A Single-Phase Voltage Sag Generator for Testing Electrical Equipments

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***Abstract*— This paper describes a transformer-based voltage sag generator (VSG) suitable to evaluate the susceptibility of electrical equipment to voltage sag. The built VSG utilized one auto-transformer and two solid state relays (SSRs) to provide nominal voltage and sag voltage to the load. The switch statuses of two SSRs are controlled by nominal voltage and sag voltage duration signal produced by electronic circuits. The VSG operating result shows that it enables effective control of sag magnitude, duration, beginning and ending points on output voltage wave. If needed, it can work as a voltage swell generator and a voltage interruption generator. By supplying high voltage (HV) transformer from the primary side, the VSG also can provide HV sag, swell, and interruption.**

The presented VSG is easier to set up in the lab, and the construction cost is much lower than buying VSG products at the current market.

***Index Terms*—Equipment susceptibility, voltage interruption, voltage sag, voltage sag generator, voltage swell.**

I. Introduction

Modern power systems are becoming more and more sensitive to the quality of supplied power. The reason is that not only does modern equipment include a vast variety of electronic components which can be very vulnerable to power disturbance, but also the customers become more susceptible to the losses produced by equipment malfunction. As one of the most common power disturbances, voltage sag typically happens randomly and usually lasts only a few cycles. However, sensitive equipment often trips or shuts down for those sags, even if nominal voltage returns in just a few cycles. Thus, voltage sag brings the greatest financial loss compared with most other kinds of power disturbances [1], [2].

There are some devices installed in power systems to mitigate voltage disturbance, such as uninterruptible power supply, voltage regulator, and dynamic sag restorers. These devices are effective but expensive. It makes more economic sense to improve the sustainability of electrical equipment so they can tolerate common power disturbances without additional support [3]. The VSG is a kind of device which can supply reliable and repeatable voltage sags to measure equipment susceptibility to the voltage sags. With the help of the VSG, engineers can have improved knowledge about the equipment susceptibility to voltage disturbance, and further adjust the design of the equipment [4], [5]. Moreover, some standard methodologies have proposed recommended performance limits for equipment response to voltage sag with specific voltage sag magnitudes and durations. To fulfill these recommendations, engineers need the help of the device like the VSG [1], [6], [7].

Depending on different realization methods, there are four types of VSGs, which are amplifier-based, transformer-based, switching-impedance-based, and generator-based. Amplified-based VSG generates output voltages and currents with desirable characteristics by using a waveform generator and power amplifier. It can provide voltage sags with varying magnitude, duration, frequency and harmonics. Normally amplified-based VSG is more complicated and expensive than transformer-based VSG [8]. Transformer-based VSG is usually realized as a combination of transformers and appropriate switching devices. It can not provide changeable frequency and harmonic distortion. However it is low cost, and it is easily constructed in the lab [9]. Switching-impedance-based VSG creates voltage sags by switching impedance into a power system by using the thyristor controlled reactor (TCR). It can provide harmonics by controlling firing angles of the TCR. Switching-impedance-based VSG is good at testing equipment in HV power circuits [10]. Generator-based VSG provides voltage sag by changing the exciting current of the generator. The weight and scale of the generator are the challenges [2]. Since transformer-based VSG is capable of generating the sag defined in reference [1] - a decrease in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min, it has more economic and reliability advantages than the other three types of the VSG.

Some VSG products are already selling in the current market, such as Industry Power Corruptor by Power Standard Lab, and Porto-Sag by EPRI PEAC Corporation. They work well, however they are very expensive. In this paper, we propose a transformer-base VSG, which is very easy to construct in the lab, and has low cost - less than $300.

This work was supported by Power Systems Engineering Research Center (PSERC).

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978-1-4244-1904-3/08/$25.00 ©2008 IEEE

II. Structure of the VSG

The structure of the VSG is demonstrated in Fig. 1. Four parts are needed for the realization of the transformer-based VSG:

1) Duration control circuit, which regulates the duration of nominal voltage and voltage sag.
2) Signal shifting circuit, used to adjust sag beginning and ending points on voltage wave.
3) Drive circuit, providing nominal voltage or voltage sag based on the control signal generated by the signal shifting circuit.
4) Single-phase auto-transformer, for generating two voltage levels: nominal voltage and voltage sag.

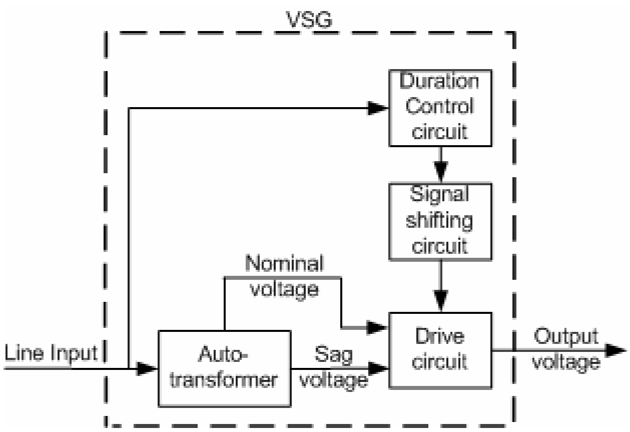

Fig. 1. The structure of the built transformer-based VSG

The functions of the duration control circuit, signal shifting circuit, drive circuit, and autotransformer are described below.

A. Duration control circuit

The duration control circuit was built and Fig. 2 shows its detailed hardware diagram for 20 cycles pre-sag nominal voltage, 2 cycles voltage sag, and 20 cycles post-sag nominal voltage. The circuit is composed of one voltage comparator (LM311), one JK flip-flop, three 10 decoded counters (CD4017), some 3-input AND gates (7411), etc.

The VSG was designed to operate after receiving a starting signal generated by an on-off-(on) toggle switch, and stop after getting an ending signal automatically produced by the duration control circuit. The debouncing circuit is used to mitigate the effects of mechanical toggle switch bounce, and provide smooth, reliable single pulse acting as a starting signal. The ending signal can be different according to the various voltage sag durations. In current design, the 115th pulse was selected to be the ending signal. The starting signal and ending signal are combined together by one OR gate. The combined signal is provided to the counters as reset signal and the JK flip-flop as its input. Since the JK flip-flop is falling edge-triggered, the output of the JK flip-flop will be low during the time after the falling edge of starting signal and before the falling edge of ending signal, which enable the counters begin to work. As a result the working time of the counters is controlled based on starting signal and ending signal and further VSG operation time is controlled.

The AC line voltage (115Vac) is supplied to voltage comparator through an isolation transformer (117/6.3Vac). The voltage comparator compares 3Vac with the ground, then output a synchronous voltage square waveform, which has the same frequency with the input AC source and 0.5 duty ratio. The synchronous voltage square waveform is supplied to the first counter as its clock signal. The carryout output (10 cycles duration and 0.5 duty ratio) of the first counter acts as the