International Journal of communication and computer Technologies, ISSN: 2278-9723

Available at http://www.ijccts.org

CONTROL ANALYSIS OF STATCOM UNDER POWER SYSTEM FAULTS

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Received: 13-01-2016, **Revised:** 15-03-2016, **Accepted:** 30-04-2016, **Published online:** 01-06-2016

ABSTRACT

Voltage source convertors based static synchronous compensators are used in the transmission and distribution line for voltage regulation and reactive power compensation. Nowadays angle controlled STATCOM have been deployed in the utilities to improve the output voltage waveform quality with lower losses compared to that of PWM STATCOMS. Even though angle control STATCOM has lot of advantages, it suffers in their operation, when unbalanced and fault conditions occur in the transmission and distribution lines. This paper presents an approach of Dual Angle control strategy in STATCOM to overcome the drawbacks of the conventional angle control and PWM controlled STATCOMS. Here, this paper will not completely changes the design of conventional angle control STATCOM, instead it add only (αac) AC oscillations to the output of the conventional angle controller output (αdc) to make it as a dual angle controlled. Hence the STATCOM is called dual angle controlled (DAC) STATCOM.

Index terms*:* Dual angle control (DAC), hysteresis controller, STATCOM.

Introduction

There are lot of devices used in the power system for voltage regulation, reactive power compensation and power factor regulation [1]. The voltage source convertor (VSC) based STATCOM is one of the widely used device in the large transmission and distribution systems for voltage regulation and reactive power compensation. Nowadays angle controlled STATCOM have been deployed in the utilities to improve the output voltage waveform quality with lower losses compared to that of PWM STATCOMS. The first commercially implemented installation was ± 100 MVAr STATCOM at TVA Sullivan substation and followed by New York Power Authority installation at Marcy substation in New York state in [13] and [16].150-MVA STATCOM at Leardo and Brownsville substation at Texas,160-MVA STATCOM at Inez substation in Eastern Kentucky, 43-MVA PG&E Santa cruz STATCOM and 40-MVA KEPCO (Korea Electric Power Corporation) STATCOM at Kangjin substation in South Korea are the few examples of the commercially implemented and operating angle controlled STATCOM on worldwide.

Even though angle control STATCOM has lot of advantages compared to other STATCOMS, it suffers in their operation by over current and possible saturation of the interfacing transformers caused by negative sequence during unbalanced and fault conditions occur in the transmission and distribution lines in [4]. This paper presents an approach of Dual Angle control strategy in STATCOM to overcome the drawbacks of the conventional angle control and PWM controlled STATCOMS [2]. Here, this paper will not completely changes the design of conventional angle control STATCOM, instead it add only (αac) AC oscillations to the output of the conventional angle controller output (αdc) to make it as a dual angle controlled. Hence the STATCOM is called dual angle controlled (DAC) STATCOM. Angle control STATCOM same degree of freedom compared to that of PWM STATCOM, but it is widely used because it has higher waveform quality of voltage compared to that of PWM STATCOM.

This paper presents a new control structure for high power angle controlled STATCOM. Here the only control input to angle control STATCOM is phase difference between VSC and ac bus instantaneous

Voltage vector. In the proposed control structure, α is split into two parts, αdc and αac. The DC part αdc which is the final output of the conventional angle controller is incharge of controlling the positive sequence VSC output voltage. The oscillating part αac controls the dc link voltage oscillations. The proposed model STATCOM has the capablity to operate under fault conditions and able to clear the faults and unbalanced occurs in the transmission and distribution lines.

In this paper, we have implemented a new control structure in STATCOM ,which has the ability to clear such as sag and swell and other types of which will appears in the power systems. The analysis of the proposed control structured STATCOM is done on the MATLAB simulations and the experimental results are satisfied.

CONVENTIONAL STATCOMS UNDER NORMAL AND SYSTEM FAULT CONDITIONS

Voltage source vectors which are basic one for the building of the FACTS devices can be divided into two types based on their control methods [17]. The first one is the PWM or vector controlled STATCOM and another is the angle controlled STATCOM. In the PWM based STATCOM, by controlling the amplitude of firing pulses given to the voltage source convertors the final output voltage of the convertor can be increased or decreased. These type of inverters will be uneconomical, because the switching loss associated with the VSC are very high.

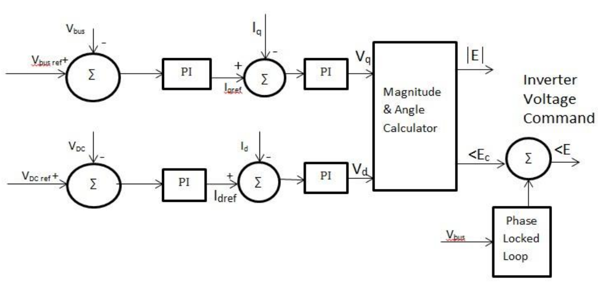


Fig.1. Control structure of vector controlled STATCOM

Then the second type is the angle controlled STATCOM .Here by changing the output voltage angle of the STATCOM for a particular time on compared to that offline voltage angle, the inverter can be able provide both inductive and capacitive reactive power.

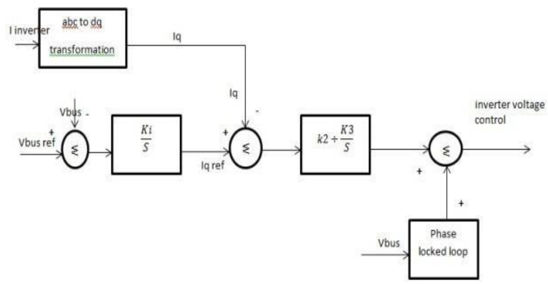


Fig.2. Control structure of angle controlled STATCOM

By controlling the α towards the positive and negative direction and varying the dc link voltage, We can able increase or decrease the final output voltage of voltage source convertors (VSC) in [2]. Here the ratio between the dc and ac voltage in STATCOM should be kept constant. If the final output voltage of the STATCOM is greater than the line voltage it will absorb reactive power from the line. But, if the output voltage of the STATCOM is lesser than the line voltage, then it will inject reactive power into the line. Throughout this paper the performance of the proposed control structure will be shown by MATLAB simulations.

ANGLE CONTROLLED STATCOM UNDER UNBALANCED CONDITIONS

VSC is the basic building block of the all conventional and angle controlled STATCOMs. Therefore, study about this method to improve the performance of VSC under unbalanced and fault conditions is important and practical. There are many methods are proposed in the literature about improving the performance of the voltage source convertors. But all cannot be applicable to the angle controlled STATCOM with only one control input angle (α).

There are only few methods proposed in the literature about the angle controlled STATCOM under ac fault conditions. The paper [8] calculates the amount of dc link capacitor that minimizes the negative sequence current flow on the STATCOM tie line. It tells that by choosing a particular value for the dc link capacitor, the tie line with the inductor will becomes an open circuit for the negative sequence current by positive sequence angle α control. In the another paper, hysteresis controller is used in addition to the conventional angle controller. In this controller, the VSC will detect and implement hysteresis switching to control their phase currents. Each VSC will have its own overcurrent limit and it should not be exceeded in normal and fault conditions.

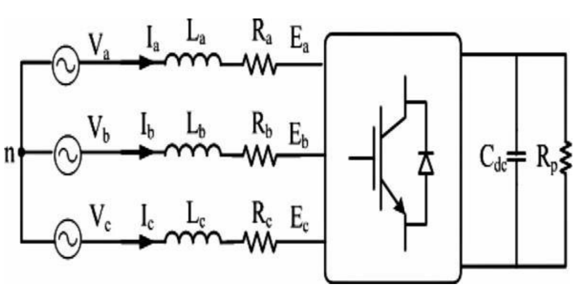


Fig.3. Equivalent circuit of an VSC connected to AC system

This system will protects the switch and limits STATCOM current under fault conditions. The dc-link voltage oscillations will be occurred in this method and it will cause the STATCOM to trip. The injection of poor quality voltage and current waveforms into faulted power system will produce undesirable stress on the power system components [7].

ANALYSIS OF STATCOM UNDER UNBALANCED OPERATING CONDITIONS

In this method a set of unbalanced three phase phasor is split into two symmetrical positive and negative sequences and zero sequence component. The line currents in the three phases of system is represented by the equations 1,2,3 and 4 mentioned below,

$$i_a = i_a^+ + i_a^- + i_a^0 \quad (1)$$

$$i_a = i^+ \sin(\omega t + \Theta_i) + i \sin(\omega t + \Theta_i) + i^0 \sin(\omega t + \Theta^0) \quad (2)$$

$$i_b = i^+ \sin(\omega t + \Theta_i^+ - 2\pi/3) + i^- \sin(\omega t + \Theta_i^- + 2\pi/3) + i^0 \sin(\omega t + \Theta_i) \quad (3)$$

$$i_c = i^+ \sin(\omega t + \Theta_i + 2\pi/3) + i \sin(\omega t + \Theta_i - 2\pi/3) + i^0 \sin(\omega t + \Theta^0) \quad (4)$$

In the angle controlled STATCOM the only control input angle α should be identically applied to all three phases of the invertor. Here the zero sequence components can be neglected because there is no path for the neutral current flow in the three phase line. The switching function for an angle control STATCOM should always be symmetric. The switching function for the three phases a,b and c are represented in the equation 5,6,7 mentioned below,

$$S_a = K \sin(\omega t + \alpha) \quad (5)$$

$$S_b = K \sin(\omega t + \alpha - 2\pi/3) \quad (6)$$

$$S_c = K \sin(\omega t + \alpha + 2\pi/3) \quad (7)$$

Where α is the angle by which the invertor voltage leads/lags the line voltage vector and K is the factor for the invertor which relates the dc side voltage to the phase to neutral voltage at the ac side terminals. The invertor terminal fundamental voltage is given in the equation 8,9,10 mentioned below,

$$V_a = KV_{DC} \sin(\omega t + \alpha) \quad (8)$$

$$V_b = KV_{DC} \sin(\omega t + \alpha - 2\pi/3) \quad (9)$$

$$V_C = KV_{DC} \sin(\omega t + \alpha + 2\pi/3) \quad (10)$$

Basically, the unbalanced system can be analysed by postulating a set of negative sequence voltage source connected in series with the STATCOM tie line. The main idea of the Dual Angle Control strategy is to generate a fundamental negative sequence voltage vector at VSC output terminals to attenuate the effect of negative sequence bus voltage. The generated negative sequence voltage will minimize the negative sequence current produced on STATCOM under fault conditions. The third harmonic voltage will be produced at VSC output terminals because of interaction between dc link voltage second harmonic oscillations and switching function. The third harmonic voltage is positive sequence and contains phase a, b and c which are 120^0 apart. Basically, the negative sequence current will be produced in the unbalanced ac system conditions generates the second harmonic oscillations on the dc link voltage and it will reflects as third harmonic voltage at the VSC output terminals and fundamental negative sequence voltage. Similar to fundamental negative sequence voltage, dc link voltage oscillations will decide the amplitude of second harmonic voltage in [3]. Here by controlling the second harmonic oscillations on the dc link voltage, the negative sequence current can be reduced. Decreased negative sequence current will reduce the dc link voltage. Reducing the dc link voltage second harmonic will reduce the third harmonic voltage and current at the STATCOM tie line in [12]. Here the control analysis of STATCOM under fault conditions are done in MATLAB

PROPOSED CONTROL STRUCTURE DEVELOPMENT

As discussed in the previous section ,the STATCOM voltage and current during unbalanced conditions are calculated by connecting a set of negative sequence voltage in series with STATCOM tie line are shown in Fig.

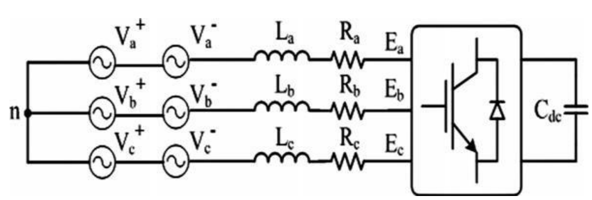


Fig.4. Equivalent circuit of STATCOM with series negative sequence voltage source

Assume second harmonic oscillation at dc link voltage as

$$V_{dch2}\cos(2\omega t+\alpha')$$

Then the reflected negative sequence voltage at phases a,b and c STATCOM terminal are calculated by the equation 11,12 and 13 mentioned below,

$$e_a^- = KV_{dch2}/2\ \sin(-\omega t+\alpha'-\alpha) \quad (11)$$

$$e_b^- = KV_{dch2}/2\ \sin(-\omega t+\alpha'-\alpha-2\pi/3) \quad (12)$$

$$e_c^- = KV_{dch2}/2\ \sin(\omega t+\alpha'-\alpha+2\pi/3) \quad (13)$$

The derivative of STATCOM tie line negative sequence currents with respect to time are calculated by the equation 14,15 and 16 mentioned below,

$$di_a^-/dt = -Ri_a/L +(e_a^- - V_a)/L \quad (14)$$

$$di_b^-/dt = -Ri_b/L +(e_b^- - V_b)/L \quad (15)$$

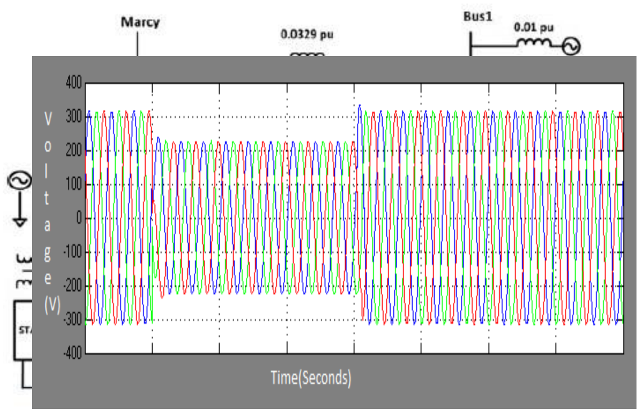
$$di_c^-/dt = -Ri_c/L +(e_c^- - V_c)/L \quad (16)$$

Transformation from abc to negative synchronous frame is defined as

$$F_{dq}^- = T(-\omega t) f_{abc} \quad (17)$$

In proposed structure, angle α is divide into two parts α_{dc} and α_{ac} .The angle α_{dc} is the output of the positive sequence controller and α_{ac} is the output of the negative sequence controller. The angle α_{ac} is the second harmonic oscillations which will generate negative sequence voltage vector at the VSC output terminals to attenuate the effect of the negative sequence bus voltage on fault conditions. The α_{ac} should be properly filtered out otherwise it will leads to higher order harmonics on the ac side.

Fig.5.Three bus AC system model



EXPERIMENTAL RESULTS

Fig.6.Voltage waveform of the grid (without STATCOM)

Here the voltage is suddenly decreasing in the particular time interval due to sudden change in the load value. When the load connected to the system does not remain constant, then the current and voltage of the line will not remain constant. During fault occurance, the current and voltage of the grid will not remain constant, so the STATCOM can be used to maintain the voltage .Because voltage is the important protection parameter, f has capacity to damage insulations of the transmission and protection device.

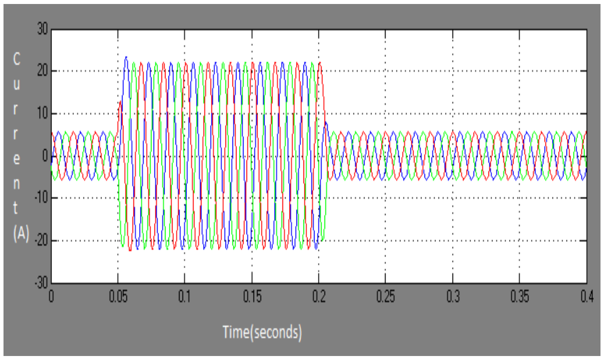


Fig.7.Current waveform of the grid (without STATCOM)

Here, the reduction in amplitude of voltage is observed because of the sudden change in the load value. This is due to the inverse proportionality nature of voltage and current value in normal power systems. This sudden increase of load is achieved by connecting a load to the grid by means of switch. By giving a time sequence to the switch for connecting it with the grid, we can able to connect and disconnect the load automatically for the particular time sequence.

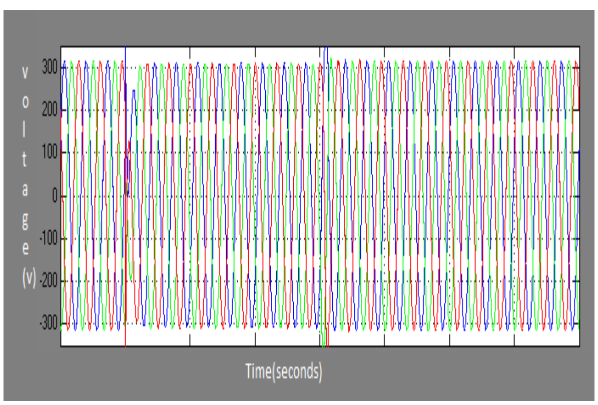


Fig.8. Voltage waveform of the grid (with STATCOM)

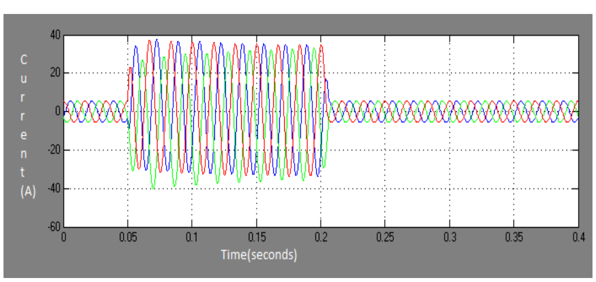


Fig.9. Current waveform of the grid (with STATCOM)

Here, the voltage is maintained on a constant value due to the reactive power compensation by the STATCOM.The reactive power compensation is done by STATCOM on supplying current in leading angle to the line voltage.Here the STATCOM is connected to the grid by means of switch.

CONCLUSION

This paper proposed a new control structure to improve the performance of the conventional angle controller STATCOM under unbalanced and fault conditions occurs on the transmission line.This method does not completely redesign the structure of the STATCOM instead it add only ac oscillations to the output of conventional angle controller.The α_{ac} oscillations will generate negative sequence voltage at the VSC output terminals to attenuate the effect of the negative sequence bus voltage generated at the line terminals during fault conditions.

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