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A Fuzzy-PD Controller to Improve the Performance of HVDC System

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ABSTRACT

In this paper, a fuzzy self adjustment controller has been designed for using in control of a high voltage direct current (HVDC) system. Fuzzy logic method via fuzzy rules based on simple experimental logical proofs, selects the coefficient of PD controller. In order to investigate the performance and accuracy of the proposed control method, a Cigre system is considered and analyzed. The proposed fuzzy - PD controller is compared with conventional PD controller. To achieve this purpose, the operations of designed controllers are investigated for different conditions. Fuzzy controllers used to control of inverter and rectifier converters, improve significantly system responses and performances as well as DC power recovering, especially on hard faults. The HVDC control system with fuzzy controllers in soft faults and variations with small amplitude, are similar conventional control, but on hard faults and variation with large amplitude, the performances are improved in compare with conventional control.

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1. INTRODUCTION

Controlling capabilities of high voltage direct current (HVDC) links has been as an efficient superiority to choose DC system than AC system. Of course, it's sensible that this superiority is sustainable when nominated control system work correctly and resistant on various disorders and on various working conditions of system. Quick controlling capability of transitive power is occurred by fire angle controlling of inverters. These controllers are not only fast, but also have high reliability and therefore have a special role on protecting the system against line and inverter faults.

Basically, any HVDC system contains several control levels that power controlling in the allowable range of voltage and current is purpose of this set. To achieve this goal, fire angles of inverter switches should be controlled. Thus, the last layers of control or the other word, controllers that are effective on fire angles directly, include most deep controlling loops of systems that usually in the rectifier side are fix current control and in the included in the inverter side are fix cut-off angle control.

In addition to close loop control on generators to increase system stability, the inferior controller is designed that providing to prolong fault time intercepts power transmission via fire angles closing of the inverter switches.

Also, to achieve the certain purposes, other controls can be imposed through the controlling system of HVDC inverter. For example, additional or emergency controls that install on DC system connected to weak AC networks, to improve the dynamic behavior of the system. It is clear that with challenges that new links DC are faced at future, despite complicated design of such specific controls, we need them unavoidably.

Connecting of different systems together and thus increasing the tension and interaction between them prove the necessity and the need to provide mortal and synchronous torques and to ensure voltage stability limit in the system.

With the traditional structure of proportional integral controller (PI controller), which are used on current control system and the cut-off angle of HVDC inverters system, we should be pointed out that despite the development of various types of modern control theories, such as optimal controller, PI and PID controller due to the relatively simple structure and easy implement in practice than other controllers, are used widely on industry and are invigorated there. Therefore, until their lack of efficiency has not been proven, they were used on scientific usage.

In order to wide usage of PI and PID controller, many methods were presented to determine the controller parameters [1],[2]. The first systematic method for determining the parameters of control PI and PID controller was presented by Ziegler and Nichols at early 40^{th} decade. All these methods was designed only based on linear model of system for specific work point that can response wrong answer in other parts of the system, not the right answer.

In recent years, intelligent methods such as fuzzy systems [3],[4], neural networks [5] and genetic algorithm [6] have been used on power systems for providing high quality and reliable power with low cost. Among intelligent methods, fuzzy systems due to the special features of their specific properties, is used to proper controller operation, design and control as well as energy management parts. [7] has been presented comprehensive research from capabilities and usages fuzzy systems on power systems.

Usage of controls based on fuzzy logic on structure of HVDC system controllers, has had more development. In [8], a controller has been designed and tested to adjust the parameters of the current PI controller and in a similar way to cut-off angle PI controller, based on fuzzy logic.All PI controls on HVDC systems which are presented with fuzzy regulator type so far, have been designed based on the specified number of fuzzy rules and membership functions with fixed parameters. Since a large system and completely different working conditions cannot expect an optimal answer of a controller with fixed parameters, it is necessary to adjust parameters regarding to operational status in order to reduce the control.

2. SYSTEM DESCRIPTION

Studied systems in this paper are shown in Figures. 1-2. These systems include an AC / DC and a DC / AC converter with a DC transmission line length equals 300 km. In this system for various controllers with considering of the following faults analysis and simulations are performed:

A: Three-phase fault on load side (Figure 1)

B: Fault on the DC transmission line (Figure 2)

The conditions of each converter at the fault time and before fault time are investigated and analyzed. The operation of system with PD and PD - Fuzzy controller for different line length are investigated and their results are compared with each other.

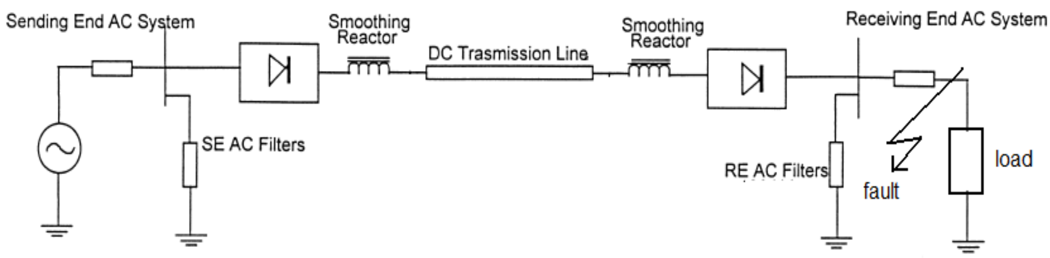


Figure 1. Single diagram of HVDC system with three- phase fault on load

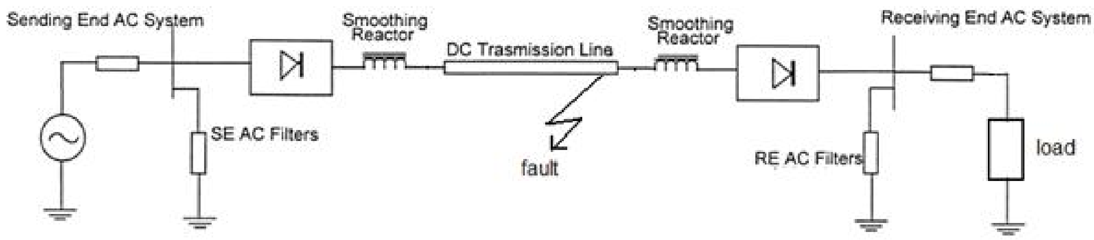


Figure 2. Single diagram of HVDC system with three-phas e fault on the DC line

2.1. PERFORMANCE OF HVDC CONVERTERS

In order to better regulation, DC link current is used to control of rectifier and to achieve desirable AC output voltage stability.

One of important terms satisfaction operation of HVDC system is fast controlling of converters in order to preventing of drastic changes at DC current. DC voltage relations at rectifying and inverting modes are as following:

For rectifier:

$$V_{dr} = V_{dor}.\mathrm{Cos}(\alpha_i) - R_{cr}I_{dr} \qquad (1)$$

$$V_{dor} = \frac{3\sqrt{3}}{\pi} E_{mr} \qquad (2)$$

And for inverter:

$$V_{di} = V_{doi}.\mathrm{Cos}(\gamma_i) - R_{ci}I_{di} \qquad (3)$$

$$V_{doi} = \frac{3\sqrt{3}}{\pi} E_{mi} \qquad (4)$$

Consider HVDC line according to Figure 3 that displays a line of communication monopole or a pole of a bipolar line. This figure shows corresponding equivalent circuit diagram and voltage vector, respectively. Direct current at DC link is determined as following:

$$I_d = \frac{V_{dor}.COS\alpha_r - V_{doi}.COS\gamma_i}{R_{cr} + R_L - R_{ci}} \qquad (5)$$

Power on rectifier terminals is:

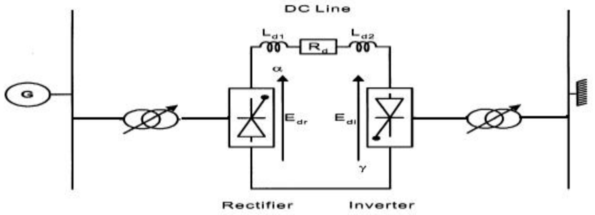
$$P_{dr} = V_{dr}I_d \qquad (6)$$

And power on inverter terminals is as following:

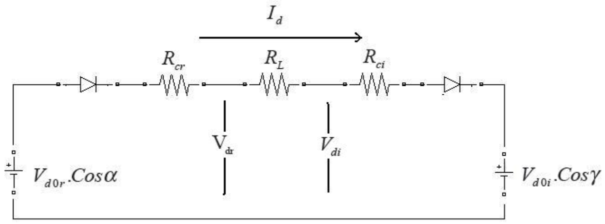
$$P_{dr} - R_L I_d^2 = P_{di} \qquad (7)$$

$$P_{di} = V_{di}I_d \qquad (8)$$

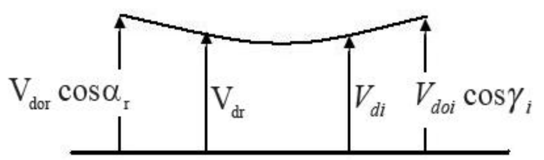
Line and inverter resistances are small, thus, as (5) is shown that small changes in V_{doi} or V_{dor} will cause major changes on I_d. Therefore if γ and α keep fixed ‹DC current can change a wide range against small changes on amplitude of AC voltage on each side. For satisfactory operation of power system, such changes generally are not acceptable.In addition, output current may be such large that redound to damage switches and other equipment. Thus, rapid inverter controlling of converter is essential for proper performance of system to prevent of oscillating direct current. Without such control, HVDC system is impractical.



(a)



(b)



(c)

Figure 3. (a) One line diagram, (b) equivalent circuit diagram and (c) voltage profile on a monopole HVDC system

2.2. HVDC CONTROL SYSTEM

Figure 4 shows constant current control system block diagram with fuzzy controller. In this control system by applying DC current fault and its rate of change to a fuzzy system, proportional and integral ratios of PD controller are tuned according to system conditions.

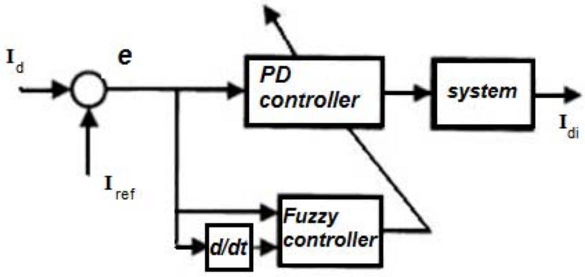


Figure 4. Rectifier control system (PD & FUZZY)

Proportional and integral ratios are determined by fuzzy system based on a set of rules (as given in table 1) that five fuzzy subsets are considered for fault and fault derivative. For example, the basic logic of PD controller coefficients change in the moments that fault derivative changing is high.

2.3. INVERTER CONTROL SYSTEM

Inverter control system is shows in Figure 5. In this figure, control system consist of inverter, DC transmission line and inverter side AC system. Since variables affected control system, inverter DC voltage control system points of view are mentioned in a single-input single-output system. Input is DC voltage and output is inverter cut-off angle (γ).

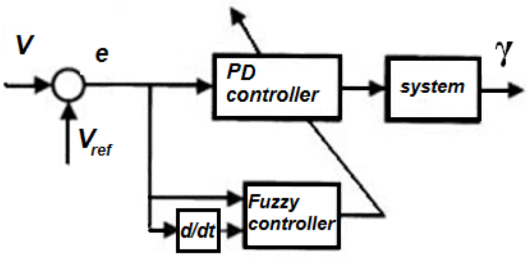


Figure 5. Inverter control system (PD & FUZZY)

3. HVDC SYSTEM SIMULATION

In order to investigate the performance and accuracy of the proposed control method, a Cigre system is considered and analyzed. Simulations are performed in MATLAB/SIMULINK environment. The simulated system consists of two converters. The DC transmission line length is 300km. Purpose of this simulation is to analyze PD -FUZZY control system to control converters used in HVDC system and to compare results with PD controller results.

SIMULINK model of the studied system (Figure 5) is shown in Figure 6. This model includes an inverter, a rectifier, a transmission line, a three phase AC voltage source, and loads.

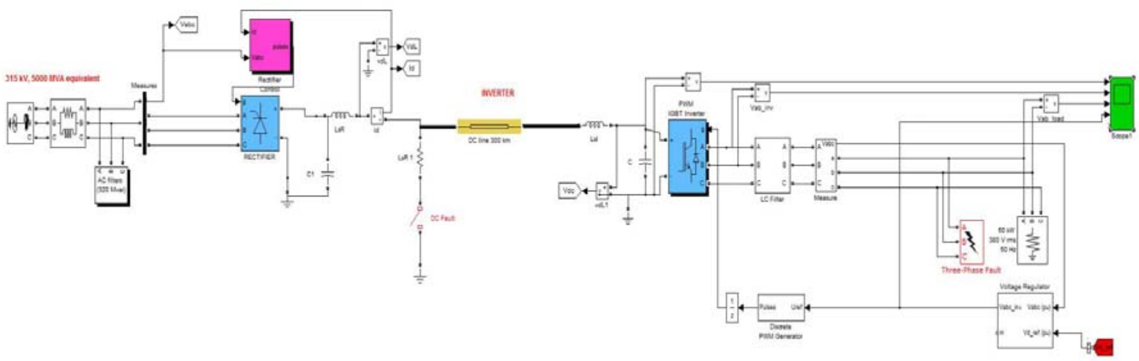


Figure 6. Simulated system model

3.1. RECTIFIER CONTROL WITH PD CONTROLLER

SIMULINK model of PD controller for control of rectifier is shown in Figure 7. DC link current is compared with reference current and proportional and derivative parts of controller are determined and the output of inverter is controlled. Comparisons of measured and reference DC link current determine the fire angle of rectifier (α) and its value changes with the output current and the voltage is maintained constant with current sampling.

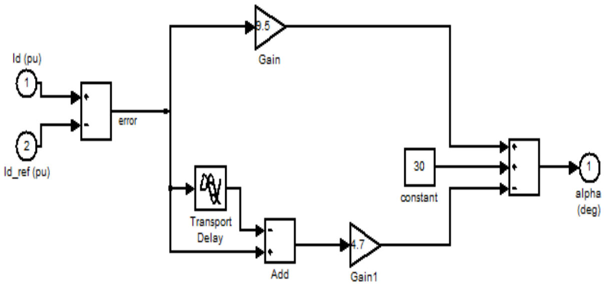


Figure 7. PD rectifier controller

3.2. RECTIFIER CONTROL WITH PD-FUZZY CONTROLLER

PD-Fuzzy rectifier controller is shown in Figure 8. Fuzzy rules of rectifier are shown in Table 1. In this table verbal variables (as NB for Negative Big, NS for Negative Small, ZO for Zero, PS for Positive Small and PB for Positive Big) are used. Figure 9 shows the membership functions of rectifier controller. The fuzzy controller has two inputs (error and change of error) and two outputs (proportional and derivative coefficients of PD controller). Five fuzzy subsets are considered for each input, where three fuzzy subsets are considered for each output.

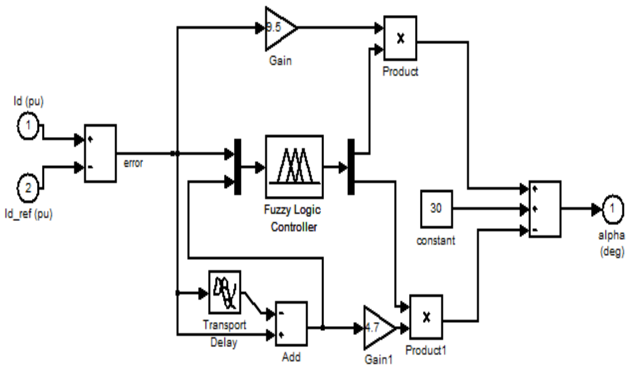


Figure 8. PD-Fuzzy rectifier controller

TABLE 1:Fuzzy Rules for Rectifier Controller

		Error				
		NB	**NS**	**ZO**	**PS**	**PN**
Error derivative	**NB**	L,L	L,L	L,L	H,H	H,L
	NS	L,L	M,L	L,M	M,H	M,M
	ZO	L,L	M,M	M,M	M,M	M,L
	PS	L,L	L,M	H,M	M,L	M,M
	PN	L,L	L,M	M,L	L,L	L,H

The following equations are used for computing of the error (E) and change of error (CE):

$$E(k) = I_d(k) - I_{dref}(k) \quad (9)$$

$$CE(k) = E(k) - E(k-1) \quad (10)$$

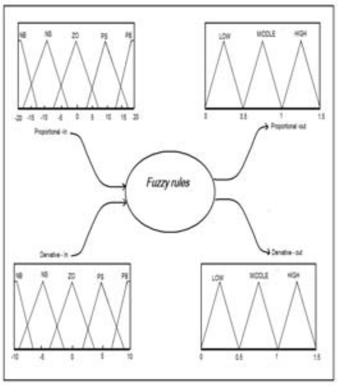


Figure 9. Membership functions for fault and derivative fault

3.1. INVERTER CONTROL WITH PD CONTROLLER

Two parameters of inverter are controlled. These parameters are frequency and cut-off Angle. To have constant voltage on load, according to DC voltage, the cut-off time is determined to fix the load voltage (Figure 10). Peak voltage of the inverter is constant but load voltage is dependent to cut-off time. This cut-off time can be controlled with PD controller.

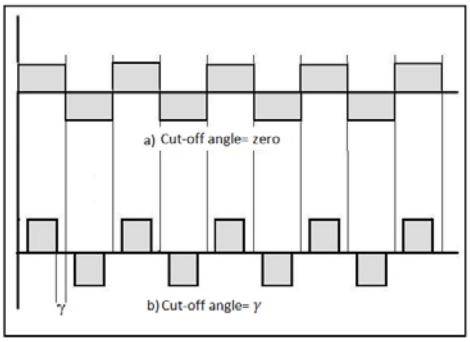


Figure 10. Cut-off angle for a phase

3.2. Inverter Control with PD -Fuzzy Controller

In order to achieve better characteristics the fuzzy controller is used. This controller includes the fuzzy processor to determine PD coefficients. The fuzzy rules of this controller are as following:

If DC voltage is low, then the cut-off angle becomes low.
If the DC voltage is average, then the cut-off angle becomes average.
If DC voltage is high, then the cut-off angle becomes high.

4. RESULTS AND DISCUSSIONS

The simulation results are shown in Figures.11 to 17. In order to control of inverter and rectifier, different controllers are investigated, the comparisons are performed for different conditions (as shown in Table 2)Results are shown in Figures. 11-14.

According to three phase fault on the load at the time of t=1sec, and different types of controller are shown in Figures. 11-14. These results show that in cases witch both converters use fuzzy-PD controller, the answer is more agreeable.

TABLE 2:Comparison of Different Controller

Comparison	Case I		Case II	
Figure number	Rectifier	Inverter	Rectifier	Inverter
Fig. 11	PD	PD	Fuzzy-PD	PD
Fig.12	Fuzy-PD	PD	Fuzzy-PD	Fuzzy-PD
Fig.13	PD	Fuzzy-PD	Fuzzy-PD	PD
Fig.14	PD	PD	Fuzzy-PD	Fuzzy-PD

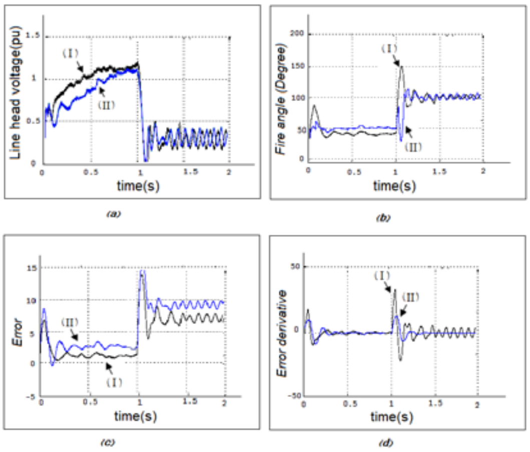


Figure 11. Comparison of performances of PD and Fuzzy-PD controllers; a: line head voltage; b: fire angle; c: error; d: error derivative; (I: PD controller on both converters; II: Fuzzy-PD controller on rectifier and PD controller on inverter)

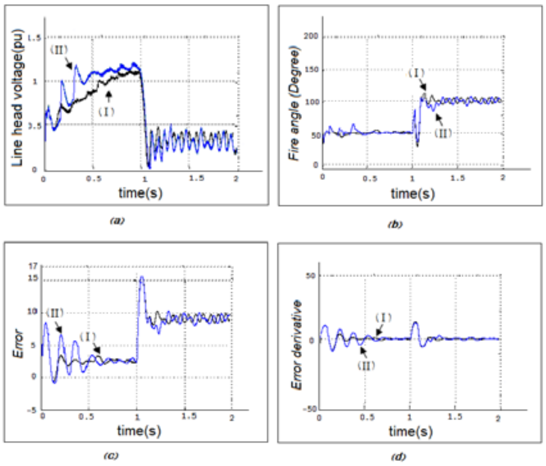


Figure 12. Comparison of performances of PD and Fuzzy-PD controllers; a: line head voltage; b: fire angle; c: error; d: error derivative; (I: Fuzzy-PD controller on rectifier and PD controller on inverter; II: Fuzzy-PD controller on both converters)

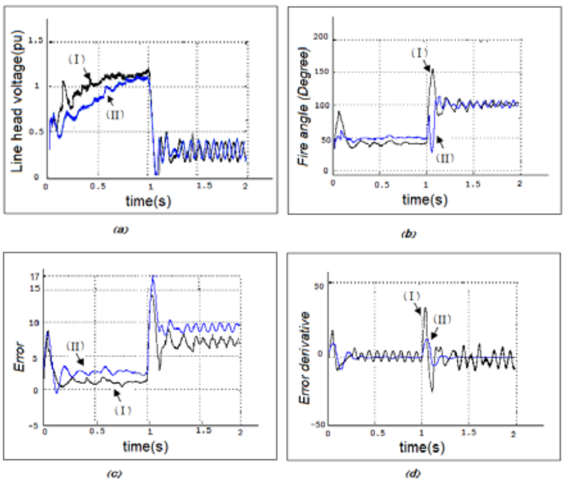


Figure 13. Comparison of performances of PD and Fuzzy-PD controllers; a: line head voltage; b: fire angle; c: error; d: error derivative; (I: PD controller on rectifier and Fuzzy-PD controller on inverter; II: Fuzzy-PD controller on rectifier and PD controller on inverter)

Figure 15 show the simulation results for two different following faults include:

Case I - Three phase fault on load.

Case II - DC fault on transmission line.

In these conditions Fuzzy- PD controller is used to rectifier and inverter in HVDC system. According to the Figure 15, first case is better than the second case. Because the length of the current pass at the time of fault occurred, is less.

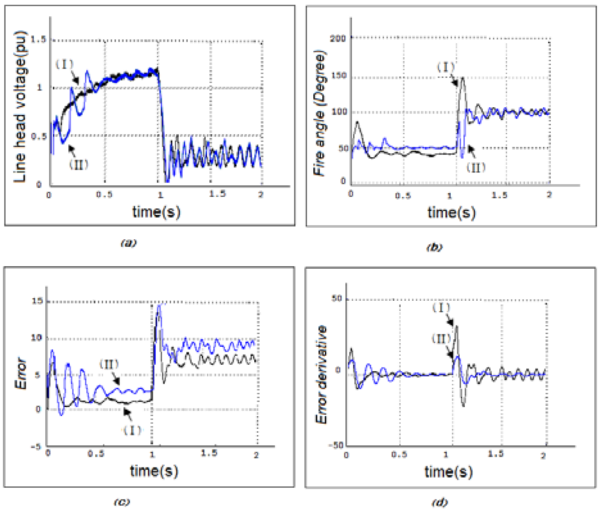


Figure 14. Comparison of performances of PD and Fuzzy-PD controllers; a: line head voltage; b: fire angle; c: error; d: error derivative; (I: PD controller on both converters; II: Fuzzy-PD controller on both converters)

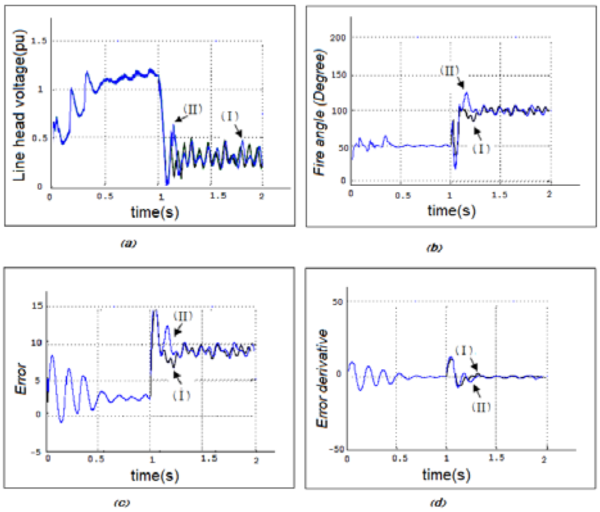


Figure 15. Performance comparison of Fuzzy-PD controller to both converters; a: line head voltage; b: fire angle; c: error; d: error derivative; (I: three phase fault on load; II: DC fault on transmission line)

Figure 16 show the simulation results for three phase fault on load in two following conditions:

Case I - controller works continually

Case II - line power is disconnected when fault isn't removing.

In these two conditions Fuzzy- PD controller is used to rectifier and inverter in HVDC system. According to the Figure 16, second case is better than the first case.

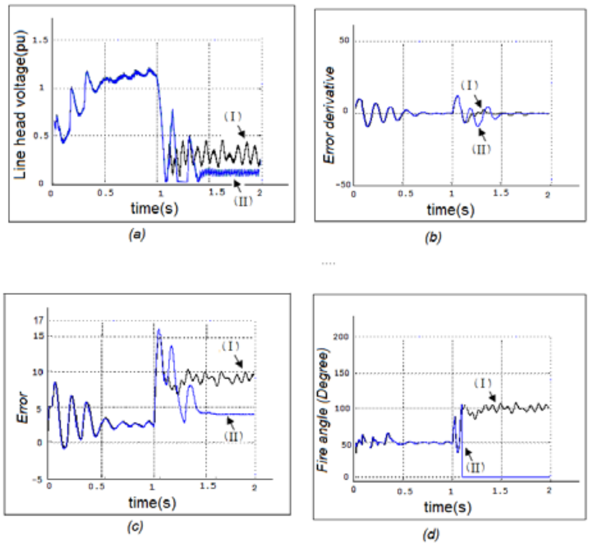


Figure 16. Performance comparison of Fuzzy-PD controller on both converters with three phase fault on load; a: line head voltage; b: error derivative; c: error; d: fire angle; (I: controller working continually; II: line power is disconnected when fault isn't removed)

Figure 17 show the simulation results for two different line lengths (300Km and 600Km); In this analysis, a three phase fault on load is appeared at t=1sec, and Fuzzy- PD controller is used for inverter and rectifier. According to the Figure 17, first case (line length is equal to 300 Km) is better than the second case. Because the transmission line is longer and therefore its resistance is greater, the fault current is less.

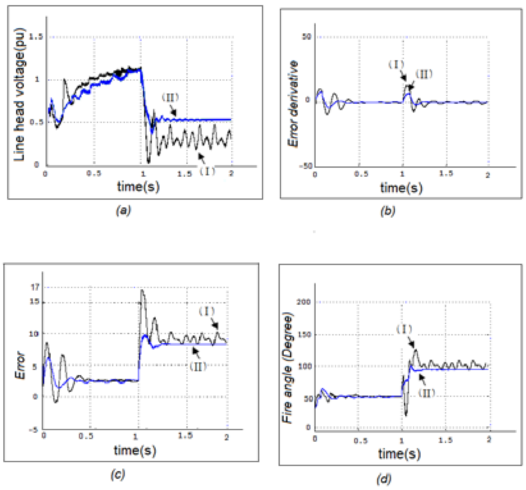


Figure 17. Performance comparison of Fuzzy-PD controller on both converters with three phase fault on load; a: line head voltage; b: error derivative; c: error; d: fire angle; (I: DC line length = 300 km; II: DC line length= 600 km)

5. CONCLUSION

In order to control of inverter and rectifier, different controllers are investigated, the comparisons are performed for different conditions and cases. In order to investigate the performance and accuracy of the proposed control method, a Cigre system is considered and analyzed. Simulations are performed in MATLAB/SIMULINK environment. According to results, the main conclusions of this paper are as following:

- Fuzzy controllers used to control of inverter and rectifier converters, improve significantly system responses and performances as well as DC power recovering, especially on hard faults (such as three-phase to ground short circuit).

- The HVDC control system with fuzzy controllers in soft faults and variations with small amplitude, are similar conventional control, but on hard faults and variation with large amplitude, the performances are improved in compare with conventional control.
- The fluctuations of fire angle and line head voltage improve extremely with increasing of the DC transmission line length due to resistance system growing.

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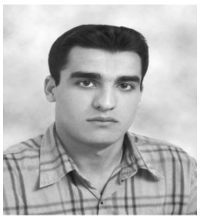

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