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A MEDIUM-VOLTAGE REACTIVE POWER COMPENSATION FOR AN IMPROVED TRANSFORMER WINDING TAP INJECTION D-STATCOM TOPOLOGY

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ABSTRACT

This paper describes an improved transformer winding tap injection distribution static synchronous compensator (WTI-DSTATCOM) for medium-voltage reactive power compensation. The cascaded multilevel converter (CMC)-based DSTATCOM is connected to the special-designed winding taps on the primary windings of the transformer instead of the conventional point of common coupling (PCC). The voltage stress for DSTATCOM to handle is reduced. The winding tap injection (WTI) method can make full use of the spare capacity of the transformer and obtain a flexible connection voltage for DSTATCOM. The compensation mechanism and winding current distribution after currents injection are analyzed by phasor diagrams under steady state. A nonlinear passivity-based control (PBC) algorithm is designed for inner loop current control and a three-layer voltage balancing control strategy is applied to balance the dc capacitor voltage. The results obtained from the MATLAB/Simulink simulations and a down-scaled laboratory prototype experiment of 800-V verify the feasibility and effectiveness of the proposed WTI-DSTATCOM system with PBC algorithm in reactive power compensation.

1. INTRODUCTION

Distribution static synchronous compensators (DSTATCOMs) becomes more and more attractive in distribution network due to their fast response and small size [1], [2]. They are connected to the utility grid either directly or via a step-up transformer to provide isolation and voltage matching. Three common connection types of DSTATCOM system are summarized. The attainable capacity of type-I and type-II may reach mega volt-ampere. Therefore, they are suitable for centralized reactive power compensation in medium voltage (MV) or high voltage (HV) systems. However, the coupling transformer in type accounts for nearly forty percent of the total weight and its losses can be nearly half of the total losses, which make it less favorable than transformer-less structure of type-II. Type-III is popular in customer-side and its typical connection voltage is low, which limits its compensation capacity (kilo volt-ampere). Hence, it is only suitable for decentralized compensation. With the development of power switches technology, the transformer-less DSTATCOM of type-II seems to be more and more popular. A variety of cascaded multilevel converter (CMC)-based transformer-less DSTATCOM. However, a compromise between the cascaded count and the sizing of a CMC module must be made due to the high AC line voltage. If the HV insulated gate bipolar transistors(IGBTs, 3300V, 4500V, 6500V) are chosen, the cascaded count will be decreased and the attainable capacity can be improved. In practice, the HV IGBTs are not so cost-effective. They are not always available on the markets. On the contrary, if we choose the most cost-effective LVIGBTs, the cascaded count, system complexity and unreliability will increase.

2. SCOPE OF THE PROJECT

The scope of the project is the cascaded multilevel converter(CMC)-based DSTATCOM is connected to the special-designed winding taps on the primary windings of the transformer instead of the conventional point of common coupling (PCC)

3. OPERATNG PRINCIPLES OF DSTATCOM

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator (similar in many respects to the DVR) that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations.

The major components of a DSTATCOM

- dc capacitor, one or more
- inverter modules, an ac filter,
- a transformer to match the inverter output to the line voltage, and
- a PWM control strategy.

In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter).

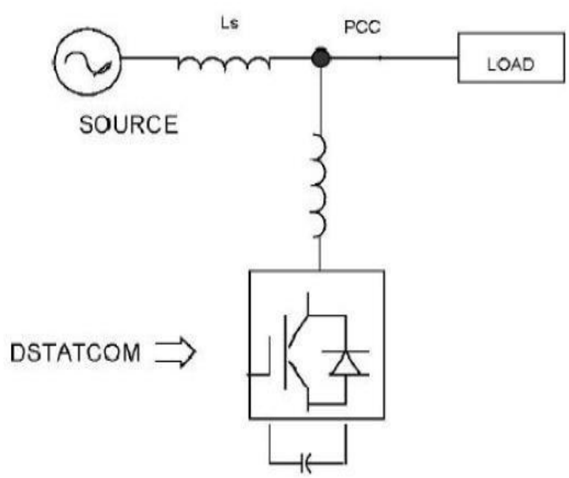

Fig 1:block diagram of DSTATCOM circuit

A. VOLTAGE REGULATION WITHOUT COMPENSATOR

Voltage E and V mean source voltage and PCC voltage respectively. Without a voltage compensator, the PCC voltage drop caused by the load current.

IS = IL + IR

B. COMPENSATION OF REACTIVE POWER

Basic operating principle of a DSATCOM is similar to that of synchronous machine. The synchronous machine will provide lagging current when under excited and leading current when over excited. DSTATCOM can generate and absorb reactive power similar to that of synchronous machine and it can also exchange real power if provided with an external device DC source.

- Exchange of reactive power:- if the output voltage of the voltage source converter is greater than the system voltage then the DSATCOM will act as capacitor and generate reactive power(i.e.. provide lagging current to the system)
- Generation of reactive power: DSTATCOM provides reactive power as needed by the load and therefore the source current remains at unity power factor (UPF).

I. MODULE

- ✓ STATCOM
- ✓ Reactive power compensation
- ✓ Transformer
- ✓ Inductive load

A. STATCOM

A static synchronous compensator (STATCOM), also known as a static synchronous condenser (STATCOM), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. It is inherently modular and electable.

STATCOM (Static Synchronous Compensator, also known as SVG). It is an important device for Flexible AC Transmission System (FACTS), which is the third generation of dynamic VAR compensation device after FC, MCR, and TCR type of SVC (Static VAR Compensator). Its appearance represents the application of most advanced technology for dynamic VAR compensation. It is also known as DSTATCOM when apply in power distribution. STATCOM is connected parallel in power grid and works as reactive current source. Its reactive current can be flexibly controlled and compensate reactive power for system automatically. It solves problem of harmonics interfere switching parallel capacitor banks. In another hand, it can restrain harmonics and improve power quality according to customers' needs. STATCOM has superior performance in lots of aspect such as

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responding speed, stabilize voltage of power grid, reduce system power loss and harmonics, increase both transmission capacity and limit for transient voltage. It also has advantage of smaller in dimension.

B. Reactive power compensation

Consumer load requires reactive power that continuously and increases transmission losses while affecting voltage in the transmission network. To prevent unacceptably high voltage fluctuations or the power failures that can result, this reactive power must be compensated and kept in balance.

This function has always been performed by passive elements such as reactors or capacitors as well as combinations of the two that supply inductive or capacitive reactive power.

The more quickly and precisely the reactive power compensation can be accomplished, the more efficiently the various transmission characteristics can be controlled. For this reason, slow mechanically switched components have been almost completely replaced by fast thyristor switched and thyristor controlled components.

C. Effects of reactive power flow

Reactive power flow has the following effects:

- Increase in transmission system losses

-Adding to power plant installations
-Adding to operating costs

- Major influence on system voltage deviation

-Degradation of load performance at under voltage
-Risk of insulation breakdown at overvoltage
-Limitation of power transfer
-Steady-state and dynamic stability limits

D. Transformer

Y-D multifunction balance transformer-based power quality control system is presented. The VSC is connected to the taps on the windings to eliminate the auxiliary transformer. The approach is interesting and cost-effective, but it is not suitable for three phase power system. Motivated by the structure of autotransformer, a novel integrated DSTATCOM topology was firstly presented in our previous work. DSTATCOM is connected to the taps on the primary windings of the transformer. Three kinds of integrated structures were presented in that paper, but only the multi-group taps structure was discussed in detail. The compensation mechanism was not clearly described. The winding-taps-injection DSTATCOM (WTI DSTATCOM) is further developed in this paper. The power transformer is used as the coupling transformer at the same time. The rated voltage of DSTATCOM is reduced, which is helpful to reduce the cascaded count and obtain a lower dc-link voltage. The capacity utilization of the transformer is also improved.

E. Inductive load

An inductive load converts current into a magnetic field. Inductive reactance resists the change to current, causing the circuit current to lag voltage

4. EXISTING SYSTEM

This project proposes a hybrid static synchronous compensator (hybrid-STATCOM) in a three-phase power transmission system that has a wide compensation range and low DC-link voltage. Because of these prominent characteristics, the system costs can be greatly reduced. In this paper, the circuit configuration of hybrid-STATCOM is introduced first. Its V-I characteristic is then analyzed, discussed, and compared with traditional STATCOM and capacitive-coupled STATCOM (C-STATCOM). The system parameter design is then proposed on the basis of consideration of the reactive power compensation range and avoidance of the potential resonance problem. After that, a control strategy for hybrid-STATCOM is proposed to allow operation under different voltage and current conditions, such as unbalanced current, voltage dip, and voltage fault. Finally, simulation and experimental results are provided to verify the wide compensation range and low DC-link voltage characteristics and the good dynamic performance of the proposed hybrid-STATCOM.

A. EXISTING SYSTEM TECHNIQUE EXPLANATION

The dynamic performance of hybrid-STATCOM for different loadings compensation. When the load reactive power changes from capacitive to inductive, hybrid-STATCOM takes about one cycle to settle down. However, when the load reactive power is changing within the inductive range, the transient time is significantly reduced and the waveforms are smooth. Meanwhile, the fundamental reactive power is compensated to around zero even during the transient time. In practical situations, the load reactive power seldom suddenly changes from capacitive to inductive or vice versa, and thus hybrid-STATCOM can obtain good dynamic performance.

The objective of the experiment results is to verify that the proposed hybrid-STATCOM has the characteristics of a wide compensation range and low DC-link voltage under different voltage and current conditions, such as unbalanced current, voltage dip, and voltage fault. The detailed settings of a 110-V, 5-kVA hybrid-STATCOM experimental system are provided in the Appendix A, and its DC-link voltage is maintained at VDC=50V for all experiments. Figs. 7 and 8 show the dynamic compensation waveforms of load voltage vx, source current isx, and reactive power Qsa of phase a by applying hybrid-STATCOM for inductive load and capacitive load compensation. Fig. 9 gives the corresponding source current harmonic spectrums for inductive and capacitive reactive power compensations.

DSTATCOM PROPOSED SYSTEM

A. TYPES OF DSTATCOM

Three various types of DSTATCOM are

- Type 1
- Type 2

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- Type 3

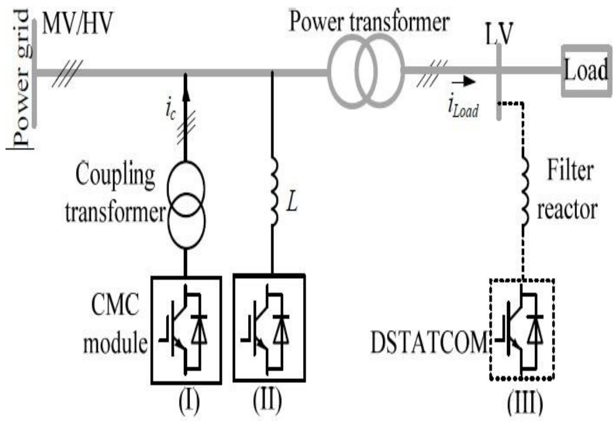

Fig. 1. Connection alternatives for STATCOM system.

The type-I and type-II may have capacity to reach mega volt ampere. Therefore, they are suitable for centralized reactive power compensation in medium voltage (MV) or high voltage (HV) systems. However, the coupling transformer in type-I accounts for nearly forty percent of the total weight and its losses can be nearly half of the total losses, which make it less favorable than transformer-less structure of type-II. Type-III is popular in customer-side and its typical connection voltage is low, which limits its compensation capacity (kilo volt-ampere). Hence, it is only suitable for decentralized compensation.

B. DSTATCOM COMPARISON

COMPARISON OF DIFFERENT CONNECTION TYPES.

Proposed winding taps connection
Type-I

- The auxiliary step-up transformer makes the whole system bulky and inefficient.
- They both have flexible connection point voltage for VSC (lower voltage stress) in the beginning. However, the voltage can't change any more once the transformer is selected.
- The capacity utilization may be relative low in the first few years.

Type-II

- It has lower harmonic distortion and higher power capacity.
- The voltage stress is higher, so more cells are connected in series to block the line voltage. More cascaded count increases the initial investment, system complexity and unreliability.
- The rated capacity may be much greater than actual compensation requirements at first.

Type-III

- This connection type has lowest voltage stress and power capacity.
- Multi-parallel DSTATCOMs can be used to increase total compensation capacity, but it is challenging to achieve power sharing control between different modules.

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5. PROPOSED SYSTEM

The multi-group taps structure was discussed in detail. The compensation mechanism was not clearly described. The winding-taps-injection DSTATCOM (WTI-DSTATCOM) isfurther developed in this paper. The power transformer is used as the coupling transformer at the same time. The rated voltage of DSTATCOM is reduced, which is helpful to reduce the cascaded count and obtain a lower dc-link voltage. The capacity utilization of the transformer is also improved. Unlike previous work, the major contribution of this paper can be summarized as follows:

- The compensation mechanism is first elaborated and validated by both simulation and experimental results. The compensation mechanism consists of two important parts: transformer core saturation problem and winding currents distribution after compensation.
- The nonlinear passivity based control (PBC) is first introduced to control WTI-DSTATCOM in this paper. Compared with PI controller, the robustness are enhanced and the design and tuning process are simplified.
- A new test bench is developed in this paper. A 7-levelCMC-based DSTATCOM with *LCL* filter is designed for current injection. More comprehensive tests, including both steady-state and dynamic performance, are done and analyzed in this paper. The winding currents distribution after compensation is studied clearly, so the load ratio of the transformer is also increased in experiment.

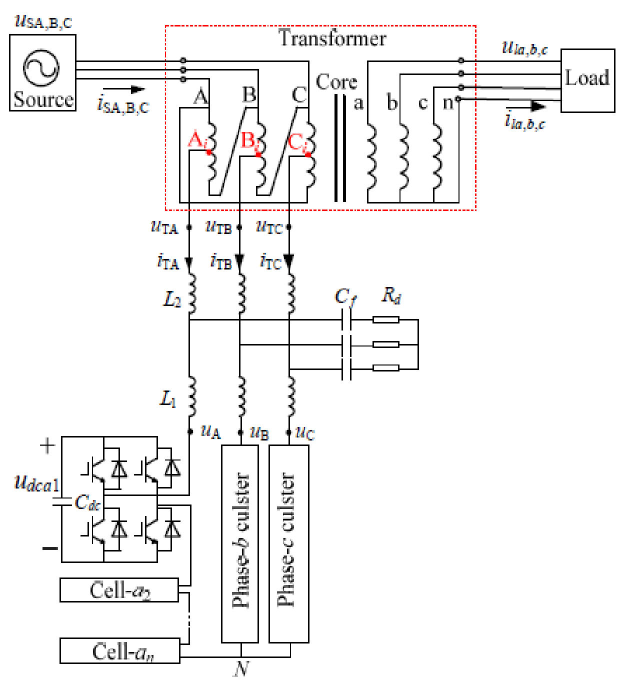

Fig 2:Circuit configuration of the proposed WTI- DSTATCOM

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A. PROPOSED ALGORITHM EXPLANATION

The circuit configuration of the proposed WTI-DSTATCOM. There are three winding taps (labeled as Ai, Bi and Ci) on the primary windings of the Dyn11connection distribution transformer. uS A,B,C and iS A,B,C are the three-phase voltage and current of the system. ula,b,c and ila,b,c are the three-phase voltage and current of the load. uTA, uTB, and uTC are the three-phase voltage of the winding taps(connection point voltage). uA, uB and uC are the three-phase voltage of DSTATCOM. iTA, iTB, and iTC are the three-phase injection current. L1 is the inductor at the converter side, and L2 is the inductor at the grid side. Cf is the filter capacitor. Rd is the damping resistance, which is used in series with Cf to provide passive damping. The power distribution transformer is also used as the coupling transformer at the same time. Note that there are various connection alternatives for DSTATCOM. Three groups of winding taps labeled as A1-B1-C1,A2-B2-C2, and Am-Bm-Cm (central taps).To guarantee the system working normally, the positions of the taps must be symmetrical, i.e. that must satisfy |AAi|=|BBi|=|CCi| (i=1, 2, 3…).

WTI-DSTATCOM. The strengths of the proposed connection type are listed as follows:

- The capacity utilization of the distribution transformer is improved. The actual load ratio of the distribution transformer and future load growth are considered when DSTATCOM is designed. The spare capacity of the transformer is fully used for the connection of DSTATCOM.
- A compromise between voltage and current rating is achieved. The voltage stress of conventional connection types is neither too high (type-II) nor too low (type-III). The voltage stress for CMC-based DSTATCOM is reduced ,as well as the cascaded count, which is helpful to reduce initial investment.
- Easy to realize and expand. It is not difficult to design taps on the windings and the cost is scarcely increased. When reactive power requirements increase over time, we can change connection taps to increase connection point voltages. We can also add extra H-bridges owing to the good expansibility of CMC-based DSTATCOM. Finally, DSTATCOM can be connected to the system directly via A,B and C, which is the same as type-II.

B. DSTATCOM components

IGBT or GTO based dc-to-ac inverters:
These inverters are used which create an output voltage wave that's controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required.

L-C filter:
The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter.

Control block:
Control block is used which switch Pure Wave DSTATCOM modules as required. They can control external devices such as mechanically switched capacitor banks too.

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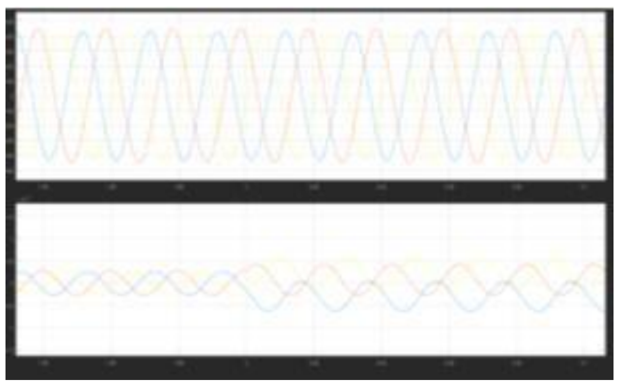
SIMULATION RESULT

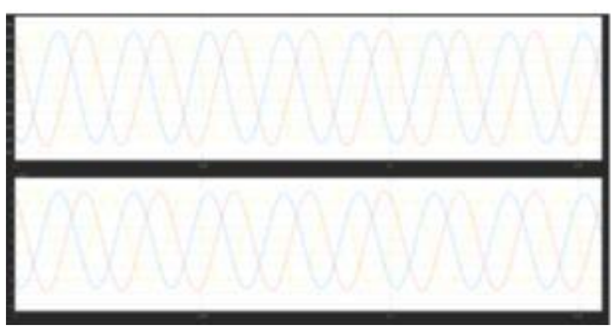
MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, you can analyze data, develop algorithms, and create models and applications.

SIMULINK, developed by Math Works, is a data flow graphical programming language tool for modeling, simulating and analyzing multi domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. SimPower Systems, the part of SIMULINK provides component libraries and analysis tools for modeling and simulating electrical power systems. Harmonic analysis, calculation of total harmonic distortion (THD), load flow, and other key electrical power system analyses are automated. SimPower Systems was developed by Hydro-Québec of Montreal.

WTI STATCOM Output before compensation



WTI STATCOM Output after compensation



CONCLUSION

An improved WTI-DSTATCOM for medium-voltage reactive power compensation. DSTATCOM is connected to the taps on the primary windings of the transformer to eliminate the auxiliary coupling transformer. This connection type can increase the capacity utilization of transformer and gain a compromise between the voltage ratings and current ratings of DSTATCOM. The winding current distribution is also analyzed by phasor diagram. A modified nonlinear passivity-based control is also presented to control the DSTATCOM. The viability and effectiveness of the proposed WTI-DSTATCOM system have been verified by both simulation and laboratory prototype experiment results, in which it can achieve a good reactive power compensation performance and fast dynamic response. The capacity utilization of the transformer is improved. Therefore, it is a cost-effective solution for medium voltage reactive power compensation.

FUTURE WORK

In the future we can use some other converter in the proposed system. That may increases the efficiency and output of the system.

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