

Using Statcom for voltage dip mitigation

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Voltage dips are a major power quality problem for modern industrial processes, causing millions of Rands worth of plant outages. Static synchronous compensators (Statcom) are the latest generation of dynamic reactive power compensation equipment that can be used to effectively mitigate voltage dips amongst other power quality problems.

In this article, we consider the nature and impact of voltage dips, Statcom technology and compare it to other alternatives.

Understanding voltage dips

Voltage dips are the most important power quality problems faced by many industries and utilities. They contribute more than 80% of power quality (PQ) problems experienced. By definition, a voltage dip is an RMS (root mean square) reduction in the AC voltage at the power frequency, for duration from a half-cycle (10 ms) to a few seconds. (They are known as voltage sags in America and voltage dips in IEC standards.) Voltage dips are defined by the residual voltage (eg: 0,6 pu for a 0,4 pu depth of dip) and duration (e.g. 100 ms).

Dips are caused by high currents such as fault currents, which cause high voltage drops due to the various system impedances that act as a voltage divider. The most common causes of over currents leading to voltage dips are motor starting, transformer energising, over loads and short-circuit faults. The location of the cause of the dip in the system determines the depth of the dip. The duration of the dip is normally determined by the time that it takes to clear the fault or other cause of the dip.

Voltage dips are not tolerated by sensitive equipment used in modern industrial plants such as computers, process controllers, programmable logic controllers (PLC), variable speed drives (VSD) and robotics. This equipment can trip out if the voltage goes below the allowable voltage for a particular duration. Hence this type of equipment has a dip ride through capability curve similar to the example in Fig. 1. These loads are not normally the bulk of the power demand, but they control many of the other processes in the plant.

Other loads, such as motors, etc., are affected by the dip in that they slow down or reduce their effectiveness but do not stop if the dip is short enough. Therefore these loads normally return to full output when the voltage returns.

The objective is reducing cost of dips

To minimise the cost of dips, we need to

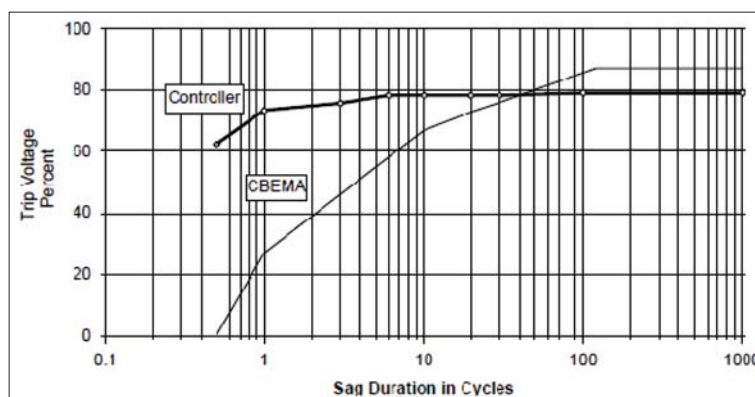


Fig. 1: Typical dip ride through capability curve.

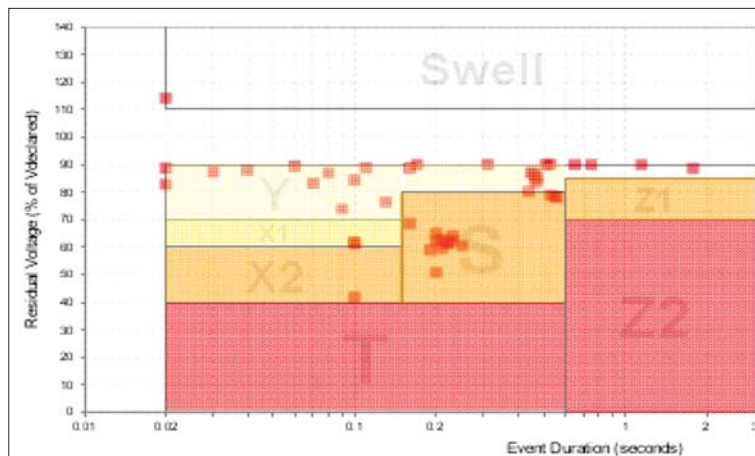


Fig. 2: Dip depth vs. duration analysis.

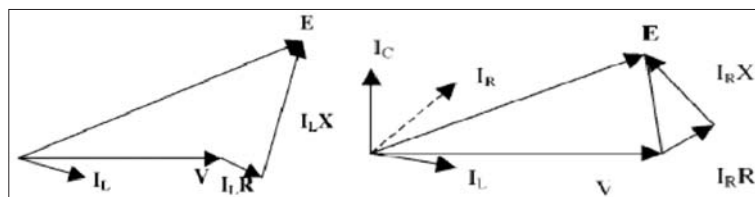


Fig. 3: Volt drop vector diagrams.

stop the sensitive equipment from tripping out. Therefore we need to analyse the dips being experienced in problem situations. Fig. 2 shows the dips experienced at an industrial customer that is having a severe impact on the variable speed drives in the plant. Critical drives are tripping frequently, which then requires the process to be cleared and cleaned and interrupts the whole plant for a number of hours.

Dips in the Y zone have a 10% probability of tripping sensitive equipment, X1 25%

probability and Z1, S and X2 have a 75% probability of tripping. Z2 and T have a 100% probability of tripping. By reducing the depth of the dip, we will reduce the probability that the dip will cause the sensitive equipment to trip out.

Using reactive power to reduce dips

The voltage drop in the line mainly depends on the current taken by the load (I_L) as well as the resistance and inductance in the line. It can also be

seen that the angle between the voltage and the current plays a major role in maintaining the voltage. Consider a supply voltage of E . A volt drop develops due to IL_R and IL_X to get the voltage at the load V . By introducing a capacitive current I_C , we change the magnitude and phase angle of the current flowing through the line impedance to I_R . Therefore, we are able to increase the voltage V at the load.

To effectively reduce the depth of the dip, we need dynamic reactive power compensation systems that will have a fast response time and controlled to inject the correct amount of reactive power for the required duration. Fig. 4 shows how the dynamic reactive power source injects the 'missing voltage', to correct for the depth of the dip. The network diagram can be considered at the source voltage and residual voltage V_{dip} at the load during the dip. The reactive current source adds ΔV to the V_{dip} which is effectively $I_C \cdot Z_s$.

The voltage boost at the point of compensation will be more notable at the distribution level due to the higher source impedances. Therefore dip mitigation is usually done at the medium voltage distribution level.

Principle of Statcom

Statcom is the latest generation of reactive power compensation. Statcom generates a sine wave from a voltage source converter (VSC) with the voltage source typically being a DC capacitor. Statcom is effectively like an inverter with a battery connected to it. Statcoms use IGBT semiconductors which can switch on or off, as required, to generate the voltage waveform desired by the controller. Full inverter bridges are bi-directional and the number of modules determines the smoothness of the output voltage waveform. The output waveform can be also be adjusted to dynamically inject or filter harmonic currents for active filtering. Fig. 5 illustrates the principle.

The Statcom is shunt connected to the supply through a reactor. Therefore the Statcom acts like a controlled reactive current source depending on the voltage waveform that is developed (U_d). The response time of the Statcom is between 3 ms and 5 ms, which is much faster than other alternatives.

The voltage U_c is developed independently of the supply voltage, based only on the voltage across the DC capacitor voltage sources. When $U_c > U_s$, then the current injected into the system is capacitive. When $U_c < U_s$, then the current injected into the system is inductive. The amount of missing voltage injected by the Statcom and the duration that it is able to do so for, is determined by the energy in the DC capacitors, similar to the capacity of the batteries connected to an inverter.

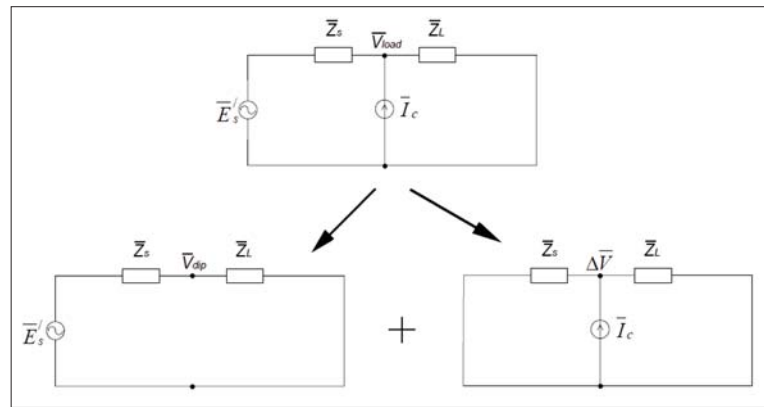


Fig. 4: Voltage increase with capacitive current source.

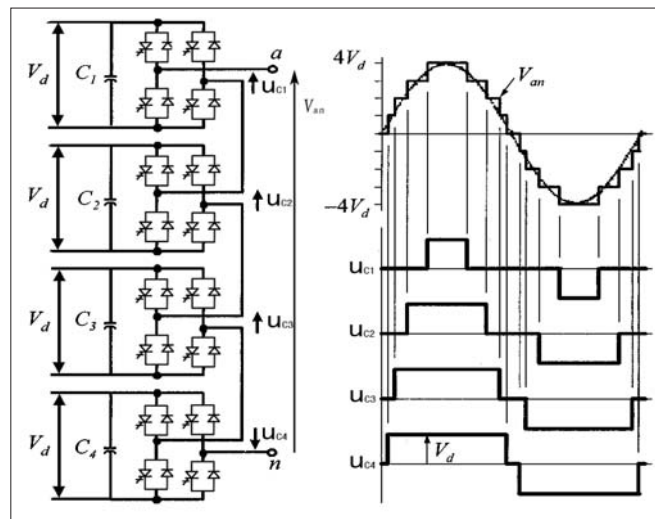


Fig. 5: Statcom principle of cascaded voltage sources.

A 30 Mvar Statcom therefore can output from 30 Mvar inductive to 30 Mvar capacitive continuously. The Statcom can also output real power by changing the phase angle of the voltage waveform, depending on the "energy" available. In most cases the DC voltage support for the VSC will be provided by DC capacitors of relatively small energy storage capability - hence, in steady state operation, active power injected has to be maintained at zero.

When not being used for voltage dip mitigation, Statcom can provide power factor correction to maintain the power factor near unity and / or voltage support to maintain the voltage at the target level. This will typically serve to improve the productivity and output of the customer's industrial processes. Statcom does not have any moving parts, so maintenance requirements are low. It is modular, so transport, installation and maintenance are relatively easy. Previously, Statcoms were done at low voltage and connected to the supply via a transformer. Now the level of IGBT technology is such that the Statcoms are able to connect directly to medium voltages up to about 66 kV. Because they are becoming more commonplace, the price levels make Statcoms more cost effective than other alternatives.

Performance of Statcom for voltage dips

Various load types require varying amounts

of real and reactive power. Therefore the response and capacity of the Statcom can be affected by the load type. Transient simulations are necessary to predict the performance of the Statcom in the real situation. For the example above, a 30 Mvar Statcom was proposed; and EMTDC simulations were conducted to determine that it would improve dips with a residual voltage of 0,4 pu to above 0,75 pu, 0,6 pu to above 0,9 pu and 0,72 pu to 1 pu. The proposed Statcom moves dips of T to X1/X2, Z2 to Z1, X1 to Y, X2 to Y, S to Y, while eliminating Y and Z1 dips.

Alternate solutions for voltage dip mitigation

There are several alternative methods to mitigate voltage dips:

- Improve the network design to reduce the number of faults and the fault-clearing time, e.g.: strengthening the network, reducing system impedances, improving insulation levels and using faster protection;
- Increasing equipment immunity, e.g.: change the dip ride through capability, install capacitors on the DC side of VSDs, install dip mitigating equipment at critical loads (in this article, we will consider the dynamic voltage restorer (DVR));
- Mitigation equipment at the interface,

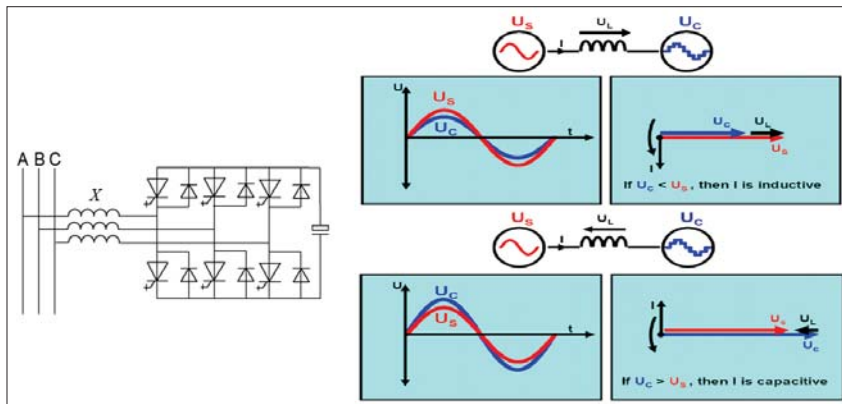


Fig. 6: Controlled reactive current source.

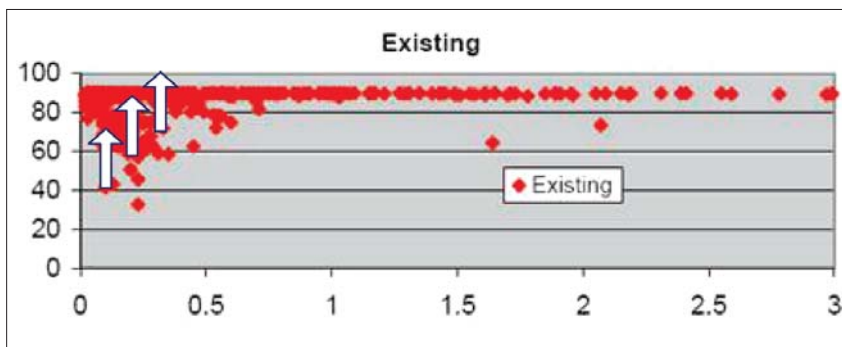


Fig. 7: Dip improvement performance of 30 Mvar Statcom.

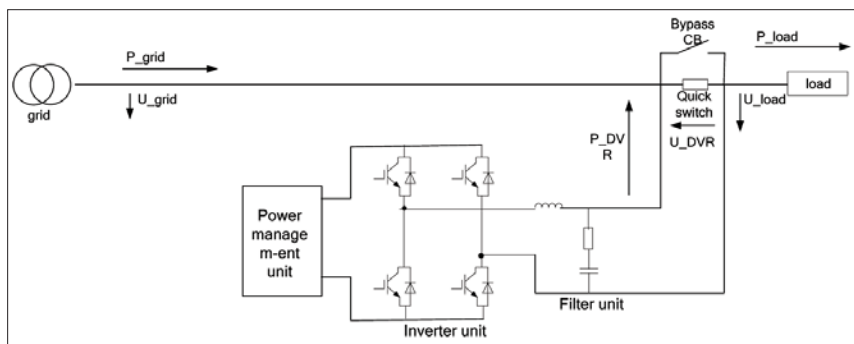


Fig. 8: DVR connection diagram.

e.g. Statcom, static var compensator (SVC), synchronous rotating machines.

Modifications in the process equipment itself tend to be the cheapest to implement but are not always possible because manufacturers have not made suitable equipment readily available in the market.

Static var compensator

A static var compensator (SVC) normally comprises fixed reactive power output in the form of capacitor banks or harmonic filter banks (FC) and a thyristor controlled reactor (TCR) (with variable output). Closed loop response times are typically around 20 ms.

During normal operation, the output of the SVC is controlled to ensure the power factor is near unity or the voltage is near the target level. If the SVC is designed for voltage dip mitigation, then there would be significantly more FC capacity

available and the TCR output would be increased to "offset" this spare capacity.

SVCs have a number of disadvantages compared to Statcom as follows:

- The TCR generates significant harmonics across the spectrum
- The FC introduces a risk of harmonic resonance
- The output of the FC is proportional to the square of the supply voltage (the output capacity is lower at low voltages)

Shunt connected synchronous machine

Shunt connected synchronous machines can be used for voltage dip mitigation. During normal operation they act as a spinning reserve. During a dip, the spinning of the machine tends to generate real and reactive power output, but without any other power source, the machine will slow down until it loses synchronisation

(below about 0,6 pu). While spinning, the reactive power output can be increased by changing the excitation of the generator. Additional rotational energy can be provided by provided with a flywheel, which can improve the capability to several seconds. Therefore the synchronous machine can regulate the voltage through real and reactive power during the disturbance.

Synchronous machines have a number of disadvantages compared to Statcom as follows:

- As a rotating machine, it is noisy and requires significant maintenance
- It is large and heavy, and therefore difficult to transport and install
- Because it is always spinning, the losses are high and continuous.

Dynamic voltage restorer (DVR)

A DVR is effectively a low voltage Statcom is series connected and provides individual unit compensation. During a dip, the DVR opens a quick switch to temporarily connect the DVR in series with the load. The response time is about 5 ms. During a voltage dip, the DVR adds the missing voltage through a series connected impedance, and therefore DVR compensation capacity is not dependent on the system capacity or supply impedance. The load remains connected to the grid and the DVR calculates the missing part of the voltage waveform, and corrects it.

The DVR output is up to 1,5 MW, depending on the energy storage capacity, and can compensate for 100% dips for up to about 3 s. Connected at the 400 V level, it is small, safe, fast to manufacture and easy to connect. It is therefore a rapid solution that can be implemented in an emergency and is a well established technology. Due to the size and voltage limit, DVR is only suitable for individual unit compensation. Fig. 9 shows the DVR connection diagram.

Conclusion

Statcom is the latest generation of dynamic reactive power compensation technology that is best suited to voltage dip mitigation because of its fast response time less than 5ms and independent reactive current generation capability. Statcom provides a shunt connected controlled current source using a voltage source converter. Statcom offers many advantages over older technology alternatives such as SVCs and synchronous machines. As Statcoms become more common, the price levels have also decreased to a level where they are now more economical than the alternatives. Therefore Statcoms are now the technology of choice for voltage dip mitigation from both technical and economic points of view.

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