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A Comparative Study of Voltage Sag & its Mitigation Technique

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ABSTRACT: Electrical energy is that the most effective and popular sort of energy and therefore the modern society is heavily hooked in to the electrical supply. The life can't be imagined without the availability of electricity. At an equivalent time the standard and continuity of the electrical power supplied is additionally vital for the efficient functioning of the top user equipment. Most of the commercial and industrial loads demand top quality uninterrupted power. Thus to maintain the qualitative of power is of utmost important. The presence of harmonics, voltage and frequency variations deteriorate the performance of the system. In this paper the frequently occurring power quality problem- voltage variation is discussed. The voltage sag/dip is the most frequently occurring problem. There are many methods to overcome this problem. Among them the use of flexible alternating current transmission devices is an efficient one. This presents an overview of the FACT devices like- Ferro-resonant transformer, Auto-Transformer etc in mitigating voltage sag.

KEYWORDS: Power quality, Voltage sag, Voltage mitigation, D-STATCOM, Ferro-resonant, Auto-transformer.

I.INTRODUCTION

The electrical energy is one of the easily used forms of energy. It can be easily converted to other forms of energy. With the advancement of technology, the dependency on the electrical energy has been increased greatly. Computer and telecommunication networks, railway network banking, post office, life support system are few application that just cannot function without electricity. At the same time these applications demand qualitative energy. But, the quality of power supplied is affected by various internal and external factors of the power system. The presence of harmonics, voltage and frequency variations deteriorate the performance of the system. In this project the frequently occurring power quality problem- voltage variation is discussed. The voltage sag/dip is the most frequently occurring problem. The power quality is affected many problems which occur in transmission and distribution system. Some of them are like- harmonics, transients, sudden switching operations, voltage fluctuations, frequency variations etc. These problems also are responsible in deteriorating the buyer appliances. In order to reduce the behaviour of the facility system, these all problems should be eliminated.

The quality of power delivered to the top user is extremely important because the performance of the consumer's equipment is heavily hooked in to it. But the facility quality is suffering from various factors like voltage and frequency variations, presence of harmonics, faults within the power network etc. Among them the voltage variations (sag) is one among the foremost frequently occurring problem. There are many methods to mitigate the voltage sag and among them the simplest way is to attach a FACT device at the purpose of interest. The well-known devices like Ferro-resonant transformer, STATCOM, and UPS etc are used for this purpose.

II. POWER QUALITY PROBLEMS & ITS TYPES

There are many reasons by which the quality of power is affected. The occurrence of such problems within the power grid network is nearly indispensable. Therefore, to take care of the standard of power care must be taken that suitable devices are kept operational to stop the results of those problems. Here is a list of different problems of power quality with their causes and consequences are presented.

1. <u>Interruptions</u>: - It is the failure in the continuity of supply for a period of time. Here, the supply (voltage or current) may be close to zero. This is defined by IEC (International Electro-technical Committee) as "lower than 1 percentage of the declared value" and by the IEEE (IEEE Std. 1159:1995) as "lower than 10%". Based on the time period of the interruption, these are classified into two types: If the duration for which the interruption occurs is of few mill seconds then it is called as *short interruption*. If the duration that the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as *long interruption*.

2. Transient: - The transients are the momentary changes in voltage and current signals in the power grid over a short period of time. These transients are categorized into two types: impulsive & oscillatory. The impulsive transients are unidirectional whereas the oscillatory transients have swings with rapid change of polarity. There are many causes due to which transients are produced in the power system. They are- Arcing between the contacts of the switches, sudden switching of loads, poor or loose connections, and lightening strokes.

3. Voltage Sag: - The voltage sag is defined as the dip in the voltage level by 10 percent to 90 percent for a period of half cycle or more. The causes of voltage sag are- starting of an electric motor which draws more current, faults in the power system, sudden increase in the load connected to the system. The voltage signal with sag in shown in Fig.1

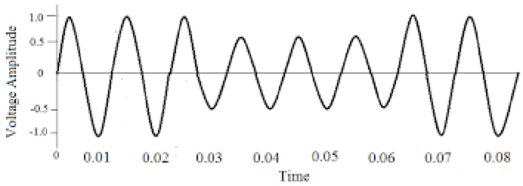

Fig.1 Voltage Sag

4. Voltage Swell: - Voltage swell is defined as the rise in the voltage beyond the normal value by 10 percent to 80 percent for a period of half cycle or more. The causes of voltage swell are- De-energization of large load, energization of a capacitor bank, abrupt interruption of current, change in ground reference on ungrounded phases.

5. Voltage Fluctuation:- These are a series of a random voltage changes that exist within the specified voltage ranges. Fig. 2 shows the voltage fluctuations that occur in a power system. These are caused by the- frequency start/ stop of electric ballasts, oscillating loads, starting of electric arc furnaces etc.

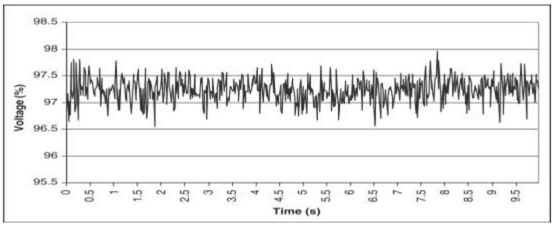

Fig.2 voltage fluctuation

6. Frequency Variations: - The electric power network is meant to work at a specified value (50 Hz) of frequency. The frequency of the framework is identified with the rotational rate of the generators in the system. The frequency variations are caused if there is any imbalance in the supply and demand. Large variations in the frequency are caused because of the failure of a generator or sudden switching of loads.

7. Harmonics: - These are voltage and current signals at frequencies which are integral multiples of the fundamental frequency. These are caused because of the presence of non-linear loads in the power grid network.

8. Noise: - This is caused by the presence of unwanted signals. Noise is caused due to interference with communication networks.

Among the various power quality problems discussed, the under voltage or voltage sag is the most prominent one because it occurs often and affects the power system network largely. Therefore, in this seminar main focus is given on voltage sag and its mitigation techniques.

III. CHARACTERISTICS OF VOLTAGE SAG

According to standard IEEE 1346-1998, Voltage Sag is defined as- “A decrease in rms voltage or current at the power frequency for duration of 0.5 cycles to 1 min., typical values are 0.1 pu to 0.9 pu.” The voltage sag is characterized by its magnitude, duration and phase angle jump. Each of them is explained below in detail.

1. Magnitude of Sag: - A sag magnitude is defined as the minimum voltage remaining during the event. The magnitude is often defined during a number of the way. The most common approach is to use the RMS voltage. The other alternatives are to use fundamental RMS voltage or peak voltage. Thus, sag is taken into account because the residual or remaining voltage during the event. In case of three-phase system where the dip in voltage isn't same altogether

phases, the phase with lowest dip is employed to characterize sag. The magnitude of voltage sag at a particular point depends on- type of fault, fault impedance, system Configuration, distance of the fault from the point of consideration.
2. Duration of Sag: - The duration of sag is that the time that the voltage is below a threshold value. It is determined by the fault clearing time. In a 3-phase system all the three RMS voltages should be considered to calculate the duration of the sag. Sag starts when one among the phase RMS voltage is a smaller amount than the edge and continues until all the three phase voltages are recovered above the edge value. Based on the duration of sag, the voltage sags are classified as shown in table 1,

Types of Sag	*Duration*	*Magnitude*
Instantaneous	0.5-30 cycles	0.1-0.9 pu
Momentary	30cycles-3sec	0.1-0.9 pu
Temporary	3sec-1min	0.1-0.9 pu

Table 1: Classification of Voltage Sag

3. Phase-Angle Jump: - The short circuits in power system not only cause a dip in voltage, but also change the angle of phase of the system. The change of angle of phase is called as "Phase-Angle Jump". It gives the shift in zero crossing of the instantaneous voltage. This phenomenon affects the facility electronic converters which use phase information for his or her firing.

4. Point-on-Wave: - To perfectly characterize sag, the point-on-wave where the sag starts and where it ends should be found with high precision. The point-on-wave is nothing but the angle of phase at which the sag occurs. These values are generally expressed in radians or degrees.

IV. VOLTAGE SAG MITIGATION TECHNIQUE

The voltage sag is a severe problem that the power system is facing now-days. This is a major problem and affects the functioning of the equipment. So, this problem should be mitigated in order to maintain the efficiency of the power network. The use of power devices solves this problem. This section presents the basic structure and working principle of different devices.

1. Ferro-resonant Transformer: - Ferro-resonant transformer also known as Constant Voltage Transformer (CVT). Ferro-resonant transformer (CVT) uses a transformer core that is operated in saturation. This means a change of magnitude of flux density is relatively independent of the magnetic flux inside the core. Regular power transformers are not operated in saturation as this is not very efficient. Since the transformer core is operated under saturation, small change in input voltage does not cause any significant change in the output voltage.

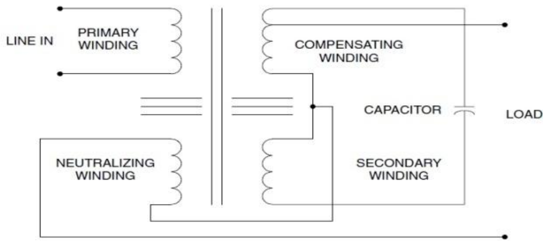

Fig.3 Ferro-resonant Transformer

Secondary circuit side of the CVT comprises of a resonant tank circuit. If the resonant tank circuit is not present, the voltage output will be a square wave with high harmonic voltage distortion. By adding the resonant circuit, a quasi-sine wave voltage can be obtained. If sinusoidal output is desired, a 'harmonic neutralized' design should be specified which will provide a voltage distortion of 3 % or less.

A Ferro-resonant transformer is made up of a core, a primary winding, two secondary windings (one for the load and one for the capacitor) and a magnetic shunt that separates the primary and secondary windings. The magnetic shunt provides a path for the imbalanced flux of the primary and secondary by allowing a portion of the primary flux to return to the primary winding without coupling the secondary. At the same time, it allows the secondary winding flux to return to the secondary winding without coupling the primary.

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Operation: - When a voltage is applied to the primary, the secondary voltage increases as the primary voltage increases. As the primary voltage increases the secondary voltage continues to increase up to a point of discontinuity, or secondary resonance, where an abrupt increase, about 20 percent, in secondary voltage occurs. The effect of resonance immediately increases the secondary flux density and causes saturation of that portion of the core. This partial core saturation is the main key to the magnetic design of the Ferro-resonant transformer. The voltage induced in the capacitor winding by the primary flux gives a capacitive current to flow. The flux due capacitive current is in phase with the primary flux. This flux addition occurs in the secondary part of the core. The increased flux saturates the portion of the core on the secondary winding only. The primary of the core is operating below saturation or below the "knee" of the magnetization curve. Ferro-resonant transformer is naturally self-protected against short circuits. And they are able to supply large surge currents if required due to the large amount of energy stored in the secondary circuit.

Advantages of Ferro-resonant Transformer (CVT):

- CVT has excellent voltage regulation when the RMS load current is constant or slowly changing.
- Voltage sag mitigation.
- Brief loss of input voltage for 2-4 ms will not result in any change in output voltage. This is because during the brief interruption period the resonant circuit will continue to supply the necessary load current.
- CVT using Ferro-resonant circuit has few components and has high reliability. There are no moving parts or semiconductors in the basic design.

The disadvantages of a Ferro-resonant transformer:

- Frequency sensitive.
- Temperature sensitive.
- External magnetic field may require shielding for sensitive component.

2. Auto-Transformer: - An auto transformer is a single winding transformer and there is no isolation between the primary and secondary windings. This device requires less conductor material in its construction and is of less size and weight when compared to the normal two winding transformer. It is used in mitigating the voltage sag when controlled properly. For the purpose of sag mitigation the secondary voltage is more than the primary voltage and the transformer operates as a *step-up transformer*. This configuration is used in voltage sag mitigation.

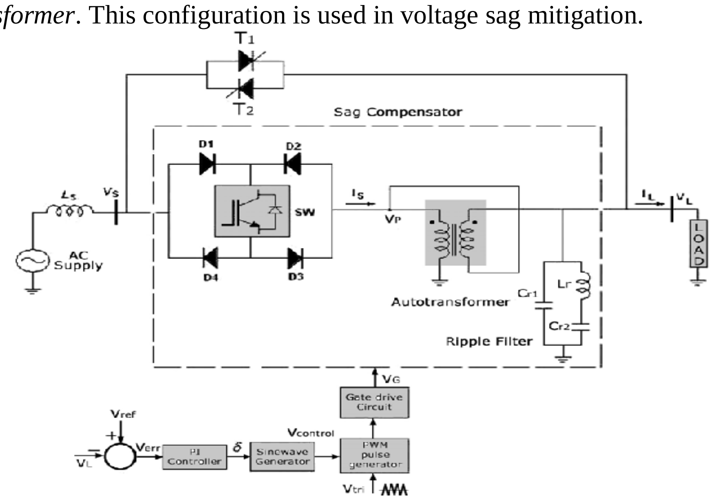

Fig.4 Voltage Sag Mitigation Using Auto Transformer

This auto transformer is controlled by a PWM operated power electronic switch. The single-phase diagram of a power system network with a PWM switched auto transformer used for voltage sag mitigation is shown in Fig.4

The circuit contains the following components-

- IGBT Switch: This switch is operated based on the pulses generated by the PWM generator and controls the auto transformer operation.
- Auto-Transformer: It is used to boost the voltage so that the load voltage remains constant irrespective of the variations in the supply voltage. It is controlled by the IGBT switch.

- Ripple Filter: The output voltage given by the auto-transformer contains harmonics along with the fundamental component. So, these harmonics should be filtered out to maintain the THD for the given system voltage at the load should be within the IEEE standard norms. Therefore, a ripple filter is connected at the output of the auto-transformer.
- Bypass Switch: There is a bypass switch made of SCR's connected in anti-parallel. The working of switch is to bypass the auto-transformer during the normal operation. During voltage sag condition, this switch remains off and auto-transformer operates.

Advantages of PWM switched auto-transformer:-
The PWM switched auto-transformer is advantageous over the other devices in mitigating the voltage sag. The advantages are as follows-

- Less cost
- Less number of switches required
- Reduced gate driver circuit size
- No energy storage device

3. <u>D-STATCOM</u>: - A Distribution Static Compensator is also known as D-STATCOM. It is a power electronic converter based device used to protect the distribution bus from voltage unbalances. It is generally connected in shunt to the distribution bus at the PCC (Point of common coupling). D-STATCOM is a shunt/parallel connected device designed to regulate the voltage either by generating or absorbing the reactive power. The schematic diagram of a D-STATCOM is as shown in Fig. 5. It contains- DC Capacitor, Voltage Source Converter (VSC), and Coupling Transformer.

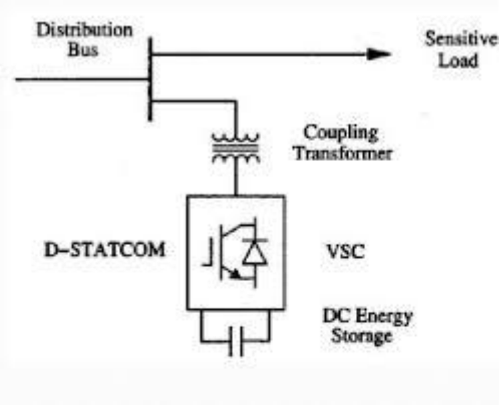

Fig.5 Schematic Diagram of D-STATCOM

The VSC gives voltage by taking the input from the charged capacitor. It uses PWM switching technique for this purpose. This voltage is delivered to the system through the reactance of the coupling transformer. The voltage difference across the reactor is used to produce the active and reactive power exchange between the STATCOM and the transmission network.

Operation: - D-STATCOM is capable of compensating either bus voltage or line current. The basic operating principle of a D-STATCOM in voltage sag mitigation is to regulate the bus voltage by generating or absorbing the reactive power. So, the DSTATCOM operates either as an inductor or as a capacitor based on the magnitude of the bus voltage.

- Inductive Operation: If the bus voltage magnitude is more than the rated voltage then the D-STATCOM acts as an inductor absorbing the reactive power from the system.
- Capacitive Operation: If the bus voltage magnitude is less than the rated voltage then the D-STATCOM acts as a capacitor generating the reactive power to the system.

To achieve the specific characteristics, the firing pulses to VSI are controlled. The actual bus voltage is then compared with the reference value and the error is given to the PI controller. Then controller generates a signal which is given as an input to the PWM generator. Then PWM generator finally generates triggering pulses such that the voltage imbalance is corrected.

The applications of the D-STATCOM are-

- Stabilize the voltage of the power grid
- Reduce the harmonics
- Increase the transmission capacity
- Reactive power compensation
- Power Factor correction

This section represents different devices used for mitigating the voltage sag. It presents the basic structure and operating principle of three main devices used for voltage sag mitigation- Ferro-resonant Transformer, Auto-Transformer, and D-STATCOM.

V. COMPARATIVE STUDY

A comparative study is made between three devices for mitigating voltage sag. The comparative study is based on the THD (Total Harmonic Distortion) of the load voltage and is shown in Table 2.

Device Name	*THD of Load Voltage*
Ferro-resonant Transformer	Approx. 3 %
Auto-Transformer	Approx. 2 %
D-STATCOM	Approx. 8 %

Table 2: Comparative Study

From this study it's clear that the Auto-Transformer is more efficient in mitigating the voltage sag. And also the advantage of auto transformer is that the number of power electronic switches used is reduced. Hence the switching losses are reduced.

And between Ferro-resonant Transformer and D-STATCOM, Ferro-resonant Transformer is better in terms of harmonic reduction. And also DSTATCOM requires more apparent power injection for a given voltage sag.

VI. CONCLUSION

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 which affecting the performance of the end user appliances.

From this study, the following conclusions are made-.

- The FACT devices like Ferro-resonant Transformer, D-STATCOM are helpful in overcoming the voltage unbalance problems in power system
- Ferro-resonant Transformer is a shunt connected device which compensates the voltage imbalance.
- D-STATCOM is a shunt connected device and drive current into the system
- These devices are connected to the power network at the PCC to protect the critical loads
- Also these devices have other advantages like harmonic reduction, power factor correction.
- But the disadvantage of Ferro-resonant transformer is that, it is temperature sensitive and frequency sensitive.
- Also, the amount of apparent power infusion required by D-STATCOM is higher. Again D-STATCOM requires more number of power electronic switches and storage devices for their operation.
- To overcome from this problem, PWM switched auto-transformer is used for mitigating the voltage sag
- Here the numbers of switches required are less and hence the switching losses are also reduced. The size and cost of the device are less and hence PWM switched auto-transformer is an efficient and economical solution for voltage sag mitigation.

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