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Multi-objective Performance Study of Dynamic Voltage Restorer (DVR) for Power Quality Enhancement

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INTRODUCTION

1.1 Introduction to DVR

In current era, where the growing concern is preserving the climate for next generations and increase the use of renewable energy sources rather than non-renewable energy sources. With almost 21 countries came together with increased funding and incentives in recent years has led to an increase in the number of grid-tied renewable energy sources for economic and environmental benefits become more prominent. Unfortunately, the energy variability of renewable energy sources (such as solar, wind, geo-thermal etc.) is significantly high which causes several disruptions in power supply (due to random voltage sags, swells) which is already a major issue in current power sectors of the developingcountries.

It is a well-known fact that the outputs of these renewable resources are often highly variable, resulting in undesirable voltage disruption that are harmful to sensitive loads. Recent advances in power electronic devices have provided a platform for new solutions to the voltage support problem in power systems. Voltage regulator and Dynamic Voltage Restorer (DVR), are commonly used to mitigate the effects of voltage dips. The major difference is that a voltage controller has no power store other than has a transformer secondary winding in series with the supply whereas DVR has an power store which provides the improve to the voltage during a dip. Unsurprisingly, DVRs are more expensive than voltageregulators.

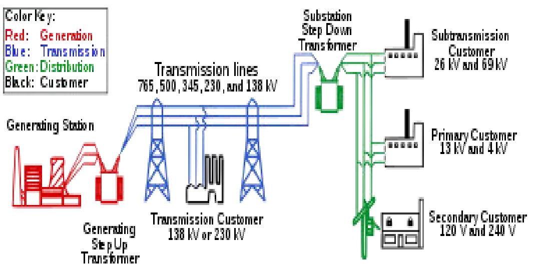

Fig.1.1 Power systems schematic consisting of power plants, transmission systems, sub transmission systems, and distribution systems.

Power Quality related issues are growing concern nowadays as they include a wide assortment of turbulence such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions. The extensive use of electronic equipment, such as information technology equipment, power electronics such as energy-efficient lighting, adjustable speed drives (ASD), programmable logic controllers (PLC), led to a total transform of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality troubles. Due to their non-linearity, all these loads cause turbulence in the voltage waveform as presented in the Table 1.1

1.2 Advance Technology

With the technology advance, the worldwide organizations and power houses has evolved towards globalization and the profit margins tend to decrease due to voltage sags/swells which occur more frequently than other Power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system. The increased sympathy of the vast bulk of process (industrial, services and even residential) to PQ troubles turns the accessibility of electric power with quality a critical issue for competitiveness in every activity sector. During a disturbance which occurs would introduce loss of productivity and competitiveness along with huge financial losses. One of the most vital tradition power devices that is been produced to advance the performance of power quality is Dynamic Voltage Restorer (DVR). The DVR maintain the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics obtainable at the point of common coupling. These systems are able to compensate voltage sags by raisingAlthough electrical transmission and distribution systems have reached a very high level of reliability, disturbances cannot be totally avoided. This increasing interest to improve efficiency and eliminate variations in the industry has resulted more complex instruments sensitive to voltage disturbances such as voltage sag, voltage swell, interruption, phase shift and harmonic. Voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage. In some cases, these disturbances can lead to a complete shutdown of an entire production line, in particular at high tech industries like semiconductor plants, with severe economic consequences to the affected enterprise. The DVR is a power quality tool, which can defend these industries against the bulk of these disturbances, i.e. voltage sags and swells related to remote system faults.

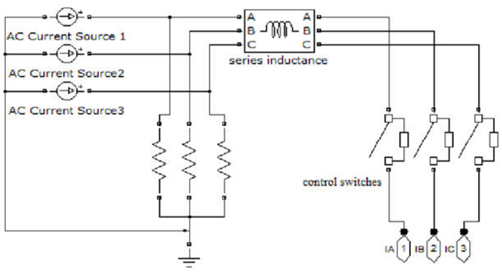

Fig 1.2 DVR Compensator model

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A DVR compensates for these voltage excursions, provided that the supply grid does not get disconnected completely through breaker trips. Modern pulse-width modulated (PWM) inverters proficient of generating exact high quality voltage waveforms form the power electronic heart of the new Custom Power devices like DVR. Because the performance of the overall control scheme mainly depends on the quality of the practical control strategy, a high performance controller with fast transient response and good steady state characteristics is required. The main considerations for the control system of a DVR include: sag detection, voltage reference generation and transient and steady-state control of the injected voltage. The distinctive power quality turbulence are voltage sags, voltage swells, interruptions, phase shifts, harmonics andtransients.

FLEXIBLE AC TRANSMISSION SYSTEMS

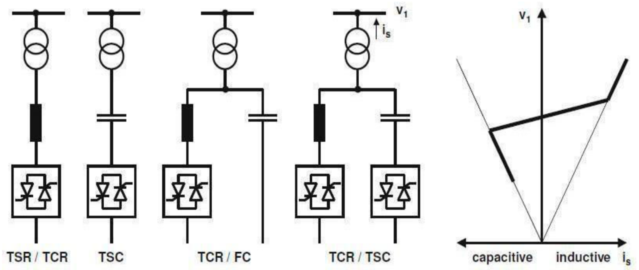
2.1 Introduction

The power industry term FACTS (Flexible AC Transmission Systems) covers a number of technologies that enhance the security, capacity and flexibility of power transmission systems. FACTS solutions enable power grid owners to increase existing transmission network capacity while maintaining or improving the operating margins necessary for grid stability. As a result, more power can reach consumers with a minimum impact on the environment, after substantially shorter project implementation times, and at lower investment costs - all compared to the alternative of building new transmission lines or power generation facilities.

2.2 FACTS Controllers

FACTS is defined by the IEEE as —a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfercapability.‖

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in



power systems by means of power electronic devices. Several FACTS- devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. Even more concepts of configurations of FACTS-devices are discussed in research and literature.

2.3 The basic applications of FACTS-devices are:

- Power flowcontrol,
- Increase of transmissioncapability,
- Voltagecontrol,
- Reactive powercompensation,
- Stabilityimprovement,
- Power qualityimprovement
- Powerconditioning
- Flickermitigation

In all applications the practical requirements, needs and benefits have to be considered carefully to justify the investment into a complex new device. Fig.3.1 shows the basic idea of FACTS for transmission systems. The usage of lines for active power transmission should be ideally up to the thermal limits. Voltage and stability limits shall be shifted with the means of the several different FACTS devices. It can be seen that with growing line length, the opportunity for FACTS devices gets more and moreimportant.

The influence of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The power electronic allows very short reaction times down to far below one second. In the following a structured overview on FACTS-devices is given. These devices are mapped to their different fields of applications. Detailed introductions in FACTS-devices can also be found in the literature with the main focus on basic technology, modeling andcontrol[5,6].

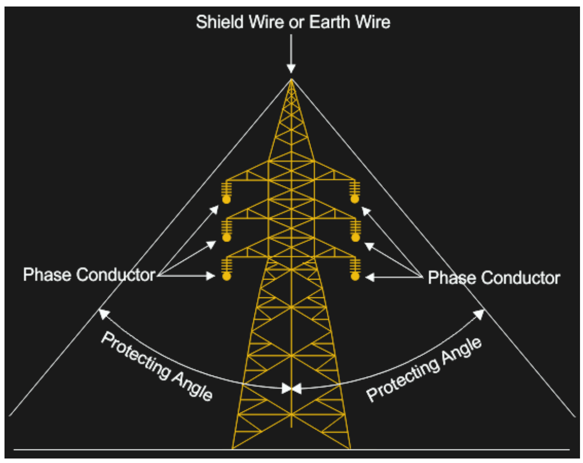


Fig. 2.1. Operational limits of transmission lines for different voltage levels

Fig 2.2. SVC voltage / current characteristic

Air core reactors and high voltage AC capacitors are the reactive power elements used jointly with the Thyristor valves. The step-up connection of this apparatus to the transmission voltage is achieve through a power transformer. The Thyristor valves jointly with auxiliary systems are situated indoors in an SVC building, while the air core reactors and capacitors, together with the power transformer are located outdoors. In principle the SVC consists of Thyristor Switched Capacitors (TSC) and Thyristor Switched or Controlled Reactors (TSR / TCR). The coordinated control

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of a combination of these branches varies the reactive power as shown in Fig 3.3. The first commercial SVC was installed in 1972 for an electric arc furnace. On transmission level the first SVC was used in 1979. Since then it is widely used and the most accepted FACTS-device.

2.4 STATCOM

In 1999 the first SVC with Voltage Source Converter called STATCOM (Static Compensator) go into action. The STATCOM has a quality similar to the synchronous condenser, but as an electronic apparatus it has no inertia and is higher to the synchronous condenser in several ways, such as improved dynamics, a lower venture cost and lower working and preservation costs. A STATCOM is build with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs. The structure and operational characteristic is shown in Figure 3.4where V_1 is the voltage and I_S is the source current. The static line between the current limitations has a certain sharpness determining the control characteristic for the voltage. The advantage of a STATCOM is that the reactive power stipulation is independent from the actual voltage on the connection point. This can be seen in the diagram for the maximum currents being independent of the voltage in comparison to the SVC in Fig3.4.

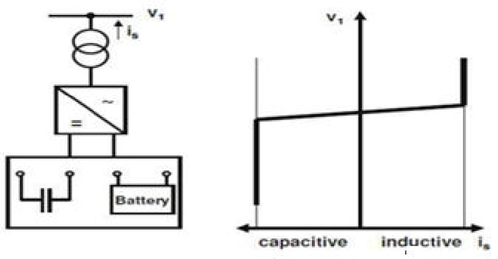

Fig 2.3.SVC voltage / current characteristic

Series devices have been further developed from fixed or mechanically switched compensations to the Thyristor Controlled Series Compensation (TCSC) or even Voltage Source Converter based devices. The main applications are:

1. Reduction of series voltage decline in magnitude and angle overapower
2. Reduction of voltage fluctuations within defined limits duringchanging powertransmissions,
3. Improvement of system damping resp. Damping ofoscillations,
4. Limitation of short circuit currents in networks orsubstations,
5. Avoidance of loop flows resp. Power flowadjustments.

2.4.1 SeriesCompensation

The world's first Series Compensation on transmission level, counted nowadays by the manufacturers as a FACTS-device, went into operation in 1950. Series Compensation is used in order to decrease the transfer reactance of a power line at rated frequency. A series capacitor installation generates reactive power that in a self-regulating manner balances a fraction of the line's transfer reactance. The result is that the line is electrically shortened, which improves angular stability, voltage stability and power sharing between parallel lines. Series Capacitors are installed in series with a transmission line, which means that all the equipment has to be installed on a fully insulated platform. On this steel platform the main capacitor is located together with the over voltage protection circuits.

The over voltage protection is a key design factor, as the capacitor bank has to withstand the throughput fault current, even at a severe nearby fault. The primary over voltage protection typically involves non-linear varistors of metal-oxide type, a spark gap and a fast bypass switch. Secondary protection is achieved with ground mounted electronics acting on signals from optical current transducers in the high voltage circuit. Even if the device is known since several years, improvements are ongoing. One recent achievement is the usage of dry capacitors with a higher energy density and higher environmental friendliness.

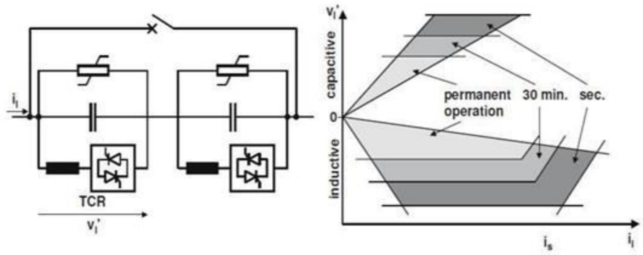

Fig.2.4. Principle setup and operational diagram of a Thyristor Controlled Series Compensation (TCSC)

Likewise the control and protection is located on ground potential together with other auxiliary systems. Fig 3.5 shows the principle setup of a TCSC and its operational diagram. The firing angle and the thermal limits of the thyristors determine the boundaries of the operational diagram. The main principles of the TCSC concept are two; firstly, to provide electromechanical damping between large electrical systems by changing the reactance of a specific interconnecting power line, i.e. the TCSC will provide a variable capacitive reactance. Secondly, the TCSC shall change its apparent impedance (as seen by the line current) for sub-synchronous frequencies, such that a prospective sub synchronous resonance is avoided. Both objectives are achieved with the TCSC, using control algorithms that work concurrently. The controls will function on the Thyristor circuit in parallel to the main capacitor bank such that controlled charges are added to the main capacitor, making it a variable capacitor at fundamental frequency but a ―virtual inductor‖ at sub-synchronous frequencies.

While the TCSC can be modeled as a series impedance, the SSSC is a series voltage source. The principle configuration is shown in Figure 3.6, which looks basically the same as the STATCOM. But in reality this device is more complicated because of the platform mounting and the

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protection. A Thyristor protection is absolutely necessary, because of the low overload capacity of the semiconductors, especially when IGBTs are used.

System-IV- Constant dc-link voltage: Direct energy storage method such as SMES, batteries or super capacitors can be used in a DVR by adding separate high power rating converter to the system. Energy transferred from large energy storage to a similar rated dc-link storage using this converter during sag. Hence the dc-link voltage remainsconstant. Experimental test using 10 KVA DVR show that the no energy storage concept is feasible, but an improved performance can be achieved for certain voltage sag using stored energytopology.

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

3. **Operating Modes:** Generally, the DVR is characterized into three-operation mode: protection mode, standby mode (during steady state) and

$$S_{DVR} = V_{DVR} I_L^*$$

injection mode (duringsag).

3.1 **Protection Mode:** The DVR will be remote from the system if the system parameters exceed the prearranged limits primarily current on load side. The main reason for parting is protecting the DVR from the over current in the load side due to short circuit on the load or large inrush currents. The control system detect faults or irregular conditions and handlebypass (transfer) switch to take away the DVR from systethus prevent it from damages as shown in Fig. 4.5. During the over current period, *S*1 will be closed; *S*2 and *S*3 will be opened so there will be another path for current to flow. By eliminating the DVR from system at fault condition, the effects of additional turbulence that can be caused by the DVR are prevented onto the system. The DVR is protected from the over current in the load side due to short circuit on the load or large inrush currents. The bypass switches eliminate the DVR from system by supplying another path for current as shown inFig.4.6

3.2 StandbyMode:

In standby mode (normal steady state conditions), the DVR may either go into short circuit function or inject small voltage to reimburse the voltage drop on transformer reactance or losses. Short circuit function of DVR is generally preferred solution in steady state because the small voltage drops do not disturb the load requirements. The solid-state bypass switches are used to execute short circuit operation and they are placed between the inverter and secondary (low side) of series injection transformer as shown in Fig. 4.7. If the distribution circuit is weak there is need to inject small compensation voltage to operate correctly. During short circuit operation, the injected voltages and magnetic fluxes are virtually zero thereby full load current pass through the primary. The DVR will be most of the time in usual mode operation. During stand-in mode usual operation, the short circuit impedance of the injection transformer determines the voltage drop across the DVR.

V_s is the source voltage, V_1 is the incoming supply voltage before compensation, V_2 is theload voltage after compensation, V_{DVR} is the series injected voltage of the DVR, and is the line current. The restorer typically consists of an injection transformer, the secondary winding of which is connected in series with the distribution line, a voltage-sourced PWM inverter bridge is connected to the primary of the injection transformer and an energy storage device is connected at the dc-link of the inverter bridge [3]. The inverter bridge output is filtered in order to mitigate theswitchingfrequencyharmonicsgeneratedintheinverter.Theser iesinjectedvoltageofthe DVR V_{DVR} is synthesized by modulating pulse widths of the inverter-bridge switches. While online, the DVR can get heated-up due to switching and conduction losses in semiconductor switches. Therefore, it is necessary to provide proper means of heat sinking in order to operate the DVR safely and to increase the life-span of semiconductor switches. The injection ofan appropriate V_{DVR} in the face of an up-stream voltage disturbance requires a certain amount of real and reactive power supply from the DVR. It is quite usual for the real power requirement of the DVR be provided by the energy storage device in the form of a battery, a capacitor bank, or a fly-wheel.Thereactivepowerrequirementisgeneratedbytheinverter. Widelyusedinpresent DVR control is the so-called in-phase voltage injection technique where the load voltage V_2 is assumed to be in-phase with the pre sag voltage. As the DVR is required to inject active power into the distribution line during the period of compensation, the capacity of the energy storage unit can become a limiting factor in the disturbance compensation process. For sags of long duration,thiscouldresultinpoorloadride-throughcapability.Aswasrecognizedbyseveral researchers, it is not necessary for V_2 to be in-phase with the pre sag voltage. Indeed, V_2 vector can lie anywhere on the periphery of a circle, the radius of which equals to the amplitude of the pre sag voltage. See Fig. 5.2.

This idea was considered in but the method proposed there is based only on reactive power compensation(V_{DVR}isperpendiculartotheloadcurrent)and byassumingsolelymagnitude changesofV_1.Thislastassumptionishypotheticalbecausein practice,almostallvoltage disturbances are associated with some degree of phase shift.

The disturbance correction capability of the restorer depends very much on the maximum voltage injection capability of the device and the amount of energy it can supply over the sag period. In an analysis of the energy requirement of the DVR was presented and a control scheme proposed.Itisnowproposedthattheresultsofbeextendedtoinclud etheDVRoperationwith zero or minimum energy injection through advancing V_{DVR} . This method is referred as phase advance compensation (PAC). Furthermore, the PAC method is to include a new closed-loop load voltage and inner-loop current mode control. In essence, the control scheme requires the filter capacitor current to be fed back to achieve a sinusoidal capacitor current while an outer voltage loop is

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included to regulate the output voltage. A feed-forward loop has also been incorporated to reduce the steady-state error in the load voltage. The scheme alleviatesthe drawbacks commonly seen in existing schemes which use supply-side voltage feed-forward control methods.

4.RESULT & DISCUSSION

The developed model of three-phase DVR system and the proposed control scheme in the MATLAB/ SIMULINK environment is shown in Fig.6.1 and Fig.6.2. The performance of DVR is evaluated in terms of voltage harmonics mitigation, SAG and SWELL correction under different load conditions. The load under consideration is a combination of balanced linear loads. The performance of the proposed control scheme of three-phase DVR is evaluated for sinusoidal supply voltages as well as distorted supply mains

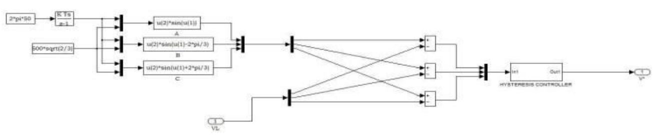

Fig.4.1 MATLAB model of UPQC Controller

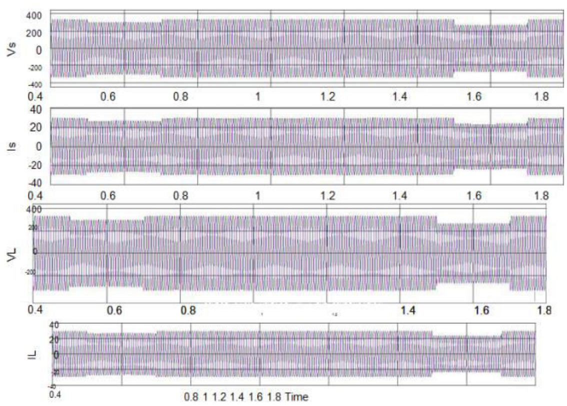

Fig.4.2 Result of Linear Load without DVR under SAG

4.1 Performance of DVR for SAG Correction

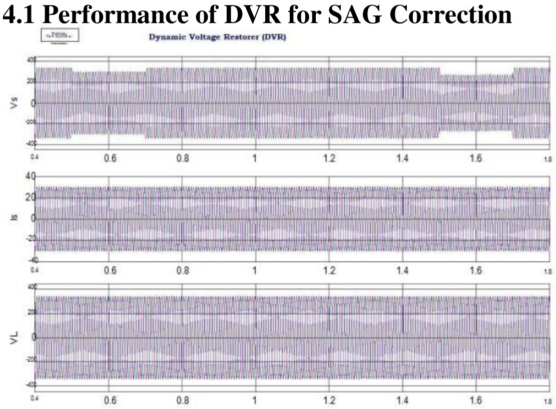

Fig.4.3 Performance of DVR for Sag Correction

Fig.4.3 shows the response of system without DVR for linear load. The distributed network was put into operation

5. CONCLUSION

In this work the main purpose for the use of DVR to restrained the voltage sag and voltage swells. In order to defend serious loads from more sever fault in distribution network. The facility available in MATLAB/SIMULINK is used to carry out widespread simulation study. Supply voltage is compared with reference voltage to get error signal which is given to the gate pulse generation circuit as a reference sine wave which is compared with carrier signal to get pulses forinverter.

Dynamic Voltage Restorer (DVR) , is a series compensating device used to protect a sensitive load that is connected downstream from voltage sag or swells. This thesis is present the modeling and analysis of a DVR system using MATLAB software. The results from simulation will demonstrate the DVR's ability to protect a sensitive load from voltage sag and swell as well as regulate the load bus voltage to its rated value. Using a robust in-phase compensation strategy for series voltage injection, the DVR dynamically corrects large voltage sags and swells in only a few cycles. The DVR module is developed in this thesis provides a useful engineering tool for future analysis and placement of DVR systems.

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