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ENHANCING POWER QUALITY THROUGH POWER ELECTRONICS TECHNOLOGY

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ABSTRACT:
The technological progress in the field of power electronics in the recent years has been achieved due to the advancement in power semi conductor devices which in turn have directly affected the power electronics converter technology and its application. Power electronics technology has affected every aspect of electrical power system networks including HVDC transmission system apart from AC transmission, distribution, utilization and also atgeneration level (e.g. static AVR). In this paper, an attempt has been made to study the performance of a power electronics based Custom power controller, DVR for use in the distribution network so as to enhance power quality andsupply to the end consumers using MATLAB/ SIMULINK. Results of the simulation runs are also presented with various settings of parameter used in the model so as to support the validity of the role of DVR in improving the quality of power supply at distribution side.

KEY WORDS:
Dynamic voltage restorer, automatic voltage regulator, flexible alternating current transmission system, high voltage direct current transmission, voltage source converter, static synchronous compensator, unified power flow controller, and voltage source inverter are all abbreviations for similar devices..

1. INTRODUCTION

In order to provide their customers with reliable electricity, power distribution

companies in a deregulated power system environment have made the installation of power electronics controllers a key priority. Constant voltage magnitude (without fluctuations or sudden changes), constant frequency, constant power factor, balanced phases, a sinusoidal waveform (without constant harmonics), uninterrupted service, and the ability to withstand and recover from defects all contribute to what is known as "electrical power quality" for consumers. Generators, transformers, transmission lines, loads, protective devices, and control devices are the backbone of any electrical power grid. When all of these parts work together, power may be produced where it will do the least harm and in sufficient quantities to meet demand. Once at the load center, it is delivered at an affordable rate.

To keep generators running reliably in the emerging market, engineers are creating electronic power controllers. Newer versions of FACTS and specialized power research power electronics controllers rely heavily on the voltage source converter (VSC). Three prospective high-voltage transmission technologies are the STATCOM, UPFC, and HVDC lite. At the low voltage distribution level, the VSC is the backbone of the distribution STATCOM (D-STATCOM), the distribution voltage regulator (DVR), and the active filters. There has been a dramatic increase in the past decade in the variety of programs that can be damaged by a poor power source. Certain large industrial customers are extremely sensitive to any fluctuations in the quality of their electrical power supply, and any interruptions, no matter how slight, could result in catastrophic financial losses. Several factors, including ongoing deregulation and the presence of open access electricity markets, have contributed to the dramatic change currently taking place in the distribution industry.

Using controllers based on power electronics is an impressive technological development in the distribution system. Because of this, high-quality electricity can be efficiently delivered to individual customers. To address power outages and poor power quality, the utility is looking into bespoke power as a possible option. Custom power is a standardized and all-purpose technology that is analogous to FACTS but runs on a lower voltage. Despite sharing a technological basis, the technical and economic aims of FACTS and customized power initiations are distinct.

Custom power controllers are designed to be installed at the point of connection of an organization's electricity distribution on customers who have sensitive loads and independent generators, while FACTS systems controllers are intended for installation at the transmission level.

The dependability and quality of power transmission is a primary focus of custom power. The advantages of this method, however, include better voltage management, voltage balancing, and cancellation of harmonics.

The two most well-known Custom Power Controllers/equipment are D-STATCOM and DVR. Parallelly coupled D-STATCOM devices may control voltage, perform active filtering, and handle reactive power. The Dynamic Voltage Restorer (DVR) is an electrical device that successfully mitigates the effects of waveform distortion and disturbances on one or more sensitive loads in its proximity. PWM switching is utilized to regulate the D-STATCOM used in custom power applications, as opposed to the fundamental frequency switching techniques typically used in FACTS applications. Due to its low power consumption, pulse-width modulation (PWM) is often employed in niche power applications. Theoretical investigations were carried out in a number of power electronics and DVR-related fields for this work. The purpose of this MATLAB/SIMULINK study was to do analysis on a canonical DVR model. The simulation experiments with varying parameter settings have demonstrated the model's superior fitness for use in a power distribution system.

POWER SWITCHING DEVICES:

On the basis of their degree of controllability, the various power switching devices can be divided into three classes:

The diode is used as an example of an uncontrolled switch. Whether the device is active or inactive is determined by the power circuit.

In a semi-controlled switch, the thyristor or silicon controlled rectifier (SCR) is activated by a gate signal. Once the gadget is activated, it is no longer under user control, and its shutdown is determined by the power circuit.

In the last twenty years, engineers have developed a wide variety of power semiconductors with advanced regulation features. Bipolar junction transistors (BJTs) and metal oxide semiconductor field effect transistors (MOSFETs) are two examples of the most prevalent types of transistors included here. New hybrid devices include the insulated gate bipolar transistor (IGBT) and the gate turn-off thyristor (GTO), respectively.

THYRISTOR:

The Silicon Controlled Rectifier (SCR), also known as a thyristor, is a four-layer, three-electrode power semiconductor device. The A, K, and G electrodes make up the anode, cathode, and gate, respectively. The four-layer design of the device allows for three separate connections. A two-transistor model can be used to shed light on the device's operational features. In the absence of an IG pulse supplied to the gate, a perfect thyristor has infinite resistance to positive anode current. Following this, the thyristor enters its conducting condition, which is characterized by extremely low resistance. Until the current through the anode becomes zero, we shall remain in this state. In the absence of the gate pulse IG, the thyristor reverts to its initial state, where current flows from the anode to the cathode against extremely high resistance. When a thyristor is turned on, the anode current is never zero, even if the gate pulse current IG is 0. This is what sets thyristors apart from other types of fully controlled semiconductors.

POWER MOSFET:

A metal-oxide semiconductor field-effect transistor (MOSFET) is a high-speed transistor with low switching losses. It works better with low-power uses and is not suited for high-power applications. Switch-mode power supplies (SMPS) and low voltage adjustable speed motor drives are used in a wide variety of electronic devices. Megahertz (MHz) frequencies are well within the range of feasibility for any converter with low power requirements. In order to activate and deactivate, this device uses an electric field that is gate-controlled, making it the quickest switching power semiconductor. A pulse of electrical current is required to turn on a bipolar junction transistor (BJT). When compared to MOSFETs, this device has noticeably longer response times. Despite MOSFETs' limited power-handling capacity, knowing how they work and how they're put together is crucial because of how widely used this technology is in cutting-edge new consumer goods. Control of the device is achieved by applying a voltage signal between the gate (G) and the source (S) that is greater than the threshold voltage of the device.

INSULATED-GATE BIPOLAR TRANSISTOR (IGBT):

An IGBT is a three-terminal power semiconductor device recognized for its high efficiency and rapid switching speeds. This style of switch can be found in many typical modern home appliances. Radios, freezers, air conditioners, electric vehicles, and variable speed motor drives are just some of the many uses for switching amplifiers. These amplifiers are built for fast switching, therefore they use techniques like pulse width modulation and low-pass filters to generate complex waveforms. The isolated-gate field-effect transistor (IGFET) is the control input to the device, while the bipolar power transistor (BPT) is the switch. It combines the great current handling capacity and low saturation voltage of bipolar transistors with the simple gate-drive characteristics of MOSFETs. Medium- to high-voltage uses for IGBTs include switched-mode power supply, traction motor control, and induction heating. Large IGBT modules are occasionally made up of a series of parallel devices, each with its own set of impressive characteristics. These include the ability to withstand currents of hundreds of amps and block voltages of up to 6,000 volts.

GATE TURN-OFF THYRISTOR (GTO):

High-power semiconductor devices like the gate turn-off thyristor (GTO) are thyristors. Unlike standard thyristors, GTOs are completely programmable switches. The gate, a third terminal, controls their activation and deactivation. A normal thyristor lacks the capacity to be turned on and off at will, but a fully programmable switch, such a Silicon-Controlled Rectifier (SCR), does. The GTO can be turned on and off by a gate signal of positive or negative polarity. By connecting the gate and cathode terminals, a "positive current" pulse is used to turn on the device. Since the gate-cathode forms a PN junction, there will be a potential difference between them. However, the GTO turn-on phenomena is less reliable than an SCR (thyristor), hence a modest positive gate current must be kept even after turn-on to improve reliability. When "negative voltage" is discharged between the gate and cathode terminals, the device turns off. The GTO is turned off (enters the "blocking" state) and the forward current is decreased by redirecting about 30% to 20% of it to form a cathode-gate voltage. There is a noticeable lag time after the forward current drops off because of the GTO thyristor's extended turn-off period. This lag, or tail time, ensures that the device's residual current flows until all charge has been removed. Therefore, about 1 kilohertz is the highest frequency at which switching may occur. When compared to a Gate Turn-Off Thyristor (GTO), the off time for a Silicon Controlled Rectifier (SCR) is significantly longer by a factor of ten. GTO has a significantly higher switching frequency than SCR.

2. ADVANCEMENT IN POWER SWITCHING DEVICES

Improved semiconductor functionality can be achieved by using substances such as silicon carbide (SiC), semiconducting diamond, gallium arsenide, and others. The greatest promise lies with the first grouping of gadgets. These novel power semiconductor materials offer many desirable properties, such as a large band gap, a high mobility of their carriers, and good electrical and thermal conductivity.

These features confer a number of benefits on this new class of power transmission devices. This product's benefits include its high power handling, high frequency performance, minimal voltage loss during conduction, and high junction temperature operation. These devices will function properly up to 600 degrees Celsius. Similar semiconductors to those described in the preceding section could be manufactured using this technique. Matrix converters are a significant development because they eliminate the requirement for a DC-link stage in the AC-to-AC conversion process. The converter calls for the creation of components that can toggle the flow of current in both directions. Several promising findings are emerging from current research efforts. The likelihood of a commercial product becoming available over the next decade or so is, however, minimal. The last twenty years have seen significant advancements in semiconductor devices, and further innovation and improvement are sure to follow. This bodes well for the future of power electronic systems. Completely regulated semiconductors of the future will be able to operate without snubbers even when subjected to extremely high currents, voltages, and rates of change. These semiconductors will find new and expanding applications in areas like high voltage industrial motor circuits and power transmission and distribution. The thyristor will continue to be the sole component in some setups due to its exceptional properties. However, it may become antiquated due to the ongoing development of GTO and IGBT technology and the appearance of new gadgets.

3. POWER ELECTRONIC CONVERTER

Solid-state DC-AC power electronic converters can be divided into two categories: those that take a voltage source as input and those that take a current source.

A voltage source converter (VSC) or voltage-source inverter (VSI) is a type of converter that takes a voltage source—typically a capacitor—as its input and outputs alternating current (AC). The voltage source can accept either a positive or negative current. By switching the direction of the current, electricity can be transmitted in both the direct current and alternating current directions.

In current source converters (CSC) or current-source inverters (CSI), a current source (often an inductor in series with a voltage source) is connected directly to the DC bus as the input to the converter. Both positive and negative voltages are acceptable across the DC bus. Furthermore, switching the polarity of the voltage allows current to flow in both ways between the DC and AC terminals.

Phase-controlled thyristor-based converters are limited to current sources in conventional applications. It is possible to create both types of modern semiconductor-based converters. When fully regulated power semiconductors are used, applications requiring reactive power adjustment utilize converters based on voltage sources. To this day, traditional thyristor-controlled converters are still used in conventional high power HVDC systems.

APPLICATIONS OF VOLTAGE SOURCE CONVERTER:

One category of power electronics is the voltage-source converter, which can generate sinusoidal voltages of arbitrary amplitude, frequency, and phase. In addition to their use in variable-speed drives, voltage source converters have the capability of compensating for voltage fluctuations. When there is a discrepancy between the nominal and actual voltages, the VSC is used to either entirely substitute the voltage or to introduce the "deficient voltage." Typically, the converter is powered by a source of direct current (DC) voltage, such as an energy storage device. Then, the desired output voltage is achieved by adjusting the converter's solid-state electronics. Common applications of the VSC include correction of voltage swings, flashing, and harmonic distortion.

VSC IN SERIES VOLTAGE CONTROLLER (DVR):

Connecting the series voltage controller and the protected load in series. A coupling transformer is typically used to make the connection. However, a direct connection can be made with the use of a power electronics system. To calculate the load bus bar voltage, add the grid voltage to the voltage provided by the DVR. Active power is supplied by the energy storage, while reactive power is produced by the converter. Compensation needs may dictate a different energy storage technology. The amount and duration of voltage reductions sometimes limit the DVR's capacity to fix them.

VSC IN SHUNT VOLTAGE CONTROLLER (D-STATCOM):

Parallel connections between a direct current (dc) energy storage device, a coupling transformer, and a two-level Voltage Source Converter (VSC) make up a D-STATCOM. The voltage across the storage device is converted to three-phase alternating current via the Voltage Source Converter (VSC). The reactance of the coupling transformer links the voltages to the alternating current system and keeps them in sync. Controlling the flow of active and reactive power between the D-STATCOM and the AC system is made feasible by altering the phase and magnitude of the D-STATCOM's output voltages. This apparatus in its current configuration is capable of reversibly absorbing active and reactive power, or producing it under control.

4. INTRODUCTION TO DYNAMIC VOLTAGE RESTORER SYSTEM

The DVR system is a customized Custom Power controller that provides outstanding dynamic performance and protects critical and/or sensitive loads from transient reductions and increases in voltage. The DVR's injection transformer, VSC, and energy storage unit are seen in Figure 1.

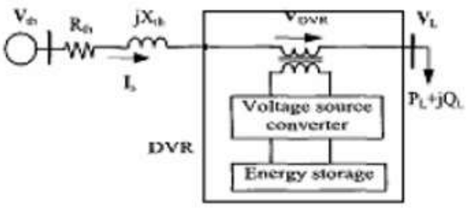


Figure 1: Schematic Diagram of DVR

The DVR is connected to the primary distribution feeder of the power company. Power quality and reliability issues including voltage fluctuations, voltage asymmetry, harmonic distortion, power factor optimization, and power interruptions can all be addressed with the help of this controller. The DVR initiates a pattern of three-phase alternating current voltages that are timed to coincide with the voltages of the AC system's distribution feeders. Active and reactive power transmission between the DVR and the ac system can be regulated by adjusting the amplitude and phase angle of the injected voltages. Limits on the inflow and outflow of energy (positive and negative, respectively) govern the scope of these exchanges.

MAIN COMPONENTS OF DVR:

A DVR system is comprised of four main parts: a battery pack, a voltage source converter circuit, a filter unit, and a series injection transformer. The following are expanded upon below

ENERGY STORAGE SYSTEM:

Depending on the topology in place, the Dynamic Voltage Restorer (DVR) can draw power for regulating the load voltage during a dip either from an auxiliary source with energy storage or directly from the grid. When the DVR is receiving a weak grid signal, the additional supply method is used to boost performance. In this setting, the DC link voltage might be either variable or constant. With the second setup, the DVR is connected to the resilient grid and draws power from the residual voltage on either the supply or load side. The DC link voltage is stable in a load-side connected architecture because it is continuously supplied by the constant load voltage. The investigation will use a converter architecture with the load side attached.

VSC CIRCUIT:

The voltage source converter circuit allows the DVR to receive output voltages of varying strengths. Power-cutting semiconductors are used in inverter circuits. At its input, the VSC receives a steady, low-impedance DC voltage. The discharge current has no effect on the output voltage. The output voltage of VSCs is only slightly affected by the presence of a capacitor. The capacitor makes it more challenging to limit current flow. In this analysis, the most generally deployed VSC inverter type is the three-phase pulse width modulation (PWM)-based kind. The voltage is regulated by modulating the inverter's output voltage waveform.

FILTER SYSTEM:

To deal with harmonics in a VSC's output voltage, a filtering method is applied. Inverter-side filtering and line-side filtering are the two primary filtering algorithms. Located on the low voltage side and in close proximity to the harmonic source, the inverter side filter prevents harmonic currents from flowing into the series injection transformers. This can cause the inverter's primary output component's voltage to drop and its phase to shift. Because of how close the high voltage side is to the line side, a transformer with a greater rating is required. The voltage drop and phase shift issues caused by the filter have no effect on this setup. In both filtering methods, the inverter ratings are increased by the use of filter capacitors. While a larger filter capacitor reduces harmonics, a higher rated inverter is directly proportional to the value of the capacitor. This investigation makes use of the inverter-side filtering method.

SERIES INJECTION TRANSFORMERS:

The system voltage is increased with the help of three single-phase injection transformers. Selecting the electrical properties of the series injection transformer with precision is essential for achieving the highest level of reliability and efficiency. The MVA rating, primary winding voltage and current ratings, turn ratio, and short-circuit impedance values of the Transformers are required for proper integration of the injection transformer into the DVR.

OPERATING MODES OF DVR:

Protection, standby (during steady state), and injection (during decline) are the three modes of operation for the DVR.

PROTECTION MODE:

The DVR is safe from damage caused by high inrush currents or a short circuit on the load side. Bypass switches provide a current path around the DVR, removing it from the system.

STANDBY MODE:

The DVR can either short circuit or introduce a minor amount of voltage to make up for voltage reductions caused by transformer reactance and losses during standby mode, the typical steady state setting. Since modest voltage drops do not influence load needs if the distribution circuit is strong, short-circuit operation of DVRs is generally favored in steady-state conditions.

INJECTION MODE:

The DVR enters injection mode when it senses a drop in voltage. Three separate single-phase alternating current voltages with the correct magnitude, phase, and waveform are injected in series to achieve compensation.

5. SIMULATION RESULTS AND DISCUSSIONS

A Matlab/Simulink model of the DVR is shown in Figure 2 for the purpose of evaluating different settings for the model's parameters. Using the model's VSI subsystem, we connected a dc voltage source, a VSI with three phases, and the necessary control circuits to create the energy storage system. Voltage waveforms under various situations are examined using three scopes. One, two, and three. The voltage distribution at the sensitive load is monitored with Scope1, voltage injection patterns on the secondary sides of the series injection transformers are monitored with Scope2, and voltage patterns during fault conditions are examined with Scope3. By modeling IGBT and GTO switches, a model of the VSI for the DVR system might be built.

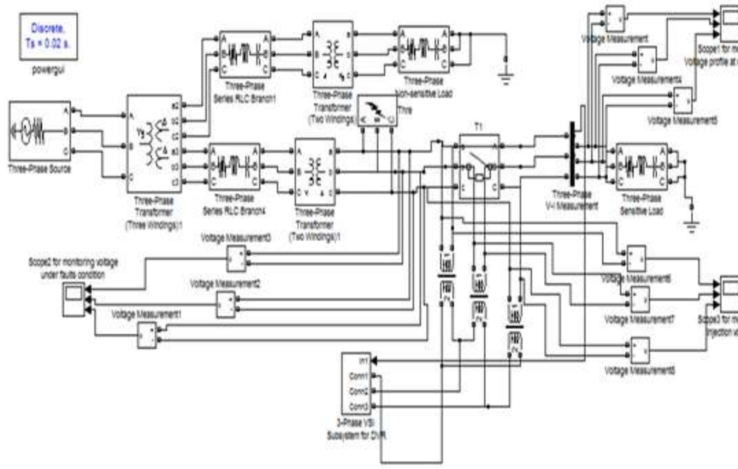


Figure 2: Simulink model of the DVR

RESULTS OF SIMULATION RUNS WITH IGBT SWITCHES: Figure 3 (a) shows the output voltagewaveforms under line to ground fault condition.

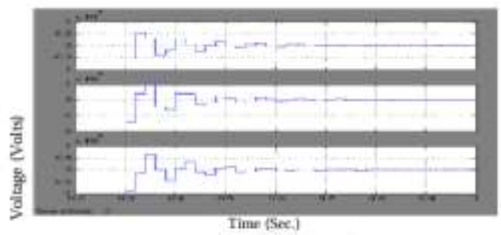


Figure 3: (a) Fault voltage waveforms

In order to compensate for the drop in load voltage, the DVR system introduces the appropriate 3-phase voltages, as shown in Figure 3 (b).

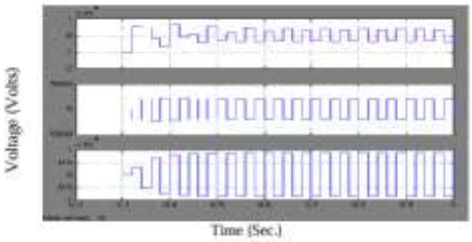


Figure 3: (b) Injected voltage waveforms

DVR system voltage injection results in compensated output voltage waveforms across the load, as seen in Figure 3(c).

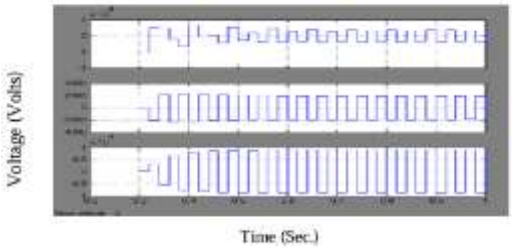
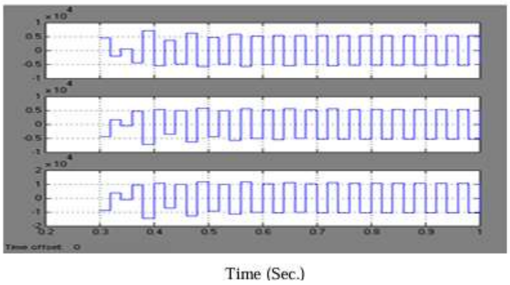


Figure 3: (c) Compensated output voltage waveforms

(i) RESULTS OF SIMULATION RUNS WITH GTO SWITCHES:

(ii) Sag/fault voltage waveforms generated by the model were identical to those depicted in Figure 3 (a) when GTO switches were used in the VSC circuit to mimic a single line to ground fault. The DVR's effect on the voltage waveforms is shown in Figure 4(b).



(iii)

Figure 4: (a) Injected voltage waveforms

The compensated output voltage waveforms for all the 3 phases are depicted in figure 5 (b).

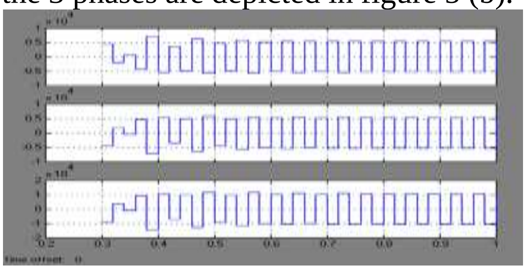


Figure 4: (b) Compensated output voltage waveforms

6. CONCLUSION

The purpose of this research was to investigate the role of controllers based on power electronics in the functioning of power systems, with special emphasis on the application of Custom power controllers. As an example, we'll use a DVR design. The output waveforms of the examined DVR model are virtually identical in simulation when both IGBT and GTO switching devices are utilized in the VSI circuit. It has also been discovered that electricity consumers with sensitive loads experience the most discomfort from voltage sag at the distribution level during fault conditions. However, a well-designed DVR system can solve this issue.

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