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A Novel Distributed Facts Controller Based on Combined Two Half-Bridge Inverters

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Abstract: *Flexible AC Transmission Systems (FACTS) devices are used to control flow of power in the transmission line to relieve congestion and limit loop flows. Due to, high cost and reliability concerns the widespread deployment of FACTS solutions have been limited. The concept of Distributed FACTS (D FACTS) devices, as an alternative approach to realizing cost effective power flow control, has been proposed by different researchers. This paper discusses design of a novel Distributed FACTS controller based on two half-bridge inverter combined as an alternative approach to realize cost effective power flow control. The cost of D-FACTS controller based on combined two half-bridge is lower than recently D-FACTS controllers mentioned in literature. Simulation using PSCAD/EMTDC has been performed for conventional controllers and the proposed controller and the result are compared with respect to each other.*

Keywords: *FACTS, Distributed FACTS, DSSC, Combined two half-bridge.*

I. Introduction

A new technology that holds the promise of realizing a smart grid and achieving power flow control is Flexible AC Transmission Systems or FACTS [1]-[3]. FACTS devices allow control of power flows on ac power systems. Through the use of large power converters (10–300 MW) [1]. While several FACTS installations are operating worldwide, wide scale deployment has not occurred [4]. FACTS devices, such as STATCOM, SVC, SSSC and UPFC can be inserted in series with a line, connected in parallel, or a combination of the two, to achieve a myriad of control functions, including voltage regulation, system damping and power flow control [5]-[6].

Flexible AC Transmission Systems devices can be inserted in existing transmission lines to achieve control functions, including enhancement of transient stability, mitigation of system oscillations and so on. Even though FACTS technology is technically proven, it has not seen widespread commercial acceptance due to high voltage (up to 345 kV), high power (multi-hundred MVA), high cost, etc [4]-[8].

Wherefore, the concept of distributed FACTS (D-FACTS) devices has recently been proposed as an alternative approach for realizing the functionality of FACTS devices [4], [8]. According to the distributed static series compensator (DSSC) are a D-FACTS controller that can be clipped on to an existing power line and can, dynamically and statically, change the impedance of the line so as to control power flow [8].

Each DSSC module, which is rated at about 10kVA and is clamped on the power line as Fig. 1 shown, can be controlled so as to increase or decrease the impedance of the line or to leave it unaltered. With a large number of modules operating together, it is possible to have significant effects on the overall power flow in the line. The low kVA ratings of modules are in line with mass manufactured power electronics components, using mature power conversion techniques to demonstrate the potential for low-cost implementation and high system reliability[9]-[10].

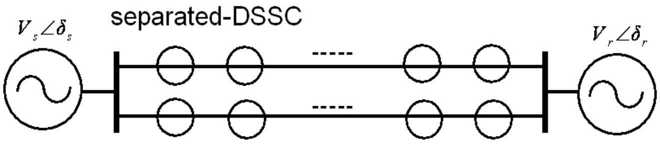

Fig. 1. compensation by separated-DSSC modules

As we know separated-DSSC are power flow controllers with cost-effective which are built in the basis of full bridge invertors. In this paper in order to reduce the cost of these modules (separated-DSSC) we have built them on the basis of half bridge invertors and to elevate the poorness of the halfbridge invertors we have combined them together. Hence instead of using two separated-DSSC on the basis of full bridge inverter, a combination of two DSSC modules on the basis of half inverter is used. Combined-DSSC modules are coupled and clamped on the transmission line as show in figure 2. Structure and principal of combined-DSSC module is discussed in this paper. Combined and separated-DSSC are simulated using PSCAD/EMTDC and the simulation results are shown and compared.

Fig. 2. compensation by combined-DSSC modules

II. Structure Of Combined-Dssc Module

Separated-DSSC modules clamped to the transmission line are based on full-bridge inverter. In figure 3. the circuit schematic of separated-DSSC is shown.

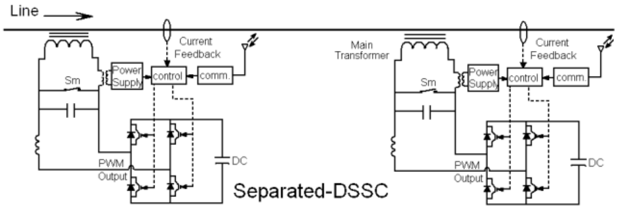

Fig. 3. circuit schematic of separated-DSSC module

The proposed method uses half-bridge inverter instead of full-bridge inverter in separated-DSSC modules in order to reduce the number of switches (the number of switches used in half-bridge invertors are half of the switches used in a full bridge inverter.) at the cost of doubling the number of DC capacitors (figure 4).
In order to elevate the disadvantage of half-bridge inverter, two half-bridge invertors are combined together in a way that the DC capacitor is shared between them. So instead of using two DC capacitors for each controller and four DC capacitors in total (two modules), two DC capacitors are need totally, where one DC capacitor is used for each module. With this new configuration of DSSC module, the number of switches is reduced to half not effecting the functionality and the result between the separate and combined-DSSC modules. Structure of combined-DSSC module is show in figure 4

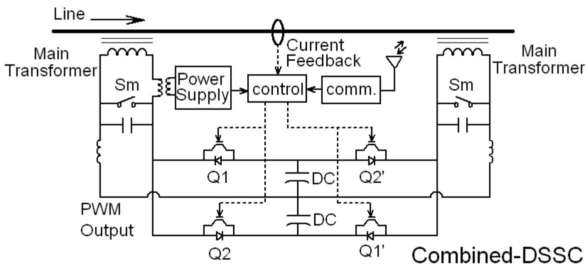

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Fig. 4. circuit schematic of combined-DSSC module

It can be seen that, the combined-DSSC module consists of two parts and each part has a DSSC module on the basis of half-bridge inverter. Each part has a single turn transformer (STT), a single phase half-bridge inverter and two DC capacitors which are shared between the two parts. Also both parts consist of a number of control circuits, power supply and built in-communication shared between them. As figure 4.shows in combined-DSSC module a number of control circuits, power supply and built in-communication is used which when compared to the separate-DSSC module needing twice as many control circuits, power supplies and built-in communications, it is much more cost effective and the circuitry is reduced to half.

III. Principal Of Combined-Dssc Module

Combined-DSSC module is based on half-bridge inverter which consists of two half-bridge invertors and a shared DC capacitor. Each half-bridge converter has two choppers (figure 4). For each half-bridge inverter when switch Q1 is turned on for the time T/2, output effective voltage (injected voltage) is equal to Vq (the demanded injection voltage) and when switch Q2 is turned on for the period of T/2, the output voltage reaches –Vq [11]. The effective voltage at the output can be shown with equation [11]

$$V_\circ = \left(\frac{2}{T_\circ} \int_\circ^{T_\circ/2} V_q^{\,2} dt \right)^{1/2} = V_q$$

The control circuit is designed so the switches Q1 and Q2 and switches Q3 and Q4 turn on together in one cycle and turn of in the next cycle. As we know in half-bridge invertors one of the capacitors is active in one cycle and in the next cycle the other capacitor is active. This method of operation leads us to this idea that in cycles which a capacitor is inactive it can be used by the other half-bridge inverter which at that cycle needs an active capacitor. By doing this two half-bridge invertors are combined together by sharing the same DC capacitor between them. So the controller circuit is designed so that the switching is done in a way that when a capacitor is inactive for a half-bridge inverter it can be activated for the other half bridge inverter.

So using this approach the problem of doubling the DC capacitors which was a disadvantage of using half-bridge invertors instead of full-bridge invertors is elevated and only two capacitors are used for the joint half-bridge invertors.

Each part of the combined-DSSC module shown in figure 4 is clamped to the transmission line with a small distance from each other and are connected through a cable.

The distance between combined-DSSC modules is several kilometers. The single turn transformer (STT) uses the transmission line as the secondary winding which injects the demanded voltage directly into the transmission line. Inverter can control the injected quadrature voltage using pulse width modulation (PWM). The module can be clamped to the transmission line where it does not see the line voltage and therefore it doesn't need high levels of insulation. Combined- DSSC module can be used easily for any level of transmission voltage.

The module combined-DSSC is self-excited from the power line itself. The unit normally sits in bypass mode untilthe inverter is activated. Once the inverter is turned on, the combined-DSSC module can inject a quadrature voltage or reactive impedance in series with the line. This allows the module to inject positive inductance, so as to increase line impedance and 'push' current into other parts of the network. Alternatively, it can inject a 'negative inductance', thus reducing line impedance so as to 'pull' current in from other parts of the network. The overall system control function is achieved by using a large number of modules coordinated through communications and smart controls. Half-bridge inverter uses two IGBTs and a lowpass filter in the output, and two capacitors in the DC bus.

IV. Simulation And Results

To show the result and functionality of the proposed method (combined-DSSC) for D-FACTS controller and comparing it to functionality of the conventional D-FACTS controller (separated-DSSC) a transmission line is simulated in PSCAD/EMTDC. For a change in impedance separated and combined-DSSC are simulated and are used for compensation of the simulated line.

The simulated transmission line has two busses where the bus voltage is 138KV(L-L) with the length of 50km. The impedance characteristics of the line is L=1.212 mH/km and R=0.074ohm/km and the difference of voltage phase between two busses is $\delta = 8.12^0$. The value of transmission active power before compensation P=116MW and the rated current before compensation I=487A.

In this transmission line we reduce the reactive impedance of the line by 30%. The compensation was performed first by the separate-DSSC and then by the combined-DSSC (the proposed method) and are then compared together.

In this simulation, first modules are in the bypass mode. After a certain amount of time they enter the line and then are removed from the line shortly. The result of the simulation is as follows.Figures 5 and 6 show the transmission active power before and after the compensation for both the separate and combined-DSSC modules.

In this compensation the reactive impedance of the line is reduced by 30% which results in an increase of the transmission reactive power. Both figure 5 and 6 show the same result for separate and combined-DSSC modules.

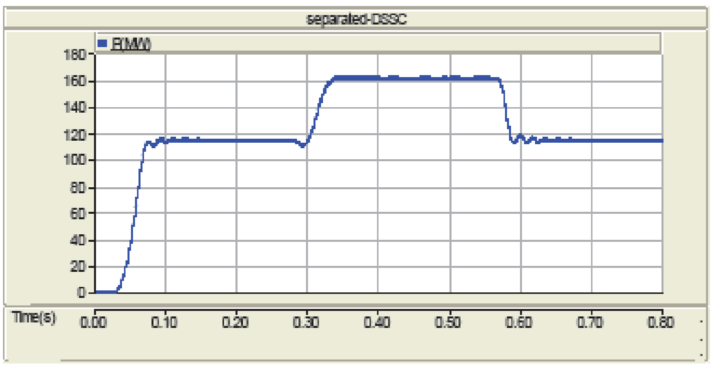

Fig. 5. transmission reactive power for separate-DSSC module combined-DSSC

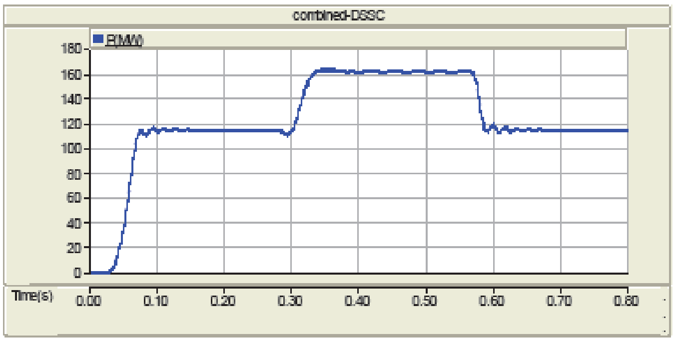

Fig. 6. transmission reactive power for combined-DSSC module

Figure 7 and 8 show the current of one phase and the injected voltage Vq to the transmission line, before and after the compensation. As it can be seen in the figures the voltage that has a 90o phase delay is injected to the line, and has resulted in an increase in the current of the line.

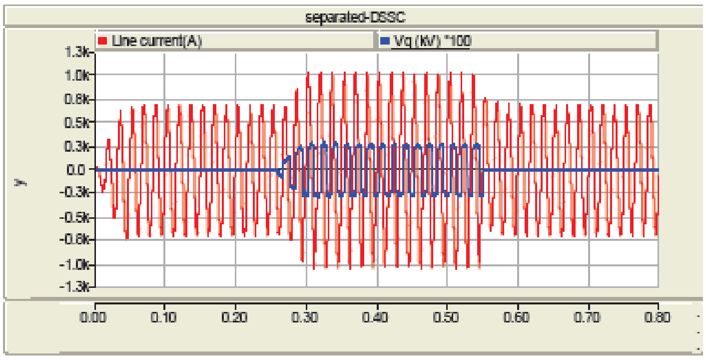

Fig. 7. The current in one phase and the injected voltage Vq by the separated-DSSC module

In this simulation filters are not used so all the harmonics are available, which are shown for both modules in figures 9 and 10. According to the figures the even harmonics are not present in both modules.

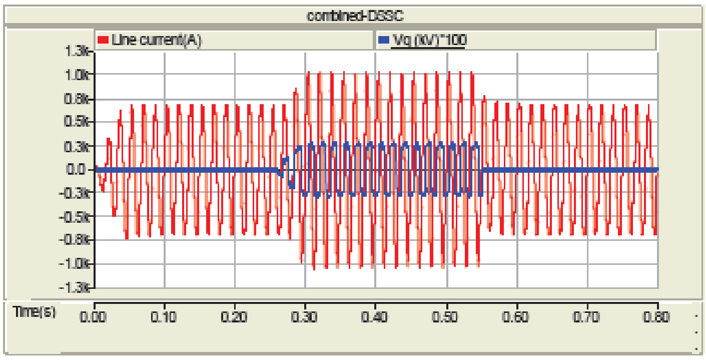

Fig. 8. The current in one phase and the injected voltage Vq by the combined-DSSC module

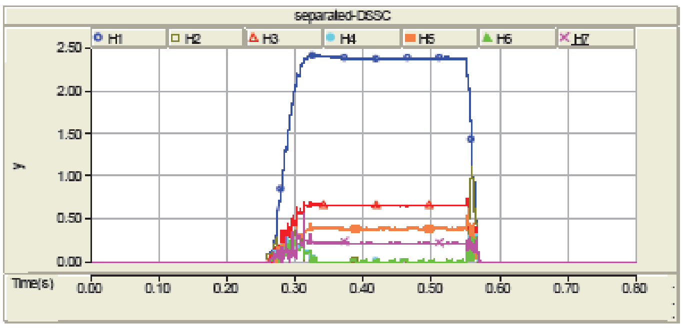

Fig. 9. harmonics of the injected voltage by separated-DSSC

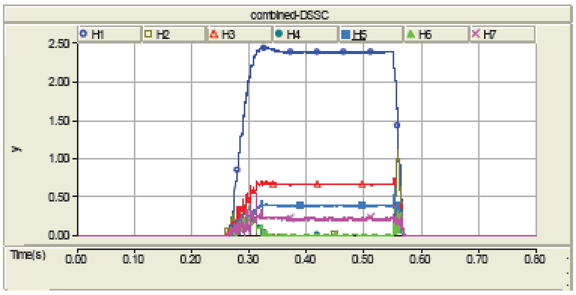

Fig. 10. harmonics of the injected voltage by combined-DSSC

V. Conclusions

This paper introduced a novel D-FACTS controller (combined-DSSC) on the basis of two half-bridge invertors. The modules (separate-DSSC and combined-DSSC) where simulated in PSCAD/EMTDC. According to the result of simulation and comparing both modules with equal output

power, the following are resulted The figures of transmission reactive power, injected voltage and also the produced harmonics show the exact same result of compensation for both separate and combined-DSSC module with the difference that the circuitry used in the proposed method is reduced to half when compared to the conventional modules.

This is done by reducing the number of switches to half in the proposed controller (combined-DSSC). In the separate- DSSC eight switches are needed where in the proposed controller only four switches are needed. For two separate-DSSC controllers, two control circuits, two power supplies and two built-in communications are needed for each module. Where in the combined-DSSC, for each controller with the same power output two separate modules, only one control circuit, power supply and built-in communication is required.

Finally with the configuration of the proposed method the number of elements and circuitry used are reduced which leads to cost-efficiency and increasing the reliability of these devices.

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