MS IEC 61643-1:2004 [5]. SPD is convenient and easy to install as protection for electronic components.

PQ problem impulsive transient can occur from lightning. Without a surge protection device PV system has a risk of damage to electronic devices, even the risk of fire. SPD is a protection device used to protect electronic devices from the impulsive transient. In this project, Type 2 SPD will be used to prevent overvoltage from spreading in electrical systems and to protect equipment connected to them. It is commonly made with MOV technology and has a voltage wave characterized by 1.2/50µs. MATLAB Simulink is used to simulate the project's test case.

2. Methodology

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Project design

Figure 1 shows the block diagram of the overall system. The figure illustrates the inputs followed by the process and ended with the output. From the input supply, the PV panel will generate a DC supply. After that, the DC supply from the PV panel through the inverter changes to AC. LC filter connected to smooth the waveform of AC and finally to the load for the steady state test case. In a lightning test case, there will be a lightning block as an impulsive transient is injected to the system. Finally, in the mitigation technique test case, SPD will be connected to the system. All of the test cases will be monitored, recorded and analysed with the output voltage by scope.

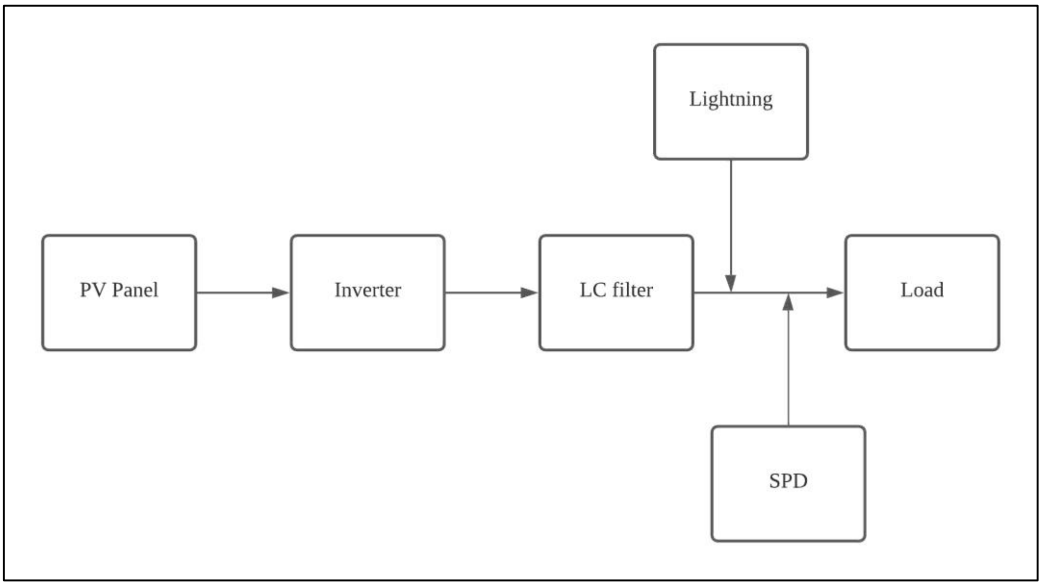

Figure 1: Block diagram for overall system

2.2 Test case: steady-state circuit

Figure 2 shows the steady-state circuit of the PV system. PV panels are connected to IGBT as inverters to convert DC to AC. LC filter is used to smooth the AC waveform. Three-phase parallel RL load is connected to the test circuit for drawing current. The scope is used to see the output. Table 1 shows the parameter of this test case used.

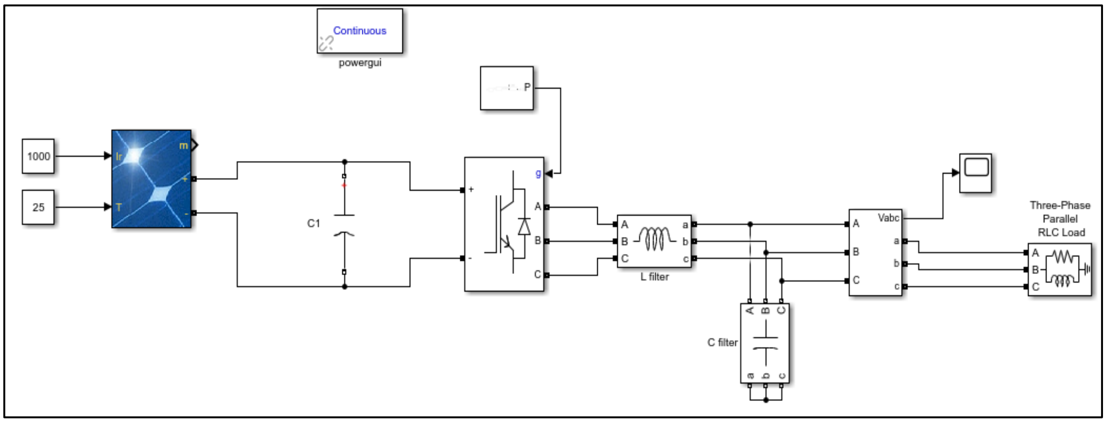

Figure 2: Test case: steady-state circuit of the PV system.

Table 1: Parameters used in steady state test case circuit.

Block/ Component name	Parameter
Irradiance	1000w/m^2
Temperature	25^{o}C
Capacitor, C1	50mF
PWM generator	0.9 modulation index, 50Hz
Inductance filter, L	23mH
Capacitor filter, C	180µF
Three-phase parallel RL load	Vn= 400V, Fn = 50Hz, P = 10kW, PQL= 100var

2.3 Test case: design transient circuit

Figure 3 shows the lightning surge circuit with a combination RC circuit from High Voltage Engineering Theory and Practice by M.Khalifa. In lightning surge circuits, a pre-charged capacitor (C1) is discharged to the wave shaping circuit quickly by shutting the switch, G. The discharged voltage e(t) in the double exponential waveform is the output voltage at C2. This circuit is typically used to generate impulsive transient. The calculation are made to know the value of R1, R2 and source to generate 6kV impulsive transient with constant C1 & C2.

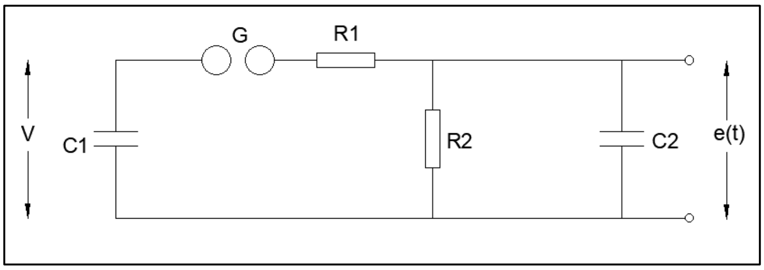

Figure 3: The lightning surge circuit.

2.4 Test case: mitigation technique

Figure 4 shows the mitigation impulsive transient circuit developed in MATLAB Simulink. The mitigate technique used is MOV-based Type 2 SPD which is connected to the circuit. The connection of SPD is parallel with the load from line to ground. The SPD is designed according to IEC 61643-11 standard. Table 2 shows the parameter of MOV protecting the 230V PV system.

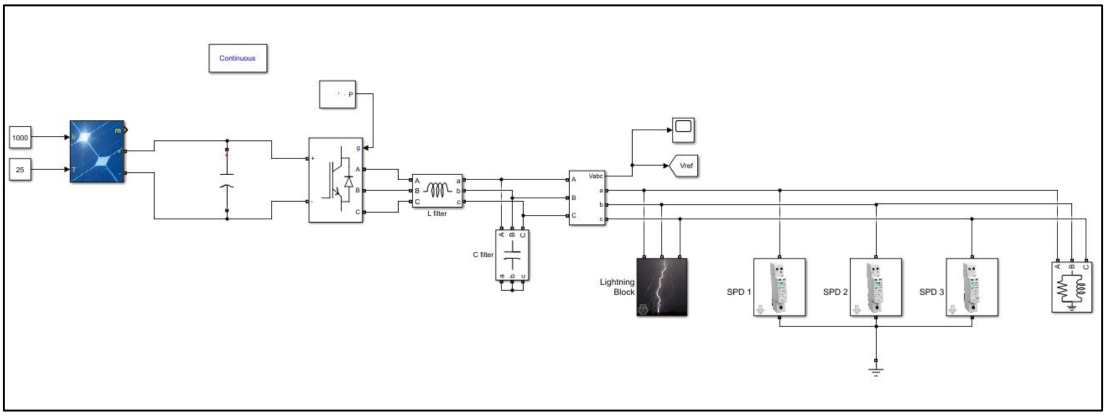

Figure 4: Test case: mitigation of impulsive transient circuit.

Table 2: Parameter of MOV.

	Parameter
Voltage protection, Up	230V
Nominal discharge current, In	60A

3. Results and Discussion

The result shows the steady state is clear from any disturbance, while the transient state shows the PQ problem which is impulsive transient, and the mitigation state clears the PQ problem using the mitigation technique SPD. All of the output voltage test cases were simulated by MATLAB Simulink with time 0.1s and monitored using the scope of voltage.

3.1 Steady state condition

The PV system is at a steady state when the voltage reaches its final values and stops changing. Furthermore, there is no disturbance of PQ problem occurred. Figure 5 shows the output voltage waveform of a steady-state PV system.

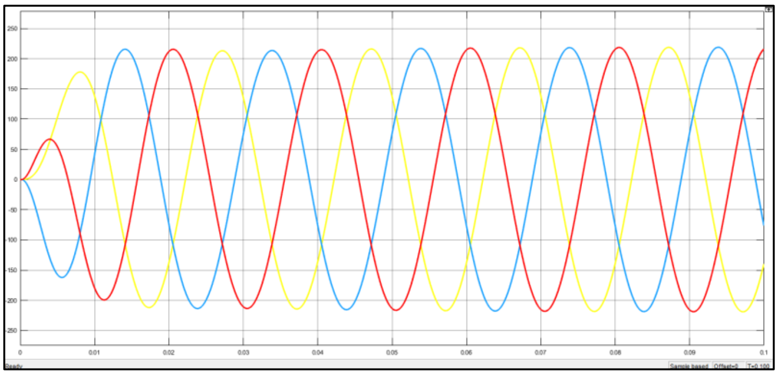

Figure 5: Output voltage waveform of steady state.

3.2 Transient state condition

Table 3 shows the parameter of lightning surge used for the circuit. Figure 6 shows the lightning surge circuit developed in MATLAB Simulink. The output voltage at C_2 will be monitored by the waveshape of the lightning surge. The DC source is connected to C_1, then through the switch. The switch will be active at 0.06s to generate 1.2/50µs waveshape.

Table 3: Parameter of lightning surge circuit.

Parameter	**Value**
V_{in}	6153V
C_1	0.125µF
R_1	206.951Ω
R_2	557.714Ω
C_2	1nF

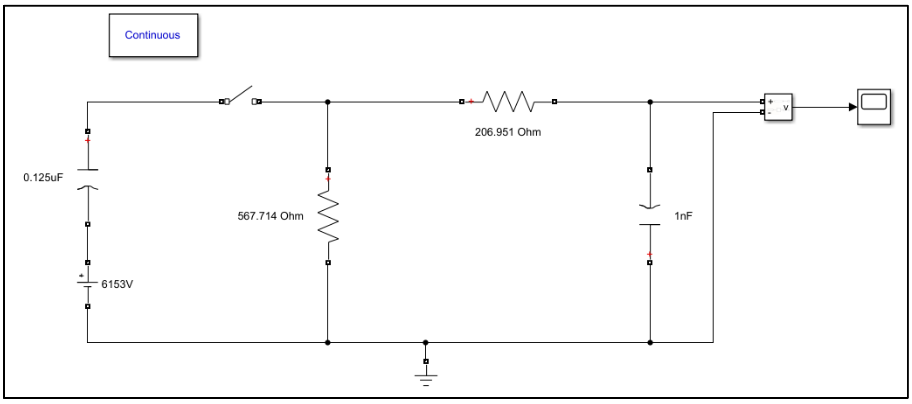

Figure 6: Lightning surge circuit develops in MATLAB Simulink.

The output of the lightning surge circuit is 6kV impulsive transient as shown in Figure 7. By following the IEEE standard this lighting surge circuit generates 1.2/50µs impulsive transient. The lightning surge circuit will be the subsystem to the MATLAB Simulink and injected into the steady state circuit.

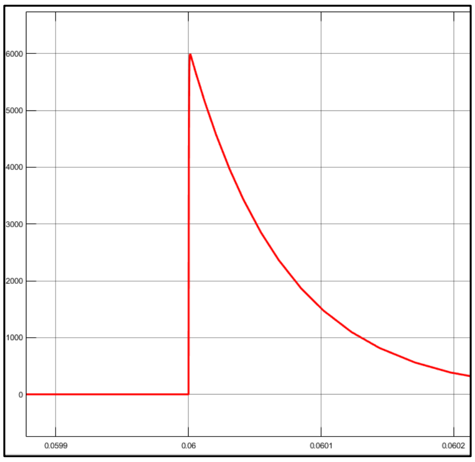

Figure 7: Standard impulsive transient of 6kV (1.2/50µs).

In this condition, the result shows the injected impulsive transient at 0.06 seconds as shown in Figure 8. The voltage peaks from 230V to 280V at 0.06s. The impulsive transient resolve after 50µs. This impulse is so dangerous that if it is not mitigated it will cause electronic components damaged at can melt or crack. Damaged electronic components are extremely costly to repair or replace.

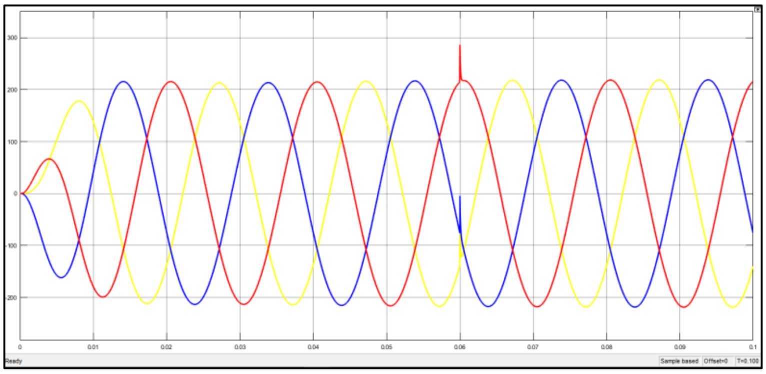

Figure 8: Output voltage waveform due to injected lightning.

3.3 Mitigate condition

After MOV-based Type 2 SPD is connected to the circuit, there is no impulsive transient occurring at 0.06s output voltage waveform. Figure 9 shows the output voltage waveform due to injected SPD. The overvoltage from impulsive transient has been mitigated. SPD discharge the overvoltage from the circuit to the ground. The result of the output waveform same as the steady state condition.

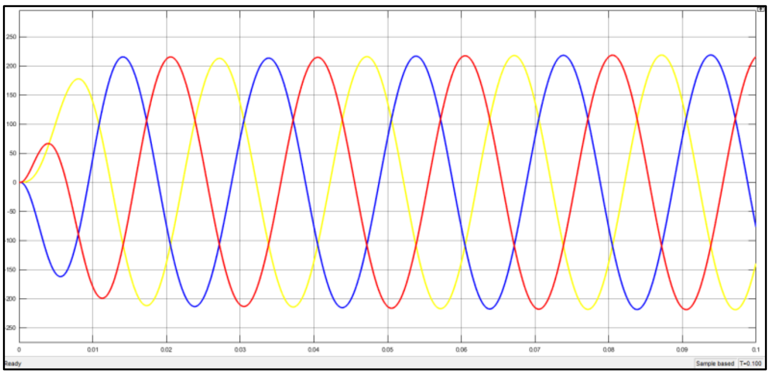

Figure 9: Output voltage waveform with connected SPD.

3.4 Comparison voltage between all test case conditions

Table 4 shows the comparison voltage between all test case conditions. The value of comparison monitors at 0.06s of the system simulated. Based on the result, during the transient state, there is an increment of voltage to 280V. After SPD is connected to the system, the impulsive transient does not occur because protected by SPD. The waveform and voltage of mitigate state condition same as the steady state condition.

Table 4: Comparison of voltage between all test case conditions.

	Steady-state	**Transient state**	**Mitigate state**
Voltage	230V	280V	230V

4. Conclusion

In conclusion, all the objectives were successfully achieved. Firstly, the identification of the PQ problem related to the lightning effect on the PV system. Impulsive transient is the most happen during lightning. After that, the test case steady-state circuit of the PV system is designed and used in this project. The PV system creates a 230V output voltage system. For test cases, lightning surge circuits are designed with a combination of RC circuits. The mathematical model is designed to create an impulsive transient of 6kV 1.2/50μs as defined by IEEE standard impulsive transient characteristics. The lightning surge circuit is injected into the steady state circuit as the PQ problem. Lastly, the test case mitigation technique sued MOV-based Type 2 SPD. The SPD connected parallel to the load to the ground. The SPD is able to discharge overvoltage to the ground. As a result of the project, the SPD can mitigate impulsive transient well.

Acknowledgement

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