An SCR Thyristor Based Three-Phase Voltage Disturbance Generator

Heung-Soo Han *, Jae-Hun Jung *, Eui-Cheol Nho *, In-Dong Kim *, Heung-Geun Kim **, and Tae-Won Chun ***

Abstract – This paper deals with a 3-phase voltage disturbance generator for a performance test of custom power devices such as dynamic voltage restorers (DVR), dynamic uninterruptable power supplies (UPS), etc. The operating principle of the proposed circuit is described in each mode of voltage sag, swell, outage, and unbalance. The main components of the proposed disturbance generator are silicone controlled rectifier (SCR) thyristors, variable autotransformers, and transformers. Therefore, the disturbance generator can be implemented with a considerably low cost compared to the conventional pulse width modified (PWM) inverter and converter type generators. Furthermore, it has good features of high reliability with simple structure, high efficiency caused by no PWM switching of the SCR thyristors, and easy control with a wide variation range. To verify the validity of the proposed scheme, simulations and experiments are carried out.

Keywords: Voltage disturbance generator, SCR thyristor, Sag, Swell

1. Introduction

Recently information technology based on electrical and electronic equipment is widely used for the demand of automation, internet data centers, etc. Usually the equipment is sensitive to the variation of the supplied power source voltage. The occurrence of voltage disturbances such of voltage sag, swell, outage, unbalance, over and under voltage increases as modern industry develops and expands. Such voltage disturbance may cause severe damage to the system and produce loss in an automation process. For instance, variation of the total load of a distribution system, operation of transformer tap changers, and switching of capacitor banks or reactors cause utility voltage magnitude variation. Components used in electronic equipment such as process controllers, programmable logic controllers, adjustable speed drives and robotics, etc. are actually becoming more sensitive to voltage disturbance as the performance and complexity of equipment increases. In order to mitigate the voltage disturbance, custom power devices such as dynamic uninterruptible power supplies [1], [2], dynamic voltage restorers [3], static VAR compensators and dynamic sag corrector s[4] have been proposed.

Through the method of testing the performance of the device it is necessary to generate arbitrary voltage disturbances to feed the input terminals of the device. However, unfortunately, the conventional voltage disturbance generators are too expensive to use, especially, in the laboratory of universities or small sized research groups. Furthermore, if the power rating of the devices increases above 10 kVA the cost of the test equipment increases considerably. Recently, cost-effective voltage disturbance generators have been proposed [5], [6]. The scheme proposed by Chung et al. [5] has the significant problems of huge reactive power requirements and additional harmonic filter components. The scheme in [6] has overcome the most severe problems in [5], however, it does not provide the proper disturbance output voltage in the case of nonlinear load.

This paper describes a 3-phase voltage disturbance generator having the ability of linear and nonlinear load drives. The proposed circuit operation is described and its characteristics are analyzed. The usefulness of the generator is verified through simulation and experimental results.

2. Proposed Circuit Diagram

Fig. 1 shows the proposed circuit diagram for the voltage disturbance generator with nonlinear load.

The voltages of Va, Vb, and Vc represent utility source

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voltage, having almost constant magnitude in normal conditions. A series transformer is inserted between the source and output terminals in each phase to produce disturbed output voltages Vas, Vbs, and Vcs. The first group of silicone controlled rectifier (SCR) thyristors (SBa1, SBs2, SBb1, SBb2, SBc1, SBc2) is used to bypass the source voltages to output terminals by turning on all the 6 thyristors in normal mode.

The purpose of the second group of thyristor (Sa1, Sa2, Sb1, Sb2, Sc1, Sc2) is providing a desired amount of voltage disturbance to the primary side of the series transformers.

The required voltage disturbance value can be adjusted by the variable autotransformer. If the movable contact point is in I-region, the secondary side voltage of the series transformer Vad is negative, which is added to the source voltage Va, resulting in a voltage sag of the output voltage Vas.

In the case of a fixed value of voltage disturbance, for example, 20% or 50% voltage sag, the variable autotransformer can be replaced with an autotransformer with several tap terminals.

3. Operating Principle of the Circuit

The operating principle of each phase of the circuit in Fig. 1 is the same. Thus, it is enough for the a-phase circuit operation to be described. Normally, voltage sag and outage swell, and unbalance modes for *a*-phase are described as follows.

Table I shows the switching state of SCR thyristors according to the kind of output voltage disturbance. I-and II-region means the upper and lower sides of the sliding type autotransformer, respectively.

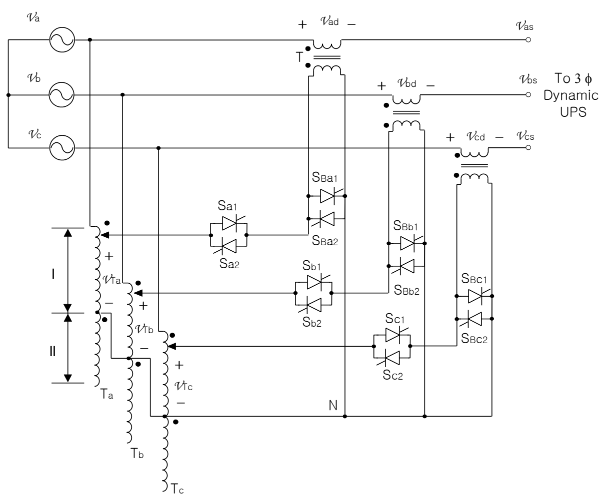


Fig. 1. Proposed voltage disturbance generator

Table 1. Switching State of SCR Thyristors

V_{as}	S_{Ba1}, S_{Ba2}	S_{a1}, S_{a2}	T_a
Normal	ON	OFF	-
Sag	OFF	ON	I-region(Low)
Swell	OFF	ON	II-region
Outage	OFF	ON	I-region(High)
Unbalance	OFF	ON	-

3.1 Normal Mode

In normal mode the output terminal voltage V_{as} is almost equal to the source voltage V_a. Therefore, the series transformer voltage V_{ad} should be made nearly zero by turning on the SCR thyristors S_{Ba1} and S_{Ba2}. It is assumed that the leakage impedance of the transformer is ignored. During this mode the second group thyristors (S_{a1}, S_{a2}) should be turned off.

3.2 Voltage Sag and Outage Mode

In this mode the first group thyristors (SBa1, SBs2) are turned off and second group thyristors (Sa1, Sa2) are turned on.In Fig. 1 a-phase output voltage Vas is determined by the sum of Va and Vad, or

$$V_{as} = V_a + V_{ad} . \quad (1)$$

The secondary voltage of the series transformer is expressed as

$$V_{ad} = -V_{Ta} / n , \quad (2)$$

where n is the turn-ratio of the series transformer, and VTa is given by

$$V_{Ta} = -V_a / n_{Ta} , \quad (3)$$

where nTa is the turn-ratio of the variable autotransformer Ta. Finally, Vas is given by

$$V_{as} = V_a \{1 - 1/(n \times n_{Ta})\} . \quad (4)$$

The negative polarity of V_{ad} is obtained by setting the contact point in I-region of the variable autotransformer,

and n_P increases as the point moves toward the neutral point N. The turn-ratio n_P is easily adjusted by sliding the contact point. Therefore, a wide range of voltage sag can be achieved from 0% to 100%. In the case of 100% voltage sag, the contract point is located at the top area of the autotransformer, which results in and outage is generated.

$$V_{ad} = -V_a \,, \tag{5}$$

3.3 Voltage Swell Mode

A voltage swell can be generated by setting the contract point in II-region in Fig. 1, with the same switching state of the SCR thyristors as shown in Table I. The basic operation is quite similar to that of the voltage sag, and the output voltage is found to be

$$V_{as} = V_a\{1 + 1/(n \times n_{Ta})\}. \tag{6}$$

3.4 Voltage Unbalance Mode

The three contract points of the autotransformer can be set independently with each other. Therefore, it is easy to generate unbalanced 3-phase voltage by adjusting the nP in equation (4) and (6) as follows:

$$V_{as} = V_a\{1 \pm 1/(n \times n_{Ta})\} \tag{7}$$

$$V_{bs} = V_a\{1 \pm 1/(n \times n_{Tb})\} \tag{8}$$

$$V_{cs} = V_a\{1 \pm 1/(n \times n_{Tc})\} \tag{9}$$

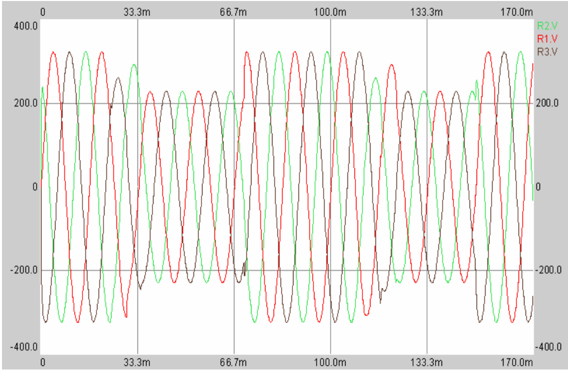
where, n_{Ta}, n_{Tb}, and n_{Tc} are the turn-ratio of the autotransformers T_a, T_b, and T_c, respectively.

4. Simulation

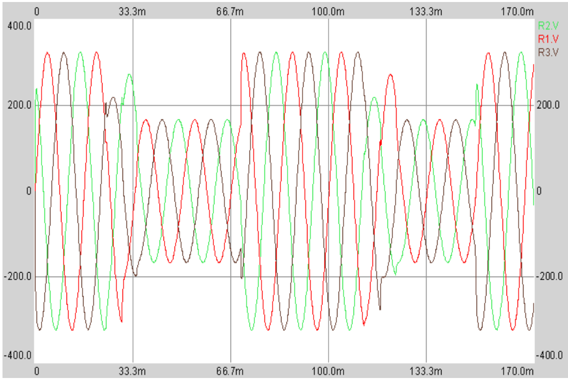
4.1 Linear Load

Simulations are carried out with the circuit diagram as shown in Fig. 1. The line-to-line source voltage is 220 V, and the out power rating is 10 kVA. The turn ratio of the series transformer n is 1.

Fig. 2(a) and 2(b) show 30% and 50% voltage sag, respectively, under balanced voltage conditions of the three phase generator in Fig. 1. Fig. 3(a) and 3(b) show 30% and 50% voltage swell, respectively. Fig. 4 shows the generation of voltage unbalance. The magnitude of the generator output voltage Vas, Vbs, and Vcs are 100%, 80%, and 50% of the source voltage.

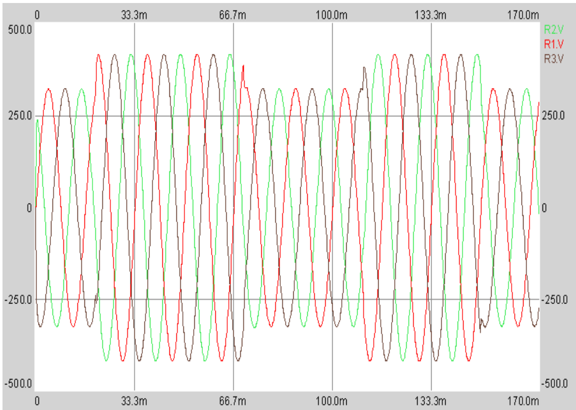


(a) 30 % sag

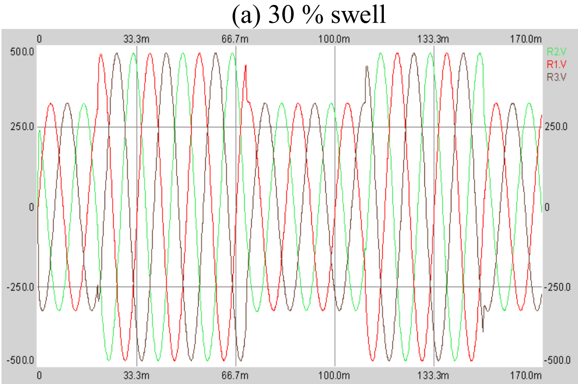


(b) 50 % sag

Fig. 2. 3-phase output voltage sag waveform



(a) 30 % swell



(b) 50 % swell

Fig. 3. 3-phase output voltage swell waveform

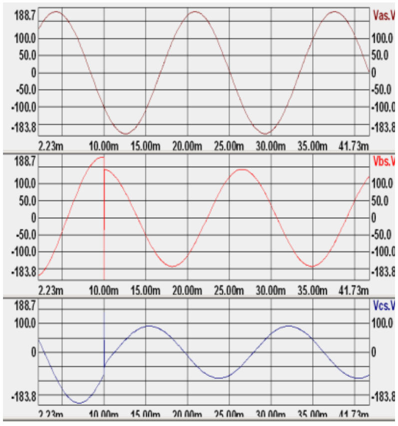


Fig. 4. Voltage unbalance waveforms: V_{as} (top), V_{bs} (middle), and V_{cs} (bottom)

Fig. 5 shows the 3-phase outage generation. The magnitude of the 3-phase secondary voltages of the series transformer is equal to that of the source voltage; however, the polarity of the two voltages is opposite each other.

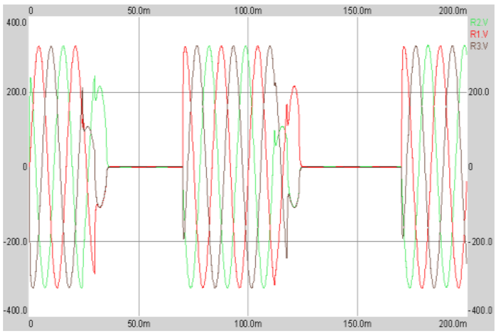


Fig. 5. 3-phase outage generation

4.2 Nonlinear Load

Simulations are carried out with a nonlinear load as shown in Fig. 6.

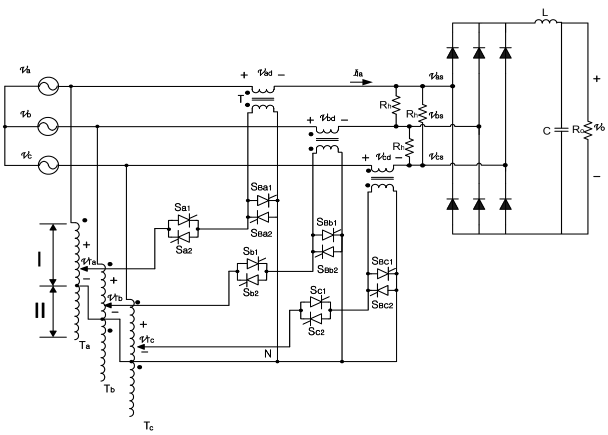


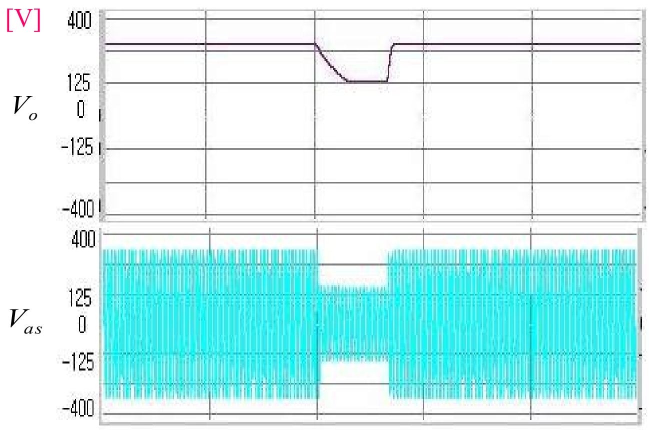
Fig. 6. Proposed voltage disturbance generator with nonlinear load

Table 2 shows the parameter values used in simulation.

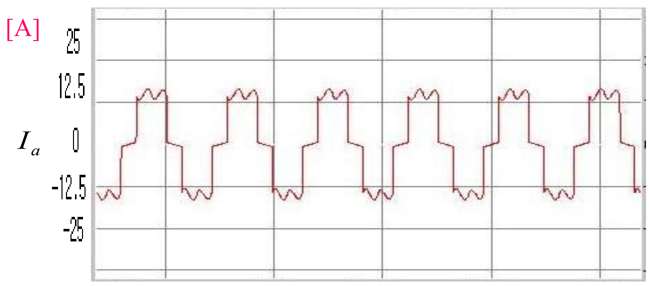
TABLE 2. Simulation Parameters

PARAMETER	VALUE
3-phase input voltage	220 V
Series transformer L_l	323 uH
Resistor, R_h	500 ohm
Filter, L	1 mH
Filter, C	13,600 uF
Load Resistor, R_o	20 ohm

Fig. 7 shows load voltage Vo, generator output terminal voltage Vas, and a-phase current Ia in case of 50% voltage sag generation. As soon as the voltage sag is generated, the load voltage decreases with the Ro-C time constant. When the generator output voltage Vas returns to the normal source voltage, Vo increases to the rated value. The current waveform of Io is composed with pulsating load current and sinusoidal current flowing through resistor Rh, and the zoom-in waveform in time scale in normal mode.



(a) V_o and V_{as} (500 ms/div.)



(b) I_a (10 ms/div.)

Fig. 7. Waveforms of V_o, V_{as}, and I_a in case of 50% sag

Fig. 8 shows V_o and V_{as} in case of 30% voltage swell. As the generator output voltage increases, the load voltage increases. Fig. 9 shows V_o and V_{as} in the case of outage. Once the generator output voltage reduces to zero, the load voltage starts to decrease.

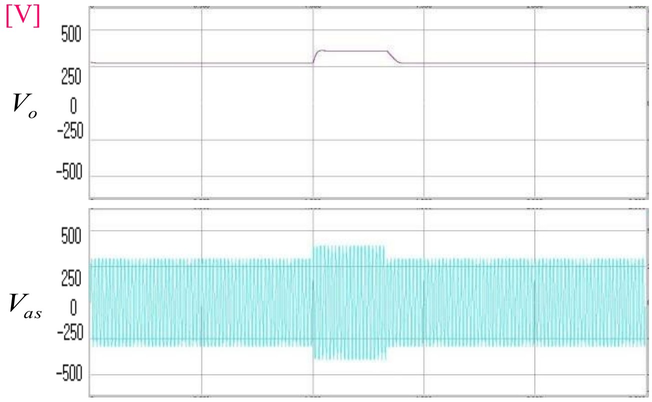


Fig. 8. Waveforms of V_o and V_{as} in case of 30 % Swell (500 ms/div.)

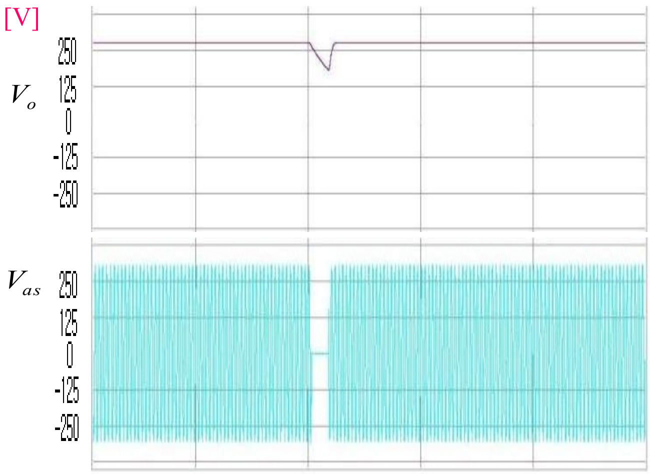


Fig. 9. Waveforms of V_o and V_{as} in case of outage (500 ms/div.)

5. Experimental Results

Fig. 10 shows the source line-to-line voltage V_{ab} and the disturbance generator output voltages V_{as}, V_{bs}, and V_{cs} in the case of 30% voltage sag generation. It is found that there are no voltage spikes during the voltage transition from normal to sag and vice versa. The voltage dip from the normal magnitude can be achieved very quickly as soon as the sag command is applied to the control unit of the disturbance generator.

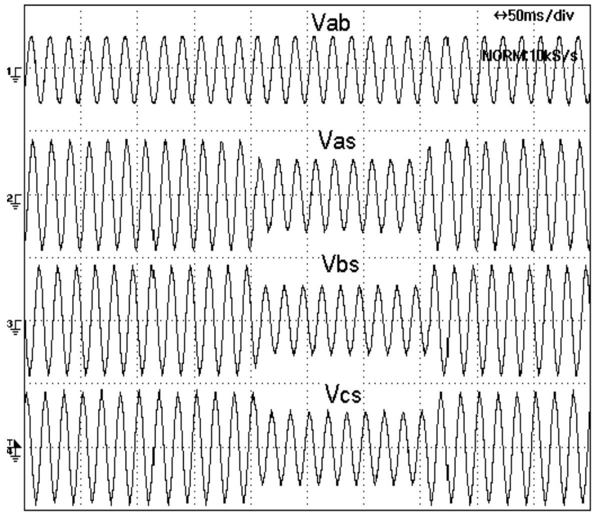


Fig. 10. Source voltage V_{ab} (500 V/div.) and generator output voltage V_{as}, V_{bs}, V_{cs} (200 V/div.) in case of 30 % voltage sag generation

If the voltage applied to the series transformer is equal to the source voltage, the generator output voltage can be zero as shown in Fig. 11. Fig. 11 shows a-phase source voltage Vas and disturbance generator output voltages V_{as}, V_{bs}, and V_{cs} in the case of outage. These output voltages are reduced almost zero during 9 cycles without any voltage spike.

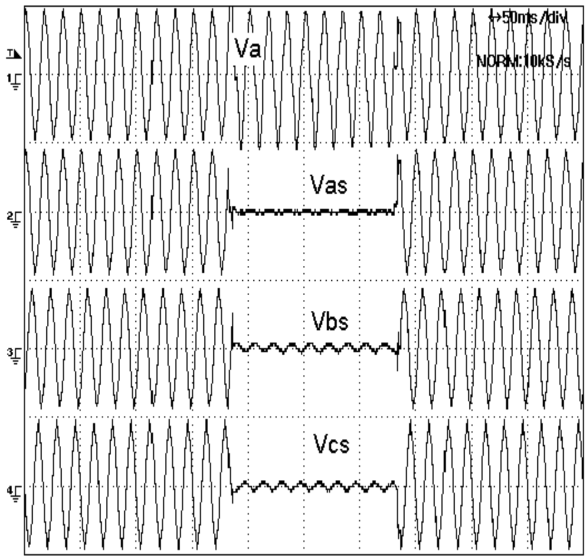


Fig. 11. a-phase source V_a and generator output voltages V_{as}, V_{bs}, V_{cs} in case of outage (200 V/div)

Fig. 12 shows source line-to-line voltage V_{ab} and disturbance output voltages V_{as}, V_{bs}, V_{cs} in the case of unbalanced voltage output generation. It is found that the magnitude of each output voltage can be adjusted independently.

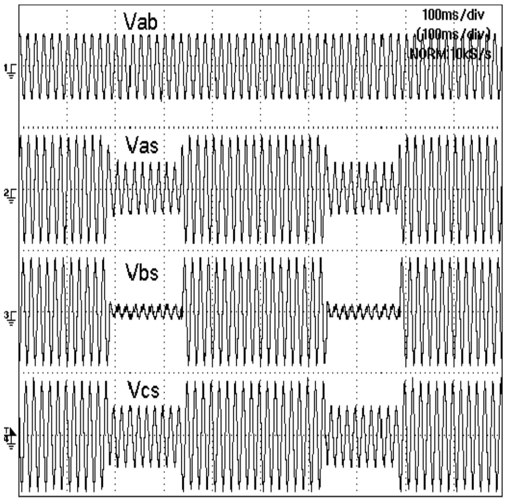


Fig. 12. Source voltage V_{ab} (500 V/div.) and generator output voltage V_{as}, V_{bs}, V_{cs} (200 V/div.) in case of voltage unbalance generation (V_{as} = 0.5, V_{bs} = 0.2, V_{ca} = 0.6)

6. Conclusion

A new voltage disturbance generator is proposed. The proposed generator can provide voltage sag, swell, outage, and unbalance with a simple structure and easy control. The voltage disturbance generation mechanism is described in each mode, and the simulation and experimental results show the usefulness of the proposed scheme. The scheme can be applied to both linear and nonlinear load. The major characteristics of the proposed generator are summarized as follows:

- A high reliability with SCR thyristors and sliding type autotransformers.
- High efficiency caused by no PWM switching losses to the thyristors.
- Easy and arbitrary setting of the desired disturbance voltage value with a wide range.
- Easy generation of the voltage sag, swell, outage, and unbalance.
- A cost effective system with a simple structure.

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