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Static Series Compensator and Static Transfer Switch for Voltage Dip Mitigation with Short Interruptions

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ABSTRACT

Voltage dips and interruptions cause major economic damage. This paper gives an overview of methods used in the mitigation of voltage sags and short interruptions. Solutions for improving the performance of the power system, as well as the immunity of the equipment, are described. The Static Series Compensator and Static Transfer Switch are described in this paper.

Keywords:Static Series Compensator, VSC, Voltage Sags, PCC, Static Transfer Switch.

1. INTRODUCTION

Short-duration power disturbances (voltage sags, swells and short interruptions) are major concerns for industrial customers. For a lot of the equipment used in industry like sensitive electronics 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. Due to the high costs associated with these issues, there is an increasing interest towards voltage sag mitigation techniques. There are various factors which need to be considered to understand the different ways to mitigate voltage sags. The most common cause of voltage sags is a short-circuit fault occurring either within the industrial facility under consideration or on the utility system. Voltage sags are also a result of starting large motors, but these are not usually very severe. The short-circuit fault causes the voltage to drop to almost zero at the fault position. This zero voltage then turns into an event of a certain magnitude and duration at the interface between the power system and the equipment. A typical voltage sag waveform is shown in Figure. 1 [1].

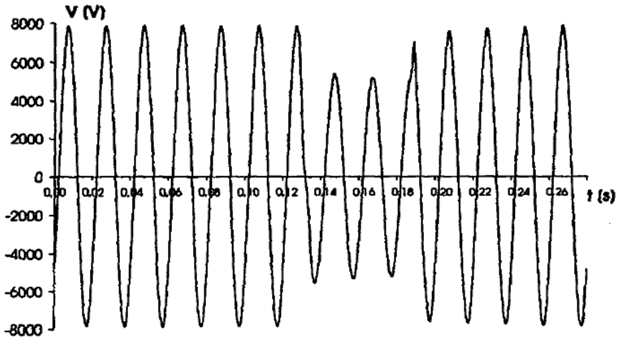

Figure 1. Typical waveform of voltage sag caused by remote fault-clearing

The magnitude of the voltage sag is mainly determined by the impedance between the faulted bus and the load and by the method of connection of the transformer windings. The voltage sag lasts until the fault is cleared by a protective device; therefore the duration of the sag is determined by the fault-clearing time of the protection system adopted. Moreover, if automatic reclosure is used by the utility, the voltage sag condition can occur repeatedly in the case of a permanent fault. Finally, depending on its magnitude and duration, the sag can cause an equipment trip, thus becoming a power quality problem. The installation of additional mitigation equipment is often the only option left for industrial customers, who do not normally have access to system or equipment improvement, to achieve the desired quality of supply at the system-load interface.Traditional devices include motor-generator sets, which use the rotational energy stored in a flywheel to provide power to the load during the dip, and constant voltage, or ferro-resonant, transformers (CVTs). In this paper, we will look at more modern devices like the static series compensator (SSC) and the static transfer switch (STS).

2. STATIC SERIES COMPENSATOR

The Static Series Compensator (SSC) is a Voltage Source Converter (VSC) which provides a controllable source, whose voltage adds to the source voltage to obtain the desired load voltage. It is connected in series on the distribution feeder. The single-line diagram of the SSC is shown in Fig. 2, the grid voltages and currents are denoted by u_g and $i_g$respectively. R_g and L_g denote the equivalent resistance and inductance of the grid, and U and I are the voltage and the current of the VSC. The load voltage is denoted by u_l. The SSC is connected to the power system at the point of common coupling (PCC). The *LC*-filter consists of a series inductor with inductance $L_F$and $R_F$resistance and a shunt capacitor with capacitance C_F. The thyristors (*thy)* are installed to bypass the SSC in the case of short-circuit faults at the load side. The three single-phase injection transformers are assumed ideal (no losses, no leakage inductance and infinite magnetizing inductance). Thus, the injected voltage $u_{inj}$of the SSC is the same as the *LC*-filter capacitor voltage u_c. Consequently, the *LC*-filter capacitor voltage is used throughout this paper.

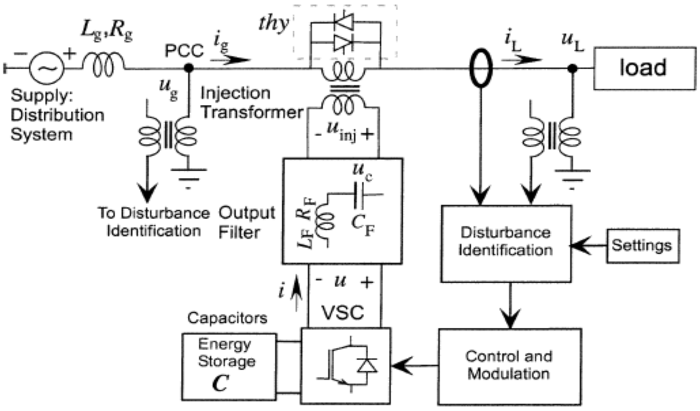

Figure.2. Single-line diagram of SSC: including details of voltage source converter, filter main components of SC, and measured signals for control [2].

The operation principle of SSC components (shown in Fig. 2) are the VSC, themodulation unit, the control unit, the output filter, the injectiontransformer, the energy storage and the bypass switch. Voltages and currents (measured) are the inputs to the disturbance identification, which sends signals to the control unit.The control unit functions when the measured quantities differ from settings of the controller.The identification module triggers the startof compensation when the supply voltage comesout of a pre-defined range. Then the control unit generatesthe voltage references. This voltage reference is the input to the modulation unit. The modulation unit generates the modulating signals for theswitches of the VSC. The energy storage provides the requiredpower to compensate the identified voltage dip. Installingan output filter reduces the dv/dt effect on the windings ofthe injection transformer and it is necessary to convert thepulse-modulated voltage of the VSC into a sinusoidal voltage. The principle of series injection for dip compensation is shown in the phasor diagram in Fig 3. V_{sag}, V_{inj}, V_{load}, I_{load} are the various phasors of supply voltage and current.

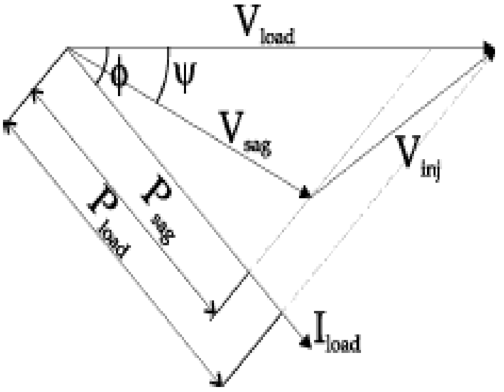

Figure 3. Phasor diagram of the series injection principle.

Fig 4 below shows one possible configuration of the SSC for voltage dip mitigation. The proper voltage that needs to be injected is generated by the converter. Hence it will be operating with unbalanced switching functions for the three phases. The converter is usually a three-phase two-level VSC with IGBT's.

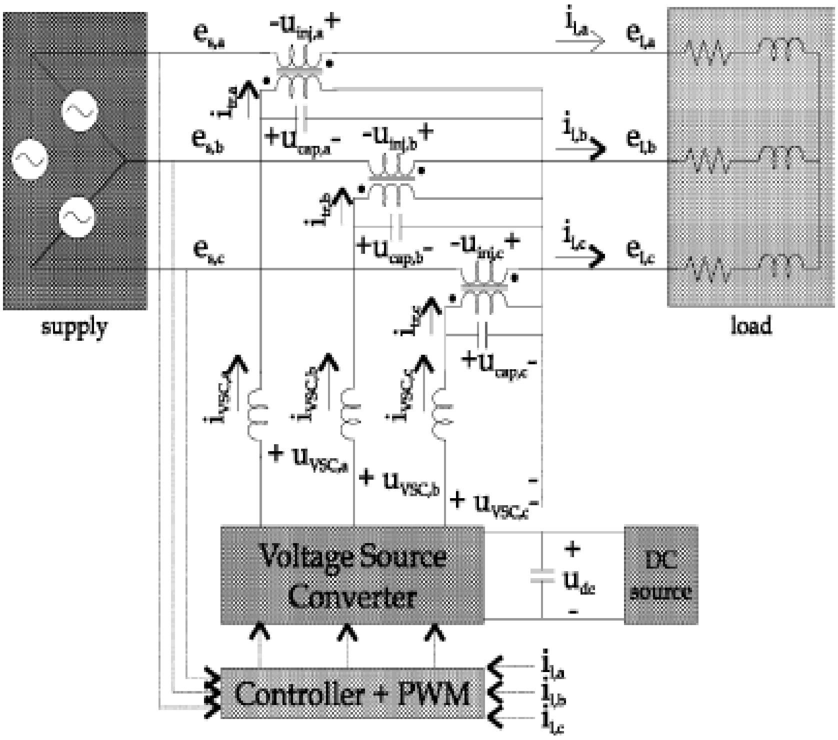

Figure 4. Scheme of series compensator for voltage dip mitigation [3].

A second-order LC filter is used between the converter and the transformer to filter the high-frequency harmonic components in the converter output voltage. Another configuration includes a line-side filter composed by the leakage inductance of the injection transformer combined with a capacitor on the line-side of the transformer. The SSC controller can be designed to provide only reactive power, i.e. by injecting a voltage in quadrature with the load current. An energy storage device is normally connected to the dc bus of the converter to provide the energy necessary for the compensation.

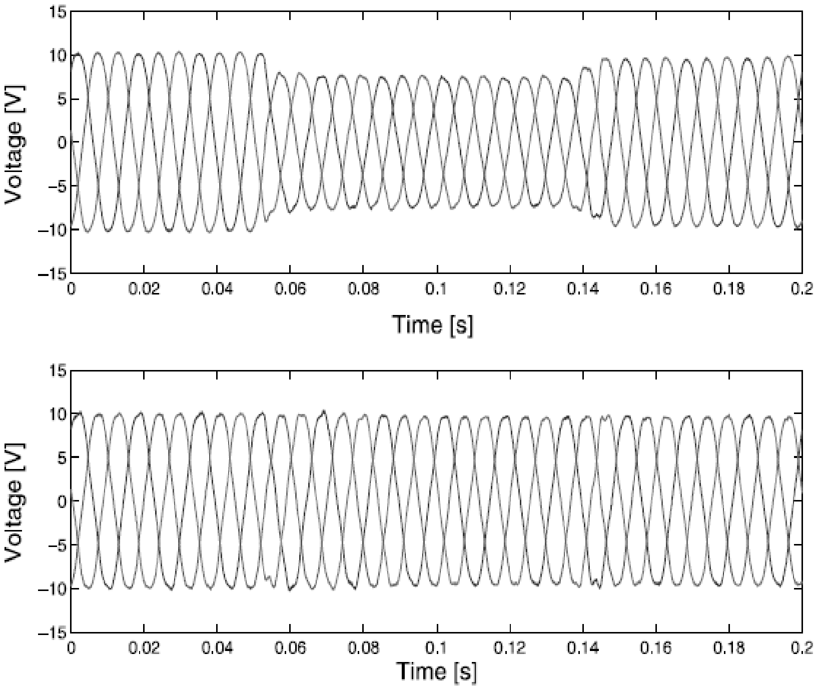

Figure 5. Measured three-phase dip on grid side (top) and load voltage (bottom) due to SSC operation, from [3]

3. STATIC TRANSFER SWITCH

The static transfer switch (STS) is an electrical device that allows instantaneous transfer of power from source to the load. This superior switching time means that if one power source fails, the STS switches to the back-up power source so quickly that the load never recognizes the transfer made. The STS is classified as low voltage STS (voltages up to 600V, current ratings from 200 amps to 4,000 amps) and medium voltage STS (voltages from 4.16KV to 34.5KV).Fast-acting STS's that can transfer between two power sources in four to 20 milliseconds are increasingly being applied to protect large loads and entire facilities from short-duration power disturbances. These products use solid-state power electronics or "static" switching as compared to electromechanical switches, which are too slow for the application. Electromechanical switches are found in automatic transfer switches (ATS) for transferring building

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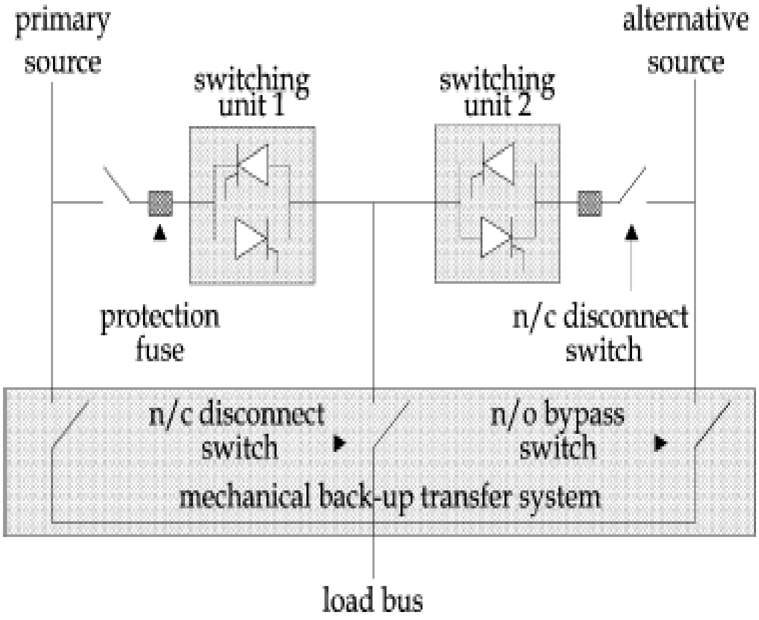

Figure 6. Structure of the STS (single phase) [3]

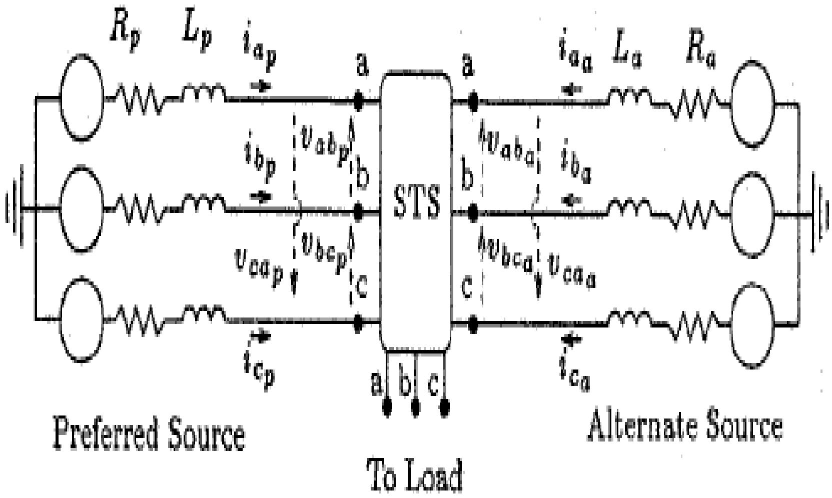

Figure 7. Schematic diagram of a STS system [4]

Schematic diagram of a STS system is given in Fig. 7. The system is composed of two power sources; a preferred source and an alternate source. The load is connected to the either of sources through the STS. The STS is composed of two main parts; the power circuit and the control circuit.

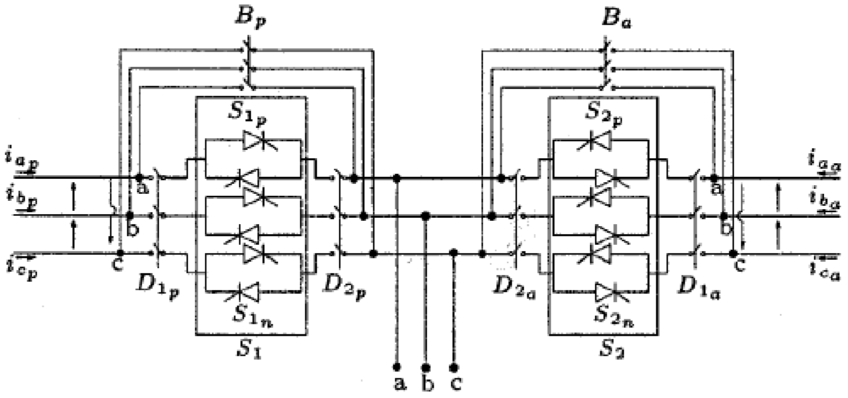

Figure 8. Power circuit of a STS [4]

Fig. 8 depicts power circuit of the STS of Fig. 6. The switch is composed of two thyristor blocks which connect the load to the power sources. Each thyristor block is composed of three thyristor modules corresponding to the three phases of the system. In each thyristor module, two sets of thyristor switches are connected in opposite directions, i.e. and , to allow the load current to flow in both positive and negative directions. The STS system must be able to supply the loads even if the thyristor switches are not in service. Therefore, mechanical bypass switches and are used in parallel with the thyristor blocks and respectively. Isolator switches are also used to isolate the thyristor blocks from the rest of the system for maintenance of thyristor modules and test purposes. The control circuit of the STS, as shown in Fig. 3, is composed of two sections; voltage-detection and transfer-and-gating sections. The control circuit is responsible for monitoring the quality of the source voltages and performing a load-transfer when needed. Line voltages and line currents from each source are the required input signals to the control circuit. The outputs of the control circuit are the gating patterns for the preferred source and alternate source thyristor switches. An example of the dip mitigation performance of the STS is given in Fig. 9(a) which shows the source voltages together with the response of the detection system, denoted as ‘‘fault signal’’, for a 70% dip (single-phase). The dip is detected in about 1 ms and the transfer occurs immediately after. As a result, only a notch of very short duration affects the load voltage (Fig. 9(b)).

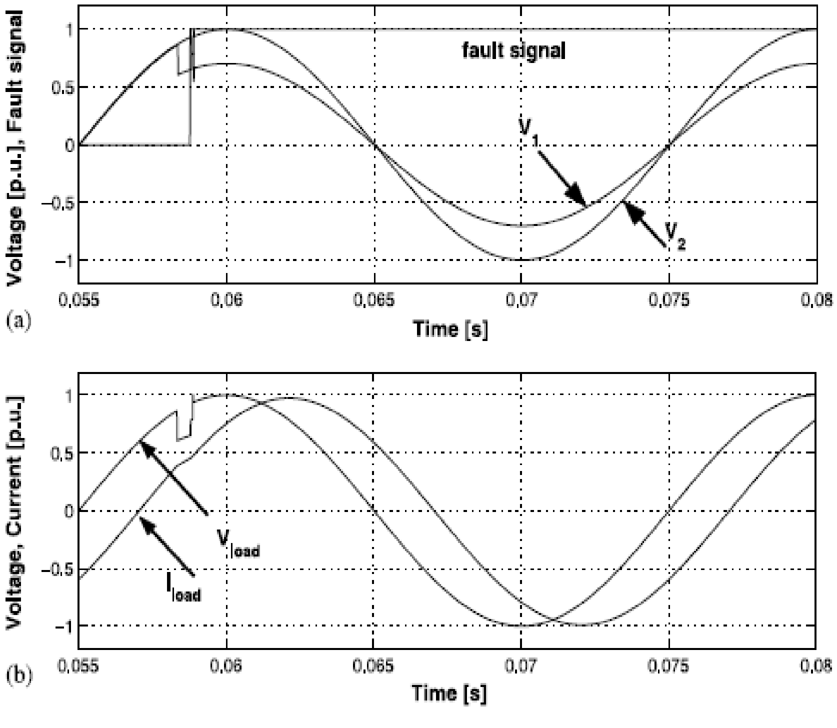

Figure 9.(a) Source voltages and fault signal, (b) load voltage and current for a 70% dip [3]

The STS cannot protect against dips originating in the transmission system, which will also affect the alternative supply. Yet, a significant improvement can be achieved in the performance of the industrial system against faults at distribution level, which normally cause long duration dips and short interruptions. The load will still see a disturbance during the interval in which the transfer takes place, therefore, it must be completed so quickly that the duration of the resulting.

CONCLUSION

It has been shown that both the SSC and the STC provide in many cases higher performance compared with traditional mitigation methods for voltage dips and short interruptions. The choice of the most suitable solution depends ultimately on the characteristics of the supply at the point of connection, the requirements of the load and economics, i.e. the customer value added by the installation of a power electronics based device.

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