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VSCHVDC Control based on Fuzzy Logic

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Abstract

In this particular paper, fuzzy logic control of VSCHVDC system is tried out. The VSCHVDC system is an existing demonstration of a highly nonlinear along with fast acting process. For nonlinear system, fuzzy logic control comes with a better alternative to popular the classical proportional plus integral (PI) controller. Both the controllers namely the PI controller and fuzzy logic controller (FLC) are designed for a simulated. It is shown how the FLC has the capacity to control the voltage and current under single line to ground fault in a very better way. The simulation is carried out in the MatLab environment using Simulink and fuzzy logic Toolbox.

Keywords: Set Defuzzification, Fuzzy control, HVDC system.

Introduction

Fuzzy logic has emerged being a profitable tool for any managing of complex professional processes as well as domestic and entertainment technology, analysis system along with other skilled systems. It is just a superset of conventional (Boolean) logic which has been extended to deal with the idea of partial truth (Truth values between “Completely true” and “completely false”). Fuzzy logic was introduced by Dr. Lofti Zadeh of UC/ Berkeley in 1960’s as being a mean to model the uncertainness of natural language, but only recently it's actually use has spread over the large range of engineering applications. Fuzzy logic techniques make an attempt to simulate human thought processes, in technical environments.

A fuzzy logic controller (FLCs) provides for a simpler humanlike procedure for control system design and never requires the mathematical model as with the situation associated with conventional control design methods. For nonlinear system, controlling with conventional controllers like PI is actually difficult. FLC provide reasonable and effective choices to classical controllers. Simply by using a linguistic strategy, fuzzy set theory could be utilized in control theory using rule of the form, IF {condition} THEN {action}. Using an adequate amount of these rules it's possible to build a functional controller. In the same manner, the input variables could be partitioned into overlapping sets which have a linguistic correlation (i. e. large, small, and very small) to create a membership function. Generally these fuzzy sets are triangular in shape. The membership values control the degree to which each rule ”fires” illustrating the interdependent relationship between rule set and membership functions[3].In this particular paper a fuzzy logic controller (FLC) is designed and implemented for the highly nonlinear VSC HVDC system having a pair of inputs and a couple of outputs. The performance of the FLC is weighed against the conventional proportional plus integral (PI) controller.

This paper is organized as follow. In Section 2, VSCHVDC system with conventional integral(PI) controller is describe, in Section 3 fuzzy controller are described, Section 4 implementation of ELC to VSCHVDC System, Section 5 represents the simulation results, Conclusions are made in Section 6.

VSCHVDC System

When utilized for connecting active network, a VSC could be considered to be a double - input and double - output nonlinear control object. The two input are the phase angle and modulation index. The two output are the reactive power and the DC voltage or DC current. The active power Pc has direct relation to the DC voltage or DC current, therefore it is taken into consideration when controlling DC voltage or DC current. Taking into consideration the influence power Qs absorbed by VSC on the AC system, it's important to manage the reactive power Qs absorbed by VSC through the AC system. Thus, we choose Pc and Qs as being the output of VSC, along with the explicit relationship between the double- input and double - output could be derived by simplified physical model of VSC . It is shown in fig 1. Us is fundamental component of the AC bus voltage, Uc is the fundamental component of the VSC’s AC bus voltage, which lags behind Us an angle of d , R is the equivalent loss resistance through which the loss of the VSC is represented, Ps and Qs are classified as the active and reactive power of the AC system output power respectively, Pc and Qc are classified as the active and reactive power absorbed through the VSC respectively.

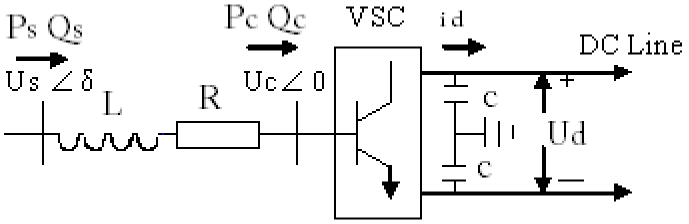

Figure 1: Simplified physical model of VSC System.

From fig 2 we van have

$$P_c = U_s U_c Y \sin(\delta + \alpha) - U_c^2 Y \sin\alpha \qquad (1)$$

$$Q_c = U_s U_c Y \cos(\delta + \alpha) - U_c^2 Y \cos\alpha \qquad (2)$$

$$P_s = U_s U_c Y \sin(\delta - \alpha) + U_s^2 Y \sin\alpha \qquad (3)$$

$$Q_c = -U_s U_c Y \cos(\delta - \alpha) + U_s^2 Y \cos\alpha \qquad (4)$$

Where Us and Uc are the r m s of line to line voltage, Ps, Pc, Qs and Qc are three phase active and reactive power

In VSC active and reactive power can be controlled simultaneously by Uc and δ.

$$U_c = \frac{M}{\sqrt{2}} U_d \qquad (5)$$

From (5) we know Uc is proportional to the modulation index and δ depends on the phase angle of the fundamental component of SPWM. So it is possible to control active and reactive power independently by M and δ, to VSC's apparent power capacity.

To evaluate the performance of VSC HVDC system a Conventional PI controller is design based on (1) to (5) as in fig 2

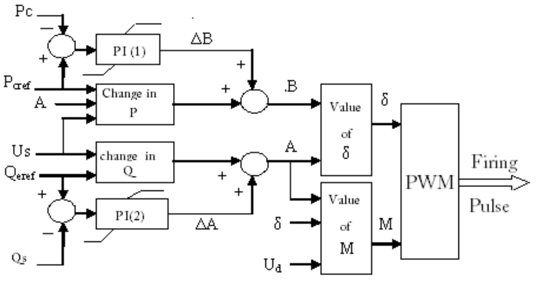

Figure 2: Conventional PI controller of VSC.

Fuzzy Controller

Fuzzification

Fuzzification can be viewed as being a mapping from an observed input space to fuzzy sets. The Fuzzification interface performs the subsequent functions:

1. Calculate the values of input variables at each and every sampling instant.
2. Normalizes the measured variables to inside the universe of discourse (UOD). UOD could be the array of values associated with an input variable to the FLC.
3. Performs the function of Fuzzification that transposes the input data into appropriate linguistic variables.

Knowledge Base

The knowledge base associated with an FLC has two components namely a database plus a rule base.

1. The database offers necessary meanings which are utilized to define linguistic variables and fuzzy data manipulation within the FLC.
2. The rule base characterized the control objective and control policy through a group of linguistic control rules.

Decision Making Logic

It determines the degree to which each measured value is really a member of a certain labeled group. A certain measurement may be classified simultaneously as belonging to a number of linguistic rules. The degree of fulfillment (DOF) of each and every rule is dependent upon applying the rule of Boolean algebra (Union and Intersection) to each and every linguistic group which is portion of the rule. This is accomplished for the entire rule inside the system. Finally, the net control action is determined by weighting the action associated with rule by the DOF.

Defuzzification

The Defuzzification changes the output fuzzy set in to a crisp solution variable. The best popular technique of Defuzzification is the "Center of Area" method that generates the center of gravity of the final fuzzy control space. It produces an outcome which is sensitive to all of the rules. It is shown in fig 3.

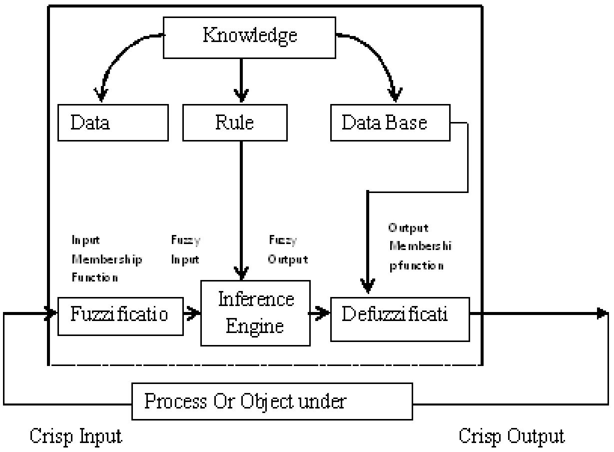

Figure 3: Basic Fuzzy Logic Controller.

Execution of ELC to VSCHVDC System

Fuzzification

Selection of FLC Parameters:

The input variables employed for the FLC are

a. Change in active power flow through the DC line

b. Change the rate of change of active power flow through the DC line.
c. Change in reactive power flow through the DC line
d. Change the rate of change of reactive power flow through the DC line.

The output variables are M (Modulation Index) and Φ (Phase Angle). The FLC output is given by

$$u(t) = U(t-1) + \Delta U(t) \tag{6}$$

Determination of the Universe of Discourse (UOD)

a. The UOD for active power change is -1 pu to 1 pu
b. The UOD for rate of active power change -0.5 to 0.5.
c. The UOD for reactive power change is -1 pu to 1pu.
d. The UOD for rate of reactive power change is –0.5 to 0.5.

Selection of Linguistic Variables

The fuzzy input and output variables, are divided into seven linguistic (fuzzy) variables namely NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), PL (Positive Large).

Knowledge Base

Data Base

The membership functions for the input and output variables i. e. change in active power, change in reactive power, rate of change in active power, rate of change in reactive power, change in Modulation index, change in the phase shift, as some of these are given in fig 4 (a) and in fig 4(b).

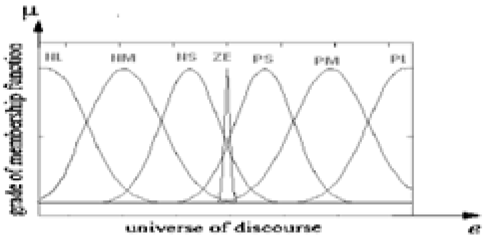

Fig 4 (a) Membership Function for Change in Active power

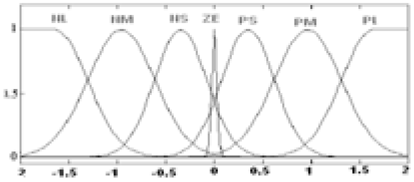

Fig 4 (b) Membership Function for the rate of change in active power

Rule Base

The rule that tie the input and output variables are given in table 1.

Table 1: Rule Base of the FLC.

CHANGE IN ACTIVE POWER(ΔP)		NL	NM	NS	ZE	PS	PM	PL
	NL	NL	NL	NL	NL	NM	NS	ZE
	NM	NL	NL	NL	NM	NS	ZE	PS
	NS	NL	NL	NM	NS	ZE	PS	PM
	ZE	NL	NM	NS	ZE	PS	PM	PL
	PS	NM	NS	ZE	PS	PM	PL	PL
	PM	NS	ZE	PS	PM	PL	PL	PL
	PL	ZE	PS	PM	PL	PL	PL	PL
	CHANGE IN OUTPUT (ΔM)							

Decision Generating Logic

From the FLC, as soon as the appropriate rule are fired, the degree of membership of the output fuzzy variable i.e. change in output is determined by encoding the antecedent fuzzy subsets, in such cases error and change in error. The max-min implication strategy is used.

Defuzzification

Basically, Defuzzification is actually a mapping from the space of fuzzy control action defined over an output universe of discourse in to a space of nonfuzzy control actions. A Defuzzification technique is targeted at producing a crisp control action that best represents the possibility distribution of an inferred fuzzy control action. The frequently used defuzzification technique is Center of Area (COA). In this particular defuzzification method the output crispy value are corresponding towards the center of gravity of the output membership function which can be defined as-

$$\Delta U_c = \frac{\int w\mu(w)dw}{\int \mu(w)dw} \tag{7}$$

Where ΔU_c is Defuzzification result, w = output variable, μ = membership function.

Simulation Result

Matlab Simulink is utilized being a simulation tool. Matlab is definitely an integrated technical computing environment that combines numeric computation, advanced graphics and visualization, along with a high-level programming language. It is just a natural environment for analysis, algorithm prototyping, and application development.

The Matlab Nonlinear Control Design Block set was adopted to optimize the PI controller parameter. This tool gives a time domain based optimization procedure for control system. The fuzzytech MCU -96 Edition was adopted to development the fuzzy logic controller. It support all deign step for fuzzy system engineering structure design, linguistic variables and rule definition. This tool generates C-code for Intel MCS-96 microcontrollers. It also produces M code utilized in Mat Lab. The fuzzytech file representing the FLC was imported through the Matlab Simulink to perform the fuzzy logic simulations. The system is tested under the single line to ground fault created near to second converter (Rectifier) fig 5(a) to (c) shows the result of simulation with PI controller (conventional) and with the Fuzzy controller

System set parameter are I_{dc} is +0.5 Pu and U_{dc} is +3.0 pu. Before the fault. At t=0.3 s the single line to ground fault occurs near to second converter (Rectifier)

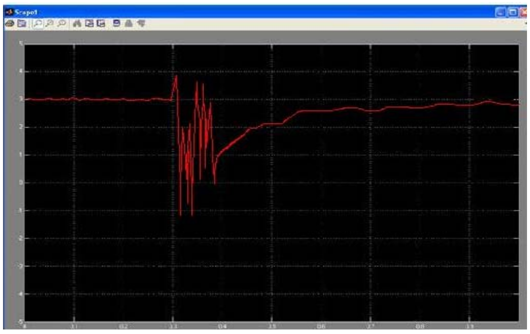

Figure 5 (a): Plot of U_{dc} for single line to ground fault with PI Controller.

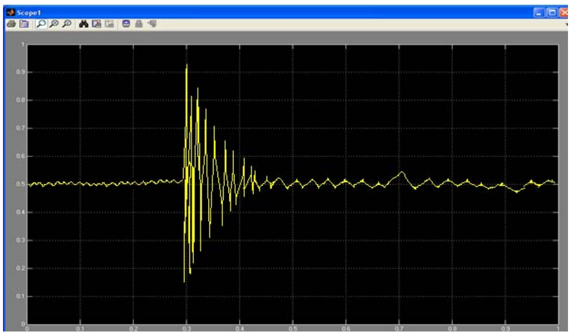

Figure 5 (b): Plot of Idc for single line to ground fault with PI Controller.

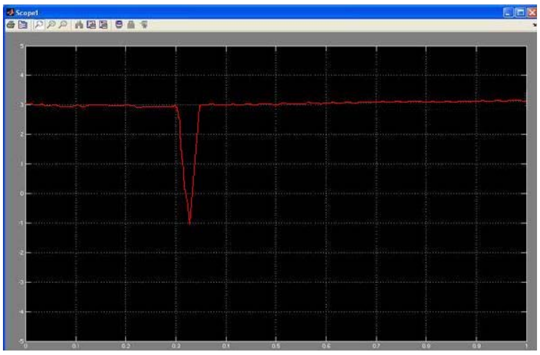

Figure 6(a): Plot of U_{dc} for single line to ground fault with Fuzzy Controller.

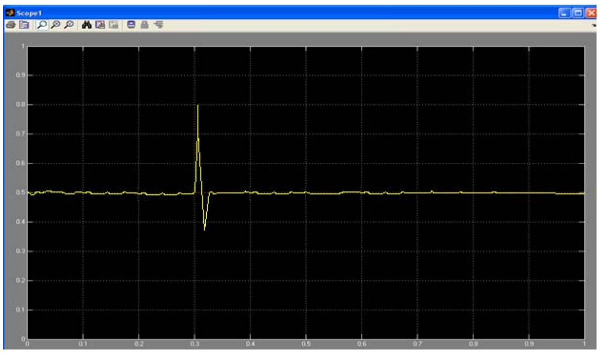

Figure 6(a): Plot of I_{dc} for single line to ground fault with Fuzzy Controller.

Conclusions

As from the result of simulation it is very clear that then the fault occur at t= 0.3s Udc decrease but as the converter one is working at constant mode there are oscillation in the Udc but it will settle down very fast for the fuzzy controller than foe the PI controller.

When the fault is created at t= 03s, the magnitude of Idc rises and as the U_{dc} settle downs I_{dc} also settle downs with large oscillation for PI controller and with very few oscillation with fuzzy controller.

A FLC is successfully designed for a VSCHVDC system. It is shown in this paper that the FLC with asymmetrical membership function shows better dynamic performance as well as less steady state error than the PI controller.

Appendix

Station 1(Rectifier side) 230kV(80°), 2000 MVA, $SCR = 10$, $L1 = 31.02$ mH,

$R = 13.79\Omega$, $L2 = 62.23$ mH.

Station 2 (Inverter side) 230kV(80°), 1000 MVA, $SCR = 5$, $L1 = 62.04$ mH ,

$R = 27.58\ \Omega$, $L2 = 124.46$ mH

Transformer Yg/Δ, 230kV/100kV,

200 MVA, 15%

Main DC capacitor 70 µF

DC Cables 100km×2 (R=0.0139 Ω /km,

$L = 0.159$ mH/km, $C = 23.1$ µF/km)

Switching frequency 1350 Hz

Nomenclature

UL = the sinusoidal AC voltage in the AC network

Uf = AC voltage in the AC network at the filterbus

UV (1) = the fundamental line to line voltage (valve side)

XL = the leakage reactance of the transformer

δ= phase shift between *UL* and *UV (1)*

IV = source current

L, R = phase reactor inductance and resistance

C = DC side capacitance

ω= source voltage angular frequency

M = modulation index

P, Q = AC active, reactive power at the filterbus

Udc, Idc, Pdc = DC side voltage, current, power

References

[1] Zhao, Chengyong; Lu, Xiangdong; Li,Guangkai; June 2007 “Parameters Optimization of VSC-HVDC Control System Based on Simplex Algorithm” Power Engineering Society General Meeting, 2007. IEEE Page(s):1 - 7 Digital Object Identifier 10.1109 / PES.2007.386085

[2] Li, W.; Choudhury, P.; Gillespie, D.; Jue, J.; Kshatriya, N.; 18-22 June 2006 “A Risk Evaluation Based Approach to replacement Strategy of Aged HVDC Components and Its Application at BCTC” Power Engineering Society General Meeting, 2006. IEEE Page(s):6 pp. Digital Object Identifier 10.1109 / PES.2006.1708868

[3] Guangkai Li; Gengyin Li; Haifeng Liang; Ming Yin; Chengyong Zhao; Oct. 2006 ”Operational Mechanism and Characteristic Analysis of Novel Hybrid HVDC system” Power System Technology, 2006. Power Con 2006. International Conference Page(s):1 - 6 Digital Object Identifier 10.1109 / ICPST .2006.321914

[4] Zheng Chao; Zhou Xiaoxin; Li Ruomei; Oct. 2006 ”Dynamic Modeling and Transient Simulation for VSC based HVDC in Multi- Machine System” Power System Technology, 2006. Power Con 2006. International Conference on Page(s):1 - 7 Digital Object Identifier 10.1109 / ICPST. 2006.321603

[5] Monsur, N.; Sood, V.K.; Lopes, L.; May 2006 “Modeling a Hybrid Diode-Thyristor HVDC Rectifier in EMTP-RV” Electrical and Computer Engineering, Canadian Conference Page(s):1258 – 1262 Digital Object Identifier 10.1109 / CCECE.2006.277441

[6] Latorre, H.F.; Ghandhari, M.; Soder, L.; Aug. 2006 “Control of a VSC-HVDC Operating in Parallel with AC Transmission Lines” Transmission & Distribution Conference and xposition: Latin America, 2006.TDC '06.

IEEE/PES Page(s):1 - 5 Digital Object Identifier 10.1109 / TDCLA. 2006.311394

[7] Qahraman, B.; Gole, A.M.; Fernando,I.T.; 18-22 June 2006 “Hybrid HVDC converters and their impact on power system dynamic performance” Power Engineering Society General Meeting, 2006. IEEE Page(s):6 pp. Digital Object Identifier 10.1109 / PES. 2006.1708891

[8] Bahrman, M.P.; 29 Oct2006 -1 Nov. 2006 “OVERVIEW OF HVDC TRANSMISSION” Power Systems Conference and Exposition, 2006. PSCE '06. 2006 IEEE PES Page(s):18 – 23 Digital Object Identifier 10.1109/PSCE.2006.296221

[9] Du, C.; Bollen, M. H. J.; Agneholm, E.; Sannino, A.; Oct. 2007 “A New Control Strategy of a VSC–HVDC System for High-Quality Supply of Industrial Plants” Power Delivery, IEEE Transactions Volume 22, Issue 4, Page(s):2386 – 2394 Digital Object Identifier 10.1109/TPWRD.2007.899622

[10] Chengyong Zhao; Ying Sun; May 2006 “Study on Control Strategies to Improve the Stability of Multi-Infeed HVDC Systems Applying VSC-HVDC” Electrical and Computer Engineering, Canadian Conference Page(s):2253 - 2257

Biographies

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Prof. (Mrs.) Gayatri Agnihotri received her B.E. degree in Electrical Engineering in 1970 from M.A.C.T., Bhopal, M.Tech. in Heavy Electrical Equipment in 1974 from M.A.C.T., Bhopal and Ph.D. on System Engineering in 1984 from I.I.T., Delhi. She has a teaching experience to UG and PG around 36 Years. She is presently working as Prof. in Electrical Engg. Dept. of M.A.N.I.T., Bhopal. Her research area is Power System and System Engg. She has guided around 90 M.Tech. Theses and 10 Ph.D. at present.