Three Phase System Multi Level Inverters or a Chain of Single Phase Inverters Used in the DVR Topology

Guguloth Ramesh
jntuh: dept. Electrical Engineering
DARE College
Hyderabad, India
e-mail: rameshguguloth221@gmail.com

Banoth Raja
Jntuh: Electrical Engineering. BOMMA College
BIET Khammam
Hyderabad, India
e-mail:banothraja205@gmail.com

Abstract— in this paper, the performance of the DSTATCOM and the DVR used for the load bus voltage control have been analyzed and compared when a nonlinear load is connected across the load bus. Both of these compensators are used under closed-loop voltage-control mode. The control The voltage related power-quality (PQ) problems, such as sags and swells, voltage dips, harmonic distortions due to nonlinear loads and voltage unbalancing in electrical power distribution systems, have been a major concern for the voltage-sensitive loads. Load voltage regulation using VSC for different grid-connected applications has been recently attempted. With the increased use of power-electronics devices in the consumer products, the loads are becoming voltage sensitive and nonlinear in nature. Depending up on the applications, these loads are connected to the distribution system having varying voltage and power levels. Also the radial feeders of the distribution system to which these loads are connected have varying length and short circuit current (SCC) levels. This depends upon the location of the load, distribution system size, and its voltage and volt-ampere (VA) ratings. This leads to the wide variations in the Thevenin's equivalent feeder impedance looking from the load side. If the load is connected at the end of the long feeder and has small short circuit current value, it is called a weak ac supply system (or non-stiff source).

***Keywords**-DVR D-STATCOM; SCC; VA RATINGS; VSC; Distribution System*

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1. INTRODUCTION

Two types of VSC-based compensators have been commonly used for mitigation of the voltage sags and swells and regulating the load bus voltage. The first one is a shunt device, which is commonly called DSTATCOM; and the second one is a series device, which is commonly called DVR. In, these compensators can address other PQ issues, such as load voltage harmonics, source current harmonics, unbalancing, etc., under steady state to obtain more benefits out of their continuous operation.

There have been a variety of control strategies proposed for load voltage control using the aforementioned two devices or DSTATCOM; this includes reactive power compensation and voltage-control mode operation. For of DSTATCOM. For DVR, it includes open-loop and closed-loop load voltage-control methods. The closed-loop voltage-control mode operation of the two devices is considered best from the point of view of precise and fast control against sudden variations in the supply voltage and the load. In a common control strategy has been proposed for the shunt and series compensator .A detailed study of the dynamic performance of these two compensating devices controlling the load voltage under closed loop is required. This study presumes a three-phase, four-wire distribution system, in which each phase is controlled independently. Under this situation, the result obtained on the per phase basis is equally applicable for the three phase system. performance of the compensator and attenuation properties against been obtained using closed-loop frequency-response characteristics.

A simple output voltage feedback control and a fixed switching frequency linear modulation have been used for the operation of the VSC under closed loop. It is shown that the performance of two compensating devices depends upon thefeeder impedance. A generalized converter topology is considered and the modulation technique based on the cascaded multilevel inverter has been proposed for medium-voltage distribution system applications. Simulation studies have been performed to verify the results in a three-phase distribution system.

1.1. POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations.

To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: 'Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago.

The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

power conversion became the way of life, did power quality issues begin to emerge. Even as harmonic distortion and power Factor issues surfaced, no one was really prepared. Even today, crane builders and electrical drive System vendors avoid the issue during competitive bidding for new cranes. Rather than focus on Awareness and understanding of the potential issues, the power quality issue is intentionally or unintentionally ignored. Power quality problem solutions are available. Although the solutions are not free, in most cases, they do represent a good return on investment. However, if power quality is not specified, it most likely will not be delivered.

Power quality can be improved through:

- Power factor correction,
- Harmonic filtering,
- Special line notch filtering,
- Transient voltage surge suppression,
- Proper earthling systems.

In most cases, the person specifying and/or buying a container crane may not be fully aware of the potential power quality issues. If this article accomplishes nothing else, we would hope to provide that awareness.

In many cases, those involved with specification and procurement of container cranes may not be cognizant of such issues, do not pay the utility billings, or consider it someone else's concern. As a result, container crane specifications may not include definitive power quality criteria such as power factor correction and/or harmonic filtering. Also, many of those specifications which do require power quality equipment do not properly define the criteria. Early in the process of preparing the crane specification:

• Consult with the utility company to determine regulatory or contract requirements that must be satisfied, if any.

• Consult with the electrical drive suppliers and determine the power quality profiles that can be expected based on the drive sizes and technologies proposed for the specific project.

• Evaluate the economics of power quality correction not only on the present situation, but consider the impact of future utility deregulation and the future development plans for the terminal.

1.2. THE BENEFITS OF POWER QUALITY

Power quality in the container terminal environment impacts the economics of the terminal operation, affects reliability of the terminal equipment, and affects other consumers served by the same utility service. Each of these concerns is explored in the following paragraphs.

ECONOMIC IMPACT

The economic impact of power quality is the foremost incentive to container terminal operators. Economic impact can be significant and manifest itself in several ways:

A. POWER FACTOR PENALTIES

Many utility companies invoke penalties for low power factor on monthly billings. There is no industry standard followed by utility companies. Methods of metering and calculating power factor penalties vary from one utility company to the next. Some utility companies actually meter kVAR usage and establish a fixed rate times the number of kVAR-hours consumed. Other utility companies monitor kVAR demands and calculate power factor. If the power factor falls below a fixed limit value over a demand period, a penalty is billed in the form of an adjustment to the peak demand charges. A number of utility companies servicing container terminal equipment do not yet invoke power factor penalties.

However, their service contract with the Port may still require that a minimum power factor over a defined demand period be met. The utility company may not continuously monitor power factor or kVAR usage and reflect them in the monthly utility billings; however, they do reserve the right to monitor the Port service at any time. If the power factor criteria set forth in the service contract are not met, the user may be penalized, or required to take corrective actions at the user's expense.

One utility company, which supplies power service to several east coast container terminals in the USA, does not reflect power factor penalties in their monthly billings, however, their service contract with the terminal reads as follows:

'The average power factor under operating conditions of customer's load at the point where service is metered shall be not less than 85%. If below 85%, the customer may be required to furnish, install and maintain at its expense corrective apparatus which will increase the Power factor of the entire installation to not less than 85%. The customer shall ensure that no excessive harmonics or transients are introduced on to the [utility] system. This may require special power conditioning equipment or filters.

B. SYSTEM LOSSES

Harmonic currents and low power factor created by nonlinear loads, not only result in possible power factor penalties, but also increase the power losses in the distribution system. These losses are not visible as a separate item on your monthly utility billing, but you pay for them each month. Container cranes are significant contributors to harmonic currents and low power factor. Based on the typical demands of today's high speed container cranes, correction of power factor alone on a typical state of the art quay crane can result in a reduction of system losses that converts to a 6 to 10% reduction in the monthly utility billing. For most of the larger terminals, this is a significant annual saving in the cost of operation.

C. POWER SERVICE INITIAL CAPITAL INVESTMENTS

The power distribution system design and installation for new terminals, as well as modification of systems for terminal capacity upgrades, involves high cost, specialized, high and medium voltage equipment. Transformers, switchgear, feeder cables, cable reel trailing cables, collector bars, etc. must be sized based on the kVA demand. Thus cost of the equipment is directly related to the total kVA demand.

would be the case if power factor correction equipment were supplied on board each crane or at some common bus location in the terminal.

D. POWER SYSTEM ADEQUACY

When considering the installation of additional cranes to an existing power distribution system, a power system analysis should be completed to determine the adequacy of the system to support additional crane loads.

Power quality corrective actions may be dictated due to inadequacy of existing power distribution systems to which new or relocated cranes are to be connected. In other words, addition of power quality equipment may render a workable scenario on an existing power distribution system, which would otherwise be inadequate to support additional cranes without high risk of problems.

II. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

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. In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS-devices are:

• Power flow control,
• Increase of transmission capability,
• Voltage control,
• Reactive power compensation,
• Stability improvement,
• Power quality improvement,
• Power conditioning,
• Flicker mitigation,
• Interconnection of renewable and distributed generation and storages.

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 more important.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.

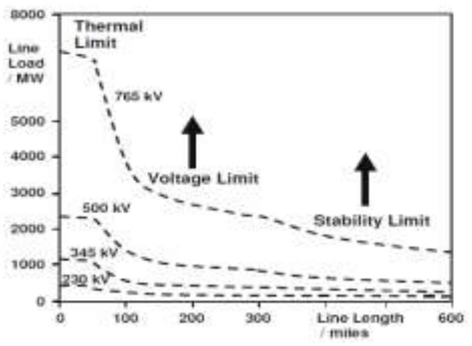


Fig. 1.1. Operational limits of transmission lines for different voltage levels

The development of FACTS-devices has started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for high and even highest voltage levels. differentiation factors from the conventional devices.

The term 'static' means that the devices have no moving parts like mechanical switches to perform the dynamic controllability. Therefore most of the FACTS-devices can equally be static and dynamic.

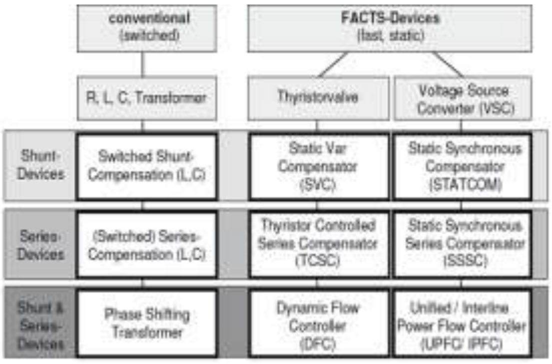


Fig.1.3. Overview of major FACTS-devices

The left column in Figure contains the conventional devices build out of fixed or mechanically switch able components like resistance, inductance or capacitance together with transformers. The FACTS-devices contain these elements as well but use additional power electronic valves or converters to switch the elements in smaller steps or with switching patterns within a cycle of the alternating current. The left column of FACTS-devices uses Thyristor valves or converters. These valves or converters are well known since several years. They have low losses because of their low switching frequency of once a cycle in the converters or the usage of the Thyristors to simply bridge impedances in the valves.

2.1. Configurations of FACTS-Devices:

Shunt Devices:

The most used FACTS-device is the SVC or the version with Voltage Source Converter called STATCOM. These shunt devices are operating as reactive power compensators. The main applications in transmission, distribution and industrial networks are:

• Reduction of unwanted reactive power flows and therefore reduced network losses.

• Keeping of contractual power exchanges with balanced reactive power.

• Compensation of consumers and improvement of power quality especially with huge demand fluctuations like industrial machines, metal melting plants, railway or underground train systems.

• Compensation of Thyristor converters e.g. in conventional HVDC lines.

• Improvement of static or transient stability.

Almost half of the SVC and more than half of the STATCOMs are used for industrial applications. Industry as well as commercial and domestic groups of users require power quality. Flickering lamps are no longer accepted, nor are interruptions of industrial processes due to insufficient power quality. Railway or underground systems with huge load variations require SVCs or STATCOMs.

SVC:

Electrical loads both generate and absorb reactive power. Since the transmitted load varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage amplitude variations or even a voltage depression, at the extreme a voltage collapse.

Applications of the SVC systems in transmission systems:

a. To increase active power transfer capacity and transient stability margin

b. To damp power oscillations

c. To achieve effective voltage control

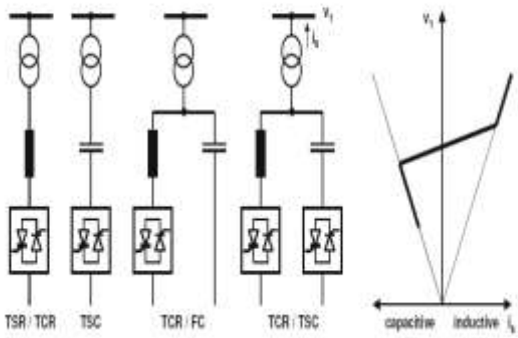
In addition, SVCs are also used

1. in transmission systems

a. To reduce temporary over voltages

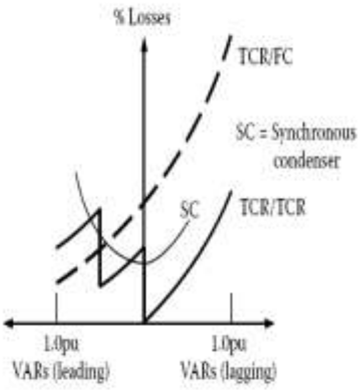
b. To damp sub synchronous resonances

c. To damp power oscillations in interconnected smooth voltage profile under different network conditions. In addition an SVC can mitigate active power oscillations through voltage amplitude modulation.



SVC building blocks and voltage / current characteristic

In principle the SVC consists of Thyristor Switched Capacitors (TSC) and Thyristor Switched or Controlled Reactors (TSR / TCR). The coordinated control of a combination of these branches varies the reactive power as shown in Figure. 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.

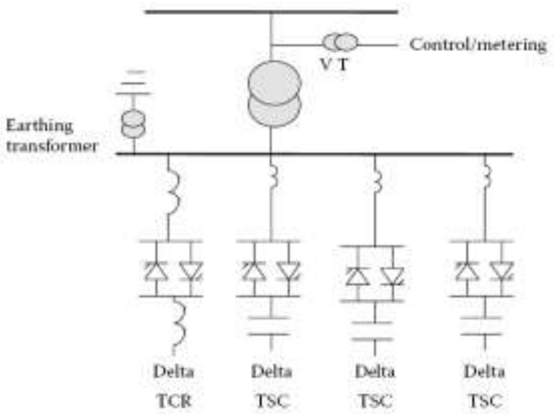


Comparison of the loss characteristics of TSC–TCR, TCR–FC compensators and synchronous condenser

These SVCs do not have a short-time overload capability because the reactors are usually of the air-core type. In applications requiring overload capability, TCR must be designed for short-time overloading, or separate thruster-switched overload reactors must be employed.

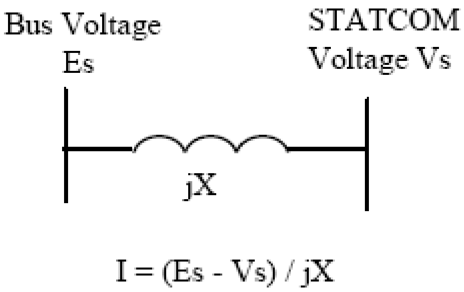
III. SVC USING A TCR AND TSC:

This compensator overcomes two major shortcomings of the earlier compensators by reducing losses under operating conditions and better performance under large system disturbances. In view of the smaller rating of each capacitor bank, the rating of the reactor bank will be 1/n times the maximum output of the SVC, thus reducing the harmonics generated by the reactor. In those situations where harmonics have to be reduced further, a small amount of FCs tuned as filters may be connected in parallel with the TCR.



SVC of combined TSC and TCR type The advantage of a STATCOM is that the reactive power provision 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. This means, that even during most severe contingencies, the STATCOM keeps its full capability.

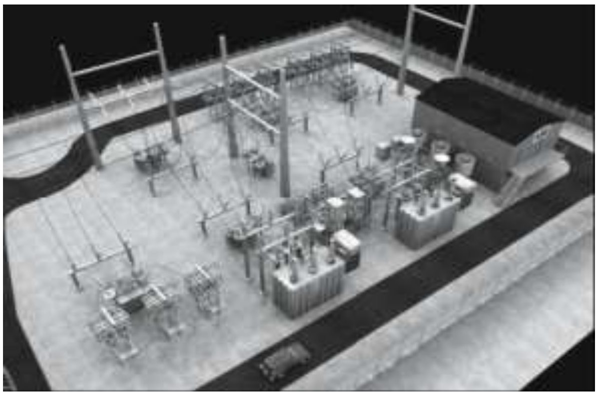
practical STATCOM requires some amount of energy storage to accommodate harmonic power and ac system unbalances, when the instantaneous real power is non-zero. The maximum energy storage required for the STATCOM is much less than for a TCR/TSC type of SVC compensator of comparable rating.



STATCOM Equivalent Circuit

Several different control techniques can be used for the firing control of the STATCOM. Fundamental switching of the GTO/diode once per cycle can be used. This approach will minimize switching losses, but will generally utilize more complex transformer topologies. As an alternative, Pulse Width Modulated (PWM) techniques, which turn on and off the GTO or IGBT switch more than once per cycle, can be used. This approach allows for simpler transformer topologies at the expense of higher switching losses.

These methods include the basic 12 pulse configuration with parallel star / delta transformer connections, a complete elimination of 5th and 7th harmonic current using series connection of star/star and star/delta transformers and a quasi 12 pulse method with a single star-star transformer, and two secondary windings, using control of firing phase shift between the two 6 pulse bridges.



Substation with a STATCOM

Series Devices:

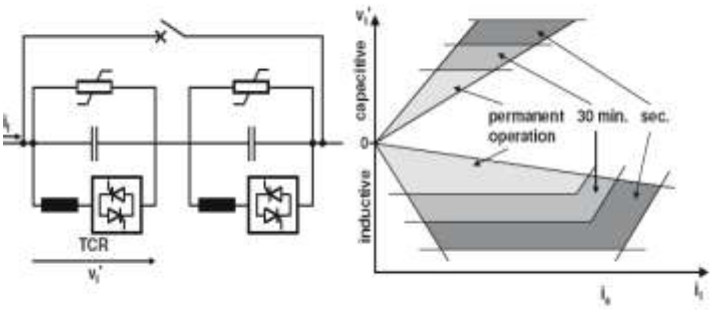
Series devices have been further developed from fixed or mechanically switched compensations to the Thyristor Controlled Series Compensation (TCSC) or even Voltage Source Converter based devices.

The main applications are:

• Reduction of series voltage decline in magnitude and angle over a power line,

• Reduction of voltage fluctuations within defined limits during changing power transmissions,

• Improvement of system damping resp. damping of oscillations,
• Limitation of short circuit currents in networks or substations,
• Avoidance of loop flows resp. power flow adjustments. isolated steel platform, including the Thyristor valve that is used to control the behavior of the main capacitor bank. Likewise the control and protection is located on ground potential together with other auxiliary systems. Figure 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.



Advantages

- Continuous control of desired compensation level
- Direct smooth control of power flow within the network
- Improved capacitor bank protection
- Local mitigation of sub synchronous resonance (SSR). This permits higher levels of compensation in networks where interactions with turbine-generator torsional vibrations or with other control or measuring systems are of concern.
- Damping of electromechanical (0.5-2 Hz) power oscillations which often arise between areas in a large interconnected power network. These oscillations are due to the dynamics of inter area power transfer and often exhibit poor damping when the aggregate power transfer over a corridor is high relative to the transmission strength.

Shunt and Series Devices

Dynamic Power Flow Controller

A new device in the area of power flow control is the Dynamic Power Flow Controller (DFC). The DFC is a hybrid device between a Phase Shifting Transformer (PST) and switched series compensation.

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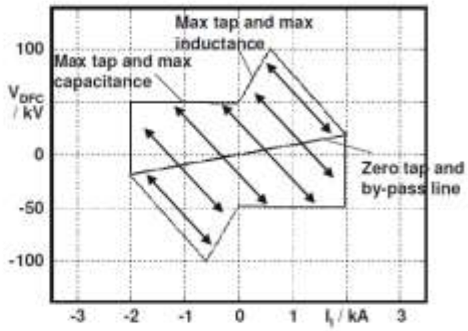


Operational diagram of a DFC

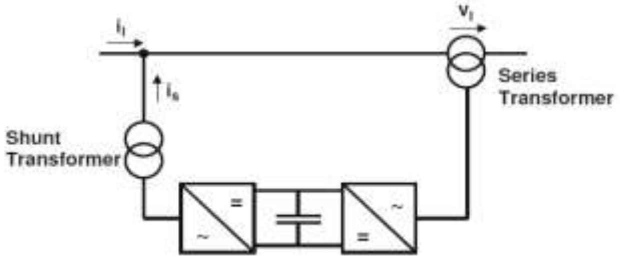
Operation in the first and third quadrants corresponds to reduction of power through the DFC, whereas operation in the second and fourth quadrants corresponds to increasing the power flow through the DFC. The slope of the line passing through the origin (at which the tap is at zero and TSC / TSR are bypassed) depends on the short circuit reactance of the PST.

Starting at rated current (2 kA) the short circuit reactance by itself provides an injected voltage (approximately 20 kV in this case). If more inductance is switched in and/or the tap is increased, the series voltage increases and the current through the DFC decreases (and the flow on parallel branches increases). The operating point moves along lines parallel to the arrows in the figure. The slope of these arrows depends on the size of the parallel reactance. The maximum series voltage in the first quadrant is obtained when all inductive steps are switched in and the tap is at its maximum.

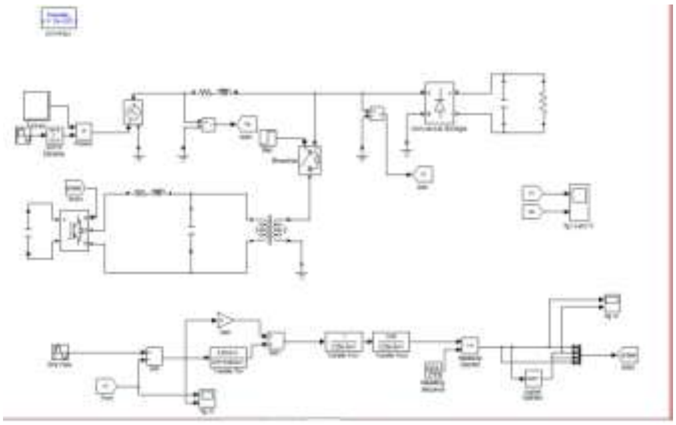
Now, assuming maximum tap and inductance, if the throughput current decreases (due e.g. to changing loading of the system) the series voltage will decrease. At zero current, it will not matter whether the TSC / TSR steps are in or out, they will not contribute to the series voltage. Consequently, the series voltage at zero current corresponds to rated PST series voltage. Next, moving into the second quadrant, the operating range will be limited by the line corresponding to maximum tap and the capacitive step being switched in (and the inductive steps by-passed). In this case, the capacitive step is approximately as large as the short circuit reactance of the PST, giving an almost constant maximum voltage in the second quadrant.

Unified Power Flow Controller:

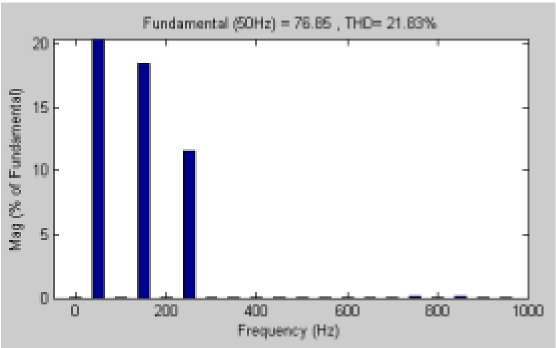
The UPFC is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously.

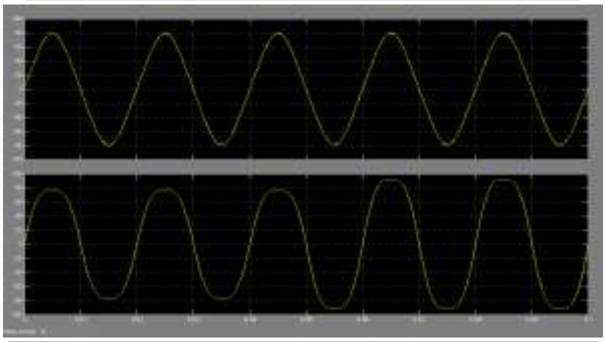


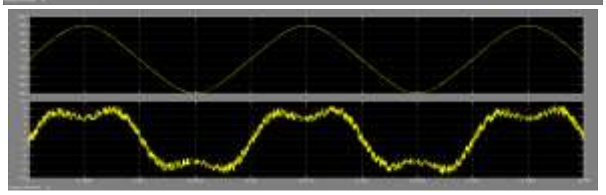
Principle configuration of an UPFC



MATLAB DESIGN OF CASE STUDY Simulation circuit diagram







CONCLUSION

The performance of the VSC-based shunt and series compensators (i.e., DSTATCOM and DVR with the presented topology) has been analyzed in voltage control mode through closed-loop frequency-response characteristics.

It is shown that for the weak ac supply system, the load voltage control using DSTATCOM has large bandwidth and good attenuation in source voltage and nonlinear load perturbations. However, the DVR in this case passes high-frequency load components almost unattenuated and causes the presence of notches in the load voltage. For the case of a strong ac supply system, the DVR has good bandwidth and attenuation properties. The DSTATCOM in this case cannot control the load bus voltage. The proposed analytical results have been verified through the laboratory experimental model. The generalized converter topology based on cascaded multilevel inverter using multi carrier phase-shifted PWM can be used for the load voltage control of an MV distribution system, following the proposed control algorithm.

The results for the three-phase load voltage control have been verified for an 11-kV distribution system, using seven-level cascaded transformer multilevel converter topology, through simulations.

Future Scope

- Three phase dynamic voltage restorer with auxiliary supply voltage has been used in the simulation study. Instead of auxiliary voltage supply we can also use capacitor bank and study the results.
- In three phase system multi level inverters or a chain of single phase inverters for each phase may be used in the DVR topology and such systems may be studied.
- The super conducting magnetic energy storage systems (SMES) may be used in the DVR structure in large systems. Such systems may be studied.

REFERENCES

[1] P. R. Sánchez, E. Acha, J. E. O. Calderon, V. Feliu, and A. G. Cerrada,"A versatile control scheme for a dynamic voltage restorer forpower-quality improvement," IEEE Trans. Power Del., vol. 24, no. 1,pp. 277–284, Jan. 2009.

[2] Y. A. R. I. Mohamed and E. F. E. Saadany, "A control method ofgrid-connected PWM voltage source inverters to mitigate fast voltagedisturbances," IEEE Trans. Power Syst., vol. 24, no. 1, pp. 489–491,Feb. 2009.

[3] P. Samuel, R. Gupta, and D. Chandra, "Grid interface of photovoltaic microturbine hybrid based power for voltage support and control usingVSI in rural applications," presented at the IEEE Power Eng. Soc. Gen.Meeting, Calgary, AB, Canada, 2009.

[4] K. Selvajyothi and P. A. Janakiraman, "Reduction of voltage harmonicsin single phase inverters using composite observers," IEEETrans. Power Del., vol. 25, no. 2, pp. 1045–1057, Apr. 2010.

[5] A. Ghosh and G. Ledwich, "Load compensating DSTATCOM in weakAC systems," IEEE Trans. Power Del., vol. 18, no. 4, pp. 1302–1309,Oct. 2003.

[6] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Std. 519-1992, Apr. 12, 1993.

[7] A. Ghosh, "Performance study of two different compensating devicesin a custom power park," Proc. Inst. Elect. Eng., Gen. Transm. Distrib.,vol. 152, no. 4, pp. 521–528, Jul. 2005.

[8] M. H. Haque, "Compensation of distribution system voltage sag byDVR and D-STATCOM," in Proc. IEEE Porto Power Tech Conf., Sep.2001, vol. 1,5, pp. 10–13.

[9] G. Ledwich and A. Ghosh, "A flexible DSTATCOM operating involtage or current control mode," Proc. Inst. Elect. Eng., Gen.,Transm. Distrib., vol. 149, no. 2, pp. 215–224, Mar. 2002.

[10] M. K. Mishra, A. Ghosh, and A. Joshi, "Operation of a DSTATCOMin voltage control mode," IEEE Trans. Power Del., vol. 18, no. 1, pp.258–264, Jan. 2003.

[11] R. Gupta and A. Ghosh, "Frequency-domain characterization of slidingmode control of an inverter used in DSTATCOM application," IEEETrans. Circuits Syst. I, Reg. Papers, vol. 53, no. 3, pp. 662–676, Mar.2006.

[12] B. Singh, A. Adya, A. P. Mittal, J. R. P. Gupta, and B. N. Singh, "Applicationof DSTATCOM for mitigation of voltage sag for motor loadsin isolated distribution