CHAPTER 2
Voltage Sag Compensations

2.1 Introduction

As mentioned in the previous chapter, voltage sag is the main problem of power quality with causing a huge loss in economy. This is such a serious subject which cannot be avoided.

Several ideas have been reported for compensations or mitigations of voltage sag. The details of voltage sag compensations are discussed in this chapter.

2.2 Voltage Sag Compensation Technologies

2.2.1 Uninterruptible Power Supplies (UPS)

Figure 2.1 shows the voltage sag compensation using UPS. Most of UPS use battery as energy storage devices. This is such a simple method to compensate the voltage sag since the battery is a basic energy storage device.

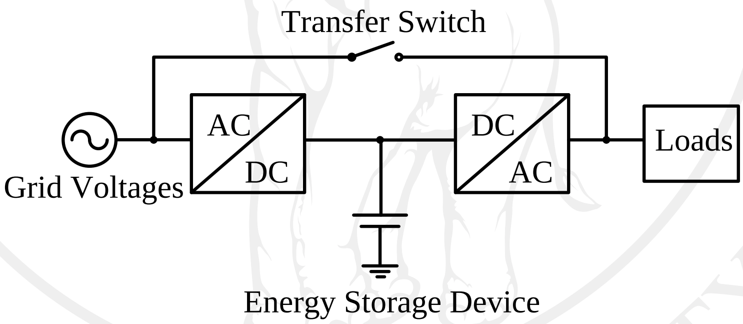

Figure 2.1 Typical voltage sag compensation method using UPS. [17]

It can be seen that the inverter input is connected to an energy storage device which acts like DC source of the inverter.

In the normal operation, the transfer switch is closed to connect grid voltage and load as long as the voltage from grid is within an acceptable range. In this normal operation, the energy storage device is charged via rectifier/charge. When the voltage sag occurs then the transfer switch is opened and the load is fed by the power from the inverter instead of the grid voltage. If the battery were used as energy storage device in this system, the battery should be always charged for reliable operation of the system.

2.2.2 Dynamic Voltage Restorer (DVR)

In the present year, several commercial products can be considered as dynamic voltage restorers [8], such as the Solid State Voltage Restorer (SSVR) from General Electric (GE), the Dynamic Voltage Restorer (DVR) from Westinghouse, SIPCON-S from Siemens, Dynacom from SP, and Active Voltage Conditioner (AVC) from ABB.

In this voltage sag compensation method, the voltage sag is compensated by the DVR which generates the added voltage so that the load voltage is still unchanged.

Figure 2.2 shows the typical DVR, it can be seen that there is a series power transformer connected between grid voltages and load. Whenever the voltage sag occurs and it is detected by DVR, the compensated voltage is then generated by means of energy storage device, DC/AC converter, and transformer. The period of compensation depends on energy storage device capacity. Electrolytic capacitors are common DC storage devices.

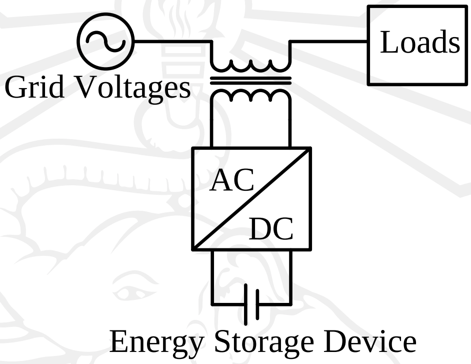

Figure 2.2 Typical voltage sag compensation method using DVR.

2.2.3 Distribution Static Compensator (D-STATCOM)

The distribution static compensator or D-STATCOM compensates the voltage sag by using a shunt transformer instead of series transformer. It can be seen that this shunt transformer is fed the power from energy storage device via voltage source inverter as shown in Figure 2.3. The inverter converts the DC power from energy storage device into a set of three-phase ac output voltages which are in phase and coupled with the grid voltages through the reactance of the coupling or shunt transformer. When the load voltage is low or voltage sag occurs then a D-STATCOM feeds the reactive power into the load to compensate the voltage sag. The reactive power exchanges between D-STATCOM and grid voltages can be controlled by varying phase and magnitude of D-STATCOM output voltages.

D-STATCOM is also used for correction of power factor and elimination of current harmonics [18].

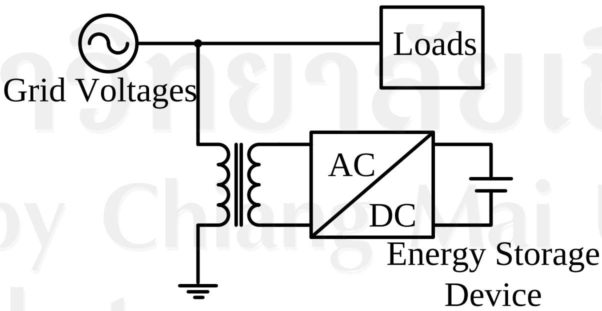

Figure 2.3 Typical voltage sag compensation method using D-STATCOM.

2.2.4 Static transfer switch (STS)

The static transfer switch (STS) is one of the most effective solutions of the voltage sag compensations [19]. It can be seen that this voltage sag compensation method is a simple method as shown in Figure 2.4. This method consists of two static transfer switches (STS) and two voltage sources. These voltages are grid voltages (as main voltage source) and alternate voltages which are identical to grid voltages (amplitude, frequency, and phase).

It can be noticed that the static transfer switch acts like single pole, double throw (SPDT) switch when STS1 (or main static transfer switch) connects to grid voltages and STS2 (or alternate static transfer switch) connects to alternate voltages.

In the normal event, STS1 is closed or turned on and the load is then fed by the power from grid voltages. In the abnormal event or when the voltage sag occurs, STS1 is then immediately turned off to separate the load and grid voltages, and after that STS2 is turned on in order to feed the power from alternate voltages to the load instead of faulty grid voltages. When the grid voltages return to normal condition, the process is then reversed by turning off STS2 to disconnect alternate voltages and then turning on STS1 to connect the healthy grid voltages to the load.

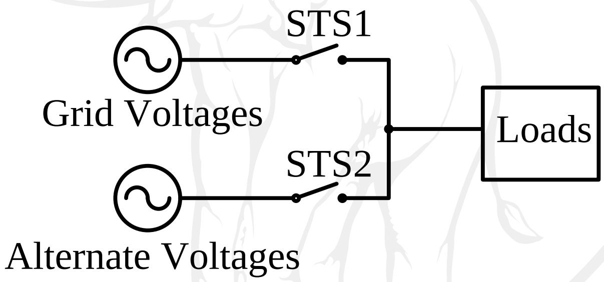

Figure 2.4 Typical voltage sag compensation method using STS.

2.2.5 Multi-tapped transformer

In this voltage sag compensation method, the power transformer is designed with additional multiple taps for supporting the voltage deviations and the static switches used to change the transformer taps as shown in Figure 2.5. This is one simple method of voltage sag compensations.

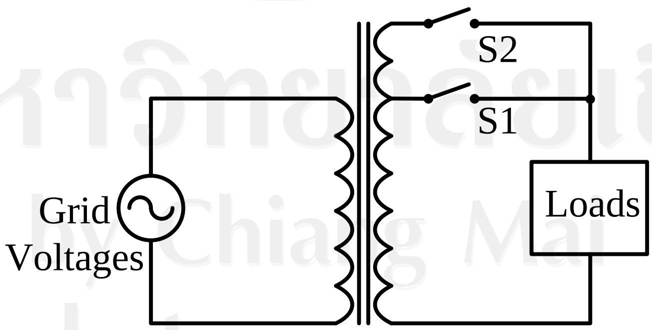

Figure 2.5 Typical voltage sag compensation method using Multi-tapped transformer.

With the normal condition of grid voltages, the switch S1 is turned on yielding normal voltages to the load. When the grid voltages are dropped i.e. voltage sag, the switch S1 is turned off and the switch S2 is turned on to regulate the load voltage. In this voltage sag compensation method, the amount of voltage amplitude compensation depends on turn ratio of each winding and the voltage compensation resolution depends on number of taps which is yielding in high volume, high weight, and high cost. Otherwise, the transient voltage due to switching taps is one considerate issue.

2.2.6 AC-AC converter with series transformer

The AC-AC converter and series transformer are used in this voltage sag compensation method as shown in Figure 2.6. It can be seen that the configuration of this method is almost similar to DVR in section 2.2.2. In this method, however, the energy storage device is not needed, the series transformer is injected the power from AC-AC converter which is directly connected to grid voltages. However, the point of common coupling (PCC) may experience noise due to AC chopper circuit.

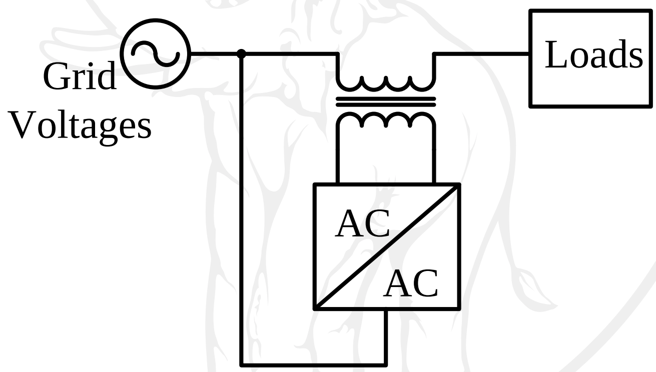

Figure 2.6 Typical voltage sag compensation method using AC-AC converter with series transformer.

2.3 Energy Storage Technologies

2.3.1 Batteries

In this technology of energy storage, energy is stored electrochemically in batteries. This is such a simple method since the batteries are basic energy storage devices.

There are currently several battery technologies available. When consider to the price, the lead acid batteries are the most common use, while lithium ion is becoming more attractive technology due to its advantages such as high energy density, low self discharge, low maintenance.

This energy storage is simple and low cost. However, batteries cannot handle high power levels for long time periods [20]. The fast discharge and charge of batteries may shorten the battery life. Battery life depends on its cycle of use (charge-discharge), environmental temperature, rate of charge and discharge then the batteries need maintenance and replacement.

2.3.2 Capacitors

Capacitors are also favorite energy storage devices since they are very simple. They have a very fast charge time and no limitation of charge cycle as batteries [21]. The life span of capacitor is then longer than battery. The capacitors are the right choice to the fast voltage sag compensation technologies such as DVR or D-STATCOM whom needs fast energy storage devices. Modern super capacitors, which are also known as ultra-capacitors or electrochemical capacitors, are another good choices of energy storage devices when considering their capacitance. However, the cost of capacitor is relatively higher than that of battery and power density of capacitor is relatively lower than battery power density.

2.3.3 Flywheels

In this method of energy storage, the flywheels are used to store the energy. This is one of the oldest storage technologies. The principle of flywheels is based on a rotating mass being spun in a very high speed and maintaining the energy as rotational energy [22]. The storage energy depends on the speed and the inertia of the flywheels. This mechanical energy is transformed into electric energy by a generator coupled to the flywheels.

Since flywheels operation is based on mechanic then it does not need an exhaustive maintenance likes batteries. Moreover, the durability of flywheels is one advantage. The weight and the footprint required by flywheels are considerable less.

However, since the flywheels are rotating mass and spinning in a high speed then safety requirements are very serious issue.

2.3.4 Fuel cells

Fuel cells are a galvanic cell or electrochemistry power source. The chemical energy from fuel can generate electricity through a chemical reaction with oxygen or another oxidizing agent. The devices that perform this process are fuel cells.

The basic fuel is hydrogen but fuel cells also require oxygen to produce electricity. Hydrocarbons such as natural gas and alcohols like methanol are sometimes used as fuels, however. To preserve the chemical reaction, fuel cells require a constant source of fuel and oxygen/air. The electricity can then continually achieve as long as these inputs are supplied.

Fuel cells have two electrodes, i.e. positive electrode and negative electrode. These two electrodes are called anode and cathode respectively. Fuel cells also have an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.

A single fuel cell generates a tiny amount of direct current electricity. In practice, many fuel cells are usually fabricated into a stack to produce more electricity.

Since the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, namely water, the fuel cells generate electricity with very little pollution i.e. environmentally friendly. The fuel cells have high reliability and high efficiency [23]. The fuel cells have no moving parts and no fossil fuel is required, however, they are unable to respond to sudden load changes and high cost.

2.3.5 Superconducting Magnetic Energy Storage (SMES)

In the superconducting magnetic energy storage (SMES), the energy is stored in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. Once the superconducting coil is charged, the magnetic energy can be stored indefinitely.

SMES technology is the one of favored research issues of superconductor applications in the past 30 years, especially when the high temperature superconducting (HTS) materials were discovered in 1986 [24].

The current density of SMES coil is about 10 to 100 times larger than the common coil since its resistivity is considered as zero, then resistive losses is also considered to be zero. Therefore the higher density energy can be accumulated in superconducting coil as long as required. The high efficiency of voltage sag compensation system that using superconducting magnetic energy storage systems is possible whereas the SMES efficiency can get up to 95%. Furthermore the energy from SMES can feed to power system within milliseconds.

2.4 Conclusions

The table 2.1 shows the summary of voltage sag compensation methods described in section 2.3 and 2.4.

Table 2.1 Summary of voltage sag compensation technologies.

Technologies	Advantages	Disadvantages
UPS	- Simple - Low cost	- High loss
DVR	- High efficiency - Fast acting	- Requiring a series transformer - Complicate
D-STATCOM	- High efficiency - Fast acting	- Requiring a shunt transformer - Complicate
STS	- Simple method - Cost effective - low loss	- Need alternate voltage source
Multi-tapped Transformer	- Simple method	- Transient voltage
AC-AC converter with series transformer	- Not using energy storage device	- Noise

Table 2.2 Conclusion of energy storage technologies.

Technologies	Advantages	Disadvantages
Batteries	- Simple - Low cost	- Unable to handle high power level for long time - Rapid discharge cycles may shorten the battery life. - need maintenance and replacement.
Capacitors	- Simple - Very fast charge time - No limitation of charge cycle	- High cost - Low power density
Flywheels	- Durable	- Stationary - Safety and maintenance are the concerns
Fuel cells	- Environmental friendly - High reliability and efficiency - No moving parts - No fossil fuel is required	- Unable to respond to sudden load changes - High cost
SMES	- Good handle of power burst - No loss of power - No moving parts	- Requiring a sophisticated cooling system (to maintain cryogenic) - High cost