FUZZY BASED MODELLING OF S-IPFC WITHOUT DC LINK FOR POWER FLOW CONTROL IN THREE PHASE TRANSMISSION LINE

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ABSTRACT

The Separated Interline Power Flow Controller presented is a new concept for a FACTS device. The S-IPFC is an adapted version of the IPFC, which eliminates the common dc link of the IPFC and enable the separate installation of the converters. Without location constrain, more power lines can be equipped with the S-IPFC, which gives more control capability of the power flow control. Instead of the common dc link, the exchange of active power between the converters is through the same ac transmission line at 3rd harmonic frequency. Every converter has its own dc capacitor to provide the dc voltage. This paper presents the basis theory of the S-IPFC, steady-state analysis, primary control loop and the corresponding simulation results. It is derived from the IPFC and possesses all the control capability of the IPFC. The master converter can adjust the voltage magnitude, transmission angle and line impedance. The slave converter provides the active power for master converter and at the same time adjusts its own line reactance. The S-IPFC eliminates the common dc link of the OPFC, which enables the long range installation of converters and gives more flexibility for the IPFC.

Keywords - *D-FACTS, Flexible ac Transmission Systems (FACTS), Fuzzy Logic Controller (FLC), Separated Interline Power Flow Controller(S-IPFC), UPFC*

1. INTRODUCTION

In recent years, greater demands have been placed on the transmission network and these demands continue to increase because of the increasing number of non utility generators and intensified competition among them. Power flow control becomes a big issue nowadays in power system network due to the aging of equipment, the increase of distributed generations, the power marketing etc. FACTS controllers have the potential to increase the capacity of existing transmission networks through functional versatility and control flexibility. FACTS controllers have the capability of direct control of transmission line flows by changing the main transmission parameters .This paper presents a concept that allows the IPFC exchange active power without common dc link and fuzzy logic controller[15] which calculates the 3rd harmonic voltage.

2. BASIC STRUCTURE AND FUNCTIONS OF IPFC

IPFC comprises a number of static synchronous series compensators. The compensating inverters are linked together at their dc terminals as illustrated in figure.1. With this scheme, in addition to providing series reactive compensation, any inverter can be controlled to supply real power to the common dc link from its own transmission line. Thus an overall surplus power can be made available from underutilized lines which then can be used by other lines for real power compensation[7]. An Interline Power Flow Controller consists of a set of converters that are connected in series with different transmission lines. In addition to these series converters, it may also include a shunt converter which is connected between a transmission line and the ground. The converters are connected through a common DC link to exchange active power. Each series converters can provide independent reactive compensation for their own transmission line. If shunt converter is involved in this system, the series converters can also provide independent active compensation.

3. ACTIVE POWER FLOW IN DPFC

This method for active power exchange in S-IPFC is based on the new concept of distributed power flow controller that combines conventional FACTS and D-FACTS devices. The active power is expressed by:

$$P = \sum_{n=1}^{\infty} Vsn\ Isn\ Cos\emptyset n \qquad (1)$$

Where $\cos\phi_n$ is the power factor in nth harmonic frequency. The distributed FACTS[9] idea presented can be applied to the series converter in the S-IPFC system. If one converter extracts active power from the fundamental frequency, the other converter absorbs harmonic power and converts it to fundamental frequency back. Thus common DC link is eliminated.

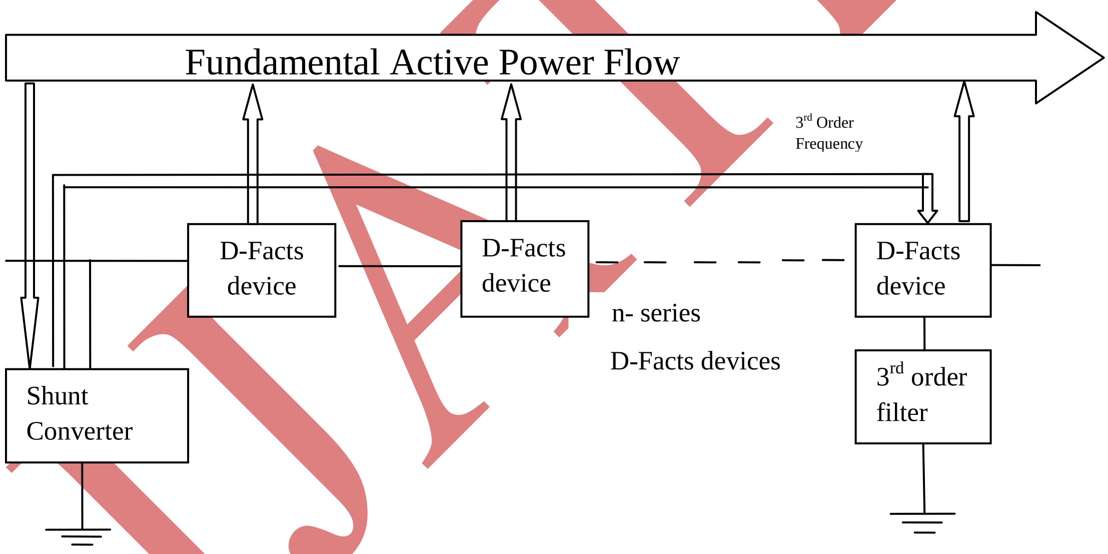

Fig.1.Active Power Flow in DPFC

4. ANALYSIS OF S-IPFC

Two three-phase converters are series connected to parallel transmission lines, each will be replaced by controlled voltage sources one at fundamental frequency other at 3^{rd} harmonic[4]. The schematic diagram of basic S-IPFC is shown in figure 2. The primary converter can inject 4-quadrant rotatable voltage, which can both active and reactive compensate the power flow of line 'a'. The converter 'b' control active power flow of line b by injecting controllable reactive voltage which means converter 'b' lose the capability of active power compensation for the transmission line b. S-IPFC provides the media to exchange active power given by the equation:

$$P_{a,ex} = \mathrm{Re}[S_{a,ex}] = \frac{|X_{a,1}||S_{a,r}||S_{a,ro}|}{|V_r|2} \sin(\emptyset_{a,ro}\emptyset_{a,r}) \quad (2)$$

The total power through line a at both frequencies is still less the maximum fundamental power flow, S-IPFC does not decrease the capability for frequency power flow[8]. The challenge of the S-IPFC is not from the transmission line, but from converter itself.

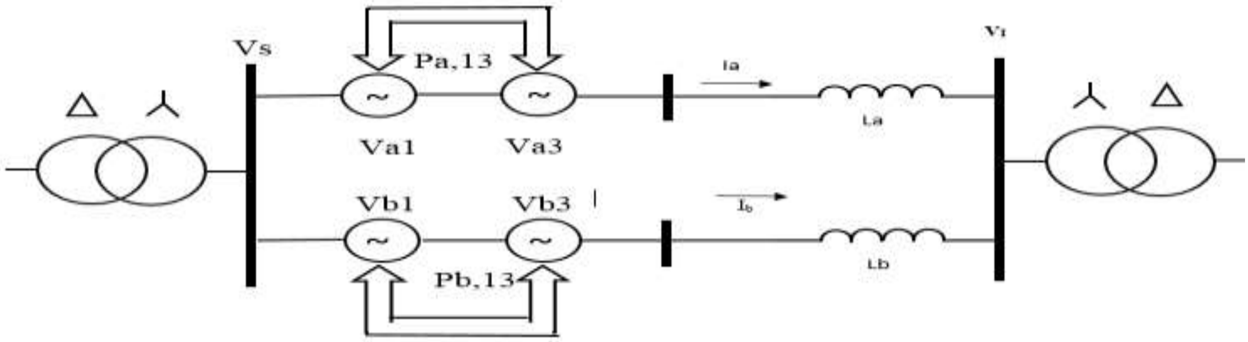

Fig.2.S-IPFC with two converters

4.1 IPFC CONSTRAINTS

The rating of IPFC can be specified by means of two quantities: maximum voltage magnitude that can be injected and the volt- ampere rating. The IPFC reaches its rated power only when the injected voltage magnitude and line current are equal to the rated values[7]. The line current depends on the power being transferred through the line. Therefore, whether the IPFC can inject rated power to the line depends on the original power flow in the line without injection. This will be obvious for analysis. In order to maintain common DC bus voltage, the total active power through the dc link must be zero. For a given voltage magnitude and phase angles at the two ends of the transmission line, the injected real power are function of the phase angle of the injected voltage.

4.2 METHOD FOR ACTIVE POWER EXCHANGE WITHOUT COMMON DC LINK

The method for active power exchange is based on the non-sinusoidal power theory[1]. According to Fourier analysis, a non-sinusoidal voltage and current can be expressed by the sum of sinusoidal functions in different frequencies with different amplitudes. Voltage and current in one frequency has no influence on other frequency component, fundamental active power can be exchanged through ac terminal instead of the common dc link between converters.

4.3 OPERATION OF S-IPFC

The exchange of active power is through ac terminal at harmonic frequency. S-IPFC converters should be installed in the power lines which have a physical ac connection to enable the harmonic current to flow through[1].The network with S-IPFC should satisfy two conditions, the network with S-IPFC is closed by Y-Δ transformers to block the 3rd harmonic and the transmission line equipped with the series converter should have physical connection to allow 3rd harmonic current to pass.

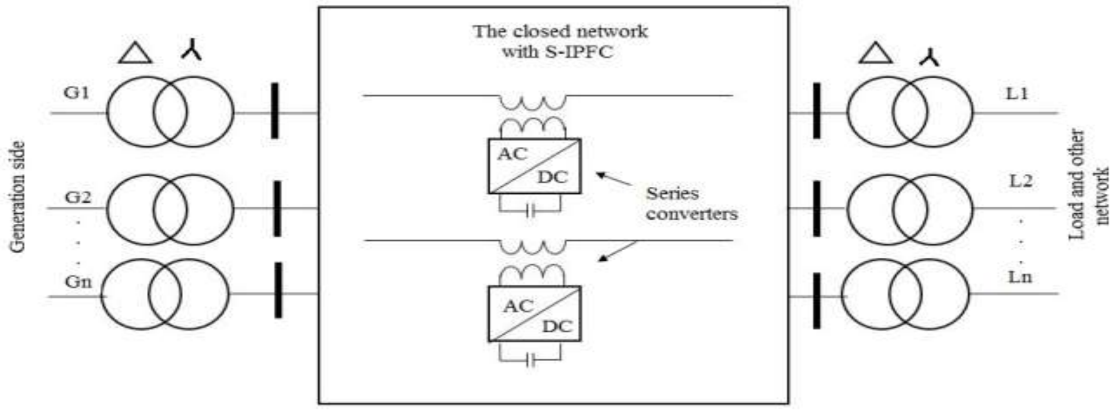

Fig.3.S-IPFC operation Network

Because the S-IPFC uses the 3rd harmonic to transmit active power , the topology of series converter should be specially designed such as 3-legs 4-wire topology, 4-legs 4-wire topology, where the fourth wire acts as a return conductor for the 3rd harmonic current[4]. The S-IPFC system with shunt converter will achieve more control capability because shunt converter can supply active power to series converter, without shunt converter the sum of active powers of all the series converters should be zero. In case of with shunt converter, every series converter can inject fully controlled voltage phasor therefore active and reactive power flow through transmission line can be independently controlled. The neutral point floating Y-Δ transformer is open circuited to 3rd harmonic current, if only one shunt converter is placed, there will be no path for 3rd harmonic current. Therefore, a 3rd pass filter is required to provide a close loop for the 3rd harmonic. In S-IPFC system, there may be more than one bus bar which requires the shunt converter to provide reactive compensation to maintain the voltage level at the fundamental frequency. In case of more than one shunt converter, the 3rd pass filter is not required because the shunt converters themselves construct a closed loop for 3rd harmonic current.

5. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy logic controller in S-IPFC calculates the d-axile of 3rd harmonic voltage[15] based on the dc voltage error. The inputs to the fuzzy controller are the dc voltage reference value and measured dc voltage. This controller use Min-Max operator and Centroid defuzzification method. The output obtained is the 3rd harmonic voltage. FLC are formed by simple rule based on “If x and then z”. Each rule defines one membership which is the function of FLC. The performance of the system is improved by correct combination of these rules. Main reason for choosing fuzzy logic controller in this study is the flexibility offered by it, in which control strategy is represented by a set of rules and it doesn't require the exact set of equations to represent the system. A simple fuzzy logic controller based on mamdani type is used in this section to damp power system oscillations in the study system[3]. The control strategy is represented by a set of rules and it doesn't require the exact set of equations to represent the system.

The inputs of the fuzzy system are assigned by using 5 membership functions and the fuzzy system to be formed in 49 rules, hence sensitivity in the control mechanism is increased. The basic if- then rule is defined as 'If(error is very small and error rate is very small) then output'. The signals error and error rate are described as linguistic variables in the FLC such as large(L), medium(M), High(H), very large(VL), Very High(VH). In the same way, the input values of the fuzzy controller are connected to the output values by if-then rules.

5.1. MATLAB/SIMULINK MODEL

Fuzzy based simulink model for S-IPFC is shown in Fig.4.(a) and Fig. 4.(b). The corresponding output is shown in Figure 4.(c).

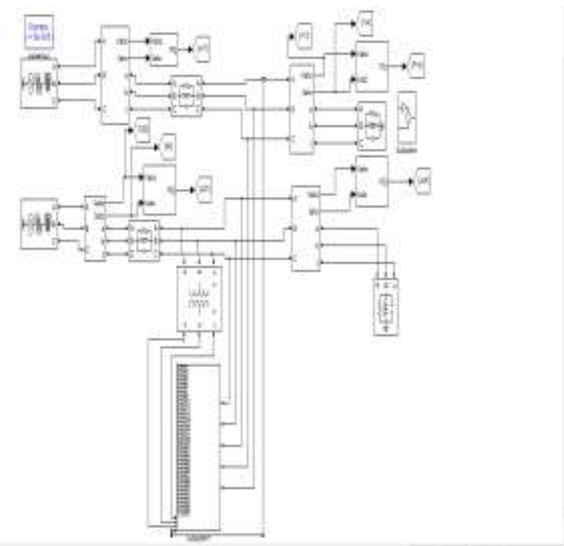

Fig.4 (a).Fuzzy based simulink model for S-IPFC

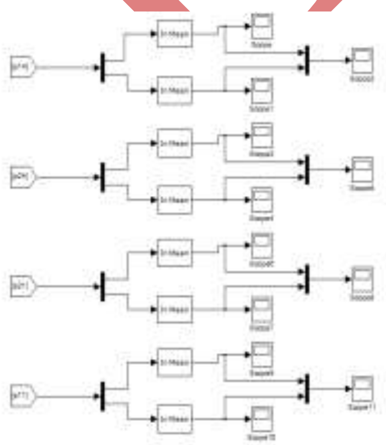

Fig.4 (b).Fuzzy simulation model for S-IPFC

From Simulink model, the two converters a and b of the S-IPFC provide series compensation for line a and b respectively. The system parameters of the simulation given as $|V_r| = |V_s| = 1.0p.u.$, with 30^0 transmission angle. The line reactance is 0.5 p.u., and the resistance is 0.01p.u. to absorb the energy stored in the inductor The master converter fully compensates line b and the slave converter injects 3^{rd} harmonic current to the system. To simplify the operation, a constant 3^{rd} harmonic frequency current $I_{b,3}$ = 0.5p.u. is injected to the grid, although it can be controlled by external controller in real system to optimize the 3^{rd} harmonic current injection. Under the steady-state case of S-IPFC system, both converters should have steady capacitor dc voltage, Vdc = 0.5p.u. as the reference value.

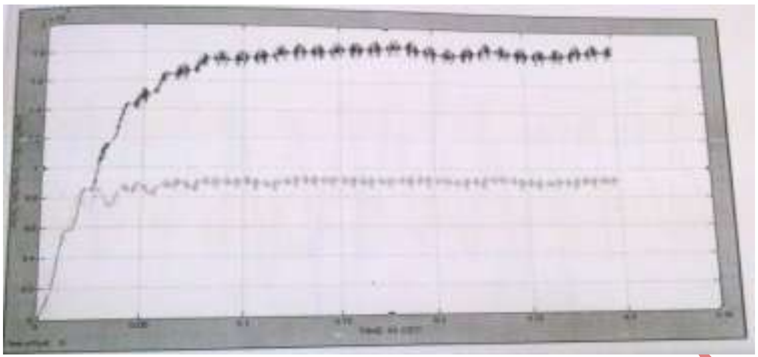

Fig.4.(c).S-IPFC Fuzzy/Control/Output-Real and Reactive Power

During the operation, converter injects a voltage vector at the fundamental frequency to compensate power flow, with open loop control. When V_{ad} is greater than 0, converter a absorbs active power from 3rd harmonic components, and works as a voltage source at the fundamental frequency, vice versa. $V_{aq,1}$ determine the working mode of the converter a. If $V_{aq,1}$ is larger than 0, converter a works at 'capacitive mode' otherwise at 'inductive mode'. $V_{ad,3}$ is closed looop controlled according to dc voltage $V_{a,dc}$. Converter b injects voltage vector with constant q components $V_{bq,1}$ = 0.2.p.u. $V_{bd,1}$ is generated PI controller which is for maintaining the dc voltage for converter b.

6. CONCLUSION

The new concept of S-IPFC is a new member of converter based FACTS devices and fuzzy logic controller used in the converter side provides wide range of variation. S-IPFC derived from the IPFC, possess all control capability of the IPFC. The S-IPFC eliminates the common dc link of the IPFC, which enables the long range installation of converters and gives more flexibility for the IPFC. The S-IPFC constructed with shunt converter will have as multiple UPFCs. All series converters are able to fully control its parameters. The shunt converter injects 3rd harmonic frequency current to the network and to provide active power for series converters. The S-IPFC is a solution for power flow control in a meshed power system. It has all advantages of converter based FACTS devices and can employ large number of converters without location constraint and significant extra cost. Hopefully, the S-IPFC will be placed in transmission network and provide a better power flow control in the future.

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