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A Review on Mitigation of Voltage Sags and Swells Techniques for Improving Power Quality

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ABSTRACT: This paper presents Brief Review of control techniques to mitigate power quality disturbances such as voltage sag, swell and harmonics. The power quality is affected mainly due to the sensitive loads which results in voltage sag and voltage swells. It is necessary to investigate the suitable methods for mitigation of voltage sags. The voltage sag/dip is the most frequently occurring problem. There are many methods to overcome this problem. Among them the use of FACT devices is an efficient one. This project presents an overview of the FACT devices like- DVR, D-STATCOM, and Auto-Transformer in mitigating voltage sag. This paper presents a comprehensive review and comparison of various Control schemes used by utilities for mitigation of voltage dips in power networks.

KEYWORDS: Auto-Transformer, Voltage Sags, Control System, Voltage Source Converter (VSC), Power Quality.

I. INTRODUCTION

A power distribution system is similar to a vast network of rivers. It is important to remove any system faults so that the rest of the power distribution service is not interrupted or damaged. When a fault occurs somewhere in a power distribution system, the voltage is affected throughout the power system. Among various power quality problems, the majority of events are associated with either voltage sag or a voltage swell, and they often cause serious power interruptions. A voltage sag condition implies that the voltage on one or more phases drops below the specified tolerance for a short period of time. A voltage swell condition occurs when the voltage of one or more phases rises above the specified tolerance for a short period of time. The causes of voltage sags and swells are associated with faults within the power distribution system. Users located a close distance to the fault experience voltage sags much greater in magnitude and duration than users located farther away, and as the electrical system recovers after removing the fault, voltage swells are produced throughout the system for short periods of time. In order to increase the reliability of a power distribution system, many methods of solving power quality problems have been suggested. The development and improvement of power switching devices capable of carrying large current with high voltage enable power electronics technologies to be applied to this area. In addition, self-commutable devices, i.e., gate turn-off device such as GTOs and high power IGBTs, give rise to a variety of schemes to mitigate power quality problems. Many of the mitigation schemes of the voltage sag based on the inverter systems. The inverter system that consists of switches and energy storage [7]. The D-STATCOM is proposed to mitigate the voltage sag and also to solve another problem of the power quality such as voltage fluctuations [8]. The D-STATCOM which is the system based on the voltage source inverter and thyristor. That thyristor system in the AC system to control the output current independently [8]. The system of the dynamic voltage restorer (DVR) requires to inject voltage of the sufficient magnitude. It can be used to maintain constant voltage based on the duration of voltage sags. The dynamic voltage restorer (DVR) can operate in boost mode [9]. By using the PWM-switched autotransformer that uses to control circuit based on RMS voltage is used to identify the voltage sag. The voltage of load and reference of voltage are always compared together to make sure that the system is stable where the error of voltage is not more than 10%. One thing for the new mitigating technique of PWM-switched autotransformer only used are IGBT switches per phase and also the circuit topology is very simple compared to other methods. That is why the PWM-switched autotransformer is very more economical compared to DVR and D-STATCOM. [10], [11].

II. VOLTAGE SAG AND SWELL

Voltage sag is a reduction in voltage compared to normal rated voltage and voltage swell is an increase in voltage outside normal rated tolerance of loads as shown in Figure.2. The voltage sag and swell are the most critical power

quality issues in distribution grid today [2]. The survey of power quality presents that voltage sags with 40-50% of the nominal value and with duration from 2 to 30 periods occurred in about 92% of all power system events [4-7].

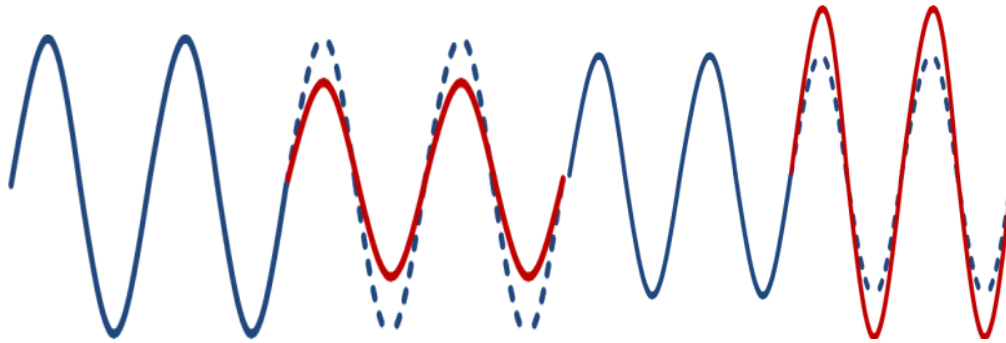


Figure 1. (a) Voltage Sag (Left) (b) Voltage Swell (Right).

Most electrical power generating authorities have an obligation to supply consumers from the grid at a constant voltage (typically within $\pm 6\%$ of nominal). However, sometimes this is not practical, particularly in rural locations. Sometimes voltage sags are caused by the power supplier during times of heavy demand, while dips are often caused by auto closers, operating within one second of fault detection. It is also possible for heavy plant to pull down the supply voltage during start-up. Compressors and pumps are good examples of loads, which require a high start-up current and switch in and out on a frequent basis, causing the supply voltage to dip. A dip is used to refer to a short-term reduction of less than half a second, whilst a sag relates to a long-term voltage reduction.

❖ Causes of dips, sag, swell and surges

1. Rural location remote from power source
2. Long distance from a distribution transformer with interposed loads
3. Unreliable grid system
4. Power distributor's tolerances not suitable for voltage sensitive equipment
5. Switching of heavy loads
6. Unbalanced load on a three phase system
7. Equipment not suitable for local supply

❖ Methods of dealing with dips, sags, swell and surges

1. Transformer with a tap changer
2. Constant voltage (ferro-resonant) transformer
3. Servo controlled voltage stabilizer
4. Switch mode power supply
5. Saturable reactor
6. Soft starters on larger electrical equipment
7. Connect larger loads to points of common coupling
8. Choose equipment with dip resilience

III. VOLTAGE SAG MITIGATION DEVICES

To better understand the most effective method of voltage sag mitigation, a brief review of existing methods is presented.

1) Tap Changers

Tap changers are the most cost-effective method for regulating the output voltage when the input voltage has a sag condition that exists for a relatively long period of time. It is possible to vary the output voltage by changing taps located in the primary or secondary side of a transformer. Most existing tap changers use mechanical moving parts to change the tap location. Usually, three or four cycles are needed to move the mechanical switch to the desired position. Therefore, its response is relatively slow [11]. To overcome this problem, thyristors have been used recently to replace the mechanical parts of the tap changer.

2) Flexible AC Transmission Systems (FACTS) Devices

FACTS devices have abilities of controlling active powers and reactive powers of the distribution system, which are able to maximize the utilization of existing lines. In addition, they can stabilize the voltage at point of common coupling and can reduce the damping of the power oscillation. FACTS devices can be divided into three categories such as series controller, shunt controller, and combined controller [12].

- ❖ Series connected controllers: Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Switched Series Reactor (TSSR), etc.
- ❖ Shunt connected controllers: Static Synchronous Generator (SSG), Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor-Controlled Reactor (TCR), Thyristor-Switched Capacitor (TSC), etc.
- ❖ Combined controllers: Unified Power Flow Controller (UPFC), Thyristor- Controlled Phase Shifting Transformer (TCPST), etc.

Recently, a dynamic voltage restorer (DVR) was introduced for mitigating a voltage sag. The DVR shown in Figure 2.6 is based on an inverter system that has energy storage for supplying active power, an output filter to make more sinusoidal voltage, and a step up transformer. The DVR is one of the FACTS devices that use the power electronics technology, especially inverter technology and is configured as a series-connected voltage controller. To control the output voltage of the DVR, the inverter supplies the missing load voltage using self-commutable electronic switches such as a gate turn-off thyristor (GTO), an insulated gate bipolar transistor (IGBT), or an insulated gate commutated thyristor (IGCT).

IV. VOLTAGE SAG COMPENSATION USING PWM SWITCHED AUTOTRANSFORMER

The ac converter topology is employed for realizing the voltage sag compensator. This paper considers the voltage mitigation scheme that use only one shunt type PWM switch[1] for output voltage control as shown in Fig. 2. The autotransformer shown in Fig. 2 is used in the proposed system to boost the input voltage instead of a two winding transformer. Switch IGBT is on the primary side of the autotransformer. The voltage and current distribution in the autotransformer is shown in Fig. 3. It does not provide electrical isolation between primary side and secondary side but has advantages of high efficiency with small volume. The compensator considered is a shunt type as the control voltage developed is injected in shunt. The relationships of the autotransformer voltage and current are expressed ,

$$\frac{V_L}{V_P} = a = \frac{I_S}{I_L} = \frac{N_1 + N_2}{N_1}$$

Where a is the turns ratio; V_P =Primary voltage; V_L =Secondary voltage=Load voltage; I_1, I_2 =Primary and secondary currents, respectively; I_S =Source current; I_L =Load current.

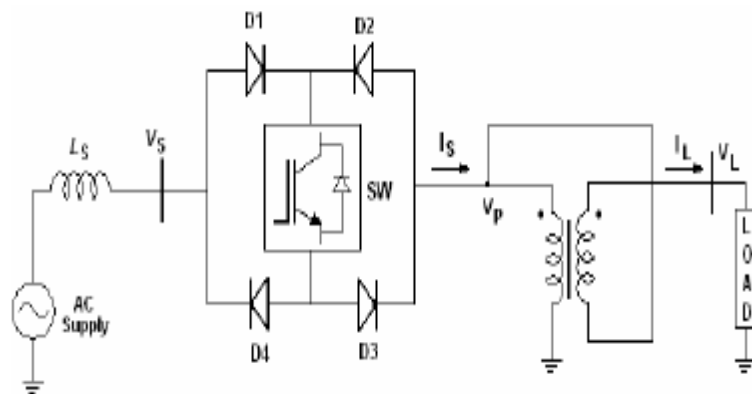


Fig. 2. Voltage Sag/Swell mitigating device

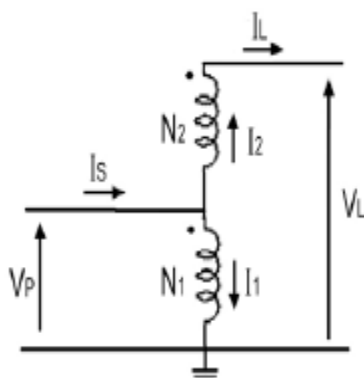


Fig. 3. Voltage and current relations in an autotransformer

The autotransformer in Fig. 3 does not offer electrical isolation between primary side and secondary side but has advantages of high efficiency with small volume. An transformer with $N_1 : N_2 = 1 : 1$ ratio is used as an autotransformer to boost the voltage on the load side when sag is detected. With this the device can mitigate up to 50% voltage sag during the sag period. As the turns ratio equals 1:2 in autotransformer mode, the magnitude of the load current I_L (high voltage side) is the same as that of the primary current I_1 (low voltage side). From Eq., it is clear that $V_L = 2V_P$ and $I_S = 2I_L$. The switch is located in the autotransformer's primary side and the magnitude of the switch current equals the load current. The voltage across the switch in the off-state is equal to the magnitude of the input voltage. When sag is detected by the voltage controller, IGBT switched ON and is regulated by the PWM pulses. The primary voltage V_P is such that the load voltage on the secondary of autotransformer is the desired rms voltage.

V. CONCLUSION

The demand for electric power is increasing at an exponential rate and at the same time the quality of power delivered became the most prominent issue in the power sector. Thus, to maintain the quality of power the problems affecting the power quality should be treated efficiently. Among the different power quality problems, voltage sag is one of the major one affecting the performance of the end user appliances. In this paper the methods to mitigate the voltage sag are presented. From this Review the following conclusions are made-

- ❖ Among the different methods to mitigate the voltage sag, the use of FACTS devices is the best method.
- ❖ The FACTS devices like DVR, D-STATCOM are helpful in overcoming the voltage unbalance problems in power system.
- ❖ DVR is a series connected device and injects voltage to compensate the voltage imbalance.
- ❖ D-STATCOM is a shunt connected device and injects current into the system.
- ❖ These devices are connected to the power network at the point of interest to protect the critical loads.
- ❖ These devices also have other advantages like harmonic reduction, power factor correction.
- ❖ The amount of apparent power infusion required by D-STATCOM is higher than that of DVR for a given voltage sag.
- ❖ DVR acts slowly but is good in reducing the harmonic content. Both DVR and D-STATCOM require more number of power electronic switches and storage devices for their operation.
- ❖ To overcome this problem, PWM switched auto-transformer is used for mitigating the voltage sag.
- ❖ Here the number of switches required is less and hence the switching losses are also reduced.
- ❖ The size and cost of the device are less and hence PWM switched autotransformer is an efficient and economical solution for voltage sag mitigation.

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