VOLTAGE SAG: A MAJOR POWER QUALLITY ISSUE

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Abstract :

This paper highlights voltage sag as one of the major power quality issue and methods used in the mitigation of voltage sags. Voltage sag are momentary reduce in voltage caused by short circuits, overloads and starting of large motors, that may effecting to the customer's sensitive loads such as Adjustable Speed drive (ASD), Programmable Logic Control to tripped and are recognized as the most important power quality problems. Different solutions are for improving the performance of the equipments.
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Keywords: Voltage sag; Power quality; Adjustable Speed Drives; Dynamic Voltage Restorer.

1. Introduction

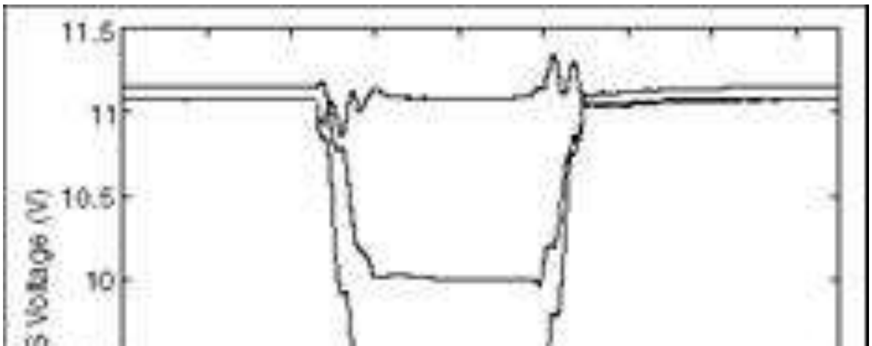
This paper gives comprehensive overview of cause, effects and mitigation methods of voltage sag. According to IEEE standard 1159-1995, a voltage sag is defined as a decrease to between 0.1 and 0.9 p.u in root mean square (rms) voltage at the power frequency for durations of 0.5 cycles to 1 min. [1]. Voltage sags have always been present in power systems. They are a nuisance for many industrial and commercial customers; they are impossible to prevent, but it is often possible to mitigate the impact on equipment [2]. Due to the wide usage of sensitive electronic equipment in process automation, even voltage sags which last for only few tenths of a second may cause production stops with considerable associated costs; these costs include production losses, equipment restarting, damaged or lower quality product and reduced customer satisfaction. The high costs associated with these disturbances explain the increasing interest towards voltage sag mitigation techniques. The cost of the mitigation intervention has to be compared with the loss of revenue and takes into account all the economic factors involved. To understand the different ways of mitigating voltage sags, various factors contributing to the problem have to be understood. The cause of most voltage sags is a short circuit fault occurring either within the industrial facility under consideration or on the utility system. The starting of large motors also results in voltage sags [3].

2. General Causes of Voltage Sag

There are various causes of voltage sags in a power system. Voltage sags can caused by faults on the transmission or distribution system or by switching of loads with large amounts of initial starting or inrush current such as motors, transformers, and large dc power supply.

2.1. *Voltage Sag Due to Faults*

Voltage sags due to faults can be critical to the operation of a power plant, and hence, are of major concern. Depending on the nature of the fault such as symmetrical or unsymmetrical, the magnitudes of voltage sags can be equal in each phase or unequal respectively.
For a fault in the transmission system, customers do not experience interruption, since transmission systems are looped or networked. Fig. 1. Shows voltage sag on all three phases due to a cleared line-ground fault.



2.2. ***Voltage Sag Due to Motoring Starting***

Since induction motors are balanced 3 phase loads, voltage sags due to their starting are symmetrical. Each phase draws approximately the same in-rush current. The magnitude of voltage sag depends on:
i. Characteristics of the induction motor
ii. Strength of the system at the point where motor is connected.
Fig.2 represents the shape of the voltage sag on the three phases

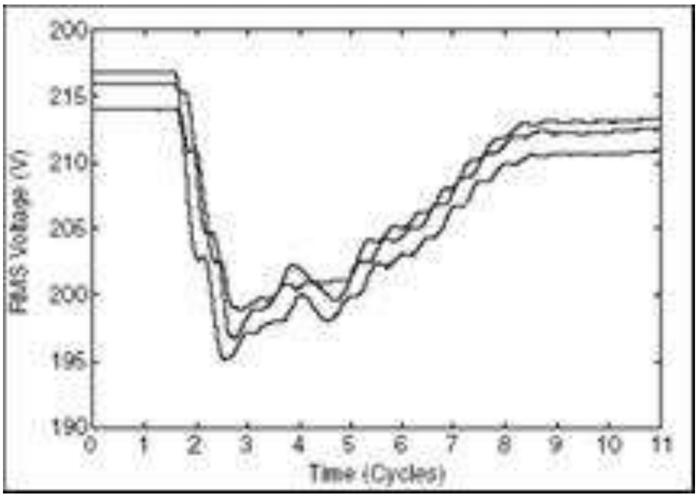
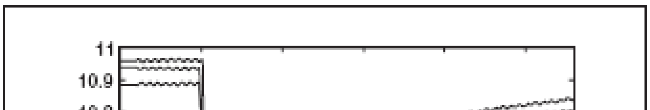


Fig. 2. Voltage sag due to fault

2.3. ***Voltage Sag Due to Transformer Energizing***

The causes for voltage sags due to transformer energizing are:
i. Normal system operation, which includes manual energizing of a transformer.
ii. Reclosing actions
The voltage sags are unsymmetrical in nature, often depicted as a sudden drop in system voltage followed by a slow recovery. The main reason for transformer energizing is the over-fluxing of the transformer core which leads to saturation. Sometimes, for long duration voltage sags, more transformers are driven into saturation. This is called Sympathetic Interaction.



3. Effect of Voltage Sag

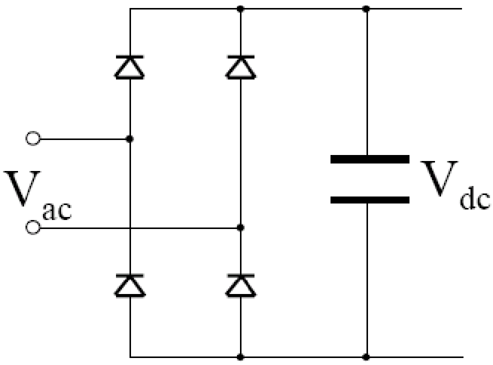
Generally speaking electrical equipment operates best when the rms voltage is constant to the nominal valve. In case the voltage is zero for a certain period of time, it will simply stop operating completely. No piece of electrical equipment can operate indefinitely without electricity. The reduction or loss of voltage causes the energy needed for normal operation not to be supplied to the equipment. This leads to degradation in the performance of the equipment and in extreme cases to a complete cessation of operation. Protective systems are often implemented for the purpose of disconnecting the supply in the event of the voltage falling below a set level. Such protection can have the effect of converting a voltage sag into a long supply interruption. This long interruption is not caused by the voltage sag, but is the intended result of a protective device's response to the reduced voltage.

If the voltage attains too low a value, or the duration of sag is excessively long, the equipment may be disconnected by a protective system or may operate in an improper manner. The economic consequences of such an event can be of considerable significance. They include loss of production, costs of restarting the technological process (this is particularly significant for continuous processes, where the time needed for restarting is, as a rule, very long), damaged equipment and materials, delayed delivery, reduced customer satisfaction, a decrease in the power delivered to the user, etc. Also the dissatisfaction of employees (if their wages depend on the production output) should be taken into account. These costs may, and probably will, have an impact on the position of utility companies in the energy market as the users can seek alternative energy sources [4].

3.1. *Computers and Process-Control Equipment*

The power supply of computers and other low-power devices normally consists of a single-phase diode rectifier followed by a dc-dc voltage regulator. The latter transforms the non-regulated dc voltage at a few hundreds volts into a regulated dc voltage. A capacitor is connected to the non-regulated dc bus in order to reduce the voltage ripple at the input of the voltage regulator. If the RMS value of the ac voltage drops suddenly, the capacitor discharges not only for half a cycle, as in normal operation, but for a longer period, until its voltage drops below the ac value of voltage again, and a new equilibrium is reached. The duration of the discharge of the capacitor is directly dependent on the magnitude of the voltage sag. The voltage regulator is normally able to maintain the output voltage constant over a certain range of variation of the input voltage. But if the voltage on the non-regulated side becomes too low, the protection will trip the device to protect the digital electronic components on the other side of the regulator. This can be a limiting factor in applying electronic equipment for the automation of production lines.

A simplified configuration of power supply is shown in fig. 4. It consists of four diodes and a capacitor. Due to voltage drop, the maximum ac voltage becomes less than the dc voltage. The resulting discharge of the capacitor continues until the capacitor voltage drops below the maximum of the ac voltage. After that, a new equilibrium will be reached. Because a constant power load has been assumed the capacitor discharges faster when the dc bus voltage is lower. This explains the larger dc voltage ripple during the sag [5].



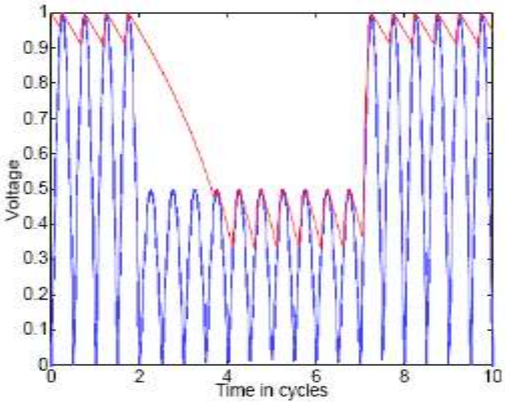


Fig. 4. Single phase rectifierFig. 5. Effect of a voltage sag on dc bus voltage

3.2. *Contractors and Relays*

Contactors and relays are used for switching of both power and control circuits. Irrespective of their application, a problem occurs when a contactor or a relay disconnects in an unpredictable manner during the electromagnetic disturbance. This usually leads to uncontrolled interruption of the process. Many manufacturers declare that their relays drop out at 50% of nominal voltage for a duration of more than one cycle. These specifications vary depending on the manufacturer; in practice, irregular operation may already occur at 70% or more of nominal voltage. Most European contactor manufacturers have designed their products according to IEC 60947-4-1. The standard gives the following limits for electromagnetic contactors, if used separately in motor starters. They:

- shall close satisfactory at any value between 85% and 110% of their rated control supply voltage.
- shall drop out and open fully between 75% and 20% of rated voltage for a.c., 75% and 10% for d.c.

The limits refer to steady-state conditions. No time limits are given and thus event-type phenomena, e.g. voltage dips, are not specifically considered [4].

3.3. *Adjustable Speed Drives*

In most of the ASD's, the electric power passes from the AC supply (utility side) to the load (motor side) through three major stages as seen in Fig.6

1) The rectification stage: at which the AC power is converted into DC power using a three phase diode rectifier circuit. The average value of the rectified voltage (in case of 3-phase full wave rectifier) is given by the following formula

$$Vdc, link = 1.35 * V_{LL} \quad (1)$$

Were V $_{dc\ link}$, is the DC voltage value output from the rectifier, V_{LL} is the RMS line-line voltage of the supply.

2) The DC link filtering: The output voltage from the rectified stage is filtered and smoothed using parallel capacitor and a shock coil in order to have a relatively constant DC voltage and current.

3) The inversion stage: Once the output voltage of the DC-link is considered constant and smooth, it can be inverted using PWM inverter to a three-phase AC waveform.

It is clear from equation 1 that in case of any voltage sags, especially in case of three-phase faults, dc link V, is directly affected by any reduction in V_{LL}. Most of ASD's are designed to trip as a safety measure once the V $_{dc,\ link}$ goes below 90% of its rated value for two reasons. The first is that the control electronics circuitry that governs the inverter operation is also fed from the same DC-link, thus it may malfunction due to that voltage sag and leads to unexpected operation of the inverter which in turn might destroy the motor [6]. The second reason is related to the operation of the motor itself, since some processes that are driven by ASD-controlled motors are sensitive to the speed or torque unplanned changes that lead to their failure. And hence, the need accurate, fast and robust voltage sag mitigation technique for ASD becomes a necessity for today's industry [7].

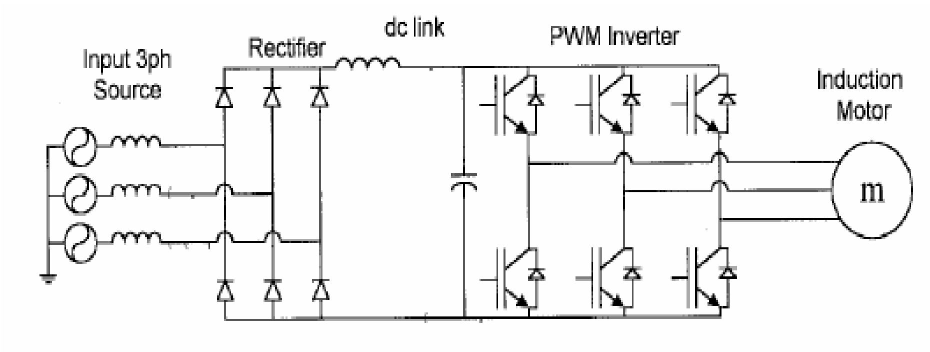


Fig. 6. Conventional of 3-phase ASD configuration schematic diagram

4. Solution to Voltage Sag Problem

Contactors and Customer solutions usually involve power conditioning for sensitive loads. Different devices are currently available for the mitigation of power quality problems. Correct understanding of their features, as well as that of load requirements, is needed for their proper application. To provide voltage sag ride-through capability, the different solutions available always include some kind of energy storage.

4.1. *Uninterruptible Power Supply*

A UPS (Uninterruptible Power Supply) consists of a diode rectifier followed by an inverter (Fig. 7). The energy storage is usually a battery block connected to the dc link. During normal operation, power coming from the ac supply is rectified and then inverted. The batteries remain in standby mode and only serve to keep the dc bus voltage constant. During a voltage sag or an interruption, the energy released by the battery block maintains the voltage at the dc bus. Depending on the storage capacity of the battery block, it can supply the load for minutes or even hours.

Low cost, simple operation and control have made the UPS the standard solution for low-power equipment like computers. For higher-power loads the costs associated with losses due to the two additional conversions and the maintenance of the batteries become too high and this solution no longer appears to be economically feasible [3].

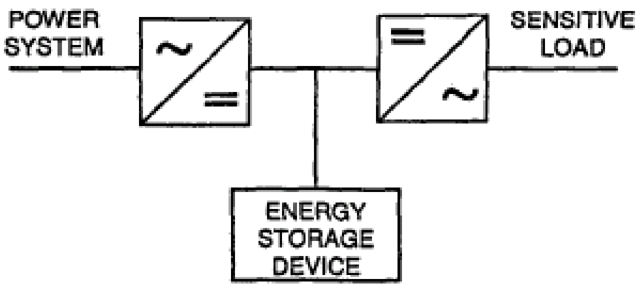


Fig. 7. Uninterruptible power supply

4.2. *Dynamic Voltag*

A DVR is a solid state power electronics switching device consisting of either GTO or IGBT, a capacitor bank as an energy storage device and injection transformers. It is connected in series between a distribution system and a load that shown in Fig.8. The basic idea of the DVR is to inject a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting transformer. A DC capacitor bank which acts as an energy storage device, provides a regulated dc voltage source. A DC to Ac inverter regulates this voltage by sinusoidal PWM technique. During normal operating condition, the DVR injects only a small voltage to compensate for the voltage drop of the injection transformer and device losses.

However, when voltage sag occurs in the distribution system, the DVR control system calculates and synthesizes the voltage required to maintain output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system to the critical load [8].

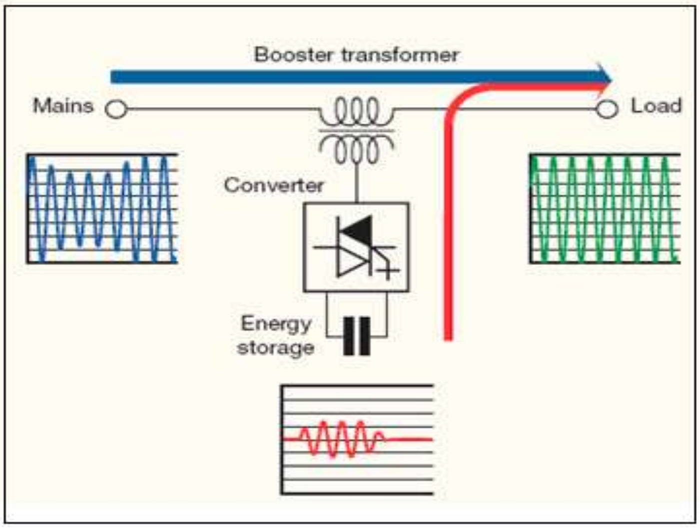


Fig. 8. Principle of DVR

4.3. *Transformer Less series Injection*

Transformer less series injection shown in Fig.9. In the event of a voltage sag, the static switch of this series injection device is opened and the load is supplied by an inverter. The power to the dc bus of the inverter is maintained by charging two capacitors connected in series. For sags down to 50% retained voltage, the rated voltage can be supplied to the load. Optional additional energy storage (e.g. extra capacitors) can mitigate a complete outage for a limited time duration and mitigate deeper asymmetrical sags, such as a complete outage of one phase [9].

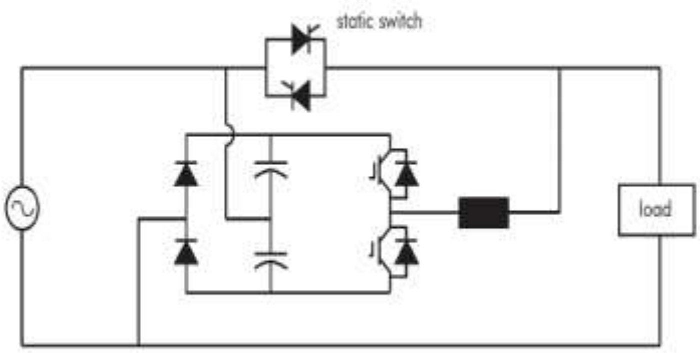


Fig. 9. Transformer less series injection

5. Conclusion

Voltage sags are one of the most important power quality problems affecting industrial processes. The utility can improve system fault performance in a limited degree, but cannot eliminate all faults. The customers will have to improve the ride-through capability of their sensitive equipment by either power quality mitigation equipment or embedded solutions. It will be much more economical in the long term to improve the voltage sag ride-through capability of the actual process equipment.

Power electronics based mitigation devices provide good solutions to voltage sag problems. The installation of these devices can improve not only individual user's sag performance, but also the sag profile of the entire network.

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