US009322881B2

(12) **United States Patent**
Sakurai et al.

(10) **Patent No.:** **US 9,322,881 B2**
(45) **Date of Patent:** **Apr. 26, 2016**

(54) **PARTIAL DISCHARGE MEASUREMENT SYSTEM AND PARTIAL DISCHARGE MEASUREMENT METHOD BY REPEATED IMPULSE VOLTAGE**

(71) Applicants: **TOSHIBA MITSUBISHI-ELECTRIC INDUSTRIAL SYSTEMS CORPORATION**, Tokyo (JP); **KABUSHIKI KAISHA TOSHIBA**, Tokyo (JP)

(72) Inventors: **Takayuki Sakurai**, Tokyo (JP); **Hiroyuki Ogawa**, Tokyo (JP); **Tetsuo Yoshimitsu**, Tokyo (JP); **Tatsuya Hirose**, Inagi (JP); **Satoshi Hiroshima**, Kawasaki (JP)

(73) Assignees: **TOSHIBA MITSUBISHI-ELECTRIC INDUSTRIAL SYSTEMS CORPORATION**, Tokyo (JP); **KABUSHIKI KAISHA TOSHIBA**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 48 days.

(21) Appl. No.: **14/384,759**

(22) PCT Filed: **Mar. 13, 2013**

(86) PCT No.: **PCT/JP2013/001674**
§ 371 (c)(1),
(2) Date: **Sep. 12, 2014**

(87) PCT Pub. No.: **WO2013/136793**
PCT Pub. Date: **Sep. 19, 2013**

(65) **Prior Publication Data**

US 2015/0015303 A1 Jan. 15, 2015

(30) **Foreign Application Priority Data**

Mar. 14, 2012 (JP) 2012-057197

(51) **Int. Cl.**
G01R 31/34 (2006.01)
G01R 31/14 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01R 31/343*** (2013.01); ***G01R 19/0084*** (2013.01); ***G01R 31/14*** (2013.01); *G01R 31/1272* (2013.01)

(58) **Field of Classification Search**
CPC .. G01R 31/14; G01R 31/343; G01R 31/1272; G01R 19/84
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,648,725 A 7/1997 Divljakovic et al.
5,963,410 A 10/1999 Iijima et al.
(Continued)

FOREIGN PATENT DOCUMENTS

DE 102 26 615 A1 1/2004
JP S 59-52410 4/1984
(Continued)

OTHER PUBLICATIONS

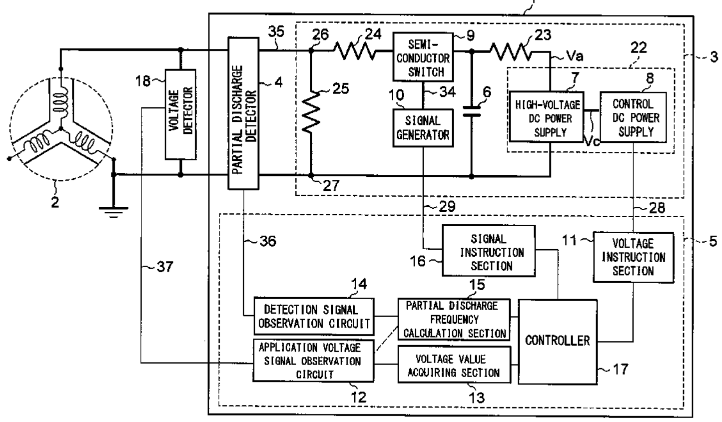
Extended European Search Report issued Oct. 9, 2015 in Patent Application No. 13761865.8.
(Continued)

Primary Examiner — Minh N Tang
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

An impulse voltage generator uses a predetermined rectangular waveform signal and a high voltage to generate an impulse voltage. The high voltage is obtained by boosting an instruction voltage of the rectangular waveform signal on a per-cycle basis. A partial discharge frequency calculation section receives detection signals based on partial discharges occurring in an object to be measured by the application of the impulse voltage and counts the detection signal on a per-cycle basis as a partial discharge frequency. An application voltage signal observation circuit observes an application voltage signal indicating the impulse voltage applied to the object to be measured. In a first cycle in which the partial discharge frequency reaches a specified frequency or more, a voltage value acquiring section sets, as a partial discharge starting voltage, the peak value of the voltage indicated by the application voltage signal output from the application voltage signal observation circuit.

10 Claims, 20 Drawing Sheets



(51) **Int. Cl.**

G01R 19/00	(2006.01)
G01R 31/12	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,051,980	A	4/2000	Divljakovic et al.	
6,242,900	B1 *	6/2001	Fawcett	G01R 31/12 324/520
6,313,640	B1 *	11/2001	Nasrallah	G01R 31/1272 324/522
2011/0320146	A1 *	12/2011	Watanabe	G01R 31/343 702/65

FOREIGN PATENT DOCUMENTS

JP	8-204455	A	8/1996
JP	9 257862		10/1997
JP	10-335089	A	12/1998
JP	2002-169200	A	6/2002
JP	2003-219677	A	7/2003
JP	2006 38471		2/2006
JP	2006-38688	A	2/2006
JP	2009 115505		5/2009
JP	2010-281673	A	12/2010
WO	WO 2009/013640	A1	1/2009

OTHER PUBLICATIONS

K. Kimura, et al., "Round-Robin Test on Repetitive PD Inception Voltage of Twisted-Pairs" 2010 Annual Report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), IEEE, XP031986216, 2010, 4 pages.

Office Action issued on Jul. 14, 2015 in Japanese Patent Application No. 2012-057197.

Kimura, K., et al."The First Round-Robin Test for Repetitive Partial Discharge Inception Voltage (RPDIV)" Institute of Electrical Engineers of Japan "40th Symposium on Electric and Electronic Insulating Materials and Applications in System D-1", pp. 95-98, (Aug. 2009) (with partial English translation).

Nakanishi, K., et al. "Effect of humidity and atmosphere pressure on repetitive partial discharge inception voltage (RPDIV) obtained by automatic measurement system", Institute of Electrical Engineers of Japan "40th Symposium on Electric and Electronic Insulating Materials and Applications in System P-7", pp. 175-176, (Aug. 2009).

International Search Report Issued May 7, 2013 in PCT/JP13/001674 Filed Mar. 13, 2013.

International Preliminary Report on Patentability and Written Opinion issued Sep. 25, 2014 in PCT/JP2013/001674 (English Translation only).

Office Action issued Nov. 24, 2015 in Japanese Patent Application No. 2012-057197 (with English translation).

Takeshi Kamura, "IEC standards on PD inception voltage under repetitive impulses" Material for Discharge Research Workshop of Japanese Institute of Electrical Engineers, Ed. 10, 125-130, Dec. 2, 2010, pp. 13-17.

Office Action mailed Jan. 11, 2016 in Canadian Patent Application No. 2,867,198.

* cited by examiner

FIG.1

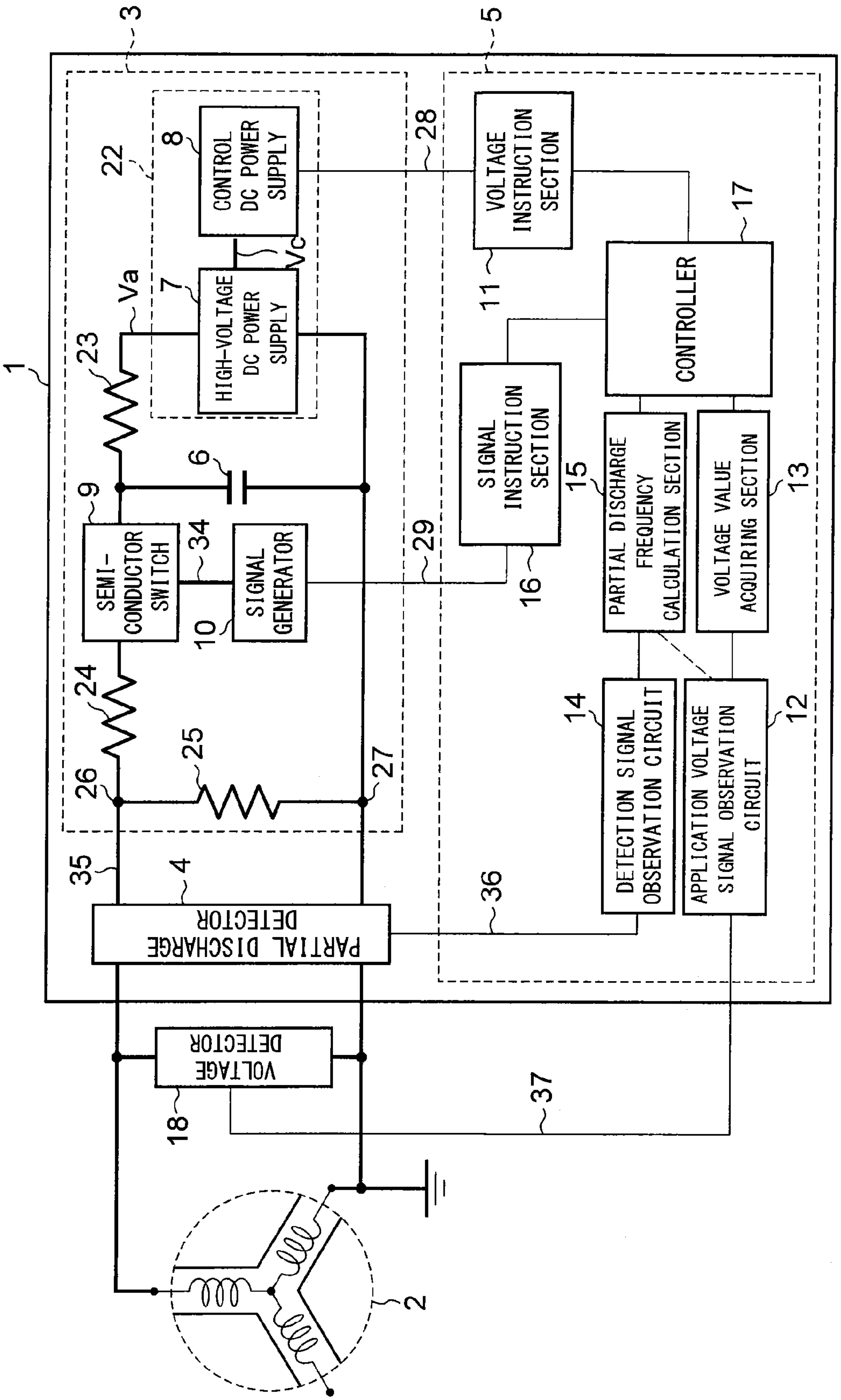

CONTROL DC POWER SUPPLY
HIGH-VOLTAGE DC POWER SUPPLY
Va
Vc
SEMI-CONDUCTOR SWITCH
SIGNAL GENERATOR
PARTIAL DISCHARGE DETECTOR
VOLTAGE DETECTOR
VOLTAGE INSTRUCTION SECTION
CONTROLLER
SIGNAL INSTRUCTION SECTION
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION
VOLTAGE VALUE ACQUIRING SECTION
DETECTION SIGNAL OBSERVATION CIRCUIT
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
22
23
24
25
26
27
28
29
34
35
36
37

FIG. 2A

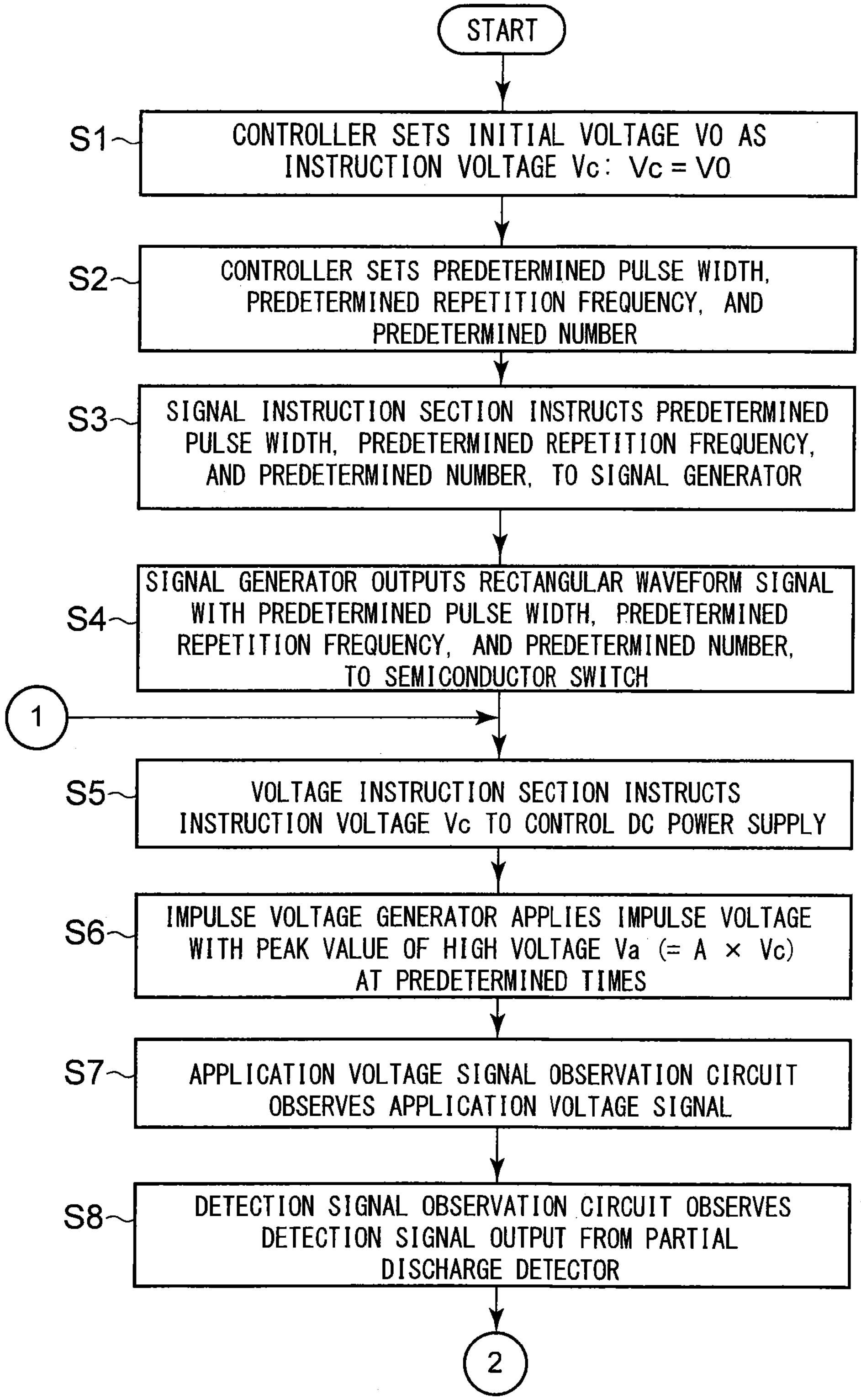

START
S1
CONTROLLER SETS INITIAL VOLTAGE V0 AS INSTRUCTION VOLTAGE Vc: Vc = V0
S2
CONTROLLER SETS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER
S3
SIGNAL INSTRUCTION SECTION INSTRUCTS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SIGNAL GENERATOR
S4
SIGNAL GENERATOR OUTPUTS RECTANGULAR WAVEFORM SIGNAL WITH PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SEMICONDUCTOR SWITCH
1
S5
VOLTAGE INSTRUCTION SECTION INSTRUCTS INSTRUCTION VOLTAGE Vc TO CONTROL DC POWER SUPPLY
S6
IMPULSE VOLTAGE GENERATOR APPLIES IMPULSE VOLTAGE WITH PEAK VALUE OF HIGH VOLTAGE Va (= A × Vc) AT PREDETERMINED TIMES
S7
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT OBSERVES APPLICATION VOLTAGE SIGNAL
S8
DETECTION SIGNAL OBSERVATION CIRCUIT OBSERVES DETECTION SIGNAL OUTPUT FROM PARTIAL DISCHARGE DETECTOR
2

FIG. 2B

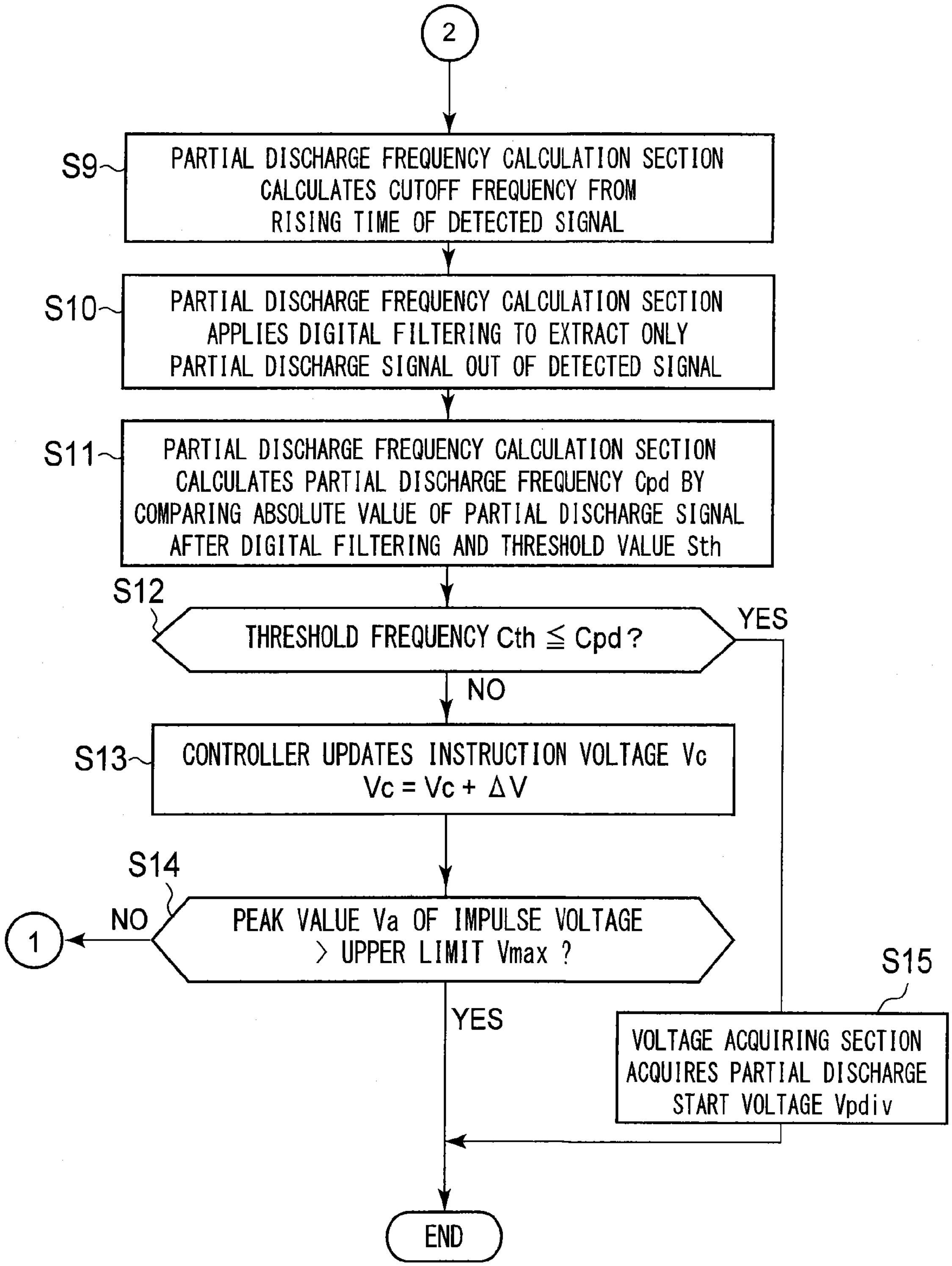

2
S9
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES CUTOFF FREQUENCY FROM RISING TIME OF DETECTED SIGNAL
S10
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION APPLIES DIGITAL FILTERING TO EXTRACT ONLY PARTIAL DISCHARGE SIGNAL OUT OF DETECTED SIGNAL
S11
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES PARTIAL DISCHARGE FREQUENCY Cpd BY COMPARING ABSOLUTE VALUE OF PARTIAL DISCHARGE SIGNAL AFTER DIGITAL FILTERING AND THRESHOLD VALUE Sth
S12
THRESHOLD FREQUENCY Cth ≦ Cpd ?
YES
NO
S13
CONTROLLER UPDATES INSTRUCTION VOLTAGE Vc
Vc = Vc + ΔV
S14
NO
1
PEAK VALUE Va OF IMPULSE VOLTAGE > UPPER LIMIT Vmax ?
YES
S15
VOLTAGE ACQUIRING SECTION ACQUIRES PARTIAL DISCHARGE START VOLTAGE Vpdiv
END

FIG. 3A

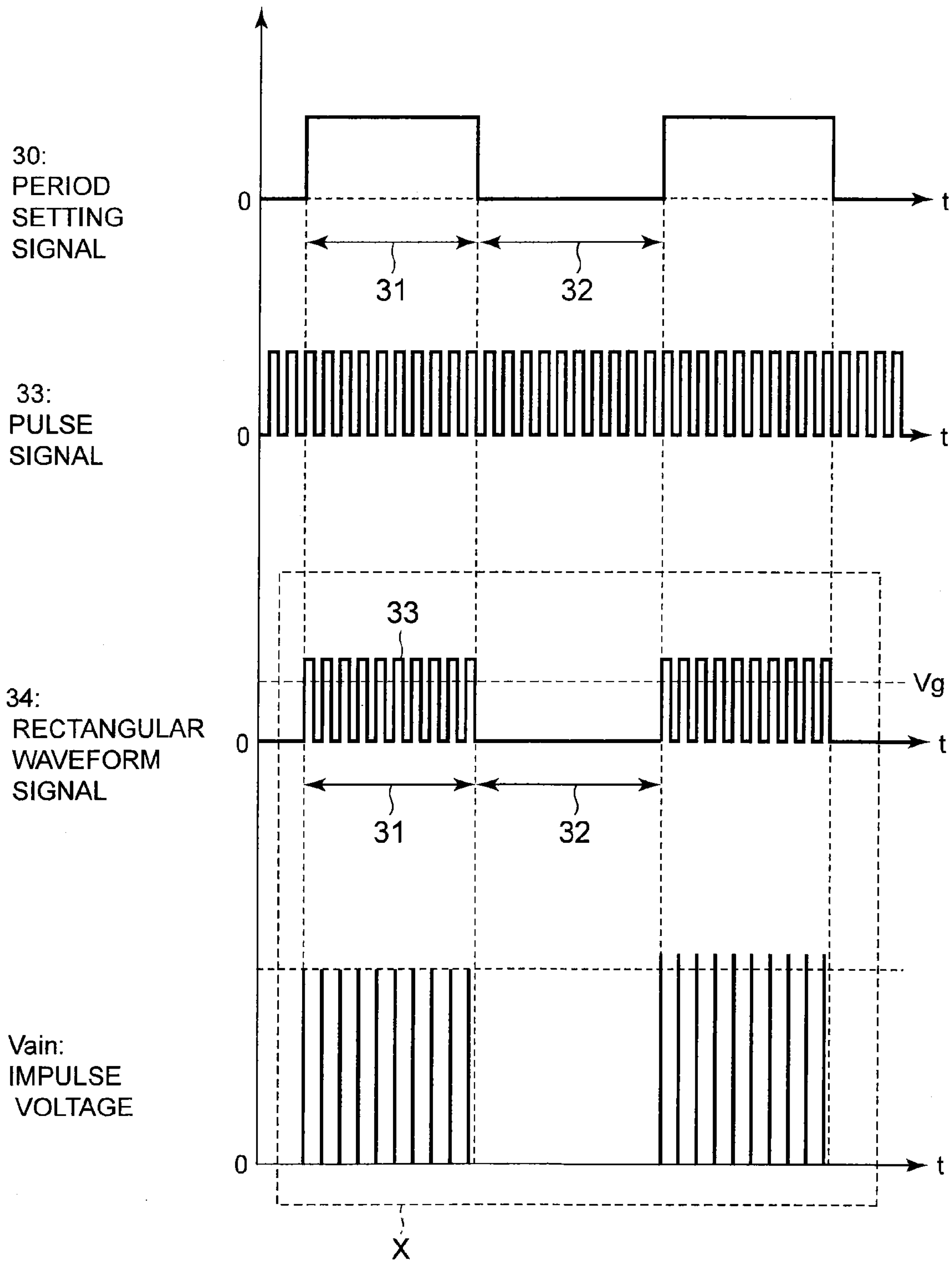

30:
PERIOD
SETTING
SIGNAL
0
t
31
32
33:
PULSE
SIGNAL
0
t
33
34:
RECTANGULAR
WAVEFORM
SIGNAL
Vg
0
t
31
32
Vain:
IMPULSE
VOLTAGE
0
t
X

FIG. 3B

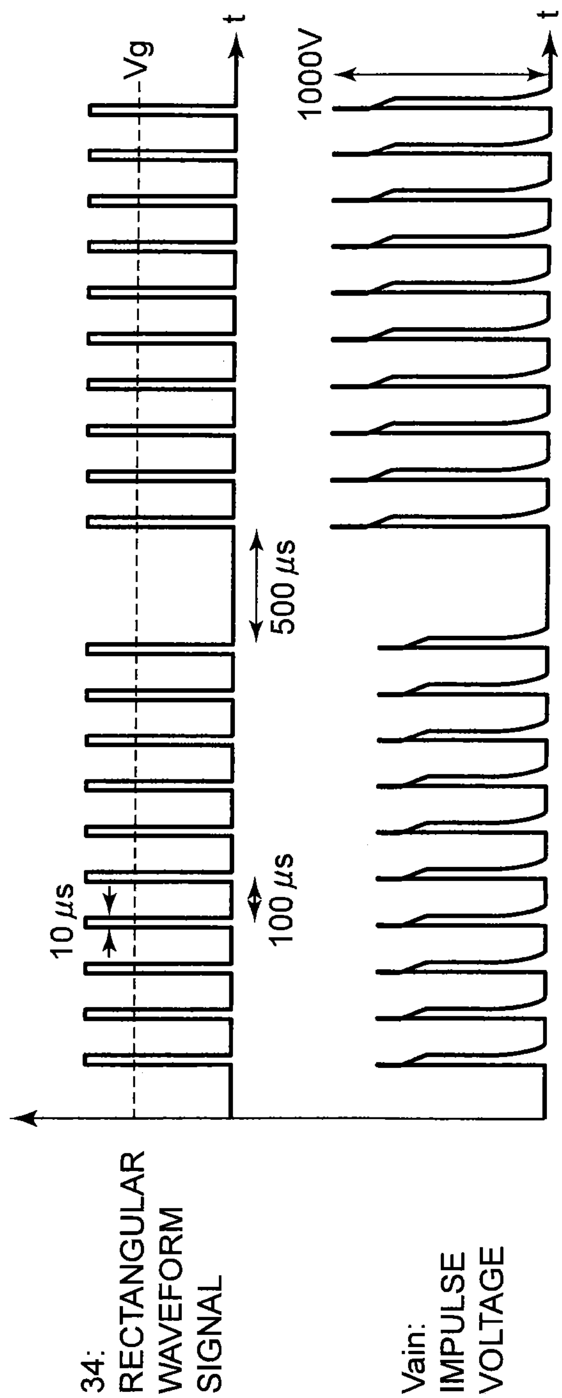

34:
RECTANGULAR
WAVEFORM
SIGNAL
Vain:
IMPULSE
VOLTAGE
Vg
t
1000V
10 μs
100 μs
500 μs
t

FIG. 4

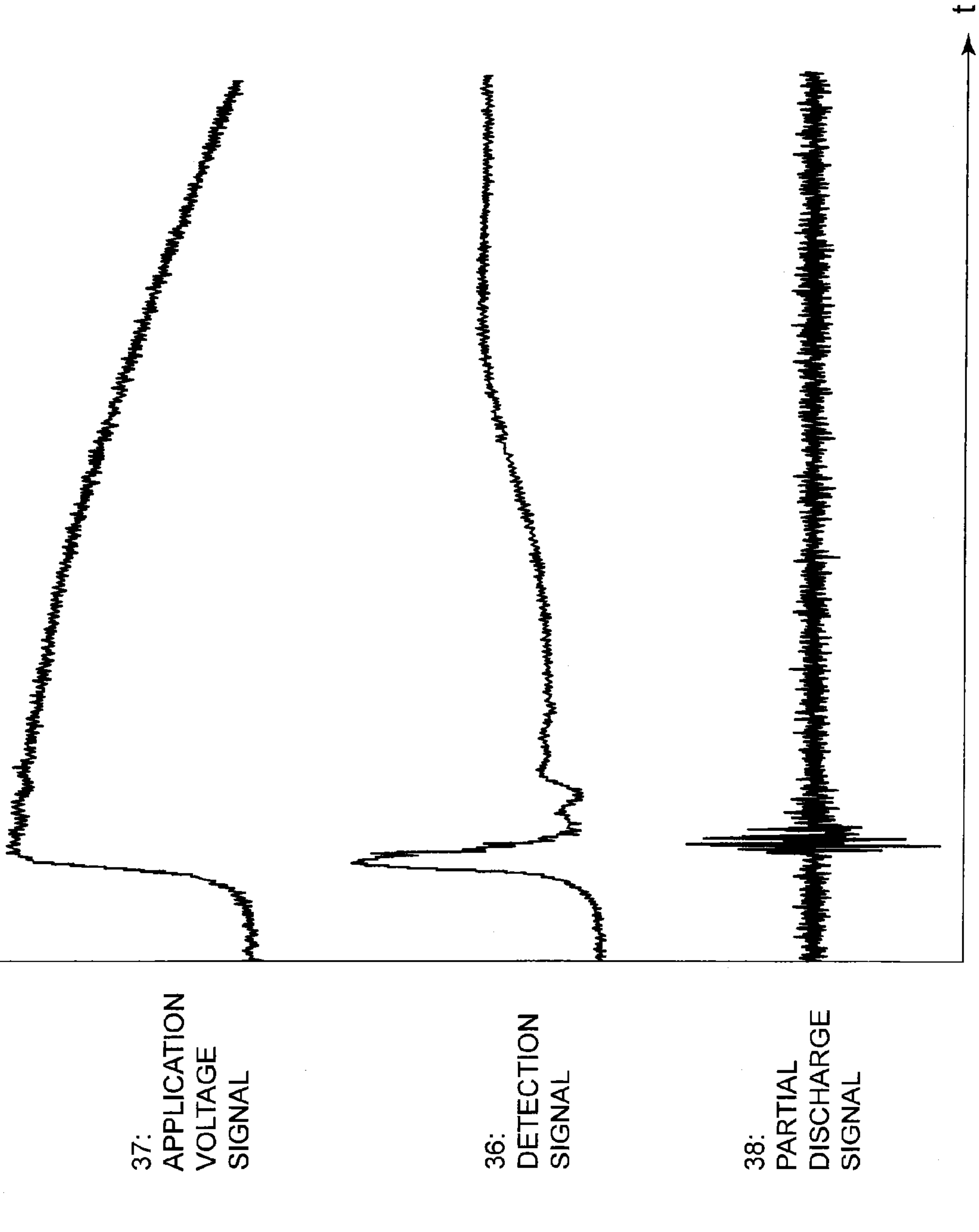

t
37: APPLICATION VOLTAGE SIGNAL
36: DETECTION SIGNAL
38: PARTIAL DISCHARGE SIGNAL

FIG. 5

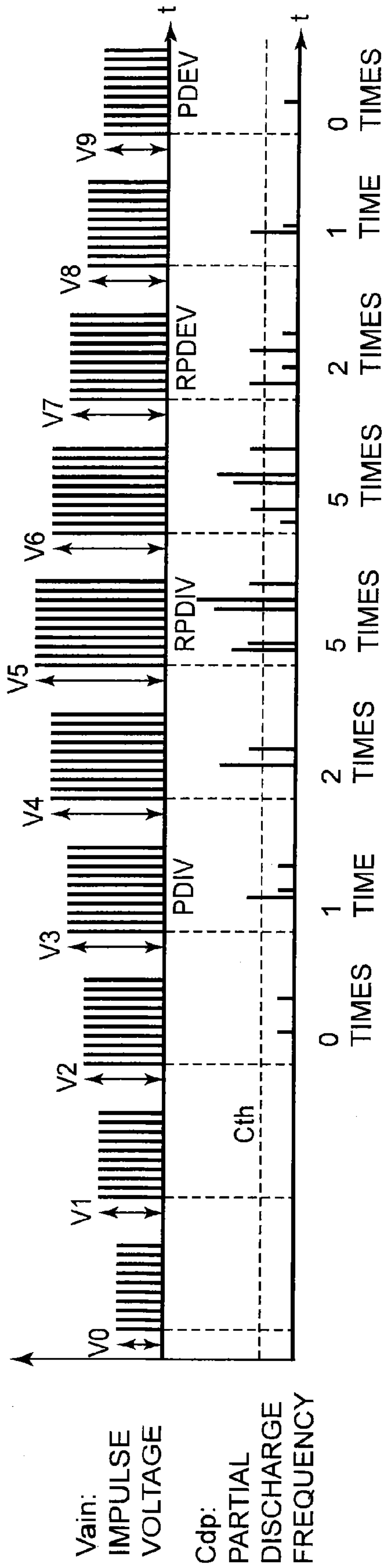

Vain: IMPULSE VOLTAGE
Cdp: PARTIAL DISCHARGE FREQUENCY
V0
V1
V2
V3
V4
V5
V6
V7
V8
V9
t
Cth
PDIV
RPDIV
RPDEV
PDEV
0 TIMES
1 TIME
2 TIMES
5 TIMES
5 TIMES
2 TIMES
1 TIME
0 TIMES

FIG. 6A

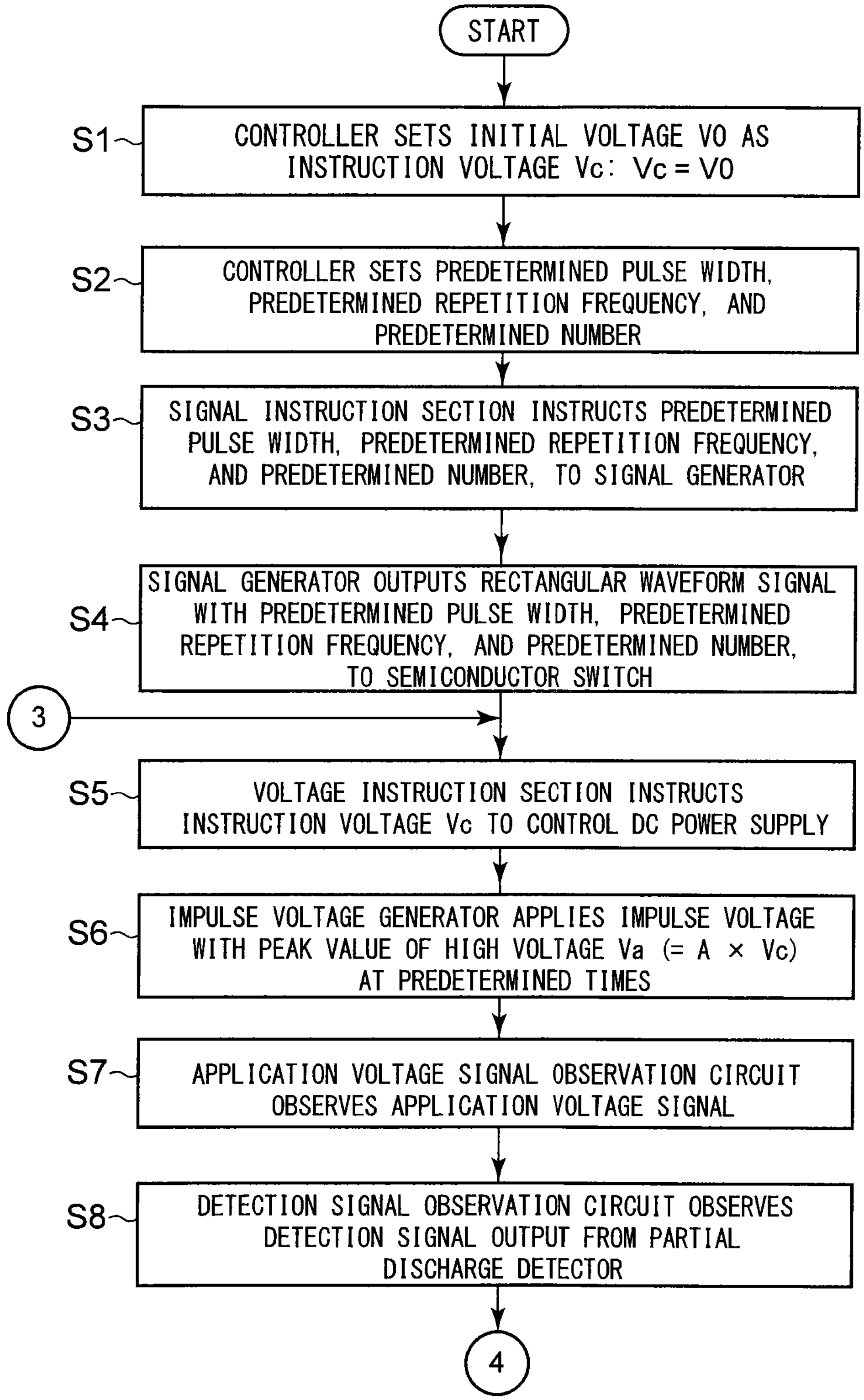

START
S1
CONTROLLER SETS INITIAL VOLTAGE V0 AS INSTRUCTION VOLTAGE Vc: Vc = V0
S2
CONTROLLER SETS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER
S3
SIGNAL INSTRUCTION SECTION INSTRUCTS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SIGNAL GENERATOR
S4
SIGNAL GENERATOR OUTPUTS RECTANGULAR WAVEFORM SIGNAL WITH PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SEMICONDUCTOR SWITCH
3
S5
VOLTAGE INSTRUCTION SECTION INSTRUCTS INSTRUCTION VOLTAGE Vc TO CONTROL DC POWER SUPPLY
S6
IMPULSE VOLTAGE GENERATOR APPLIES IMPULSE VOLTAGE WITH PEAK VALUE OF HIGH VOLTAGE Va (= A × Vc) AT PREDETERMINED TIMES
S7
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT OBSERVES APPLICATION VOLTAGE SIGNAL
S8
DETECTION SIGNAL OBSERVATION CIRCUIT OBSERVES DETECTION SIGNAL OUTPUT FROM PARTIAL DISCHARGE DETECTOR
4

FIG. 6B

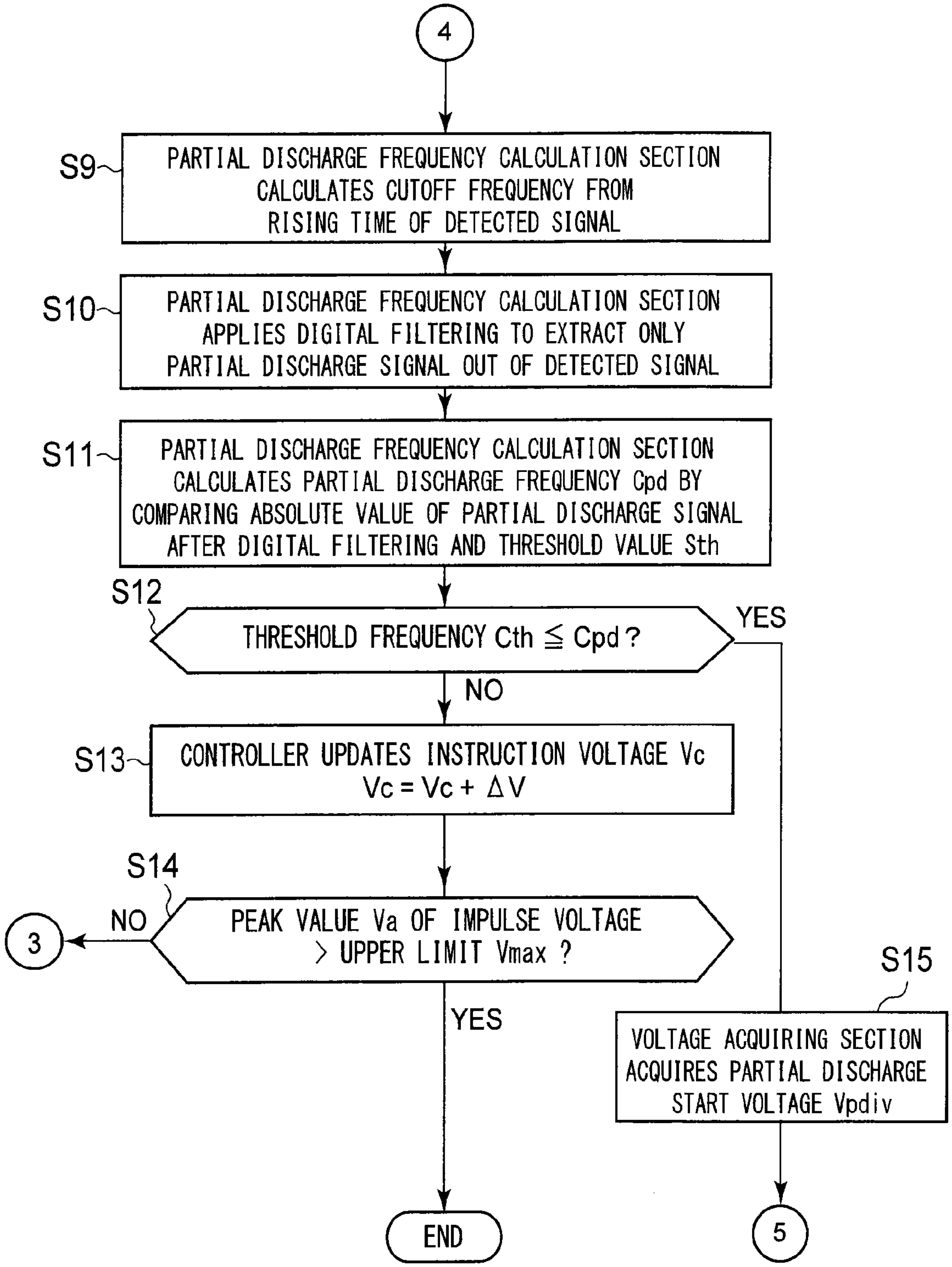

4
S9
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES CUTOFF FREQUENCY FROM RISING TIME OF DETECTED SIGNAL
S10
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION APPLIES DIGITAL FILTERING TO EXTRACT ONLY PARTIAL DISCHARGE SIGNAL OUT OF DETECTED SIGNAL
S11
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES PARTIAL DISCHARGE FREQUENCY Cpd BY COMPARING ABSOLUTE VALUE OF PARTIAL DISCHARGE SIGNAL AFTER DIGITAL FILTERING AND THRESHOLD VALUE Sth
S12
THRESHOLD FREQUENCY Cth ≦ Cpd ?
YES
NO
S13
CONTROLLER UPDATES INSTRUCTION VOLTAGE Vc
Vc = Vc + ΔV
S14
PEAK VALUE Va OF IMPULSE VOLTAGE > UPPER LIMIT Vmax ?
NO
3
YES
S15
VOLTAGE ACQUIRING SECTION ACQUIRES PARTIAL DISCHARGE START VOLTAGE Vpdiv
END
5

FIG. 6C

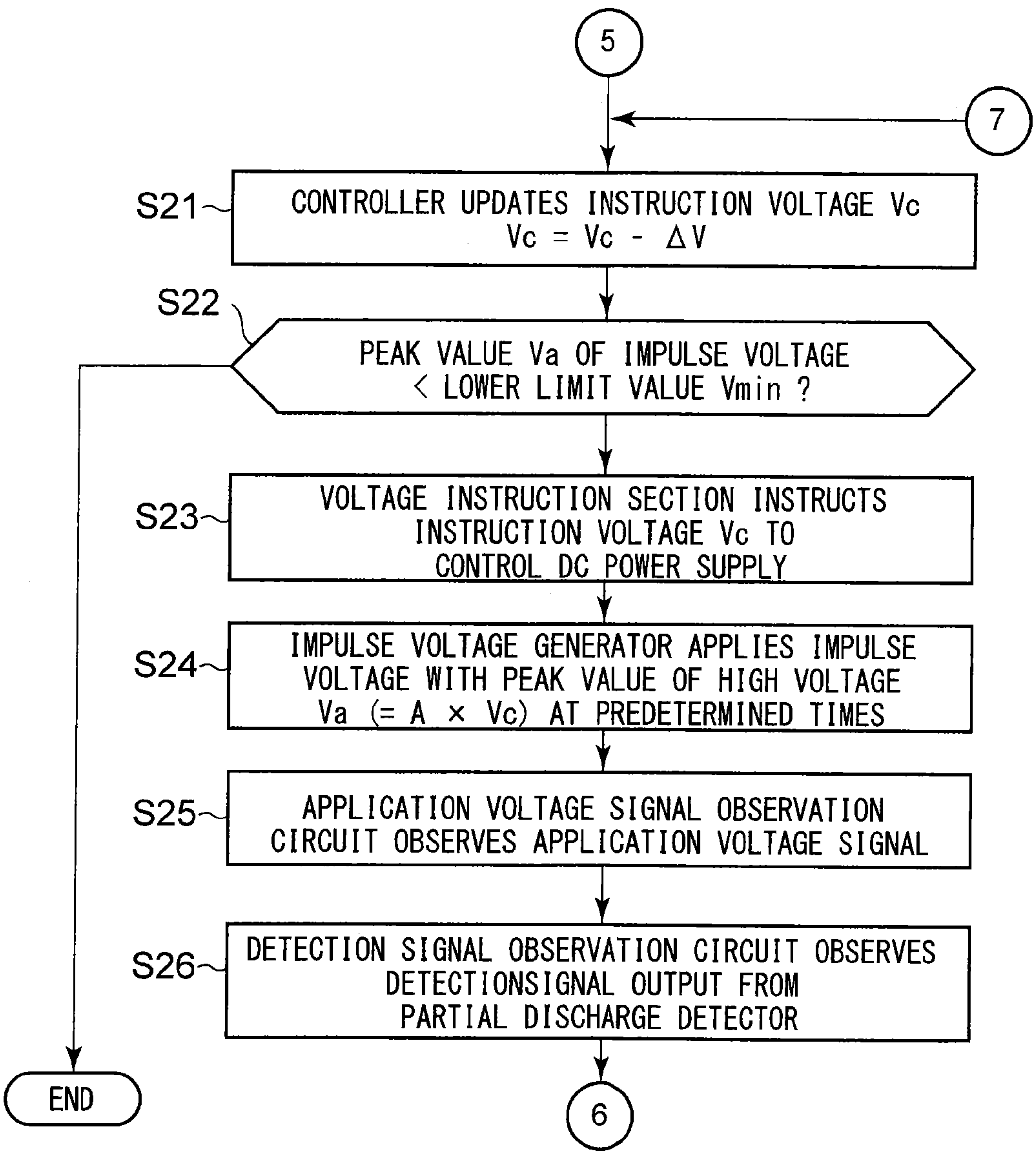

5
7
S21
CONTROLLER UPDATES INSTRUCTION VOLTAGE Vc
Vc = Vc - ΔV
S22
PEAK VALUE Va OF IMPULSE VOLTAGE
< LOWER LIMIT VALUE Vmin ?
S23
VOLTAGE INSTRUCTION SECTION INSTRUCTS INSTRUCTION VOLTAGE Vc TO CONTROL DC POWER SUPPLY
S24
IMPULSE VOLTAGE GENERATOR APPLIES IMPULSE VOLTAGE WITH PEAK VALUE OF HIGH VOLTAGE Va (= A × Vc) AT PREDETERMINED TIMES
S25
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT OBSERVES APPLICATION VOLTAGE SIGNAL
S26
DETECTION SIGNAL OBSERVATION CIRCUIT OBSERVES DETECTIONSIGNAL OUTPUT FROM PARTIAL DISCHARGE DETECTOR
END
6

FIG. 6D

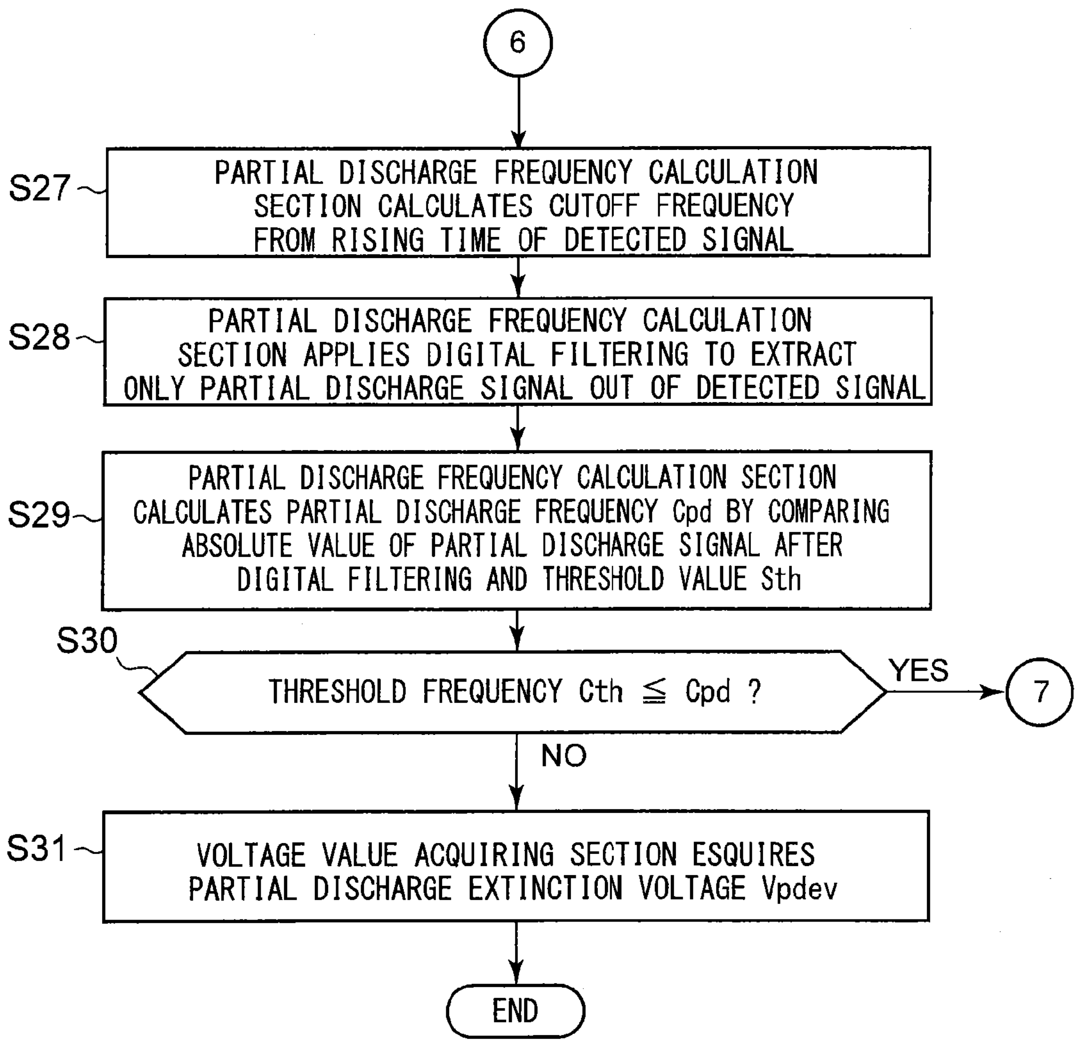

6
S27
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES CUTOFF FREQUENCY FROM RISING TIME OF DETECTED SIGNAL
S28
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION APPLIES DIGITAL FILTERING TO EXTRACT ONLY PARTIAL DISCHARGE SIGNAL OUT OF DETECTED SIGNAL
S29
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES PARTIAL DISCHARGE FREQUENCY Cpd BY COMPARING ABSOLUTE VALUE OF PARTIAL DISCHARGE SIGNAL AFTER DIGITAL FILTERING AND THRESHOLD VALUE Sth
S30
THRESHOLD FREQUENCY Cth ≦ Cpd ?
YES
7
NO
S31
VOLTAGE VALUE ACQUIRING SECTION ESQUIRES PARTIAL DISCHARGE EXTINCTION VOLTAGE Vpdev
END

FIG. 7

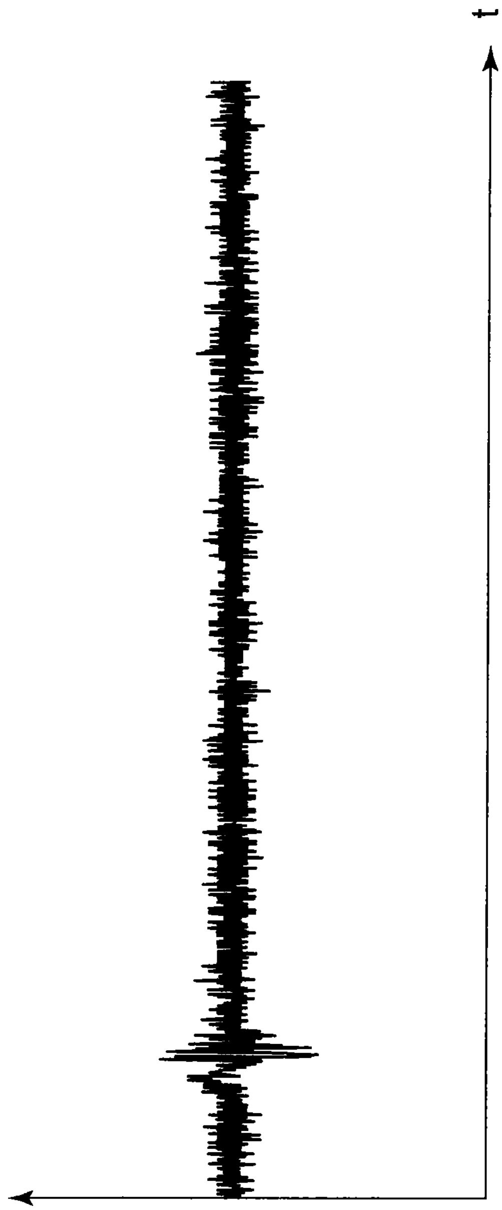


FIG. 8

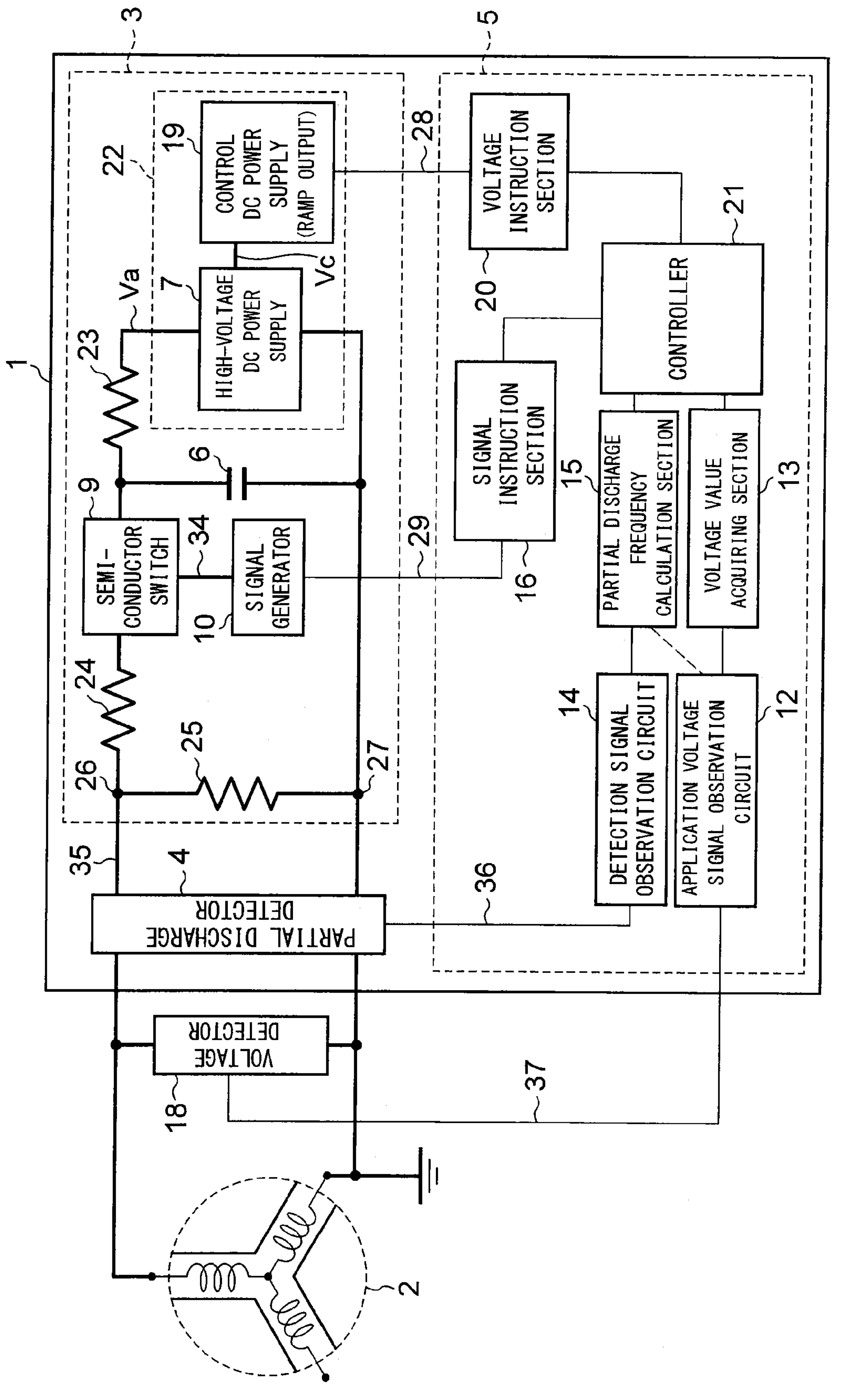

CONTROL DC POWER SUPPLY (RAMP OUTPUT)
VOLTAGE INSTRUCTION SECTION
HIGH-VOLTAGE DC POWER SUPPLY
CONTROLLER
SIGNAL INSTRUCTION SECTION
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION
VOLTAGE VALUE ACQUIRING SECTION
SEMI-CONDUCTOR SWITCH
SIGNAL GENERATOR
DETECTION SIGNAL OBSERVATION CIRCUIT
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT
PARTIAL DISCHARGE DETECTOR
VOLTAGE DETECTOR
Va
Vc
1
2
3
4
5
6
7
9
10
12
13
14
15
16
18
19
20
21
22
23
24
25
26
27
28
29
34
35
36
37

FIG. 9A

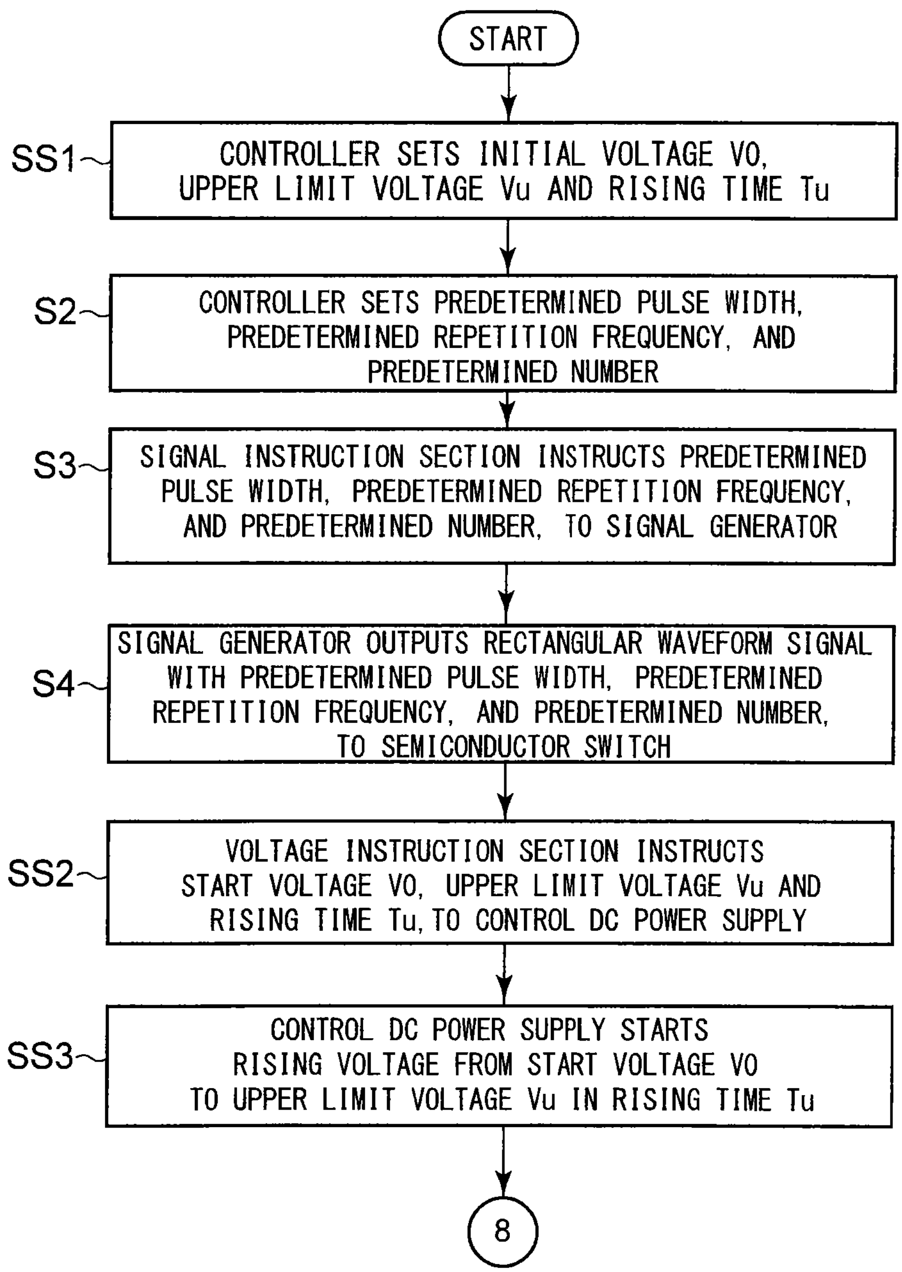

START
SS1
CONTROLLER SETS INITIAL VOLTAGE V0, UPPER LIMIT VOLTAGE Vu AND RISING TIME Tu
S2
CONTROLLER SETS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER
S3
SIGNAL INSTRUCTION SECTION INSTRUCTS PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SIGNAL GENERATOR
S4
SIGNAL GENERATOR OUTPUTS RECTANGULAR WAVEFORM SIGNAL WITH PREDETERMINED PULSE WIDTH, PREDETERMINED REPETITION FREQUENCY, AND PREDETERMINED NUMBER, TO SEMICONDUCTOR SWITCH
SS2
VOLTAGE INSTRUCTION SECTION INSTRUCTS START VOLTAGE V0, UPPER LIMIT VOLTAGE Vu AND RISING TIME Tu, TO CONTROL DC POWER SUPPLY
SS3
CONTROL DC POWER SUPPLY STARTS RISING VOLTAGE FROM START VOLTAGE V0 TO UPPER LIMIT VOLTAGE Vu IN RISING TIME Tu
8

FIG. 9B

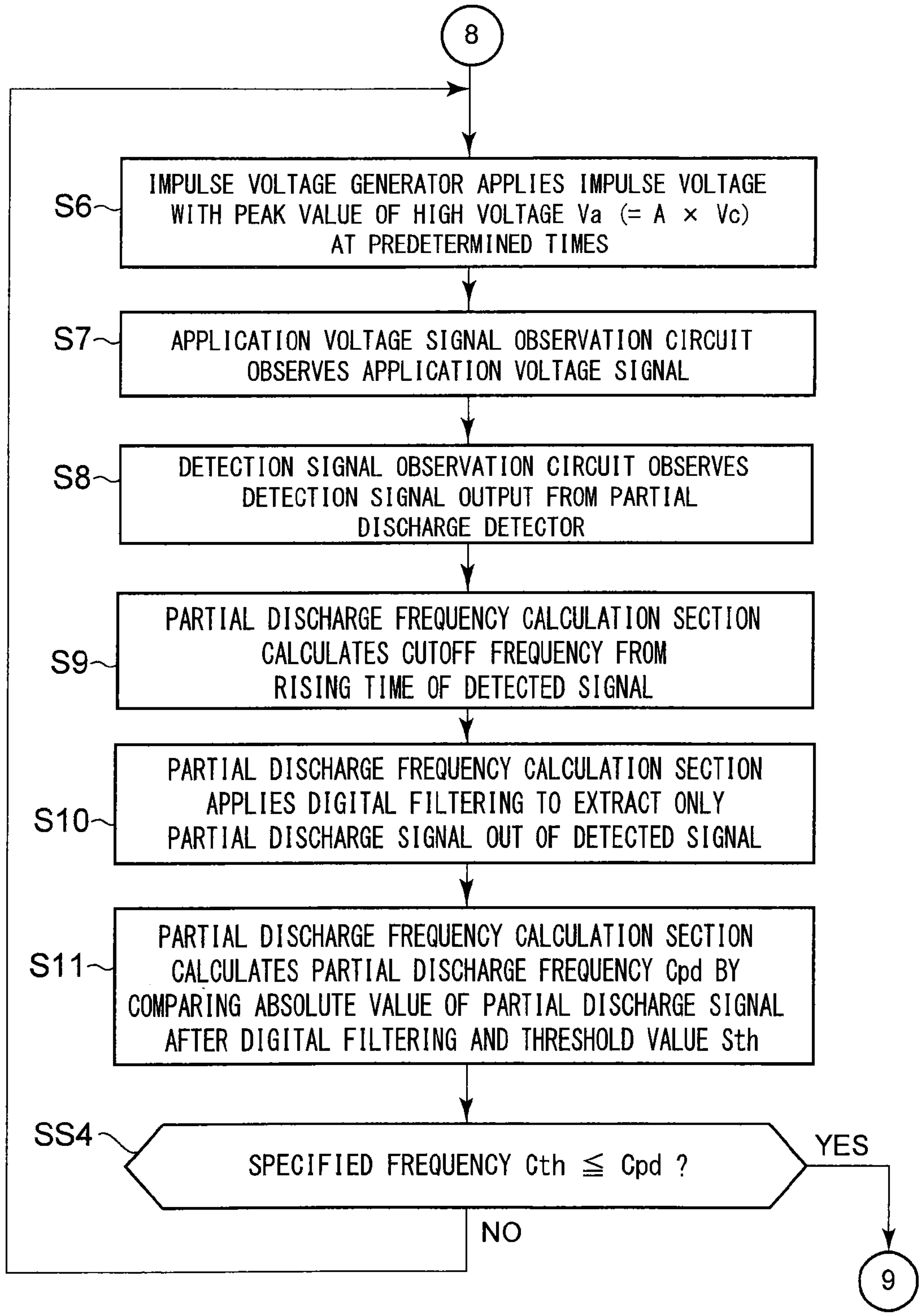

8
S6
IMPULSE VOLTAGE GENERATOR APPLIES IMPULSE VOLTAGE WITH PEAK VALUE OF HIGH VOLTAGE Va (= A × Vc) AT PREDETERMINED TIMES
S7
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT OBSERVES APPLICATION VOLTAGE SIGNAL
S8
DETECTION SIGNAL OBSERVATION CIRCUIT OBSERVES DETECTION SIGNAL OUTPUT FROM PARTIAL DISCHARGE DETECTOR
S9
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES CUTOFF FREQUENCY FROM RISING TIME OF DETECTED SIGNAL
S10
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION APPLIES DIGITAL FILTERING TO EXTRACT ONLY PARTIAL DISCHARGE SIGNAL OUT OF DETECTED SIGNAL
S11
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES PARTIAL DISCHARGE FREQUENCY Cpd BY COMPARING ABSOLUTE VALUE OF PARTIAL DISCHARGE SIGNAL AFTER DIGITAL FILTERING AND THRESHOLD VALUE Sth
SS4
SPECIFIED FREQUENCY Cth ≦ Cpd ?
YES
NO
9

FIG. 9C

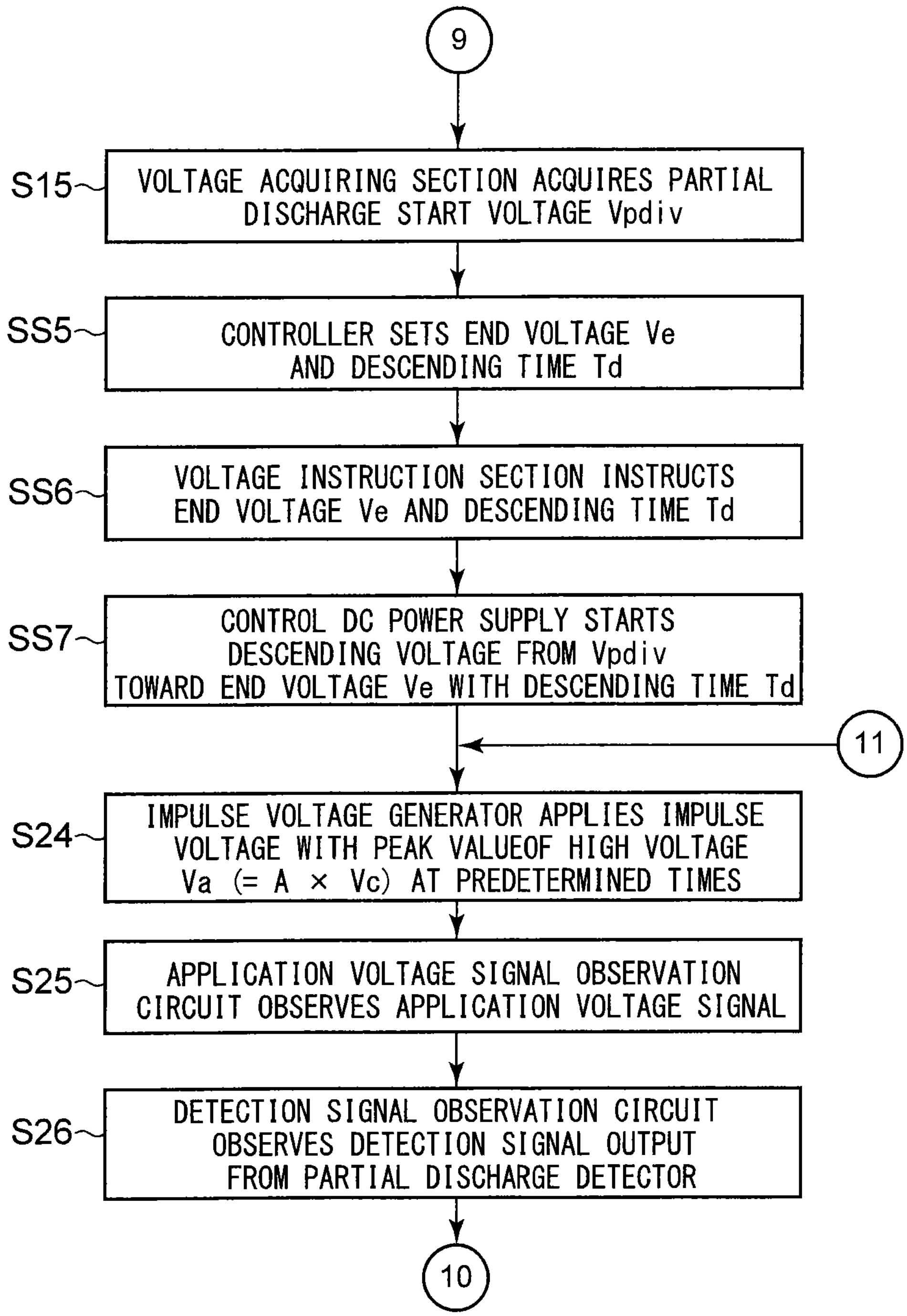

9
S15
VOLTAGE ACQUIRING SECTION ACQUIRES PARTIAL DISCHARGE START VOLTAGE Vpdiv
SS5
CONTROLLER SETS END VOLTAGE Ve AND DESCENDING TIME Td
SS6
VOLTAGE INSTRUCTION SECTION INSTRUCTS END VOLTAGE Ve AND DESCENDING TIME Td
SS7
CONTROL DC POWER SUPPLY STARTS DESCENDING VOLTAGE FROM Vpdiv TOWARD END VOLTAGE Ve WITH DESCENDING TIME Td
11
S24
IMPULSE VOLTAGE GENERATOR APPLIES IMPULSE VOLTAGE WITH PEAK VALUEOF HIGH VOLTAGE Va (= A × Vc) AT PREDETERMINED TIMES
S25
APPLICATION VOLTAGE SIGNAL OBSERVATION CIRCUIT OBSERVES APPLICATION VOLTAGE SIGNAL
S26
DETECTION SIGNAL OBSERVATION CIRCUIT OBSERVES DETECTION SIGNAL OUTPUT FROM PARTIAL DISCHARGE DETECTOR
10

FIG. 9D

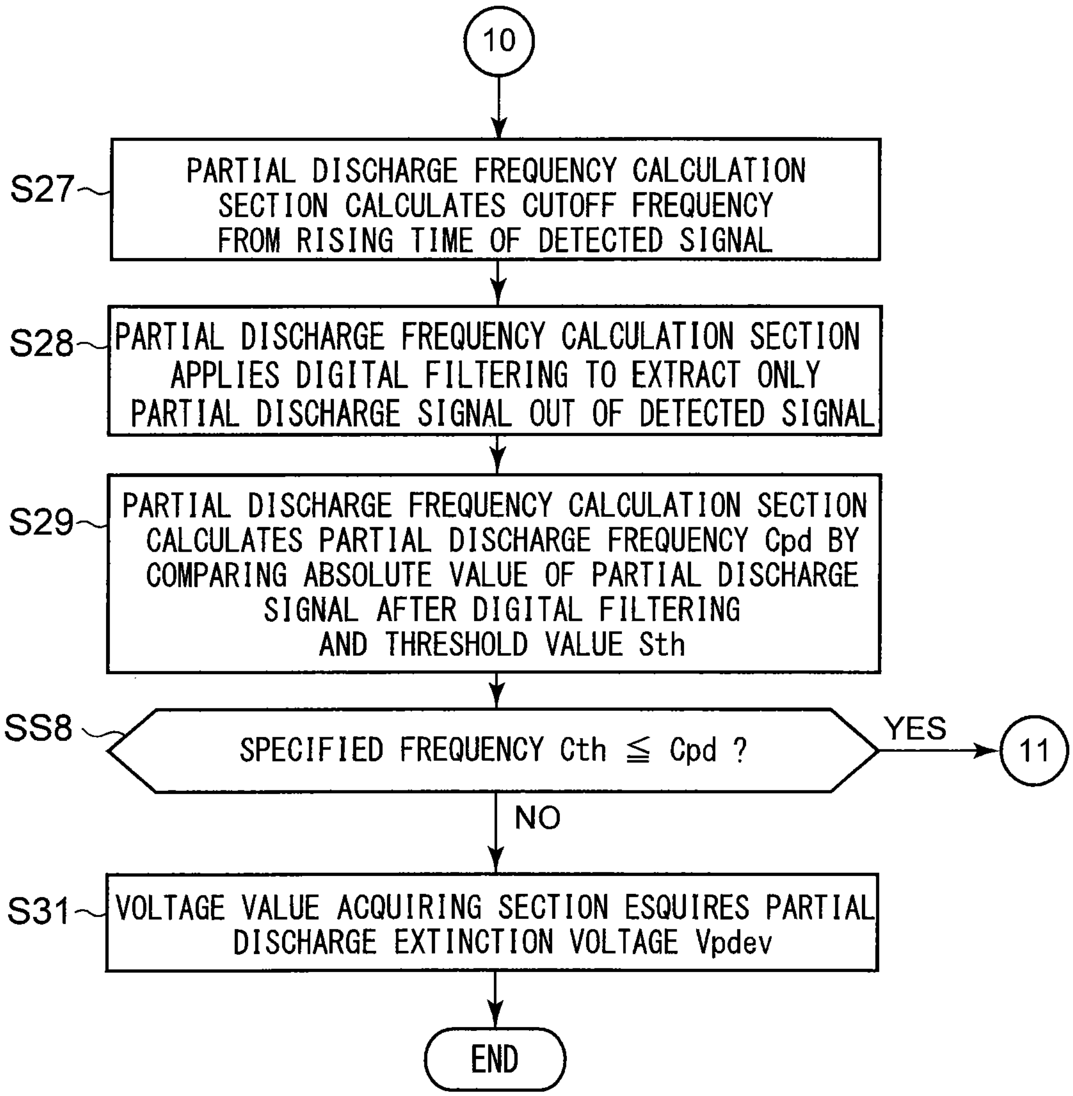

10
S27
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES CUTOFF FREQUENCY FROM RISING TIME OF DETECTED SIGNAL
S28
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION APPLIES DIGITAL FILTERING TO EXTRACT ONLY PARTIAL DISCHARGE SIGNAL OUT OF DETECTED SIGNAL
S29
PARTIAL DISCHARGE FREQUENCY CALCULATION SECTION CALCULATES PARTIAL DISCHARGE FREQUENCY Cpd BY COMPARING ABSOLUTE VALUE OF PARTIAL DISCHARGE SIGNAL AFTER DIGITAL FILTERING AND THRESHOLD VALUE Sth
SS8
SPECIFIED FREQUENCY Cth ≦ Cpd ?
YES
11
NO
S31
VOLTAGE VALUE ACQUIRING SECTION ESQUIRES PARTIAL DISCHARGE EXTINCTION VOLTAGE Vpdev
END

FIG. 10

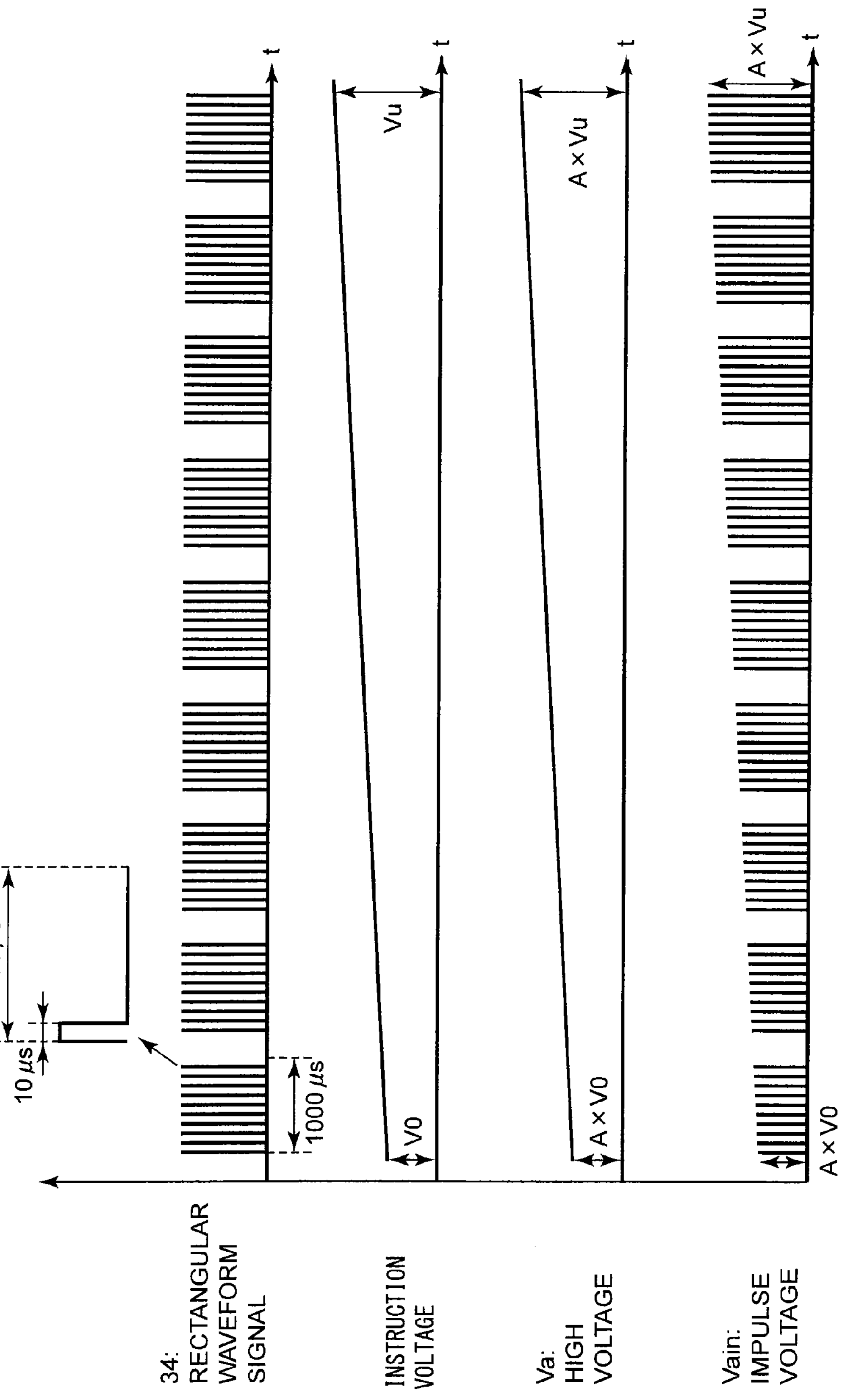

10 μs
100 μs
1000 μs
t
Vu
V0
A × Vu
A × V0
34: RECTANGULAR WAVEFORM SIGNAL
INSTRUCTION VOLTAGE
Va: HIGH VOLTAGE
Vain: IMPULSE VOLTAGE

FIG. 11

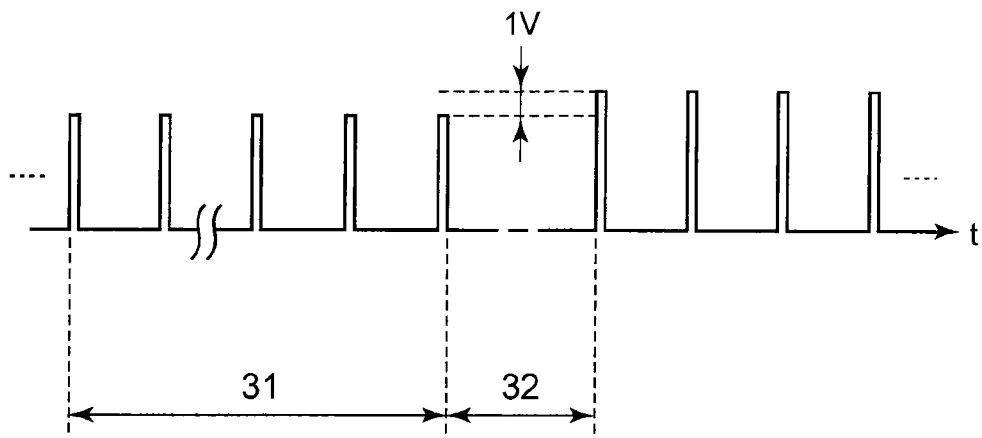
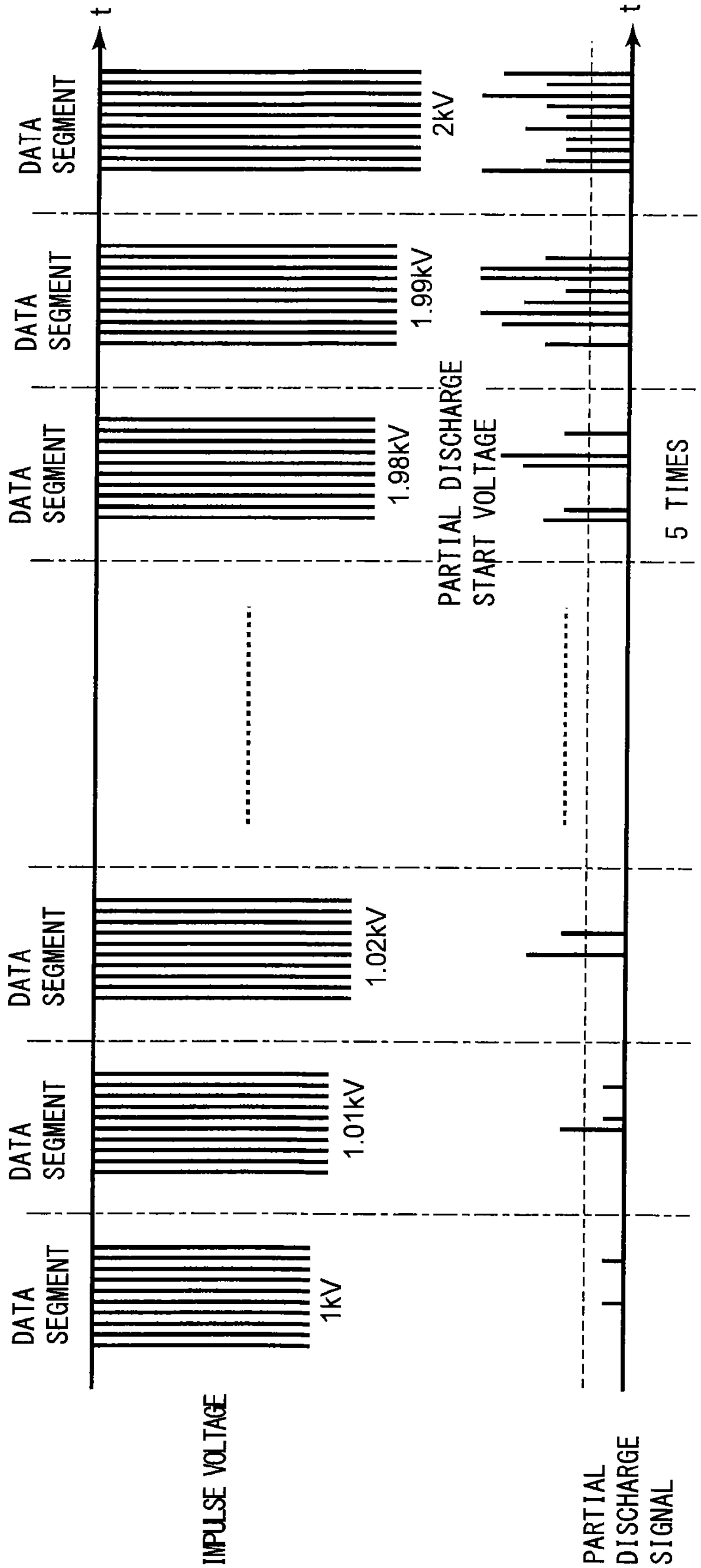


FIG. 12


IMPULSE VOLTAGE
DATA SEGMENT
1kV
DATA SEGMENT
1.01kV
DATA SEGMENT
1.02kV
DATA SEGMENT
1.98kV
DATA SEGMENT
1.99kV
DATA SEGMENT
2kV
t
PARTIAL DISCHARGE START VOLTAGE
5 TIMES
PARTIAL DISCHARGE SIGNAL
t

PARTIAL DISCHARGE MEASUREMENT SYSTEM AND PARTIAL DISCHARGE MEASUREMENT METHOD BY REPEATED IMPULSE VOLTAGE

TECHNICAL FIELD

The present invention relates to a partial discharge measurement system and a partial discharge measurement method based on repeated impulse voltage.

BACKGROUND ART

It is widely known that when an electric motor is inverter-driven, a surge voltage due to high-speed switching in an inverter is generated to affect insulation of a motor winding. Such a surge voltage is called "inverter surge" and may sometimes reach double or more the rated voltage. When the inverter surge is applied to the motor winding, a partial discharge may occur inside or outside the winding. Such a partial discharge may cause degradation of coating of an enamel wire constituting the winding. Degradation of the coating may lead to insulation breakdown. Thus, there is desired an insulation design of the electric motor that prevents the partial discharge from occurring even when the inverter surge is applied to the winding.

Conventionally, insulation performance of the motor winding is evaluated based on partial discharge characteristics obtained by application of an ordinary alternate voltage, especially, a partial discharge starting voltage. However, a potential distribution in the winding differs between when the ordinary alternate voltage is applied and when the surge voltage is applied. Therefore, the insulation performance of the inverter-driven electric motor is desirably evaluated by application of an impulse voltage simulating the surge voltage. Further, in partial discharge measurement conducted by application of the impulse voltage, voltage changes steeply at rising time (at application start time) of the impulse voltage, so that there is required a different approach from the partial discharge measurement conducted by application of the ordinary alternate voltage.

Non-Patent Document 1 describes a guideline of a partial discharge measurement method that repeatedly applies the impulse voltage in one period. More specifically, Non-Patent Document 1 defines that an impulse voltage applied when a partial discharge frequency, which is the number of the partial discharges, with respect to the number of all the applied impulse voltages (hereinafter, referred to as "number of impulses") reaches a specified frequency or more is regarded as a partial discharge starting voltage, which is called a partial discharge starting voltage in repeated impulse voltage.

Further, Non-Patent Documents 2 and 3 describe a partial discharge measurement method (all-period partial discharge measurement method) that repeatedly applies the impulse voltage for all periods. The following more specifically describes the all-period partial discharge measurement method.

FIG. **12** is a timing chart of the all-period partial discharge measurement method, illustrating an impulse voltage to be applied for each period (data segment in the drawing) to a twist pair sample simulating the winding of the electric motor and a partial discharge signal representing the partial discharge generated in the electric motor to which the impulse voltage is applied. As illustrated in FIG. **12**, in the all-period partial discharge measurement method, one period includes a pulse supply period and a pulse pause period following the pulse supply period. In the first period, ten impulse voltages are applied during the pulse supply period (e.g., 20 ms) and application of the impulse voltage is stopped during the pulse pause period (e.g., 100 ms). Subsequently, in the second period, ten 10 V boosted impulse voltage are applied during the pulse supply period, and application of the impulse voltage is stopped during the pulse pause period. Such processing is repeated for all periods until a starting value (e.g., 1 kV) of a peak value of the impulse voltage reaches a stop value (e.g., 2 kV).

In the all-period partial discharge measurement method, in all the periods, an applied voltage signal representing the impulse voltage and the above-mentioned partial discharge signal are stored in a memory. Thereafter, an operator verifies, on a per-period basis, whether or not the partial discharge frequency is a specified frequency or more (e.g., five or more) and defines, as the partial discharge starting voltage, the impulse voltage applied to the twist pair sample in a period in which the partial discharge frequency first reaches a specified frequency or more. That is, in the all-period partial discharge measurement method, application of the impulse voltage and measurement of the partial discharge are continuously performed for all periods from the start of the application of the impulse voltage to stop thereof, and the partial discharge starting voltage is derived after completion of the measurement.

Further, in Non-Patent Document 2, a voltage increment of the impulse voltage to be boosted every period is set to be 10 V. Further, in one period, an interval between one impulse voltage and the subsequent impulse voltage in the pulse supply period is set to be 20 ms, and the pulse pause period is set to be 100 ms. The above settings are based on the specification of an impulse voltage generator to be used and cannot be set arbitrarily by a user.

PRIOR ART DOCUMENTS

Non-Patent Documents

Non-Patent Document 1: IEC 61934TS

Non-Patent Document 2: Institute of Electrical Engineers of Japan "40th Symposium on Electric and Electronic Insulating Materials and Applications in System D-1" August 2009

Non-Patent Document 3: Institute of Electrical Engineers of Japan "40th Symposium on Electric and Electronic Insulating Materials and Applications in System P-7" August 2009

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

An object of the present invention is to provide a partial discharge measurement system based on repeated impulse voltage, capable of allowing a user to set an arbitrary impulse voltage and reducing user's work.

Means for Solving the Problems

According to the present invention, there is provided a partial discharge measurement system based on repeated impulse voltage, the system comprising: a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor; a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency, and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period; a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold; a signal instruction section that outputs, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set; a voltage instruction section that outputs, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal and sets in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in the immediately previous period as the instruction voltage; a detection signal observation circuit that observes a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied; a partial discharge frequency calculation section that counts the number of inputs of the detection signal on a per period basis as a partial discharge frequency; an application voltage signal observation circuit that observes an application voltage signal representing the impulse voltage to be applied to the object to be measured; and a voltage value acquiring section that sets, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

According to the present invention, there is provided a measurement device for a partial discharge measurement system based on repeated impulse voltage, the system including: a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor; a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period; and a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold, the measurement device comprising: a signal instruction section that outputs, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set; a voltage instruction section that outputs, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal and sets in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in the immediately previous period as the instruction voltage; a detection signal observation circuit that observes a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied; a partial discharge frequency calculation section that counts the number of inputs of the detection signal on a per period basis as a partial discharge frequency; an application voltage signal observation circuit that observes an application voltage signal representing the impulse voltage to be applied to the object to be measured; and a voltage value acquiring section that sets, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

According to the present invention, there is provided a measurement method for a partial discharge measurement system based on repeated impulse voltage, the system including: a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor; a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency, and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period; and a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold, the measurement method comprising steps of: outputting, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set; outputting, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal, and setting in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in an immediately previous period as the instruction voltage; observing, using a detection signal observation circuit, a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied; counting the number of inputs of the detection signal on a per period basis as a partial discharge frequency; observing, using an application voltage signal observation circuit, an application voltage signal representing the impulse voltage to be applied to the object to be measured; and setting, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

Advantage of the Present Invention

According to the present invention, the user can set an arbitrary impulse voltage and the user's work can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating a schematic configuration of a partial discharge measurement system according to a first embodiment.

FIG. **2**A is a flowchart illustrating a measurement procedure of a partial discharge starting voltage Vpdiv.

FIG. **2**B is a flowchart illustrating the measurement procedure of the partial discharge starting voltage Vpdiv.

FIG. **3**A is a timing chart illustrating a period setting signal **30**, a pulse signal **33**, and a rectangular waveform signal **34** which are generated by a signal generator, and an impulse voltage Vain generated by a semiconductor switch.

FIG. **3**B is an enlarged view of a part X of FIG. **3**A.

FIG. **4** is a timing chart illustrating waveforms of an application voltage signal **37**, a detection signal **36**, and a partial discharge signal **38** obtained by applying digital filtering to the detection signal **36**.

FIG. **5** is a timing chart illustrating an impulse voltage Vain and a partial discharge frequency Cpd on a per period basis.

FIG. **6**A is a flowchart illustrating a measurement procedure of a partial discharge starting voltage Vpdiv and a partial discharge extinction voltage Vpdev.

FIG. **6**B is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **6**C is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **6**D is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **7** is a timing chart illustrating a waveform of a partial discharge signal **38** obtained by applying digital differential processing to a detection signal **36** of FIG. **4**.

FIG. **8** is a block diagram illustrating a schematic configuration of a partial discharge measurement system according to a second embodiment.

FIG. **9**A is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **9**B is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **9**C is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **9**D is a flowchart illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev.

FIG. **10** is a timing chart illustrating the rectangular waveform signal **34**, instruction voltage of the ramp output, high voltage Va, and impulse voltage Vain.

FIG. **11** is a timing chart illustrating an example in which predetermined number of impulse voltage Vain is applied by boosting it by 1 V after 1 V.

FIG. **12** is a timing chart of an all-period partial discharge measurement method, illustrating an impulse voltage to be applied for each period (data segment in the drawing) to an electric motor (e.g., between phases of a winding) and a partial discharge signal representing the partial discharge generated in the electric motor to which the impulse voltage is applied.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

Hereinafter, embodiments of a partial discharge measurement system based on repeated impulse voltage according to the present invention will be described with reference to the drawings.

(First Embodiment)

FIG. **1** is a block diagram illustrating a schematic configuration of a partial discharge measurement system according to a first embodiment. A partial discharge measurement system **1** illustrated in FIG. **1** applies repeated impulse voltage to an electric motor **2** which is an object to be measured to measure a partial discharge in the repeated impulse voltage. The partial discharge measurement system **1** includes an impulse voltage generator **3**, a partial discharge detector **4**, a measurement device **5**, and a voltage detector **18**.

The impulse voltage generator **3** includes a capacitor **6** as a capacitive element, a DC power supply **22**, a semiconductor switch **9**, a signal generator **10**, resistive elements **23** to **25**, and output terminals **26** and **27**. The DC power supply **22** includes a high-voltage DC power supply **7** and a control DC power supply **8**.

An output of the high-voltage DC power supply **7** is connected to a first electrode of the capacitor **6**. A second electrode **2** of the capacitor **6** has the same potential as that of the output terminal **27**. More specifically, the output terminal **27** is grounded. An output of the control DC power supply **8** is connected to an input port (not illustrated) of the high-voltage DC power supply **7**.

The resistive element **23** is provided between the output of the high-voltage DC power supply **7** and the first electrode of the capacitor **6**. The resistive element **25** is provided between the output terminals **26** and **27**. For example, a section between phases (e.g., U and V phases) of a winding of the electric motor **2** is provided as a load for supplying an impulse voltage Vain. The load is not limited to the illustrated section between phases of the winding of the electric motor **2** but may be other sections between phases or a section between the winding and the iron core of the electric motor **2**.

The semiconductor switch **9** includes a first terminal (not illustrated) connected to the first electrode of the capacitor **6**, a second terminal (not illustrated) connected to the output terminal **26**, and a gate terminal (not illustrated). The resistive element **24** is provided between the second terminal of the semiconductor switch **9** and the output terminal **26**. An output of the signal generator **10** is connected to the gate terminal of the semiconductor switch **9**.

The control DC power supply **8** receives a voltage instruction signal **28** from the measurement device **5** and outputs an instruction voltage Vc set in the voltage instruction signal **28** to the high-voltage DC power supply **7**. The instruction voltage Vc is a voltage input to the input port of the high-voltage DC power supply **7** so as to control a value of voltage output from the high-voltage DC power supply **7**.

The high-voltage DC power supply **7** outputs, as a high voltage Va, a voltage obtained by multiplying the instruction voltage Vc output from the control DC power supply **8** by a set factor A.

A period setting signal is set in the signal generator **10**. One period of the period setting signal includes a pulse supply period and a pulse pause period following the pulse supply period. The signal generator **10** receives a square wave instruction signal **29** from the measurement device **5** and generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency set in the square wave instruction signal **29**. The signal generator **10** superimposes the period setting signal and pulse signal on each other to generate a rectangular waveform signal **34** in which a predetermined number of pulse signals set in the square wave instruction signal **29** are generated only in the pulse supply period of the period setting signal. Details of the period setting signal, pulse signal, and rectangular waveform signal **34** will be described later.

The semiconductor switch **9** is turned ON when a voltage value to be supplied to the gate electrode is equal to or higher than a preset voltage threshold to connect the first and second terminals. More specifically, the semiconductor switch **9** charges the capacitor **6** with the high voltage Va from the high-voltage DC power supply **7** when a voltage value of the rectangular waveform signal **34** is lower than the voltage threshold; while it applies an impulse voltage Vain having a peak value equal to a value of the high voltage Va from the capacitor **6** to the electric motor **2** when the voltage value of the rectangular waveform signal **34** is equal to or higher than the voltage threshold.

The voltage detector **18** detects the impulse voltage Vain to be applied to the electric motor **2** (section between phases of the winding of the electric motor **2**, in the above example) provided between the output terminals **26** and **27** and outputs an application voltage signal **37** representing the impulse voltage Vain to the measurement device **5**.

The partial discharge detector **4** detects the partial discharge generated in the electric motor **2** to which the impulse voltage Vain is applied, and outputs a detection signal **36** based on the partial discharge to the measurement device **5**. For example, as the partial discharge detector **4**, there may be adopted any configurations that detect a physical quantity generated with the partial discharge, such as one detecting a current flowing in the winding of the electric motor **2** by a CT (Current Transformer) and one detecting an electromagnetic wave around the winding of the electric motor **2** by an antenna.

The measurement device **5** is realized by a personal computer in which, for example, Windows® is installed as an OS (Operating System). The measurement device **5** includes various application programs to be described later running thereon and is provided with an interface for inputting/outputting a signal from/to an external device. With this configuration, the measurement device **5** can perform a function as an oscilloscope that displays an input signal on a screen as a waveform or a function for controlling measurement of the partial discharge.

The measurement device **5** includes a voltage instruction section **11**, an application voltage signal observation circuit **12**, a voltage value acquiring section **13**, a detection signal observation circuit **14**, a partial discharge frequency calculation section **15**, a signal instruction section **16**, and a controller **17**.

The constituent elements of the measurement device **5** other than the application voltage signal observation circuit **12** and the detection signal observation circuit **14**, that is, the voltage instruction section **11**, the voltage value acquiring section **13**, the partial discharge frequency calculation section **15**, the signal instruction section **16**, and the controller **17** are each constituted by hardware or software. For example, when each constituent element is constituted by software, it can be realized by a computer program.

The voltage instruction section **11** controls operation of the control DC power supply **8** through a communication interface for performing communication such as RS-232C so as to apply the impulse voltage Vain having the same voltage level to the electric motor **2**. More specifically, for controlling the control DC power supply **8**, the controller **17** generates the voltage instruction signal **28** in which an initial voltage is set as the instruction voltage Vc in a first period (corresponding to a first period of the rectangular waveform signal **34**) of the period setting signal, and the voltage instruction section **11** outputs the voltage instruction signal **28** to the control DC power supply **8**. Further, in second and subsequent periods, the controller **17** sets, in the voltage instruction signal **28**, a voltage obtained by adding a predetermined increment voltage that is lower than the initial voltage to the instruction voltage Vc in the immediately previous period as a new instruction voltage Vc, and the voltage instruction section **11** outputs the voltage instruction signal **28** to the control DC power supply **8**.

The signal instruction section **16** controls operation of the signal generator **10** through a communication interface for performing communication such as RS-232C so as to apply a predetermined number of the impulse voltages Vain having a predetermined pulse width and a predetermined repetition frequency to the electric motor **2**. More specifically, for controlling the signal generator **10**, the controller **17** generates the square wave instruction signal **29** in which a predetermined pulse width, a predetermined pulse repetition frequency, and a predetermined number are set, and the signal instruction section **16** outputs the square wave instruction signal **29** to the signal generator **10**.

The application voltage signal observation circuit **12** observes the application voltage signal **37** output from the voltage detector **18**. The application voltage signal **37** is transferred to the voltage value acquiring section **13**.

The voltage value acquiring section **13** acquires a value (peak value) of the voltage applied to the electric motor **2** based on the transferred application voltage signal **37**. More specifically, the voltage value acquiring section **13** receives the application voltage signal **37** from the application voltage signal observation circuit **12** in a period in which the partial discharge frequency first reaches a specified frequency or more and acquires a peak value (value of the high voltage Va) of the voltage represented by the application voltage signal **37**, and the controller **17** sets the voltage peak value as a partial discharge staring voltage.

The detection signal observation circuit **14** observes the detection signal **36** output from the partial discharge detector **4**. The detection signal **36** is then transferred to the partial discharge frequency calculation section **15**.

The partial discharge frequency calculation section **15** inputs thereto the detection signal **36** observed by the detection signal observation circuit **14**, and counts, on a per period basis, an input frequency of the detection signal **36** as a frequency of occurrence of the partial discharge (partial discharge frequency). More specifically, the partial discharge frequency calculation section **15** applies, e.g., digital filtering to the detection signal **36** observed by the detection signal observation circuit **14** to remove unnecessary signal component, thereby extracting only a signal (partial discharge signal) representing the partial discharge. After that, the partial discharge frequency calculation section **15** evaluates an absolute value of the peak value of the partial discharge signal using a predetermined discharge determination threshold, and counts, on a per period basis, the partial discharge frequency based on the evaluation result. In this manner, the partial discharge frequency calculation section **15** counts the number of times that the partial discharge signal is extracted on a per period basis as the partial discharge frequency.

As described above, according to the partial discharge measurement system **1**, a predetermined number of impulse voltages Vain having the same peak value, a predetermined pulse width, and a predetermined repetition frequency are applied to the electric motor **2**, and the frequency of occurrence of the partial discharge is counted every time the predetermined number of impulse voltages are applied. After that, the controller **17** raises stepwise the peak value of the impulse voltage Vain through the voltage instruction section **11**. Then, when the partial discharge frequency calculation section **15** counts the occurrence of the partial discharge by a specified frequency, the controller **17** regards the voltage at that time as the partial discharge starting voltage.

FIGS. **2**A and **2**B are each a flowchart illustrating a measurement procedure of a partial discharge starting voltage Vpdiv. FIG. **3**A is a timing chart illustrating a period setting signal **30**, a pulse signal **33**, and a rectangular waveform signal **34** which are generated by the signal generator **10** and impulse voltage Vain generated by the semiconductor switch **9**. FIG. **3**B is an enlarged view of a part X of FIG. **3**A.

The controller **17** initializes the instruction voltage Vc for indicating the peak value of the impulse voltage generator **3** to an initial voltage V0. More specifically, in a first period (corresponding to a first period of the rectangular waveform signal **34**) of the period setting signal, the controller **17** generates the voltage instruction signal **28** in which the initial voltage is set as the instruction voltage Vc (step S**1**).

Then, the controller **17** generates the square wave instruction signal **29** in which a predetermined pulse width (e.g., 10 μs), a predetermined repetition frequency (e.g., 10 kHz), and a predetermined number (e.g., 10) which are parameters of the impulse voltage Vain output from the impulse voltage generator **3** (step S**2**). The signal instruction section **16** outputs the square wave instruction signal **29** to the signal generator **10** (step S**3**). The signal generator **10** outputs the rectangular waveform signal **34** having the predetermined pulse width, predetermined repetition frequency, and predetermined number set in the square wave instruction signal **29** (step S**4**).

The above-mentioned step S**4** will be described more specifically.

The period setting signal **30** as illustrated in FIG. **3**A is set in the signal generator **10**. One period of the period setting signal **30** includes a pulse supply period **31** and a pulse pause period **32** following the pulse supply period **31**. The signal generator **10** receives the square wave instruction signal **29** from the measurement device **5**, and generates the pulse signal **33** as illustrated in FIG. **3**A. The pulse signal **33** represents the predetermined pulse width and predetermined pulse repetition frequency which are set in the square wave instruction signal **29**. The pulse repetition frequency is higher than a frequency of the period setting signal **30**. The signal generator **10** superimposes the period setting signal **30** and the pulse signal **33** on each other to generate the rectangular waveform signal **34** as illustrated in FIG. **3**A. In the rectangular waveform signal **34**, a predetermined number of pulse signals **33** set in the square wave instruction signal **29** are generated in only the pulse supply period **31**.

Then, the voltage instruction section **11** outputs the voltage instruction signal **28**, in which the instruction voltage Vc is set, to the control DC power supply **8** (step S**5**). At this time, the high-voltage DC power supply **7** outputs the high voltage Va which is a voltage obtained by multiplying the instruction voltage Vc set in the voltage instruction signal **28** by a set factor A (A is e.g., 3000). As a result, the capacitor **6** is charged with the high voltage Va. The semiconductor switch **9** repeats ON and OFF based on the rectangular waveform signal **34** output from the signal generator **10** and, thereby, the impulse voltage Vain is generated from the charged voltage of the capacitor **6** and is then applied to the electric motor **2** (step S**6**).

The above-mentioned step S**6** will be described more specifically.

The semiconductor switch **9** is turned OFF when the voltage value of the rectangular waveform signal **34** is lower than a voltage threshold Vg and charges the capacitor **6** with the high voltage Va from the high-voltage DC power supply **7**. On the other hand, the semiconductor switch **9** is turned ON when the voltage value of the rectangular waveform signal **34** is equal to or higher than the voltage threshold Vg and applies the impulse voltage Vain as illustrated in FIG. **3**A from the capacitor **6** to the electric motor **2**. As illustrated in FIG. **3**B, the impulse voltage Vain has a peak value equal to the value of the high voltage Va, and the rising time thereof is very short.

Then, the application voltage signal observation circuit **12** observes the application voltage signal **37** output from the voltage detector **18** (step S**7**). Then, the detection signal observation circuit **14** observes the detection signal **36** output from the partial discharge detector **4** (step S**8**).

FIG. **4** is a timing chart illustrating waveforms of the application voltage signal **37**, the detection signal **36**, and the partial discharge signal **38** obtained by applying the digital filtering to the detection signal **36**. The partial discharge is generated when a high voltage is applied to a contact portion of enamel wires constituting the winding of the electric motor **2** and, therefore, it is often generated especially in the vicinity of the peak of the impulse voltage Vain (application voltage signal **37**). When the impulse voltage Vain is applied, current flows in the winding of the electric motor **2**, and a winding current signal is superimposed on the detection signal **36**. When the winding current signal is superimposed on the detection signal **36**, the partial discharge starting voltage cannot be measured accurately. To cope with this, an approach that extracts only the partial discharge signal by making the detection signal pass through a filter circuit is widely employed. However, frequency components of the winding current signal and partial discharge signal vary depending on measurement conditions such as a size of the electric motor **2** and a wiring length, so that the filter circuit is provided as needed.

Thus, the partial discharge frequency calculation section **15** calculates an approximate frequency band of the detection signal **36** using a generally-known relational expression between a signal rising time and a frequency band. Assuming that the rising time of the detection signal **36** transferred from the detection signal observation circuit **14** is Tri, and the frequency band thereof is Fcut, the frequency band Fcut is calculated by Fcut=0.35/Tri. In the present embodiment, a frequency ten times the frequency band Fcut is calculated as a cutoff frequency of the digital filtering (step S**9**).

A definition of the cutoff frequency will be described more specifically.

Assuming that the rising time Tri of the detection signal **36** is about 290 ns, the frequency band Fcut is about 1.2 MHz. The partial discharge signal has a frequency band at least one digit higher than the frequency band Fcut. Thus, in the present embodiment, 10 MHz which is a frequency ten times the frequency band Fcut (1.2 MHz) is defined as the cutoff frequency.

The partial discharge frequency calculation section **15** applies the digital filtering to the detection signal **36** based on the cutoff frequency (step S**10**).

In the digital filtering, data obtained by multiplying a plurality of consecutive data in a signal data string by filter coefficients calculated based on the cutoff frequency, respectively, are added to each other to thereby calculate one new data. For example, assume that the data string of the detection signal **36** is set as P (**0**), P (**1**), P (**2**), . . . , P (n−1), the number of consecutive data in the data string of the detection signal **36** is set to three, the three consecutive data is set as P (j−1), P (j), and P (j+1), and data string of the filter coefficient is set as F (**0**), F (**1**), F (**2**), F (n−1). In this case, the new data D(j) is calculated by D(j)={{P (j−1)×F (j−1)}+{P (j)×F (j)}+{P (j+1)×F (j+1)}} (where, j is 1, . . . , n−3).

The partial discharge signal **38** illustrated in FIG. **4** is obtained by applying the digital filtering to the detection signal **38** based on the cutoff frequency 10 MHz. As illustrated in FIG. **4**, the detection signal **36** (in this case, the partial discharge signal **38**) after digital filtering is a signal from which the winding current signal, which is an unnecessary signal component, has been removed and has only a signal component caused in response to generation of the partial discharge.

The partial discharge frequency calculation section **15** counts the occurrence frequency of the partial discharge based on the partial discharge signal **38** after digital filtering as follows. The partial discharge frequency calculation section **15** compares an absolute value of the peak value of the partial discharge signal **38** after digital filtering and a discharge determination threshold Sth (step S**11**). The partial discharge signal **38** after digital filtering often exhibits an attenuation vibration waveform of a high frequency. Thus, which one of a positive side peak vale and a negative side peak value becomes larger in the partial discharge signal **38** after digital filtering cannot be determined. Therefore, even when such a partial discharge signal **38** and discharge determination threshold Sth which is a fixed value are compared, it is difficult to accurately determine occurrence of the partial discharge. Thus, the partial discharge frequency calculation section **15** compares the absolute value of the partial discharge signal **38** after digital filtering and discharge determination threshold Sth. When the partial discharge signal **38** exceeds the discharge determination threshold Sth as a result of the comparison, the partial discharge frequency calculation section **15** determines that a partial discharge has occurred. In this manner, the partial discharge frequency calculation section **15** counts a partial discharge frequency Cpd which is the occurrence frequency of the partial discharge.

Then, the controller **17** compares the partial discharge frequency Cpd transferred from the partial discharge frequency calculation section **15** and a specified frequency Cth (step S**12**). In the present embodiment, the specified frequency Cth is set to "5" which is ½ of the above-mentioned predetermined number "10". When the partial discharge frequency Cpd is less than the specified frequency Cth ("NO" in step S**12**), the controller **17** updates the instruction voltage Vc (step S**13**). More specifically, the controller **17** sets, in the voltage instruction signal **28**, a voltage obtained by adding a predetermined increment voltage ΔV to the instruction voltage Vc in the immediately previous period as a new instruction voltage Vc. The predetermined increment voltage ΔV is set lower than the initial voltage V0, and the instruction voltage Vc is set to a voltage higher by the predetermined increment voltage ΔV (e.g., 0.03 V) than the instruction voltage Vc in the immediately previous period (Vc=Vc+ΔV).

Then, the controller **17** determines whether or not a voltage obtained by multiplying the updated instruction voltage Vc by the set factor A, i.e., high voltage Va, exceeds an upper limit value Vmax (step S**14**). This step S**14** is provided for preventing an endless loop which may occur when, for example, the partial discharge frequency Cpd does not become equal to or more than the specified frequency Cth for some cause, such as a fault, even when the high voltage Va continues to be increased. Thus, the Vmax should be set to a voltage sufficiently higher than an ordinarily expected partial discharge starting voltage. When the high voltage Va exceeds the upper limit voltage Vmax ("YES" in step S**14**), this routine is ended. On the other hand, when the high voltage Va is equal to or lower than the upper limit voltage Vmax ("NO" in step S**14**), the voltage instruction section **11** outputs, in step S**5**, the voltage instruction signal **28** in which the instruction voltage Vc is set to the control DC power supply **8**, and processing of step S**6** and subsequent steps are executed once again.

On the other hand, when the partial discharge frequency Cpd is equal to or more than the specified frequency Cth ("YES" in step S**12**), the voltage value acquiring section **13** receives the voltage value applied to the electric motor **2**, i.e., the application voltage signal **37** from the application voltage signal observation circuit **12**, acquires the peak value (value of the high voltage Va) of the voltage represented by the application voltage signal **37**, and transfers the peak value to the controller **17** (step S**15**). As described above, the voltage value acquiring section **13** acquires the peak value of the voltage from the application voltage signal **37** in the period in which the partial discharge frequency Cpd first becomes equal to or more than the specified frequency Cth. The controller **17** sets the peak value of the voltage as the partial discharge starting voltage Vpdiv and ends this routine.

According to the partial discharge measurement of the present embodiment based on the above-mentioned processing, the impulse voltage Vain is applied to the electric motor **2** according to a repeated pattern in which the peak value of the impulse voltage Vain is increased stepwise by voltage A×ΔV every time the ten impulse voltages Vain have been applied until the partial discharge frequency Cpd becomes equal to or more than the specified frequency Cth ("YES" in step S**12**).

FIG. **5** is a timing chart illustrating the impulse voltage Vain and partial discharge frequency Cpd on a per period basis. In FIG. **5**, assuming that an amplification factor (the above-mentioned factor A) by the high DC voltage is 3000, an initial value of the instruction voltage Vc is V0 (e.g., 0.4 V), and the predetermined increment voltage ΔV is, e.g., 0.03 V, a boosting range of a voltage to be applied is 90 V (=3000×0.03 V), and the high voltage Va after m-th update is represented as Vm (=A×Vc). As illustrated in FIG. **5**, in a period during which the instruction voltage Vc is V0 to V4, that is, in a period during which the impulse voltage Vain is 1200 V (3000×V0) to 1520 V (3000×V4), the partial discharge frequency Cpd is less than the specified frequency Cth. Note that in a period PDIV during which the instruction voltage is V3, the partial discharge frequency Cpd is first counted. In a period RPDIV during which the instruction voltage Vc is V5, that is, in a period during which the impulse voltage Vain is 1610 V (3000×V5), the partial discharge frequency Cpd is equal to or more than the specified frequency Cth. In this period RPDIV, it is determined that the partial discharge starting voltage Vpdiv has occurred, and the boost of the impulse voltage Vain is stopped.

After calculation of the partial discharge starting voltage Vpdiv in this manner, it is possible to measure also a partial discharge extinction voltage. In this case, the voltage instruction section **11** controls the control DC power supply **8** and signal generator **10** such that the impulse voltage Vain is applied to the electric motor **2** according to a repeated pattern in which the peak value of the impulse voltage Vain is reduced stepwise every time a predetermined number of the impulse voltages Vain having the same peak value have been applied.

FIGS. **6**A to **6**D are flowcharts each illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and partial discharge extinction voltage Vpdev.

In the flowcharts of FIGS. **6**A to **6**D, the processing from step S**1** to step S**15** is the same as that illustrated in the flowcharts of FIGS. **2**A and **2**B. After step S**15**, the controller **17** updates the instruction voltage Vc (step S**21**). More specifically, the controller **17** sets, in the voltage instruction signal **28**, a voltage obtained by subtracting the predetermined voltage ΔV from the instruction voltage Vc in the immediately previous period as a new instruction voltage Vc. That is, the new instruction voltage Vc is set to a voltage lower by the predetermined increment voltage (e.g., 0.03 V) than the instruction voltage Vc in the immediately previous period (Vc=Vc−ΔV).

Then, the controller **17** determines whether or not a voltage obtained by multiplying the updated instruction voltage Vc by the set factor A, i.e., high voltage Va (=A×Vc) falls below a lower limit value Vmin (step S**22**). This step S**22** is provided for a similar reason as in step S**15** of FIG. **2**B. Thus, the Vmin should be set to a voltage sufficiently lower than the ordinary expected partial discharge extinction voltage. When the high voltage Va falls below the lower limit voltage Vmin ("YES" in step S**22**), this routine is ended. On the other hand, when the high voltage Va is equal to or higher than the lower limit voltage Vmin ("NO" in step S**22**), the voltage instruction section **11** outputs the voltage instruction signal **28** in which the instruction voltage Vc is set to the control DC power supply **8** (step S**23**). After that, processing from step S**24** to step S**29** which is similar to that from step S**6** to step S**11** illustrated in FIGS. **2**A and **2**B is executed.

Then, the controller **17** compares the specified frequency Cth and partial discharge frequency Cpd (step S**30**). When the partial discharge frequency Cpd is equal to or more than the specified frequency Cth ("YES" in step S**30**), the processing flow returns to step S**21**.

On the other hand, when the partial discharge frequency Cpd is less than the specified frequency Cth ("NO" in step S**30**), the voltage value acquiring section **13** receives the voltage value applied to the electric motor **2**, i.e., the application voltage signal **37** from the application voltage signal observation circuit **12**, acquires the peak value (value of the high voltage Va) of the voltage represented by the application voltage signal **37**, and transfers the peak value to the controller **17** (step S**31**). As described above, the voltage value acquiring section **13** acquires the peak value of the voltage from the application voltage signal **37** in a period in which the partial discharge frequency Cpd first becomes less than the specified frequency Cth after the period RPDIV in which the partial discharge starting voltage Vpdiv is calculated. The controller **17** sets the peak value of the voltage as the partial discharge extinction voltage Vpdev and ends this routine.

As illustrated in FIG. **5**, in a period RPDEV in which the instruction voltage Vc is V7, that is, the impulse voltage Vain is 1430 V (3000×V7), the partial discharge frequency Cpd is less than the specified frequency Cth. Further, in a period PDEV in which the instruction voltage Vc is V9, that is, the impulse voltage Vain is 1250 V (3000×V9), the partial discharge frequency Cpd is not counted.

As described above, the partial discharge measurement system **1** according to the present embodiment applies to the electric motor **2** a predetermined number of impulse voltages Vain having a predetermined pulse width and a predetermined repetition frequency, and calculates the partial discharge frequency Cpd, every time the impulse voltages are applied. A user can perform various partial discharge measurement works, such as measurement of the partial discharge starting voltage Vpdiv and the partial discharge extinction voltage Vpdev by using the partial discharge frequency Cpd and the like acquired by the partial discharge measurement system **1**. As described above, according to the partial discharge measurement system **1** of the present embodiment, it is possible to reduce works that the user performs such a work (e.g., reading of a meter or displayed numerical values) that may affect measurement accuracy. As a result, highly accurate partial discharge measurement can be performed.

In the measurement of the partial discharge starting voltage Vpdiv, boost of the impulse voltage Vain is stopped when it is determined that the partial discharge frequency Cpd is equal to or more than the specified frequency Cth. Further, in the measurement of the partial discharge extinction voltage Vpdev, the application of the impulse voltage Vain is stopped when it is determined that the partial discharge frequency Cpd is less than the specified frequency Cth. With the above configuration, a time required for the partial discharge measurement can be reduced. Further, application of an excessive voltage to the winding of the electric motor **2** to be measured can be suppressed to thereby prevent the object to be measured from suffering damage due to overloading.

The measurement device **5** observes the application voltage signal **37** or detection signal **36** every time a predetermined number of the impulse voltages Vain having the same peak value is applied. The impulse voltage generator **3** can change the pulse width, repetition frequency, and the number of the impulse voltages Vain to be applied, thereby reducing the amount of memory necessary for observing the application voltage signal **37** or detection signal **36**, which can in turn reduce a time required for the partial discharge frequency calculation section **15** to perform data processing.

The partial discharge frequency calculation section **15** calculates a frequency band of the winding current signal included in the detection signal **36** from the rising time Tri of the detection signal **36** observed by the detection signal observation circuit **14** and applies digital filtering to the detection signal using the calculated frequency as the cutoff frequency to remove the winding current signal included in the detection signal **36** and then counts the occurrence frequency of the partial discharge. This can enhance measurement accuracy of the partial discharge starting voltage Vpdiv. Further, even when parameters that contribute to the frequency of the detection signal **36**, such as a load and a wiring length, are changed, it is unnecessary to use a new filter.

In the present embodiment, the cutoff frequency used in the digital filtering is calculated every time the detection signal **36** is measured; however, it is no longer necessary to newly calculate the cutoff frequency after it is once determined. Alternatively, the cutoff frequency may be calculated from the rising time of the detection signal **36** that is measured before measurement of the partial discharge starting voltage Vpdiv or the cutoff frequency may be determined from a frequency spectrum result obtained through Fourier transform processing.

Further, in the present embodiment, the parameters, such as the initial voltage V0, predetermined pulse width, predetermined repetition frequency, and predetermined number, which are set in the above-mentioned steps S**1** and S**2** may be input by the user on a screen of the measurement device **5**.

Further, in the present embodiment, the above-mentioned step S**9** may be replaced by the following processing. The partial discharge frequency calculation section **15** receives the application voltage signal **37** observed by the application voltage signal observation circuit **12**, calculates the frequency band Fcut according to Fcut=0.35/Tri wherein Tri is the rising time of the application voltage signal **37**, and sets the obtained Fcut as the cutoff frequency for use in the digital filtering. A flow of a signal from the application voltage signal observation circuit **12** to partial discharge frequency calculation section **15** at this time is denoted by a dashed line of FIG. **1**.

For example, in FIG. **4**, the rising time (300 ns) of the application voltage signal **37** and rising time (290 ns) of the detection signal **36** are nearly equal to each other. Therefore, the frequency band Fcut becomes about 1.2 MHz irrespective of whether the frequency band Fcut is calculated from the rising time (about 290 ns) of the detection signal **36** or rising time of the application voltage signal **37**. The partial discharge signal has a frequency band of at least one digit higher than the frequency band Fcut, so that 10 MHz which is a frequency ten times the frequency band Fcut (1.2 MHz) can be defined as the cutoff frequency.

Further, in the present embodiment, the above-mentioned steps S**9** and S**10** may be replaced by the following processing. That is, the partial discharge frequency calculation section **15** may apply digital differential processing to the detection signal **36** transferred from the detection signal observation circuit **14**.

In the digital differential processing, one new data by calculating a difference between first and second data constituting a signal data string is obtained. For example, assuming that the data string of the detection signal **36** is set as P (**0**), P (**1**), P (**2**), . . . , P (n−1), the new data string is set as D (**0**), D (**1**), D (**2**), . . . , D (n−1), and a sampling frequency is set as Ts, the new data D (k) is calculated by D (k)={{P (k)−P (k−1)}/Ts (where, k is 1, . . . n−1). The division by Ts need not be performed. Further, to improve accuracy, the data D (k) may be calculated by D (k)={{P (k+1)−P (k−1)}/2 Ts (where, k is 1, . . . n−2).

FIG. **7** is a timing chart illustrating a waveform of the partial discharge signal **38** obtained by applying the digital differential processing to the detection signal **36** of FIG. **4**. A change of the partial discharge signal **38** is steeper than a change of the winding current signal. Thus, in the present embodiment, by performing the digital differential processing, a signal waveform similar to a signal waveform that has been subjected to the digital filtering can be obtained at a partial discharge generation portion, thereby allowing detection of the partial discharge. As described above, the partial discharge frequency calculation section **15** can count the occurrence frequency of the partial discharge after applying the digital differential processing to the detection signal **36**.

(Second Embodiment)

A partial discharge measurement system according to a second embodiment will be described focusing on only differences from the first embodiment. Parts that are not particularly described are the same as those in the first embodiment.

FIG. **8** is a block diagram illustrating a schematic configuration of the partial discharge measurement system according to the second embodiment.

The DC power supply **22** of the impulse voltage generator **8** includes, in place of the control DC power supply **8**, a control DC power supply **19**. The measurement device **5** includes, in place of the voltage instruction section **11** and controller **17**, a voltage instruction section **20** and a controller **21**, respectively. The control DC power supply **19** is a power supply that can output a ramp voltage, and the voltage instruction section **20** outputs a voltage instruction signal **28** in which a ramp voltage according to a predetermined pulse repetition frequency is set as the above-mentioned instruction voltage Vc to the control DC power supply **19**.

FIGS. **9**A to **9**D are flowcharts each illustrating a measurement procedure of the partial discharge starting voltage Vpdiv and partial discharge extinction voltage Vpdev.

The controller **21** generates the voltage instruction signal **28** in which a start voltage V0 same as the initial voltage V0 of the first embodiment, an upper limit voltage Vu, and a rising time Tu are set (step SS**1**). Processing from step S**2** to step S**4** is the same as that illustrated in the flowcharts of FIGS. **2**A and **6**A. Then, the voltage instruction section **20** outputs the voltage instruction signal **28** in which the start voltage V0, the upper limit voltage Vu, and the rising time Tu are set to the control DC power supply **19** (step SS**2**). As a result, the control DC power supply **19** starts boosting the initial voltage V0 toward the upper voltage Vu with the rising time Tu (step SS**3**).

Processing from step S**6** to step S**11** is the same as that illustrated in the flowcharts of FIGS. **2**A, **2**B and **6**A, **6**B.

Then, the controller **21** compares the specified frequency Cth and the partial discharge frequency Cpd transferred from the partial discharge frequency calculation section **15** (step SS**4**). When the partial discharge frequency Cpd is less than the specified frequency Cth ("NO" in step SS**4**), the processing flow returns to step S**6**. On the other hand, when the partial discharge frequency Cpd is equal to or more than the specified frequency Cth ("YES" in step SS**4**), the processing flow proceeds to step S**15**, where the controller **21** sets the voltage value calculated by the voltage value acquiring section **13** as the partial discharge starting voltage Vpdiv.

Then, the controller **21** generates the voltage instruction signal **28** in which an end voltage Ve and a descending time Td are set (step SS**5**). The voltage instruction section **20** outputs the voltage instruction signal **28** in which the end voltage Ve and descending time Td are set to the control DC power supply **19** (step SS**6**). The control DC power supply **19** starts descending the voltage Vpdiv toward the end voltage Ve with the descending time Td (step SS**7**).

Hereinafter, processing from step S**6** to step S**11** is the same as that illustrated in the flowcharts of FIGS. **2**A and **2**B.

Then, the controller **21** compares the specified frequency Cth and partial discharge frequency Cpd (step SS**8**). When the partial discharge frequency Cpd is equal to or more than the specified frequency Cth ("YES" in step SS**8**), the processing flow returns to step S**6**. On the other hand, when the partial discharge frequency Cpd is less than the specified frequency Cth ("NO" in step SS**8**), the controller **21** sets the voltage value acquired by the voltage acquisition section **13** as the partial discharge extinction voltage Vpdev in step S**31** of FIG. **9**D.

FIG. **10** is a timing chart illustrating the rectangular waveform signal **34**, the instruction voltage of the ramp output, the high voltage Va, and the impulse voltage Vain.

A voltage obtained by multiplying an output voltage of the control DC power supply **19** by a factor A (A is e.g., 3000) is output from the high-voltage DC power supply **7**, and the semiconductor switch **9** repeats ON and OFF based on the rectangular waveform signal **34**. As a result, the impulse voltage Vain of the ramp output is generated in the impulse voltage generator **3**. According to the partial discharge measurement based on the above processing, assuming that the amplification factor of the high-voltage DC power supply **7** is 3000, the start voltage V0 of the ramp voltage output from the control DC power supply **19** is 0.3 V, the upper voltage Vu is 0.7 V, and the rising time is 12 sec, the impulse voltage to be applied to the electric motor **2** is increased at 100 V/sec. Assuming that the pulse width of one impulse voltage Vain is 10 μs, repetition frequency is 10 kHz, and ten impulse voltages Vain are grouped into one block, a time required from the start of the one block to the end thereof is 1 msec, and a boosting voltage in 1 msec is 0.1 V. Since the start voltage which is the minimum voltage applied to the electric motor **2** is 900 V, the boosting voltage of 0.1 V in one block is sufficiently smaller than 900 V and can be negligible. Thus, even in a configuration in which the control DC power supply **19** outputs the ramp voltage, a predetermined number of impulse voltages Vain having substantially the same peak value can be applied. Further, assuming that a time interval between one block (including ten pulses) and the next block is set to, e.g., 10 msec, the impulse voltage Vain is boosted at 1 V in 10 msec. As a result, it is possible to apply a predetermined number of the impulse voltages Vain having substantially the same peak value as illustrated in FIG. **11** to the electric motor **2** while boosting the impulse voltage by 1 V.

As described above, in the partial discharge measurement system according to the present embodiment, control is performed such that the ramp voltage rising in a predetermined rising time is output from the control DC power supply **19**, and the pulse width, the repetition frequency, and the predetermined number of the impulse voltage Vain is controlled by the output signal of the signal generator **10**, so that it is possible to finely set a rising width between a predetermined number of the impulse voltages Vain having the same peak value and a predetermined number of the impulse voltages in the next block having the same peak value. The finely setting the rising width of the voltage allows the partial discharge starting voltage Vpdiv or partial discharge extinction voltage Vpdev to be measured more accurately.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

EXPLANATION OF REFERENCE NUMERALS

1: partial discharge measurement system
2: electric motor (object to be measured)
3: impulse voltage generator
4: partial discharge detector
5: measurement device
6: capacitor
7: high-voltage DC power supply
8: control DC power supply
9: semiconductor switch
10: signal generator
11: voltage instruction section
12: application voltage signal observation circuit
13: voltage value acquiring section
14: detection signal observation circuit
15: partial discharge frequency calculation section
16: signal instruction section
17: controller
18: voltage detector
19: control DC power supply
20: voltage instruction section
21: controller
22: DC power supply
23: resistive element
24: resistive element
25: resistive element
26: output terminal
27: output terminal
28: voltage instruction signal
29: square wave instruction signal
30: period setting signal
31: pulse supply period
32: pulse pause period
33: pulse signal
34: rectangular waveform signal
36: detection signal
37: application voltage signal
38: partial discharge signal

What is claimed is:

1. A partial discharge measurement system based on repeated impulse voltage, the system comprising:

a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor;

a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency, and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period;

a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold;

a signal instruction section that outputs, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set;

a voltage instruction section that outputs, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal and sets in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in the immediately previous period as the instruction voltage;

a detection signal observation circuit that observes a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied;

a partial discharge frequency calculation section that counts the number of inputs of the detection signal on a per period basis as a partial discharge frequency;

an application voltage signal observation circuit that observes an application voltage signal representing the impulse voltage to be applied to the object to be measured; and

a voltage value acquiring section that sets, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

2. The partial discharge measurement system based on repeated impulse voltage, according to claim **1**, wherein

the partial discharge frequency calculation section applies digital filtering to the detection signal to remove an unnecessary signal component from the detection signal so as to extract only a partial discharge signal representing the partial discharge, and counts, on a per period basis, the number of times that the partial discharge signal is extracted as the partial discharge frequency.

3. The partial discharge measurement system based on repeated impulse voltage, according to claim **2**, wherein

the partial discharge frequency calculation section calculates a cutoff frequency for use in digital filtering based on a rising time of the detection signal, and applies the digital filtering to the detection signal based on the calculated cutoff frequency.

4. The partial discharge measurement system based on repeated impulse voltage, according to claim **1**, wherein

the partial discharge frequency calculation section applies digital filtering to the application voltage signal to remove an unnecessary signal component from the application voltage signal so as to extract only a partial discharge signal representing the partial discharge, and counts, on a per period basis, the number of times that the partial discharge signal is extracted as the partial discharge frequency.

5. The partial discharge measurement system based on repeated impulse voltage, according to claim **4**, wherein

the partial discharge frequency calculation section calculates a cutoff frequency for use in digital filtering based on a rising time of the application voltage signal, and applies the digital filtering to the application voltage signal based on the calculated cutoff frequency.

6. The partial discharge measurement system based on repeated impulse voltage, according to claim **2**, wherein

the partial discharge frequency calculation section applies digital differential processing to the detection signal to remove the unnecessary signal component from the detection signal so as to extract only the partial discharge signal.

7. The partial discharge measurement system based on repeated impulse voltage according to claim **1**, wherein

in a period after a period in which the partial discharge starting voltage is acquired by the voltage value acquiring section, the voltage instruction section outputs, to the DC power supply, the voltage instruction signal in which a voltage obtained by subtracting the predetermined voltage from the instruction voltage in the immediately previous period as the instruction voltage, and

the voltage value acquiring section acquires, as a partial discharge extinction voltage, a peak value of a voltage represented by the application voltage signal from the application voltage signal observation circuit in a period in which the partial discharge frequency first becomes less than the specified frequency after the period in which the partial discharge starting voltage is acquired.

8. The partial discharge measurement system based on repeated impulse voltage according claim **1**, wherein

the DC power supply is a power supply that can output a ramp voltage, and

the voltage instruction section outputs, to the DC power supply, the voltage instruction signal in which a ramp voltage according to the predetermined pulse repetition frequency is set as the instruction voltage.

9. A measurement device for a partial discharge measurement system based on repeated impulse voltage, the system including: a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor; a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period; and a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold,

the measurement device comprising:

a signal instruction section that outputs, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set;

a voltage instruction section that outputs, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal and sets in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in the immediately previous period as the instruction voltage;

a detection signal observation circuit that observes a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied;

a partial discharge frequency calculation section that counts the number of inputs of the detection signal on a per period basis as a partial discharge frequency;

an application voltage signal observation circuit that observes an application voltage signal representing the impulse voltage to be applied to the object to be measured; and

a voltage value acquiring section that sets, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

10. A measurement method for a partial discharge measurement system based on repeated impulse voltage, the system including: a DC power supply that outputs high voltage as a voltage obtained by multiplying an instruction voltage by a set factor; a signal generator that generates a pulse signal representing a predetermined pulse width and a predetermined pulse repetition frequency, and superimposes a period setting signal whose one period includes a pulse supply period and a pulse pause period following the pulse supply period and the pulse signal on each other to generate a rectangular waveform signal in which a predetermined number of the pulse signals are generated only in the pulse supply period; and a semiconductor switch that charges a capacitive element with the high voltage from the DC power supply when a voltage value of the rectangular waveform signal is lower than a preset voltage threshold, while applies an impulse voltage having a peak value equal to a value of the high voltage from the capacitive element to an object to be measured when the voltage value of the rectangular waveform signal is equal to or higher than the voltage threshold, the measurement method comprising steps of:

outputting, to the signal generator, a square wave instruction signal in which the predetermined pulse width, the predetermined pulse repetition frequency, and the predetermined number are set;

outputting, to the DC power supply, a voltage instruction signal in which an initial voltage is set as the instruction voltage in a first period of the rectangular waveform signal, and setting in the voltage instruction signal, in second and subsequent periods, a voltage obtained by adding a predetermined increment voltage lower than the initial voltage to the instruction voltage in an immediately previous period as the instruction voltage;

observing, using a detection signal observation circuit, a detection signal based on a partial discharge generated in the object to be measured to which the impulse voltages are applied;

counting the number of inputs of the detection signal on a per period basis as a partial discharge frequency;

observing, using an application voltage signal observation circuit, an application voltage signal representing the impulse voltage to be applied to the object to be measured; and

setting, in a period in which the partial discharge frequency first becomes equal to or more than a specified frequency, a peak value of a voltage represented by the application voltage signal from the application voltage observation circuit as a partial discharge starting voltage.

* * * * *