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A Study on the Performance Analysis of Photovoltaic System with Digital Surge Detection device

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Abstract

This paper examines the performance improvement of a photovoltaic power generation system with a surge protection function by applying a digital surge detection device for surge suppression in a direct current distribution panel applied to a photovoltaic power generation system. The main components used for surge protection are mainly SAD, MOV, and GTA components, and a digital surge detection device was additionally applied to this. Each component has advantages and disadvantages in terms of performance and functionality for surge protection, so a surge protection device with meaningful performance and functionality must be designed in a complex device structure that harmonizes the advantages and disadvantages of each component in order to construct a surge protection device with meaningful performance and function. Through empirical experiments, a performance analysis of a complex surge detection device to which a digital surge detection device is applied was conducted. As a result of the experiment, through absorption and blocking of surges detected through a digital surge detection device, it has both absorption and blocking performance for surges and exhibits surge absorption characteristics for hundreds of voltages in micro second. This performance showed a relatively stable state against surge noise compared to conventional devices, which produced an output waveform of stable quality in the inverter output waveform.

Keywords: *photovoltaic system, digital surge protection device, junction box, DC surge protection, thunder volt, degradation, power filter, solar power*

1. Introduction

As the demand for renewable energy increases, interest and use of DC surge protection devices in photovoltaic systems are increasing. One of the important factors that ensure the safety and lifespan of photovoltaic system facilities is to protect the photovoltaic system from any power surge, and DC surge protection is designed and reflected to protect the photovoltaic system from the occurrence of events, which are risk factors for such potential damage [1-3]. Surges can be caused by various events such as lightning

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strikes, power grid interruption, and large-scale electrical load conversion in buildings. These surges can cause serious damage to solar panels, inverters, and other system components, resulting in high failure and high maintenance costs [4, 5].

Surge is defined as an electrical current, voltage, or transient waveform of power (IEC IEV 161-02-01) that is transmitted via a power line or power circuit and has characteristics that increase rapidly and gradually decrease. In a DC circuit including a coil, the magnetic line of the coil changes due to the switching action, and the transient voltage that changes severely in a short period of time is a high voltage induced to interfere with the change in this magnetic line. It appears in the form of an abnormal voltage induced by lightning to a transmission line. Surge voltage is an impact current such as lightning, switching, charging/discharging. It refers to the form of a voltage or current that causes severe waveform changes in a short period of time, and experimental regulations are defined through research and development based on the measurement results that have occurred so far by related organizations such as UL, IEC, and IEEE. In particular, the life and reliability of power devices or home appliances are important items in constructing new circuits or selecting parts to suppress surges. IEC61000-4-5 defines a representative surge voltage, and the voltage waveform is 1.2us as an increase rate, 50us as a fall rate (1.2/50[μs]), the current size is 8us as an increase rate, 20[μs] as a fall rate (8/20[μs]), and the combination of voltage and current waveforms is defined as a combination waves [16, 17, 18].

In alternating current power applications, surge voltage usually refers to a state that is 5-6% higher than the usual supply voltage range. It is expressed as a sinusoidal waveform of AC voltage and generally disappears after lasting about 8 cycles, but if the voltage increase lasts longer than 8 cycles, it is classified as over voltage. In addition, voltage rise phenomena in the form of impulses or spikes that rise 5 to 10 times higher than normal voltages during the time period of nanosecond, microsecond, and millisecond are called transient surge voltages. The transient surge voltage of the impulse is analyzed as peak voltage, waveform, and rise time. Transient surge voltages such as voltage impulse and spike have a high frequency characteristic, so it can easily jump from the primary side of the transformer to the secondary side, and once they break into the electronic circuit of the equipment, they can cause fatal damage to semiconductor components [6-9].

This paper is a study on improving the performance of a photovoltaic power generation system with a protective function against surges by applying a digital surge detection device for surge suppression in a direct current distribution panel applied to a photovoltaic power generation system. The performance of the conventional method was compared and analyzed, including a digital surge detection device designed in addition to the configuration of a standardized surge protection device. This can ensure high reliable power quality by detecting and bypassing surge voltages in direct current circuits and suppressing surges by using the troidal coil. In the configuration of the proposed system, the main components used for surge protectors include Silicon Avalanche Diode(SAD), Metal Oxide Varistor(Mov), and Gas Tube Arrestor(GTA), and a digital surge detection device was additionally applied to this. Each component has advantages and disadvantages in terms of performance and functionality for surge protection, so when designing a surge protector, a surge protector with meaningful performance and function must be designed with a complex device structure that harmonizes the advantages and disadvantages of each component.

2. Connection Panel Design of Grid-Connected Photovoltaic System

2.1 KS C 8567 for junction box integrated inverter

KS C 8567 standard stipulates evaluation criteria and test methods for performance inspection of solar cell array accessories, including opening and closing devices and control device accessories, which are mainly used in standalone or grid-connected solar power generation systems. According to the regulations, since the diode installed to prevent backflow does not have an overcurrent and overvoltage blocking function and may cause a fire in the solar power access box due to heat generation, attaching the diode to the solar power access box is defined as an option, not an essential one [10]. Fuses with quick-acting properties to direct current should be installed on the positive and negative sides of individual string circuits, respectively, but should be able to be checked through a warning sound or lamp when fuses are consumed. It is intended to prevent damage caused by the reduction of power generation by easily recognizing whether the fuse has been consumed by general users and replacing it immediately. As such, it is being used with a focus on setting standards to remove the cause of fire within the access board by direct current power output from the solar power generation array and preventing damage to solar power users. Figure 1 shows the connection of photovoltaic power generation facilities with multiple arrays from the safety facilities presented in the IEC 1146/02 standard [11, 12].

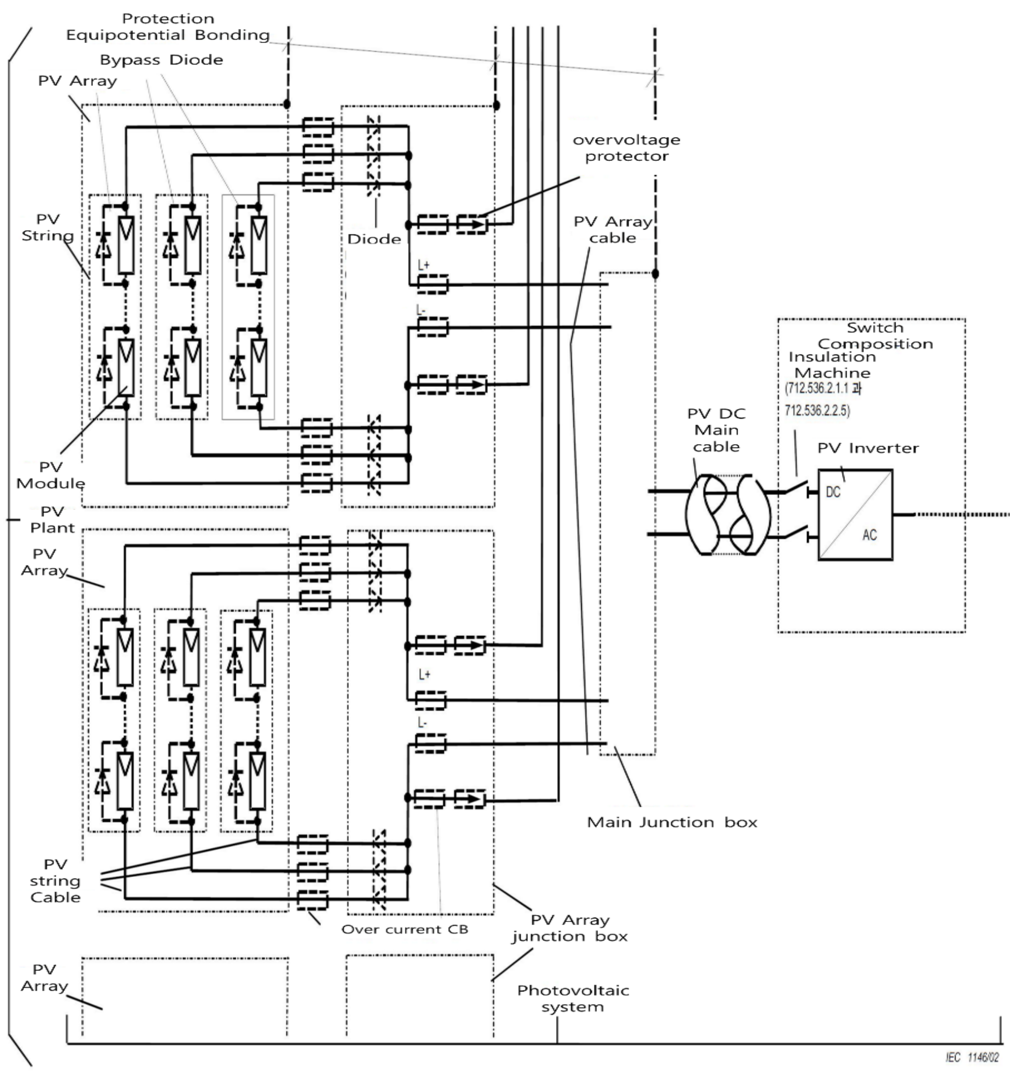


Figure 1. Connection Diagram of Photovoltaic Power Generation Facilities with Multiple Arrays

The quality standards of the junction box can be largely divided into four requirements: the strength of materials and parts, the protection level(IP) provided by the junction box, the space distance and the surface distance, and the opening and closing device and components. Protection parts and contents for surges such as protection ground, DC fuse, switch, anti-return diode, surge protection device, and terminal are included in the opening and closing device and components. Based on these contents, the matters related to surges are summarized in Table 1 [13, 14, 15].

Table 1. Classification of Protection Technologies for Surge of Solar Power Connection Box

Classification	Category	Key Features	Application
Classification by Surge Prevention Method	Discharge -typed Surge Prevention Device	- When a surge is introduced, it is momentarily conductive and current flows to the surge arrester, resulting in a drop in voltage - Gas tube, air gap, etc., which are discharge elements, are used	Mainly used for protection of power systems such as lightning strikes
	Inhibitory -typed Surge Prevention Device	- Very low impedance for surges exceeding operating voltage - Devices such as MOVs, semiconductors, and diode with nonlinear voltage and current characteristics are used - Quick response and excellent surge absorption capability for precision equipment protection	50 kA or greater surge prevention
	Combination -typed Surge Prevention Device	- Combining a high-speed suppression type and a high-capacity discharge type to control fast and large surges in small volumes	
Classified by Installation Method	Serial-typed Surge Prevention Device	- High impedance, noise filtering capability, and prevents harmonic current from non-linear loads from flowing to the system or device	Used for systems or devices that require stable power for small capacity
	Parallel-typed Surge Prevention Device	- Low impedance	Used for high-capacity power supplies such as Main-Panel, Sub-Panel, etc
Classification by Element of Use	Gap-typed Surge Prevention Device	- At a constant voltage, the gas between the pores is ionized, resulting in flame discharge	A line of communication

	Semiconduct-typed Surge Prevention Device	- Using electronic avalanche phenomenon, etc	Varistor and zener diode
	Filter-typed Surge Prevention Device	- CR Snubber	Power circuit

2.2 Multistage Surge Protection Circuit

When a surge voltage occurs, the TVS diode is the fastest response component, and the discharge current flows through the TVS diode and the upstream decoupling resistor. A voltage drop occurs by the decoupling resistor, which corresponds to the difference between the response voltage of the TVS diode and the GDT. Figure 2 shows the voltage division circuit in the two-stage protection circuit. Here, the response voltage of the gas encapsulation surge protection device, is the clamping voltage of the suppressor diode, and is the differential mode voltage through the decoupling resistor [16].

In the existing method, the surge protection circuit applied to the photovoltaic power generation system is composed of a multi-stage complex structure. Silicon Avalanche Diode(SAD), Metal Oxide Varistor (MOV), and Gas Tube Arrester(GTA) are the main parts used for surge protectors [17]. Each component has advantages and disadvantages in terms of performance and functionality for surge protection, so when designing a surge protector, it is necessary to design a complex device structure that harmonizes the advantages and disadvantages of each component to construct a surge protector with meaningful performance and function.

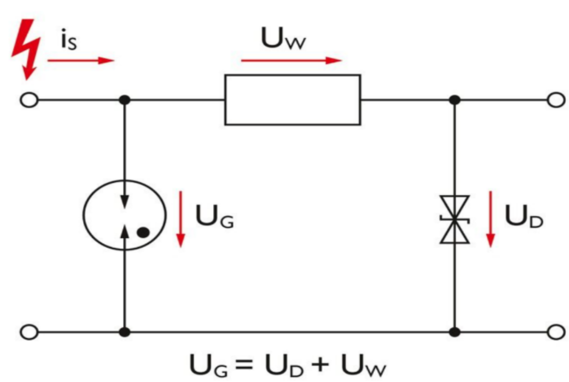


Figure 2. Voltage Distribution in the Step 2 Protection Circuit

This multi-stage surge protection method reaches the response voltage of GDT before the TVS diode is overloaded by the surge current, and when GDT responds, it means that almost the entire discharge current has passed through GDT. The residual voltage through GDT is a maximum of 20 [V], which mitigates the TVS diode, and if the discharge current is low and does not overload the TVS diode, GDT does not respond. Surge protector elements operate in accordance with the characteristics of each response to surges to protect the device from surges or sparks [18]. Figure 3 shows the surge protection characteristics according to the application of the multi-stage surge protection method.

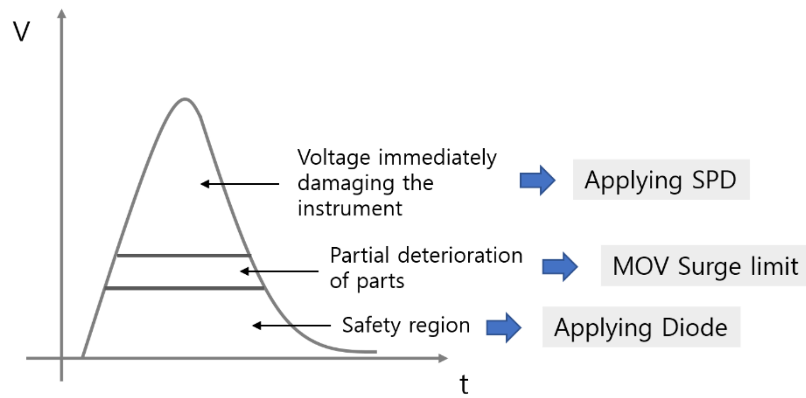


Figure 3. Surge Protection Characteristics of Multi-Step Method Application

2.3 Digital Surge Detection Device

When designing a surge protector for surge protection, the junction box constructed through components previously used for a multi-stage surge protector is designed and applied as a multi-stage system that harmonizes the strengths and weaknesses of each component to constitute a surge protector with high performance and function. A digital surge detection device can be added to this to design a junction box in a complex manner to increase the stability of DC power reception. The digital surge detection device includes surge generation and detection functions through signal detection that checks the operation state of the protection function, thereby promoting convenience. Due to the characteristics of digital devices, it has advantageous features for storing and calling the results of monitoring the state of input power.

Figure 4 shows the configuration of the distribution panel of the existing method. In the conventional distribution panel, there is no reverse voltage prevention diode that caused the fire, and it is composed of SPD, GDT, and MCCB.

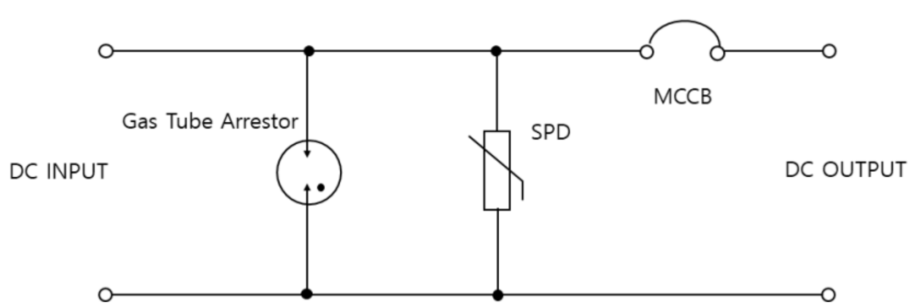


Figure 4. Conventional Distribution Panel Configuration

Figure 5 is an apparatus configuration diagram of a distribution panel of a photovoltaic system having a digital surge detection device. A toroidal coil is used to detect and bypass surges. A detection coil that outputs an induced current induced by a surge current and a detection voltage is generated by converting the induced current into a voltage, and a waveform voltage deformed through a sample & hold of the voltage waveform of the detected voltage is detected with respect to the time axis. A method of calculating a current value of a surge current from the detected voltage value, calculating a surge current value, and processing data is applied.

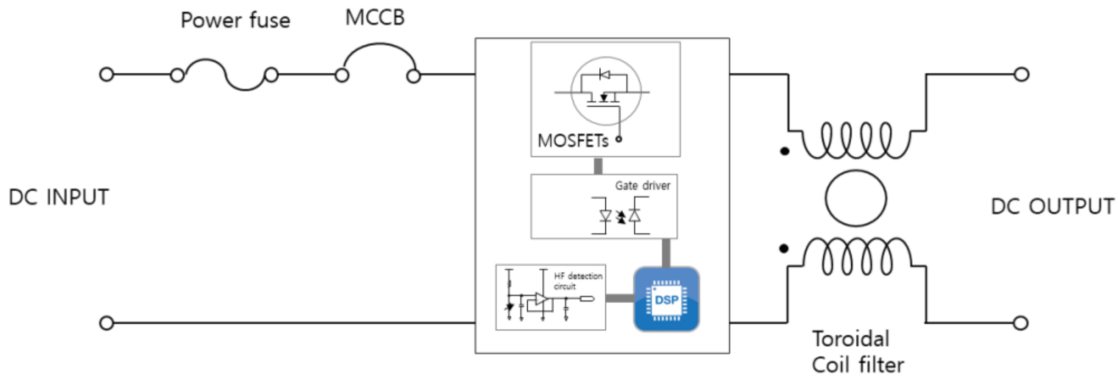
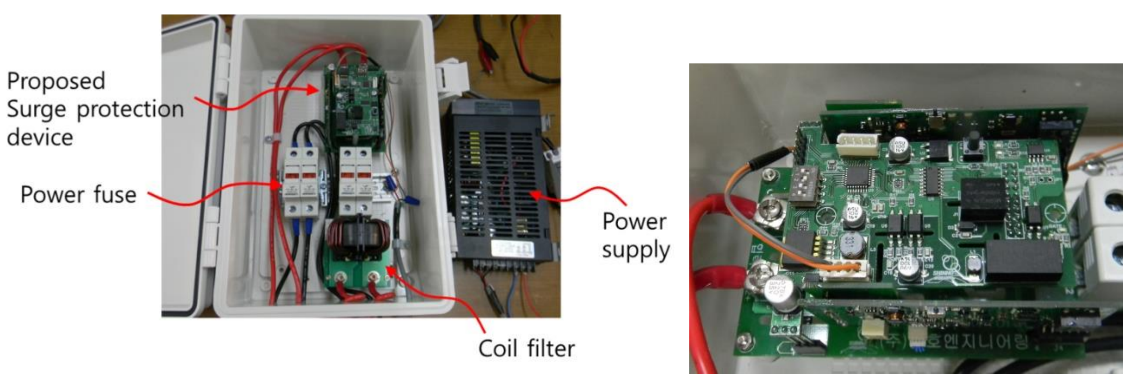


Figure 5. Configuration Diagram of Distribution Panel with Digital Surge Detector

In the surge blocking device to which the digital surge detection device is applied, arc detection and blocking is configured to detect the arc generation by applying a semiconductor switch and a DSP to detect the signal in a specific frequency band 40-100 [KHz] according to the arc generation. The electronic switch in the arc blocking unit was opened to block the electrical connection with the inverter of the photovoltaic power generation device and prevent fire. The line blocking time after arc detection is designed to have the function of absorbing and blocking through internal calculation and real-time processing using DSP technology. Figure 6 shows a picture of the device configuration of the junction box with a digital surge detection device and consists of a DSP board for digital surge detection, a power fuse, a toroidal coil filter, and a power supply.



(a) Connection Board with Digital Surge Detection Device **(b) DSP Surge Detection Device**

Figure 6. A Photo of a Distribution Panel with a Digital Surge Detector

The L filter for radiation noise blocking has an inductance value of 1.6 [μF] to a coil with a coefficient of 12 turns in the ferrite core, the time constant was measured as 7.8 seconds, and it was calculated to have a time constant of sufficient size for energy charging and discharging. Equations (1) and (2) represent equations of when a current flow through an inductance L and of a discharge current, respectively.

$$I = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right) \ [A] \qquad (1)$$

$$I = \frac{E}{R}e^{-\frac{R}{L}t} \ [A] \qquad (2)$$

In the L filter, the inductance L becomes high impedance according to a sudden change in current containing noise, and the flowing current continues to be low. When discharging, the time constant τ is caused by L/R, which generates electromotive force in the inductance according to the change in magnetic flux due to the decrease in the current in the inductance at the point of lapse, and the current continues to flow in the direction that was flowing in the normal state, and the current decreases along with the emission of electromagnetic energy.

3. Performance Experiment Results

3.1 Configuration of the System

The photovoltaic array for configuring the photovoltaic power generation system is a product of Hansol, and the model name is HS360UD-AN1 product was connected to the connection panel by forming a circuit in 10 series. The output direct current was connected to an inverter and connected to a system in a typical type of grid-connected photovoltaic power generation system. The specifications of the single crystal silicon solar cell module applied for the experiment are shown in Table 2.

Table 2. Performance Specification of Solar Cell Module

Category	Value	Unit	Note
Maximum Output	360	W	±5%
Maximum Output Operating Voltage	39.7	V	
Maximum Output Operating Current	9.07	A	
Open Voltage	47.4	V	
Short Circuit Current	9.67	A	
Maximum System Voltage	1500	V	
Fuse Rating	20	A	
Fire Rating	Class C	-	
KS Specification Number	KS C 8561	-	

The photovoltaic array for the experiment is installed at 35°09'35 ″ in north latitude and 126°51'08 ″ in longitude. Figure 7 is a picture of the photovoltaic module array for the experiment.

Figure 7. Field Pictures of Photovoltaic Module Arrays for Demonstration Experiments

The experiment was conducted in the form of a comparative analysis between the existing system and the proposed system. For comparative experiments, two sets of junction boxes were installed under the same conditions, and performance tests were performed, and Figure 8 is a photograph of the junction box installed for comparative analysis.

Figure 8. A Photo of the Installation of the Existing Connection Panel and the Connection Panel with the Digital Surge Detector

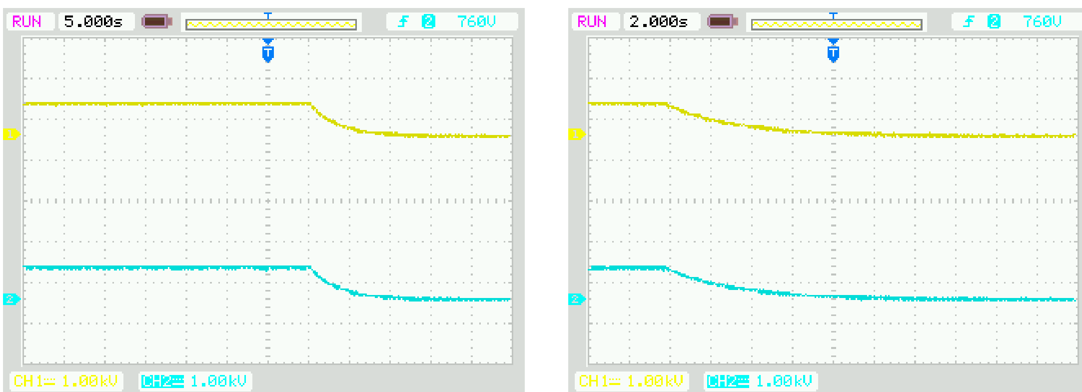
3.2 Experimental Results

In the operation experiment of the conventional connection panel and the connection panel having a digital surge detection device, the voltages at the input(Ch1) and output(Ch2) terminals of the photovoltaic array output voltage were measured and shown in Figure 9. The normal input/output voltage was observed in both types of junction boxes to be compared. The input/output voltage is 400 [Vdc].

(a) Conventional access board (b) Connection Board with Digital Surge Detection Device

Figure 9. Comparison of Steady State Input/Output Voltage Waveforms

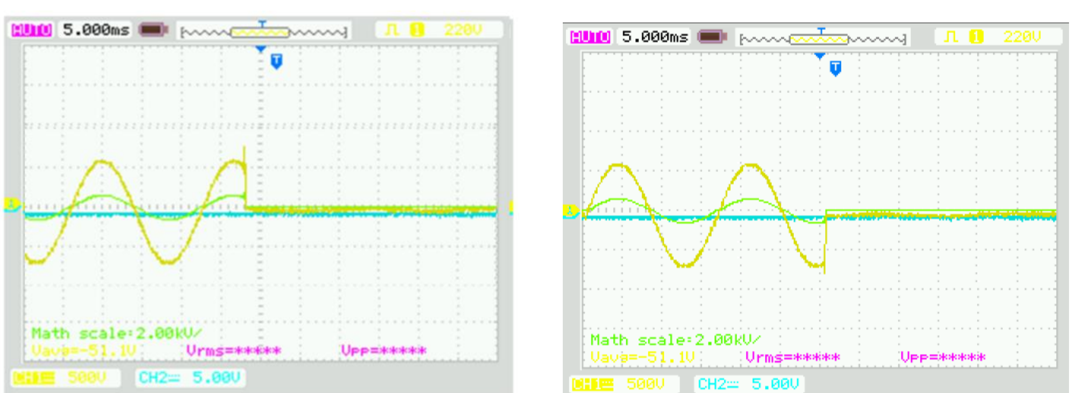
Figure 10 shows the input/output waveform of the junction box when forced off. Unlike the input/output waveform of the conventional junction panel, the junction panel with the digital surge detection device showed a phenomenon in which energy was stored and discharged in the switch-off operation due to the influence of the filter included when the switch was forcibly shut off. As shown in the output waveform of the junction panel with the digital surge detection device, the toroidal coil for surge detection simultaneously serves as a noise filter. The accuracy of arc detection in the proposed surge detection device is also improved by constructing a noise filter between the DC plus side line of the photovoltaic module array and the inverter and removing low-frequency noise(0-400[Hz]) that can be introduced from the inverter during operation.



(a) Conventional access board (b) Connection Board with Digital Surge Detection Device

Figure 10. Compare Switch Forced Cutoff Waveforms after Applying Input Power

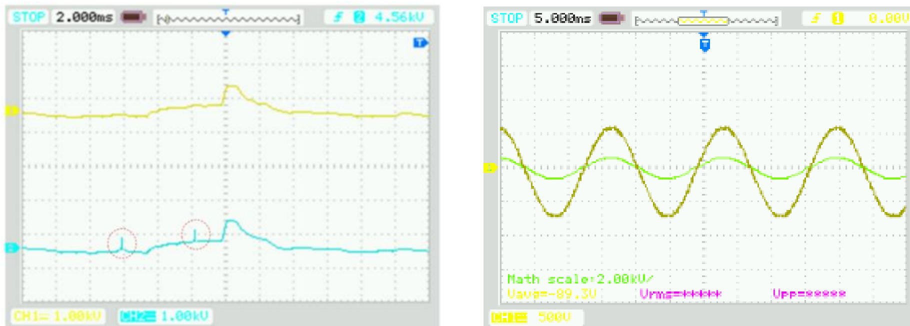
Figure 11 shows a comparison of the inverter output waveform when the system is turned off. When compared with the existing method at the time of turn-off in the case of having a digital surge detection device, noise is detected and blocked.



(a) Conventional Access Board (b) Connection Board with Digital Surge Detection Device

Figure 11. Inverter Output Waveform Comparison when System is turned off

Figure 12 shows the 20[μS] operating characteristics waveform and steady-state inverter output waveform of surge absorption when the noise signal is applied. The state of absorbing and outputting a noise voltage of 200V level, which is a small surge voltage below the applied voltage, at a time of several μS(frequency of several kHz), can be confirmed through the output waveform.



(a) Surge Absorption Operation Characteristics (b) Steady-state Inverter Output Waveform

Figure 12. 20[uS] Operation Characteristic Waveform and Steady-state Inverter Output Waveform of Surge Absorption when Noise Signal is Applied

4. Conclusion

The performance analysis of a complex surge detection device to which a digital surge detection device is applied was conducted through empirical experiments. As a result of the experiment, through the absorption and blocking processing of surges detected through the digital surge detection device, it has both absorption and blocking performance for surges and exhibits surge absorption characteristics for surges with a voltage of several hundred voltages in microsecond. This performance showed a relatively stable state against surge noise compared to the conventional device, which produced an output waveform of stable quality even in the inverter output waveform. In addition, arc detection and blocking in the digital surge detection device is configured to detect the arc by applying a semiconductor switch and DSP to detect the arc generation by detecting a signal in a specific frequency band 40-100 [KHz] according to the arc generation. It is judged that the electronic switch in the arc blocking part can play a role in blocking the electrical connection with the inverter of the photovoltaic power generation device and preventing fire. Since the detected surge has a noise inflow blocking effect through the toroidal coil filter at the front end of the inverter, it is expected to have a good effect on power quality.

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