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HVDC Transmission Using Adaptive Fuzzy Logic Controller

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Abstract:

A method for further refine the fuzzy logic formulation to improve the transient response is presented. This paper introduces a fuzzy logic-based tuning of the controller parameters or the rectifier side current regulator and inverter side gamma controller in a high voltage direct current (HVDC) system. A typical point-to-point system has been taken with the detailed representation of converters, transmission links transformers, and filters. The current error and it's derivative and the gamma error and it's derivative are used as the principal signals to adjust the proportional and integral gains of the rectifier pole controller and the inverter gamma controller, respectively, for the optimum system performance under various normal and abnormal conditions. The two approaches are compared using simulations on MATLAB simulation program. The results show that the fuzzy logic based approach can provide, at the minimum, a marginal improvement over the P-I based controller or conventional scheme.

Keywords:

Fuzzy logic, HVDC.

NOMENCLATURE:

e = Error to PI.

I_d = Steady State Current.

α_i = Firing angle given to Inverter.

V_d = Converter DC Voltage.

e_i = Current error.

e_γ = Extinction angle error.

δI= Difference between small and large Currents.

δ_γ = Difference between small and large Extinction Angles.

I_S = Small current value.

I_L= Large current value.

γ_S = Small Extinction Angle.

γ_L = Large Extinction Angle.

I_{di} = Measured Current.

I_{dref} = Reference Current.

ΔI_d = Current Margin.

γ_{min}= Minimum Value of Extinction Angle.

γ_{meas}= Measured value of Extinction Angle.

γ_{ref} = Reference value of Extinction Angle.

α_{CC} = Firing Angle for Constant Current.

α_{CEA}= Firing Angle for Constant Extinction Angle.

α_{min} = Minimum of α_{CC} & α_{CEA}.

μ_{CC}=Membership Function of Constant Current.

μ_{CEA}=Membership Function of Current Extinction Angle.

LIST OF ACRONYMS

CC = Current Controller.
CEA = Constant Extinction angle.
DI = Direct Current.
LDI = Large Direct current.
SDI =Small Direct Current.

[I] INTRODUCTION:

An HVDC transmission system often has for its innermost control loops, a constant current controller at the rectifier end and a constant extinction angle controller (or sometimes a constant voltage controller) at the inverter end. Although the above control modes may be active at the nominal operating point, for reasons of stability and recovery from system disturbances, the Overall characteristic may include other control modes resulting in a composite voltage-current relationship.

Higher-level control loops such as a dc Power control loop or various ac system damping implemented so that hey vary the Set Points of the controllers of the innermost loops.In several instances the principal control element in a feedback control loop is a proportional-integra1 (P-I) control block. The error signal is passed through this P-I block and the output of the block forms the input to the plant or process to be controlled. The controller moves this output in a direction to minimize the error. The integral part -allows for the attainment of zero steady-state error (for a constant set-point value) whereas the proportional part allows for a fast initial response. This paper presents a simple scheme of replacing fuzzy logic controller along with single P-I in place of two P-I, which select the minimum of two firing angles.This paper considers conventional scheme for converters is being replaced by FUZZY with single P-I controller.

[II] CONVERTERCONTROL CHARACTERISTICS:

The graph shows the characteristics of converters of dc link i.e. dc voltage versus dc current.

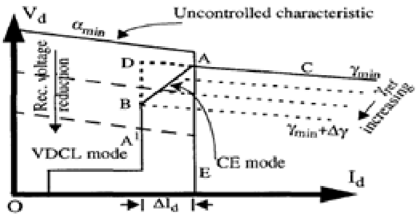


Fig 1: Operational characteristics

- Rectifier constant current (CC) - segment AE.
- Inverter constant current (CC) - segment BA'.
- Inverter constant extinction angle (CEA) -segment AC.
- Inverter current error (CE) - segment AB.

Normally the operating point is the intersection of the rectifier CC and inverter CEA characteristics (point A, Fig. 1), which results in the minimum reactive power demand, without an excessive risk of commutation failure.

System changes such as ac side voltage reduction at the rectifier end results in a control mode crossover in which the current control function is taken over at the inverter end, with the rectifier operating on its uncontrolled characteristic at the minimum firing angle. In order to prevent sudden changes in the operating point, the sharp knee is broken with a positive resistance slope from the γ control characteristic to current control characteristic of the inverter (AB instead of AD and DB Fig.1). This droop characteristic is usually called the Current Error (CE) control system.

[III] MODELLING:

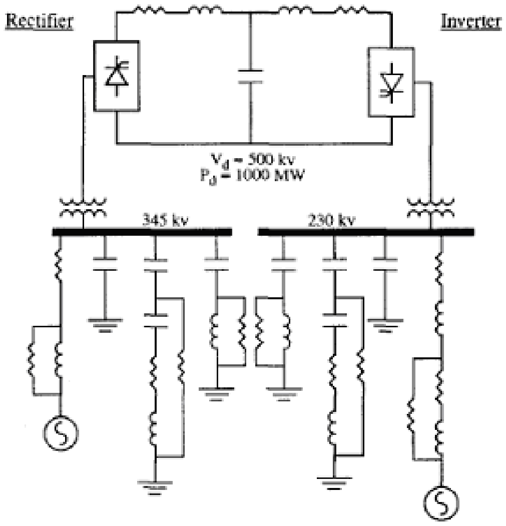
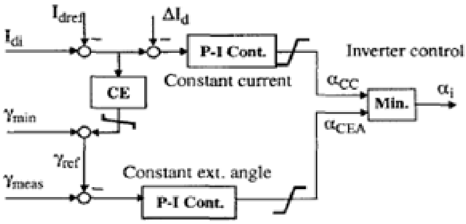


Fig 2: CIGRE benchmark

The idea of establishing a benchmark system to study certain phenomena is not new. However this is a first attempt to create a common reference for HVDC studies, especially one related to control strategies and recovery performance. Another benefit that results from such a standard system is the possible comparison of different simulation methods and results.



Conventional control scheme

The typical control scheme for the CIGRE benchmark model is briefly depicted schematically in the following figure for the inverter end.

There are two main control paths. The upper one current control (CC) compares the current order Idref-ΔId with the measured current Idi, and produces the firing angle order αcc. The firing angle αcc is controlled in a direction that would reduce the current error. Similarly, the lower path constant extinction angle (CEA) generates the firing angle order αCEA, in an attempt to make the measured extinction angle γmeas to equal the set-point value of γmin. The actual firing angle order passed on to the HVDC valve group is the smaller of the two firing angle orders, thus ensuring that only one of the paths is in control with the other path being de-selected.

Disadvantages of conventional scheme:

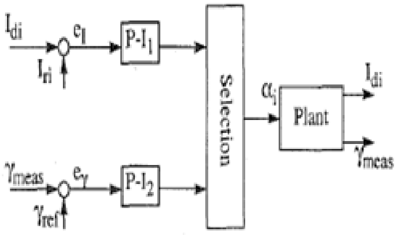


Fig.4. General inverter control scheme

One problem with P-I type control blocks is that in essentially non-linear systems (such as HVDC systems), their performance can only be optimal at one operating point. In order to improve their large-signal performance, several techniques have been used, such as adaptive gains or non-linear weighting of the errors.

The fuzzy logic approach used here uses rules based primarily on simple logical reasoning to adaptively select the controller errors, gains and time-constants of a single P-I controller. Another problem that must be overcome with the control scheme is that of controller saturation.

For example, as in the HVDC control system, where two or more control loops compete for the final control action, the P-I controller of the de-selected loop saturates at a limit. This problem has of course been overcome in conventional control Schemes. However the approach presented here is simpler, as only one P-I block is used.

FUZZY LOGIC CONRTROLLER IMPLEMENTATION:

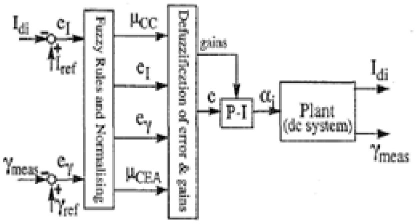


Fig.5.Fuzzy logic control scheme

In the proposed fuzzy logic approach, we perform the selection procedure on the input side of the controller by deriving a composite error as shown in Fig. 4. Two new coefficients μcc and μCEA are introduced that allow for a gradual transition in the selection process. This can be regarded as a generalization of the conventional process in Fig. 3, where exactly one of μcc or μCEA is unity and the other, exactly zero (in CEA mode μcc = 0, μCEA =1 and in CC mode μcc =1, μCEA =O). In the fuzzy logic approach these two coefficients are continuous numbers in the interval [0, 1] and not necessarily complements. At the nominal operating point, however, the controller is in extinction angle control, with μcc=0 and μCEA = 1.

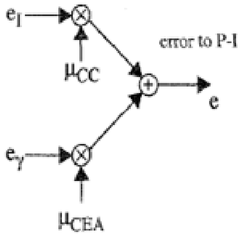


Fig. 6: Composite error detection

The two coefficients μcc and μCEA are derived from simple rules based on logical reasoning. For example whenever the measured extinction angle is smaller than its set value, the CEA mode of control should be selected in order to bring the extinction angle to its reference in order to provide sufficient commutation margin. The set of rules are explained in next section. In a similar fashion, the P-I controller gains and limits are also continuously adjusted through a weighting process (depending on the output errors, μcc and μCEA) and are continuously loaded into the P-I block as shown schematically in Fig. 4 Note that as a single P-I block is used, the problem of saturation of the de-selected controller is directly avoided.

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Also note that at the extreme limits of operation, when the controller is clearly in CC or CEA control, the P-I controller gains are the same as those in the conventional system and the system should show the same small-signal behavior as the conventional system for these operating points. Thus the fuzzy controller can be regarded as a generalization of the conventional controller.

Rules for implementing fuzzy logic:

All the rules are based on two inputs, the current (Idi) and the measured extinction angle (γmeas). The first step in the fuzzy logic procedure is to define the “fuzzy membership function” for the inputs. In deterministic logic, we assign a truth-value of “yes (I)” or “no (0)” to the statement “ ... the current is large”. In fuzzy logic, the answer can take on values between 0 and 1. At the extremities, where it is clear that the current is large (or small) we may assign a value of 1 (or 0). Thus a value of Is=l implies that the current is “definitely small” whereas Is=O means that the current is “definitely not small”; intermediate values between 0 and 1 implying something in between. Similarly IL=l implies that the current is “definitely large”, and so on. For the two inputs under consideration Idi and γ, the following simple linear sets are used. (Note: The overlap of the two sets is not necessarily at 50%).

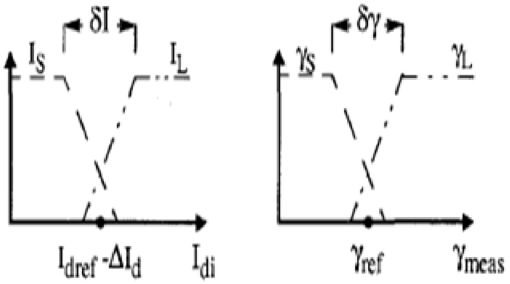


Figure 7: Fuzzy membership functions

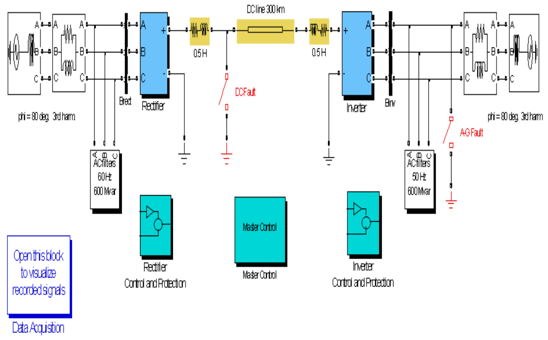
Is and I, are a measure of small and large dc current respectively. Using the membership values for Idi and γ, the following set of rules is used for control.

RULE 1: IF Is AND γs THEN μcc
RULE 2: IF Is AND γL THEN μcc
RULE 3: IF IL AND γs THEN μCEA
RULE4: IF IL AND γL THEN μcc

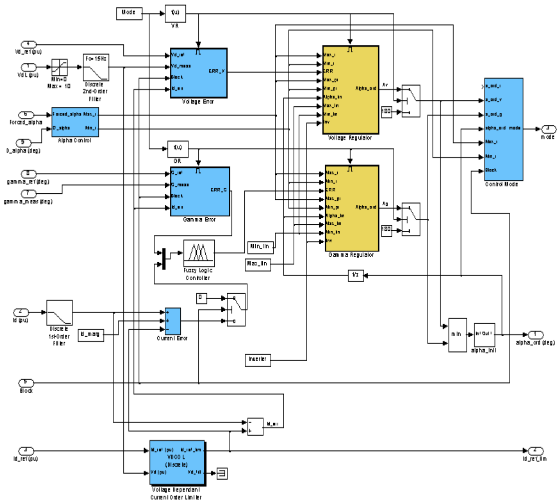
The rules are shorthand expressions for simple real language statements which describe our desired operating strategy. For example, rule 4 states that If the current is large and the extinction angle is large, current control should be used. However, unlike deterministic logic, this rule does not assign a value of 0 or 1 to μcc .

[IV] SIMULATION RESULTS:

Simulink Model For 12-Pulse Hvdc Transmission:



Fuzzy Controller For 12-Pulse Hvdc Transmission



V. CONCLUSIONS:

1.The time for recovery to 80% power is practically the same as with the conventional P-I control method, although the fuzzy method does take an extra 50 ms to make up the additional 10% to reach 90% power recovery. However, it can also be seen that with the conventional method, the extinction angle reaches about 7O, whereas the fuzzy controller never allows the commutation margin of 1.5’ to be breached.

2.It should be noted that a similar performance may be obtainable with other techniques as well. Indeed several proprietary control strategies included in modern HVDC controls do achieve excellent results. Nevertheless, the fuzzy logic approach is straightforward in its implementation.

3.Converting the P-I controller based control system for an HVDC scheme to one based on fuzzy logic, results in improved immunity to commutation failure during recovery from dc faults and during ac voltage dips. Although the initial implementation showed poor recovery of dc power following ac side faults, the inclusion of additional parameters and rules improved this response markedly.

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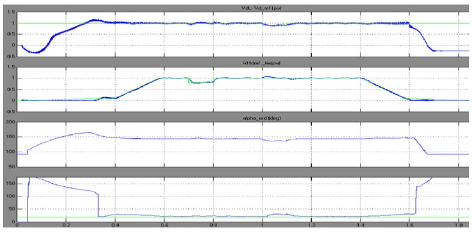
RESULTS OF CONVENTIONAL 12-PULSE HVDC CONVERTER:



SIMULATION RESULTS OF FUZZY CONTROLLER 12-PULSE HVDC CONVERTER