SAG MITTIGATION TECHNICS USING DSTATCOMS

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REZUMAT. Căderile de tensiune sunt una dintre cele mai frecvente probleme care pot apărea pe o linie de producţie. Căderile de tensiune cu o durată viaţă foarte scurta nu provoca pagube însemnate, dar dacă depăşeşte două sau mai multe cicluri, echipamentele sensibile pot fi grav deteriorate, ceea ce într-un sistem de fabricaţie, bazat pe astfel de echipamente sensibile, va avea ca consecinţe risipa de resurse materiale şi umane. Lucrare de faţa va prezenta o posibilă soluţie la această problemă prin utilizarea unui compensator static de distribuţie DSTATCOM.

Cuvinte cheie: căderi de tensiune; DSTATCOMS.

Voltage sags are one of the most frequent problems that may appear on a production line that is using sensitive electrical equipments. Short lived power sags may not cause much harm, but if the sag exceeds two or more cycles, than the sensitive equipments can be seriously damaged which in a manufacturing system using such sensitive equipments will lead to wastage of material and human resources. There are some methods used to eliminate the sag effects, in this paper will be presented a possible solution to this problem by using a distribution static compensator DSTATCOM.

Keywords: voltage sags mittigation; DSTATCOMS

1. INTRODUCTION

Electricity is one of the basic services in modern society. From the point of view of the consumers, this basic service, must meet the following conditions:

- it is available at any time;
- it allows electrical equipment to function satisfactory and safely (a high quality level power).

Electricity is treated as a product today, but one particular, due to its intangible nature. It is a product that exists only when it is used, and in addition, its quality depends not only on the equipment which is used to produce it, but also on the equipment that uses it. As a result of increasing complexity, more and more devices are becoming increasingly sensitive to changes in energy parameters, while those equipments are causing changes in the power supply characteristics.

The IEEE (Institute of Electrical and Electronics Engineers) defines voltage sag as: a decrease between 0.1 and 0.9 p.u. in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 min. The amplitude of voltage sag is the value of the remaining voltage during the SAG, the IEC (International Electro technical Commission) terminology for voltage sag is dip. The IEC defines voltage dip as: A sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds. The amplitude of a voltage dip is defined as the difference between the voltage during the voltage dip and the nominal voltage of the system expressed as a percentage of the nominal voltage.

Short lived power sags may not cause much harm, but if the sag exceeds two or more cycles, than the sensitive equipments can be seriously damaged which in a manufacturing system using such sensitive equipments will lead to wastage of material and human resources. There are some methods used to eliminate the sag effects, in this paper will be presented a possible solution to this problem by using a distribution static compensator DSTATCOM. [1]

2. DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

General considerations:

Since there are a lot of factors which could generate voltage sags, therefore to have an impact to the quality of the electrical power, there are many techniques for sags mitigation; different problems will require different solutions. Among the solutions which are available today for the sag mitigation it may be recalled: the use of a dynamic voltage restorer (DVR), the use of the solid state transfer switch (SSTS) and the use of a distribution static compensator (DSTATCOM). This paper will propose a solution, for the sag mitigation, that involves the use of a distribution static compensator (DSTATCOM).

The basic structure of DSTATCOM can be found in the figure 1 and it consists of a DC energy storage device, a voltage source inverter (VSI), a filter and a coupling transformer connected in shunt with the AC system and an associated control circuit.

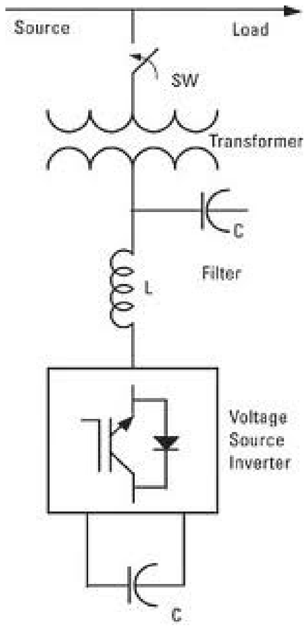

Fig. 1. DSTATCOM diagram

The VSI is used to convert the DC voltage into a set of three phase AC output voltage. Those voltages are in phase and coupled with the AC system trough the reactance of the coupling transformer. The adjustment of the phase and of the magnitude of the DSTATCOM output voltage will provide the control over the active and reactive power exchange between the DSTATCOM and the AC system.

The VSI connected in shunt with the AC system can be used in one of the following purposes:

- Voltage regulation and compensation of reactive power;
- Correction of power factor;
- Elimination of current harmonics;

The control system is the one which defines the purpose in which the VSI is used and its main functionality. In the current paper it will be analyzed the case in which the VSI is used to regulate the voltage at the point of connection for just one current phase. The control algorithm is based on the PWM and it requires the measurement of the voltage value at the load point.

2 Basic configuration and function of DSTATCOM:

The basic building blocks of a DSTATCOM can be found in figure 2. The DSTATCOM consists of a DC power supplies, a three phase inverter module (based on IGBT or thyristor), an AC filter, coupling transformer and a control algorithm (or a control strategy).

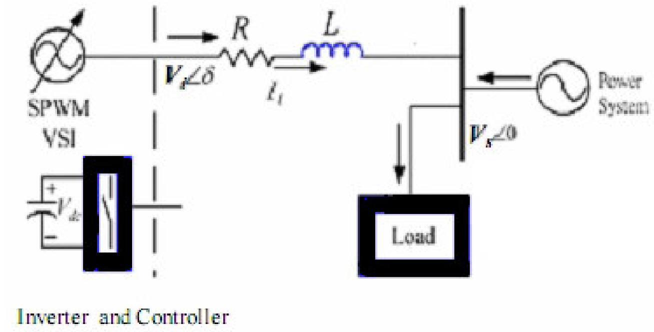

Fig. 2. DSTATCOM building blocks

The DSTATCOM uses an inverter to convert the DC voltage source to an AC voltage source of adjustable magnitude and phase. Therefore the DSTATCOM can be regarded as voltage controlled source, and also as a current controlled source. Figure 2 shows the inductance L and the resistance R which represents the equivalent circuit elements of the step-down transformer. The reactive power output of the DSTATCOM can be inductive or capacitive, depending on the operation mode of the DSTATCOM. The control system is used to adjust the phase angle between the output voltage of the inverter and the line voltage. In this way the control system will decide if the DSTATCOM will produce or it will consume VAR at the point of connection. The figure 3 shows the three basic operation modes of the DSTATCOM.

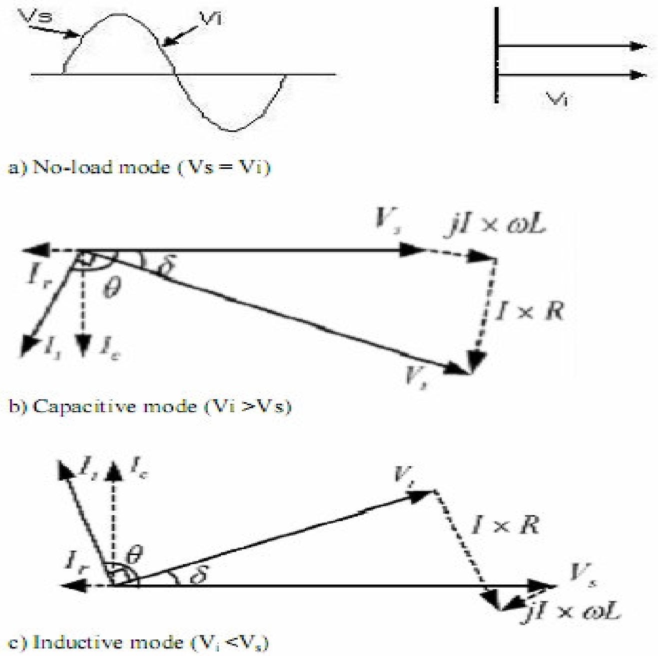

Fig. 3. Operation modes of the DSTATCOM

For instance, if Vi is equal to Vs, the reactive power is zero and the DSTATCOM does not generate or absorb reactive power. When Vi is greater than Vs, the DSTATCOM 'sees' an inductive reactance connected at its terminal. Hence, the system 'sees' the DSTATCOM as a capacitive reactance. The current, I, flows through the transformer reactance from the DSTATCOM to the AC system, and the device generates capacitive reactive power. Furthermore, if Vs is greater than Vi, the system 'sees' and inductive reactance connected at its terminal and the DSTATCOM 'sees' the system as a capacitive reactance, then the current flows from the ac system to the DSTATCOM, resulting in the device absorbing inductive reactive power.[2] [3]

3. SAG MITIGATION USING DSTATCOM

General considerations:

In order to protect the industrial sensitive equipments there are more possible solutions:

○ Modification in process equipment, but this is not always possible, and the technical changes can be expensive.

○ Modify the grid; this is the most expensive solution.

○ Protective equipments installed between the sensitive process and the grid. Among this kind of equipments are the static uninterruptable power supply (UPS), flywheels, dynamic voltage restorer and the distribution static VAR compensator (DSTATCOM).

In this paper it will be presented a solution which makes use of the DSTATCOM.

2 Hardware architecture:

The basic building blocks of the proposed hardware architecture can be found in figure 4. The DSTATCOM consists of a VSI (voltage source inverter) and a filter, and it is connected to an energy storage unit. The control system is a micro processor which runs a control algorithm for the DSTATCOM. The driver will be used as a hardware interface between the control system and the DSTATCOM. The sensor is used to read the voltage values at specifics points in time, from the supply network and from the output of the DSTATCOM. The low pass filter and the phase synchronization module will provide information to the control system in order to enable it to produce on the DSTATCOM output a signal that has the same phase with the signal provided by the power supply.

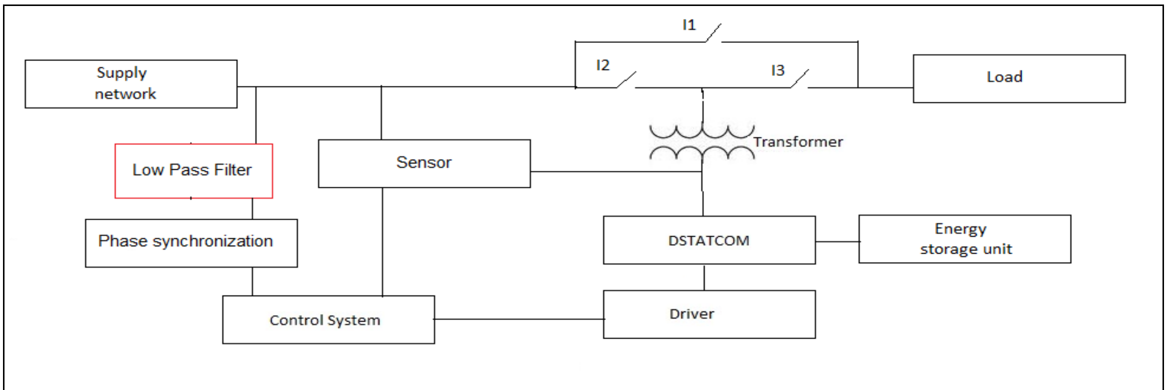

Fig. 4. Hardware architecture

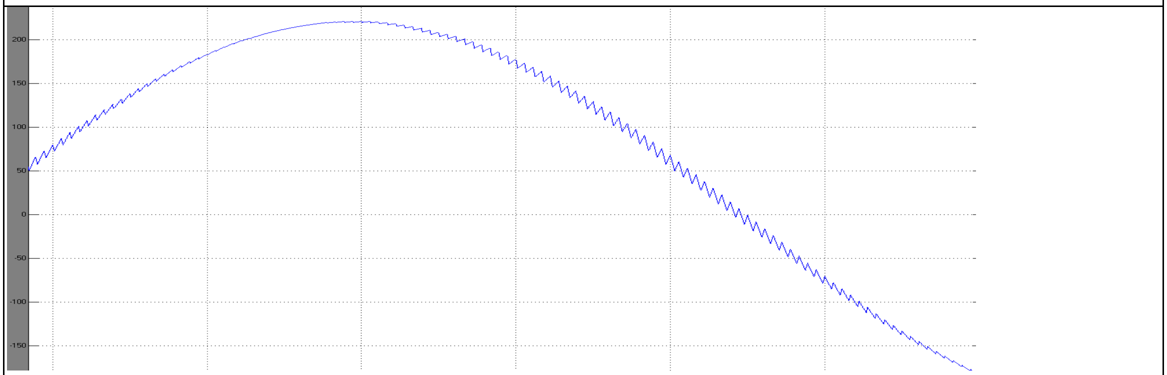

Fig. 5. Sin wave with high harmonics

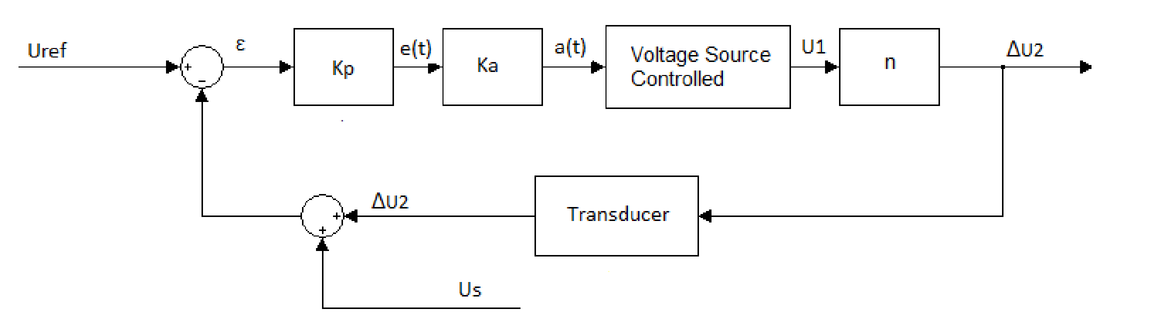

Fig. 6. Control loop

The control system. The control system can be a micro processor which provides at least one external interrupt port, at least 2 digital outputs and at least 32 digital inputs. The number of digital inputs will give us the precision of the measurements (the voltage value of the power supply and from the output of the DSTATCOM, will be read as a digital value). The digital outputs will be used to control the inverter components; in this case the inverter will make use of 2 IGTBs. Since the control system will provide the commutation commands for the DSTATCOM components in order to generate the sinusoidal signal it is important to be able to work at high frequencies. The external interrupt port will be used do read the signal provided by the phase synchronization module.

The driver. The driver is used as an interface between the control system and the DSTATCOM. The DSTATCOM is used to eliminate the SAG effects for power electronic systems, and the micro processor is quite sensitive to high voltage values, so is important to protect the control system.

The sensor. The sensor will provide to the control system information about the voltage values of the power supply and those from the output of the DSTATCOM at specific moments in time.

The Phase synchronization module. In order to be able to compensate the voltage sags that may appear the control system must be able to read at specific points in time the voltage values and the phase angle of the voltage signal provided by the power supply. The phase angle is important for the control system because it must synchronize the output of the inverter with the voltage signal provided by the power supply (the phase angle between them must be 0).

The phase synchronization is intended to be done when the voltage of the power supply goes through 0. Since usually the signal provided by the power supply contains high frequency harmonics, it must be filtered by using a low pass filter which will eliminate the harmonics effect. In figure 5 is presented a sinusoidal signal polluted with high harmonics. As we can see from the picture it is hard to determine the exact moment in which the signal goes through 0.

By using a low pass filter in front of the synchronization module it will receive on the input a clean sinusoidal signal which can be used later one for phase synchronization. The synchronization module will generate for the control system a pulsed signal based on the input signal as it is shown in the figure 7 (logical 1 while the input voltage is higher than 0 volts, and logical 0 while the input voltage is lower than 0 volts), in this way the control system will be informed by the synchronization module about the moments in which the signal received from the low pass filter goes trough 0.

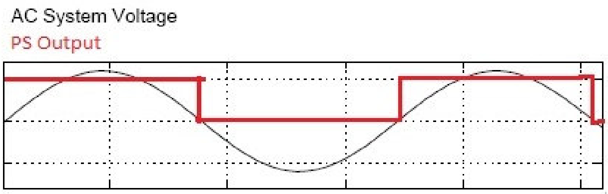

Fig. 7. Phase synchronizer signal.

It is also important the fact that the phase angle between the filtered signal and the power supply signal has the value φ*. The phase angle value can be determined out of the filter parameters, so by knowing the value of the phase angle φ* , and by knowing the moments when the filtered signal goes through 0 the control system will be able to synchronize the output of the inverter with the signal provided by the power supply.

The control loop. The control algorithm is the one that will decide the way in which the DSTATCOM will behave. According to the figure 4 the control loop is a closed one. The reference value is stored inside the control system. The process will be changed by the control system trough the DSTATCOM and the sensor will provide the feedback information.

In order to create the output signal of the inverter the control system will use a PWM algorithm, and as it is shown by the hardware architecture the output signal will be created using a DSTATCOM which contains a VSI (voltage source inverter). In figure 8 it is presented the structure of the VSI.

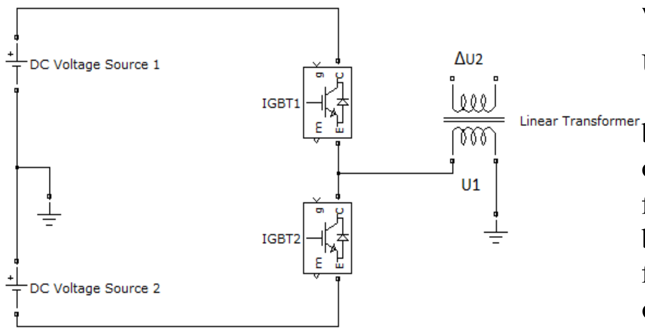

Fig. 8. VSI components.

In order to generate the desired voltage on the DSTATCOM output, the VSI will generate a train of alternative pulses (the positive one +E and the negative one -E) which will be filtered with a low pass filter in order to obtain on the output a sinusoidal voltage signal. To generate on the output of the DSTATCOM the voltage value 0, the VSI will have on the output a positive pulse followed by a negative one of the same width, as it is shown in figure 9.

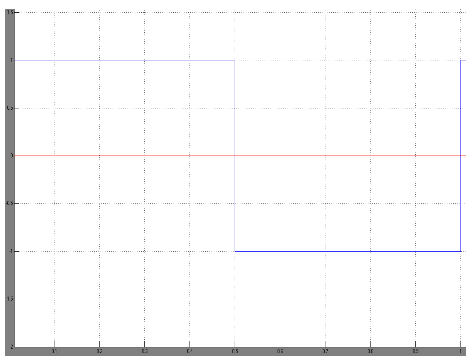

Fig. 9. The duty cycle for a 0 voltage output.

If the duty cycle needed to generate an output of 0 volts is μ_0 (μ_0 = 0.5) than the duty cycle of the pulse necessary to create a certain value on the VSI output at a specific point in time can be represented as it follows:

$$\mu(t) = \mu_0 + a(t) \sin(\omega_0 t) \quad (\mu_0 = 0.5) \qquad (3.1)$$

$$\mu(t) = 0.5 + a(t) \sin(\omega_0 t)$$

The value a(t) from 3.1 will be provided by the amplitude controller.The sinusoidal signal provided by the power supply can be described as:

$$U_s = \sqrt{2}\, U \sin(\omega_0 t) + \Sigma\, U_i \sin(\omega_i t) \qquad (3.2)$$

As we have mentioned before it is needed to filter the signal of the power supply in order to get rid of the high frequency harmonics, so the signal used as input by the control system to generate the inverter outputs will be:

$$U_{sync} = U \sin(\omega_1 t) \qquad (3.3)$$

The fact that the signal from the power supply is being filtered out by low pas filter, will produce on the output of the filter a sinusoidal signal without high frequency harmonics, and with the phase angle of φ* , between the input and the output signals of the low pass filter. Since the control system knows the phase angle φ*, and the desired output amplitude at each moment of time, it will create the output signal according to:

$$\mu(t) = \mu_0 + a(t) \sin(\omega_1 t + \varphi^*) \qquad (3.4)$$

$$\mu(t) = 0.5 + a(t) \sin(\omega_1 t + \varphi^*)$$

The inverter will be supplied by two DC power supplies which will have the output voltage of +/- E. In this case the output voltage of the inverter at the moment of time "t" will be:

$$U_1(t) = (2\,\mu(t) - 1)\, E \qquad (3.5)$$

$$U_1 = 2\, E\, a(t) \sin(\omega_1 t + \varphi^*)$$

The voltage value for the device which is powered up by the inverter will have the value:

$$\Delta U = n\, 2\, E\, a(t) \sin(\omega_1 t + \varphi^*) \qquad (3.6)$$

In formula (3.6) "n" is the transform ration of the electrical transformer.

Based on those mention before, the control loop proposed for sag mitigation is the one from the figure 6.

The error ε(t) is calculated based on the following values: U_s(the voltage value of the power supply) , ΔU_2 (the voltage value received by the load) and the reference value(which is stored inside the control device). Base on the error ε(t) the amplitude control will provide the amplitude value a(t), needed by the control system to generate the output of the VSI. The "Voltage Source Control" will receive, a phase synchronization signal. The value of the phase angle φ* is stored inside the control system, therefore by using as input the value a(t) provided by the amplitude controller and the phase synchronization signal, the controller will generate on the output of the VSI the voltage values needed for the mitigation of the sags that may appear on the power supply.

4. CONCLUSIONS

✓ The paper proposes an original control method for DSTATCOMS, aiming the SAG mitigation.

✓ The solution proposed in this paper is a flexible one. By using the same hardware architecture it can be used to eliminate the sag effects from systems which are using power supplies with different parameters, just by changing some parameters in the control software.

✓ By filtering the signal of the power supply it is obtained a clean signal which used by the control system, will enable it to create on the output of the DSTATCOM a sinusoidal signal that has the same phase with the one provided by the power supply.

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Systems Engineer of the Tehnical University from Cluj-Napoca. He worked at WirTek AS a danish company specialized in development of software for the mobile devices. In 2008 he joins the Phd program of the Technical University from Cluj-Napoca working on the thesis *Study of evolved control algorithms developement for static power converters in electro-energetics*. From 2009 he works at Softing AG, implementing specific embeded software for industrial communications (wired / wireless) in process automation. In 2009 starts working for ASML Holding N.V implementing Calibration, Performance and Diagnostic software for the photolithography systems used in the semiconductors industry.