Transient Stability Augmentation By Fuzzy Logic Controlled Braking Resistor in Multi-Machine Power System

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***Abstract*-- Dynamic braking resistor is a very effective device for transient stability control. Again, fuzzy logic has been found to be very suitable for embedded control applications. This paper makes use of the Fuzzy Logic Controller (FLC) for the switching of the thyristor controlled braking resistor to improve power system transient stability. The braking resistor is installed at each generator bus, where rotor speed of the generator is measured to determine the firing-angle of the thyristor switch. By controlling the firing-angle of the thyristor, braking resistor controls the accelerating power in generators and thus improves the transient stability. The effectiveness of the proposed method has been demonstrated by considering both balanced (3LG : Three-phase-to-ground) and unbalanced (1LG: Single-line-to ground, 2LG: Double-line-to ground and 2LS: Line-to-line) faults at different points in a multi-machine power system.**

***Index Terms*-- Braking Resistor, Balanced Fault, EMTP, Fuzzy Logic, Transient Stability, Unbalanced Faults.**

I. INTRODUCTION

Among various methods used to improve transient stability margins, the dynamic braking resistor is a very powerful tool. The Braking Resistor (BR) can be viewed as a fast load injection to absorb excess transient energy of an area which arises due to severe system disturbances [1]. Due to the inherent limitations of mechanical switching and because of the growing development of power electronics technology, the circuit breaker in the braking resistor is being replaced by thyristor-based switching systems [2]-[6]. However, continuous attempts to explore new and effective control options are ongoing.

Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. The control method of modeling human language has many advantages, such as simple calculation, as well high robustness, lack of a need to find the transfer function of the system, suitability for nonlinear systems, etc. [7]. Exploiting the concept of fuzzy logic, we proposed two works [8]-[9] for the switching of the thyristor controlled braking resistor to improve power system transient stability. However, in both of the works simulations were carried out considering a single machine connected to an infinite bus system and taking a single fault point in the system into account.

In this paper, a fuzzy logic controlled braking resistor scheme is proposed considering a multi-machine model system and taking three fault points on the transmission lines into account. The simulation is implemented by using EMTP (Electro-Magnetic Transients Program). Through the simulation results of both balanced and unbalanced faults at different points, the effectiveness and validity of the proposed method are confirmed. Therefore, it can be concluded that the proposed fuzzy control strategy is an excellent and effective method for transient stability improvement.

II. MODEL SYSTEM

Fig. 1 shows the 9-bus power system model used for the simulation of transient stability. The system model consists of two synchronous generators (G1 and G2) and an infinite bus connected to one another through transformers and double circuit transmission lines. In the figure, the double circuit transmission line parameters are numerically shown in the forms R+jX (jB/2), where R, X and B represent resistance, reactance and susceptance respectively per phase with two lines. The braking resistors are connected to each of the generator bus through the thyristor switching circuit, as shown in Fig. 2. The BR will be switched in following a fault clearing and the switching condition of BR is such that when deviation of speed of the generator is positive, BR is

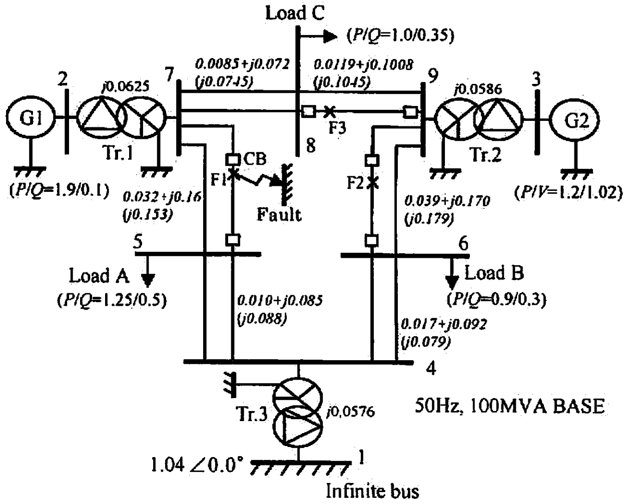


Fig. 1. 9-Bus Power System model

switched on the generator bus. On the other hand, when deviation of speed is negative and also in the steady state, BR is removed from the generator bus by the thyristor switching circuit. The AVR (Automatic Voltage Regulator) and GOV (Governor) control system models as shown in Figs. 3 and 4 respectively have been included in the simulation. The various parameters of the generators used for the simulation are shown in Table I.

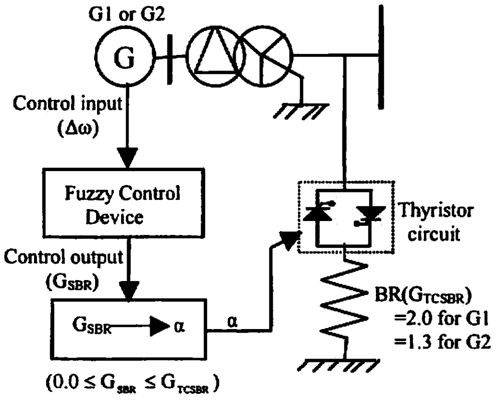


Fig. 2. BR with thyristor switching circuit

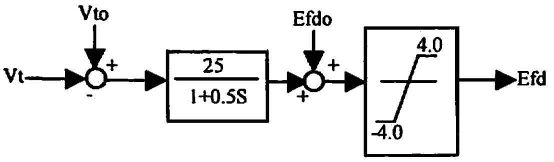


Fig. 3. AVR Model

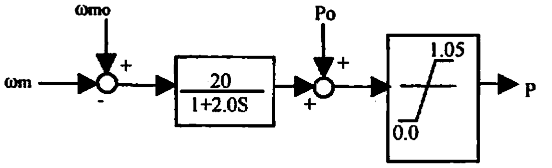


Fig. 4. GOV Model

TABLE I

GENERATOR PARAMETERS

	G1	G2
MVA	200	130
r_a (pu)	0.003	0.004
x_a (pu)	0.102	0.078
X_d (pu)	1.651	1.220
X_q (pu)	1.590	1.160
X'_d (pu)	0.232	0.174
X'_q (pu)	0.380	0.250
X''_d (pu)	0.171	0.134
X''_q (pu)	0.171	0.134
$T'do$ (sec)	5.900	8.970
$T'qo$ (sec)	0.535	1.500
$T''do$ (sec)	0.033	0.033
$T''qo$ (sec)	0.078	0.141
H (sec)	9.000	6.000

In the simulation study, three cases have been considered. First one is the fault near generator 1 at point F1, second one is near generator 2 at point F2 and third one is at point F3. In all of the three cases the fault occurs at 0.1 sec, the circuit breakers (CB) on the faulted lines are opened at 0.2 sec and at 1.0 sec the circuit breakers are closed. Time step and simulation time have been chosen as 0.00005 sec and 10.0 sec respectively.

III. DESIGN OF FUZZY LOGIC CONTROLLER

Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy logic allows expressing this knowledge with subjective concepts such as very hot, medium cold, and a long time which are mapped into exact numeric ranges. The design of the proposed FLC (Fuzzy Logic Controller) is described in the following:

A. Fuzzification

To design the fuzzy controller, it has been selected speed deviation, Δω, of the generator as the input and conductance value, G_{SBR}, of the braking resistor as the output. The triangular membership functions for the fuzzy sets of Δω have been shown in Fig. 5 in which the linguistic variables are represented by NE (Negative), ZO (Zero), and PO (Positive). The equation of the triangular membership function used to determine the grade of membership values is as follows [10].

$$A(x) = \frac{1}{b}(b - 2|x - a|) \qquad (1)$$

where A(x) is the value of grade of membership, 'b' is the width and 'a' is the coordinate of the point at which the grade of membership is 1, x is the value of the input variable (deviation of speed for the present simulation).

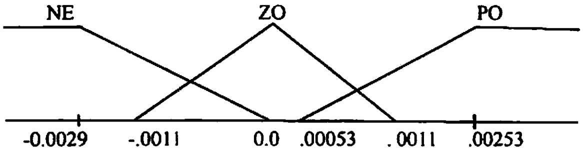


Fig. 5. Membership function of Δω (pu)

B. Fuzzy Rule Table

The proposed control strategy is very straightforward because of its simple and a few control rules which have been developed from the viewpoint of practical system operation and by trial and error and is shown in Table II where the numerical values of G_{SBR} represent the output of the fuzzy controller.

TABLE II

FUZZY RULE TABLE

Δω	G_{SBR} (pu)
NE	0.0
ZO	0.0
PO	2.0 for G1 1.3 for G2

C. Fuzzy Inference and Defuzzification

For the inference mechanism of the proposed fuzzy logic controller, Mamdani's method [10] has been utilized. The Center-of-Area method is the most well known and rather simple defuzzification method [10] which is implemented to determine the output crispy value (i.e. the conductance value of the braking resistor).

IV. CALCULATION OF FIRING-ANGLE

Firing-angle, α, for the thyristor switch is calculated from the output of the fuzzy controller i.e. from the conductance value of the braking resistor. Again, conductance value of BR is related to the power dissipated through BR. For any time step of simulation, the average power of SBR (System Braking Resistor), P_{SBR} and that of TCSBR (Thyristor Controlled System Braking Resistor), P_{TCSBR} are equal and hence firing-angle, α, can be calculated from the following equation.

$$P_{TCSBR} = P_{SBR}$$

$$or,\ \frac{V_g^2 G_{TCSBR}}{\pi}(\pi - \alpha + 0.5SIN2\alpha) = V_g^2 G_{SBR} \qquad (2)$$

where V_g is the rms value of generator bus voltage, G_{TCSBR} is the conductance value of BR specified to 2.0 pu and 1.3 pu for generator 1 and generator 2 respectively for the simulation and G_{SBR} is the conductance value of BR which is the output of fuzzy controller.

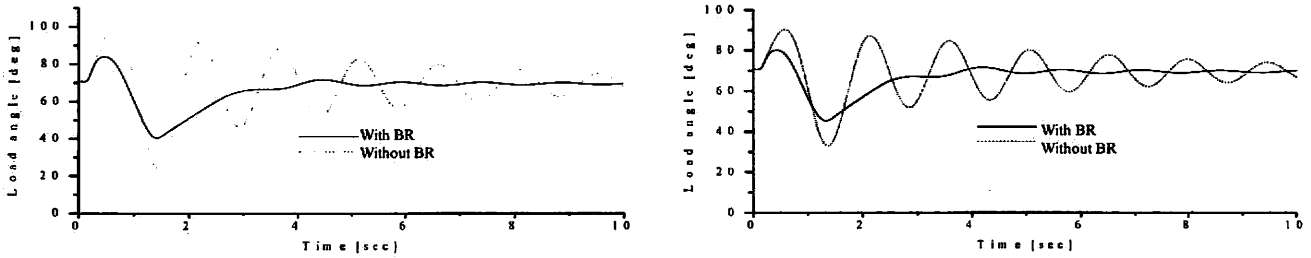
But it is complex to calculate firing-angle, α, directly from (2) using the value of G_{SBR}. So, in this simulation, firstly by using (2), a set of different values of G_{SBR} is calculated for the values of firing-angle ranging from 0^0 to 180^0 with a step of 2^0. Then by using the linear interpolation technique, firing-angle, α, is determined.

V. SIMULATION RESULTS

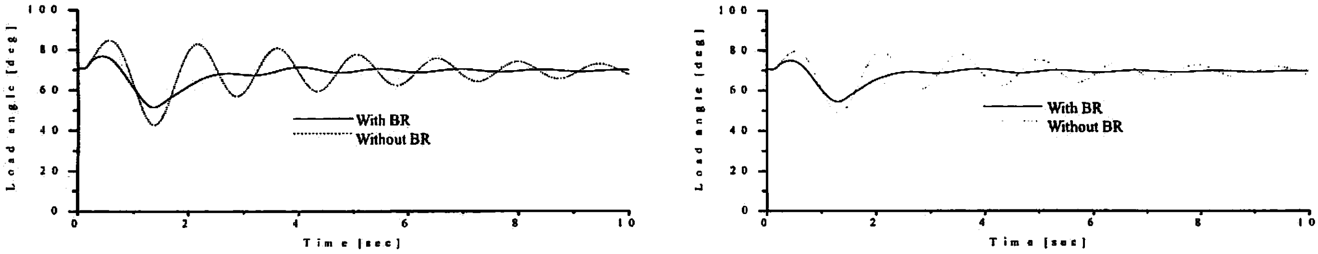
In order to show the effectiveness and validity of the proposed fuzzy logic controlled braking resistor in improving the transient stability, simulations have been carried out considering both balanced (3LG: three-phase-to-ground) and unbalanced (1LG: single-line-to-ground a-phase, 2LG: double-line-to-ground a-b phases and 2LS: line-to-line a-b phases) faults at three different points on the transmission lines. It is important to note that the fuzzy controller parameters are fixed for all the fault cases and fault points. Figs. 6-11 show the load angle responses for generator 1 and generator 2 in case of all faults at points F1, F2 and F3. It is easily seen from these responses that because of the use of BR, the system is transiently stable for all fault cases.

However, it is observed for all fault cases in Figs. 6 and 7 that the deviations of load angle from their initial values are higher in generator 1 compared to those in generator 2. This is due to the fault point F1 near generator 1 and hence, generator 1 is affected more than generator 2. Again, because of the fault at point F2 near generator 2, generator 2 is affected more compared to generator 1 as observed from Figs. 8 and 9. On the other hand, from Figs. 10 and 11 it is seen that both generators are affected almost equally because of the fault at point F3 which is far from both generators.

Figs. 12 and 13 depict the firing-angle responses of the thyristor switch for phase 'a' for BR 1 and BR 2 respectively under balanced fault at point F2. The firing-angle varies from 0 degree to 180 degree according to the value of G_{SBR}. In section 2, it has been stated that when the power system becomes stable, BR is removed from the generator bus by the thyristor switching circuit. This signifies that in that case conductance G_{SBR}, is zero and hence, firing-angle becomes 180 degree. Now, it is seen in both figures that after some variations from 0 degree to 180 degree, the firing-angle gets a constant value of 180 degree after about 2.4 sec and it remains the same upto 10.0 sec. This fact indicates that the system is in stable condition after about 2.4 sec.

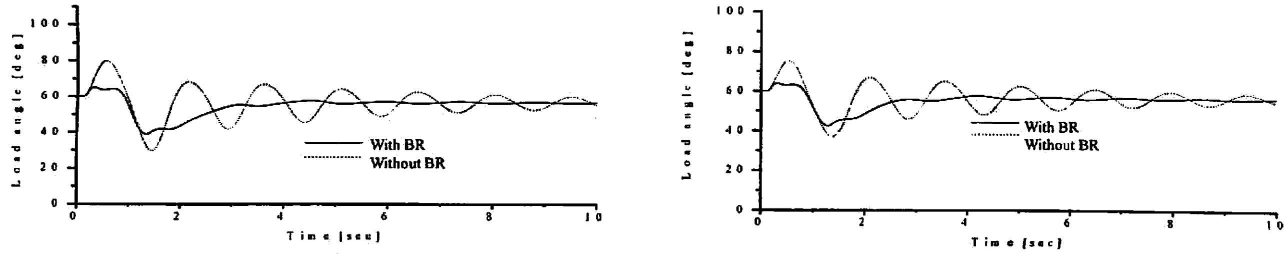


(a) 3LG fault (b) 2LG fault

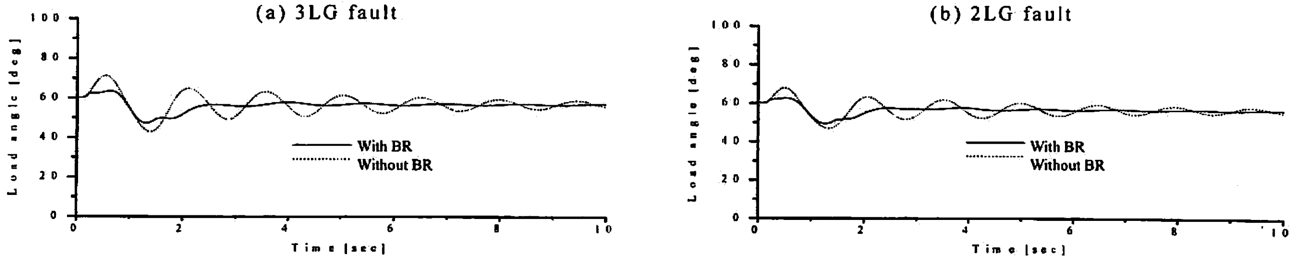


(c) 2LS fault (d) 1LG fault

Fig. 6. Load angle responses for generator 1 with fault at point F1

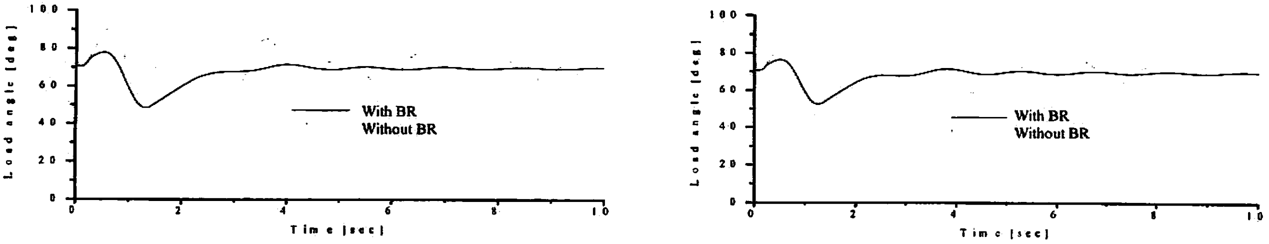


(a) 3LG fault (b) 2LG fault

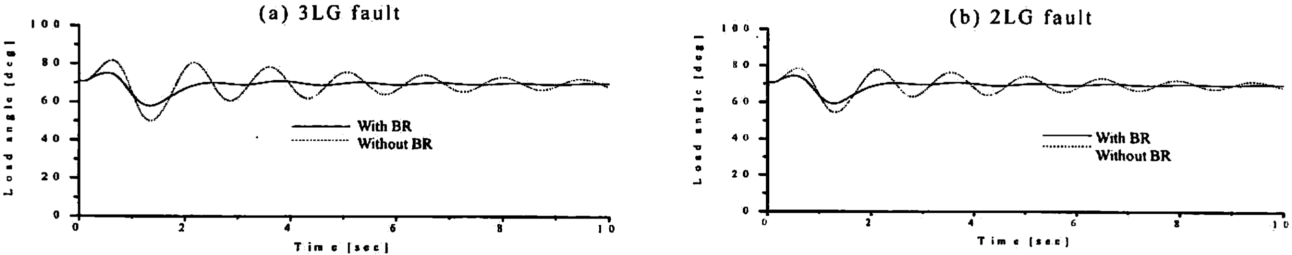


(c) 2LS fault (d) 1LG fault

Fig. 7. Load angle responses for generator 2 with fault at point F1

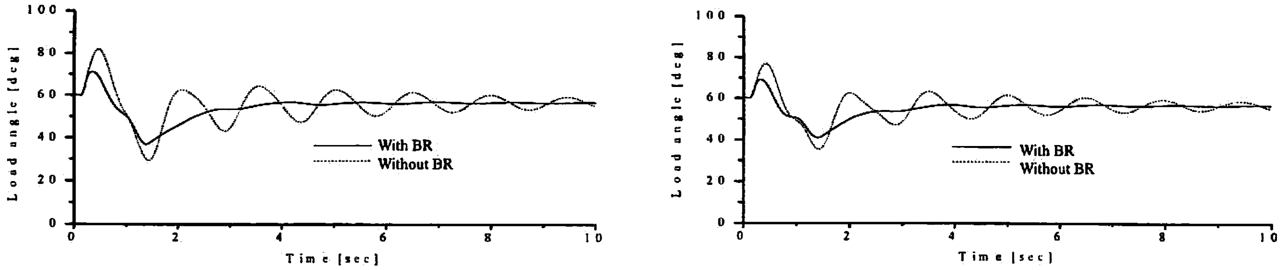


(a) 3LG fault (b) 2LG fault

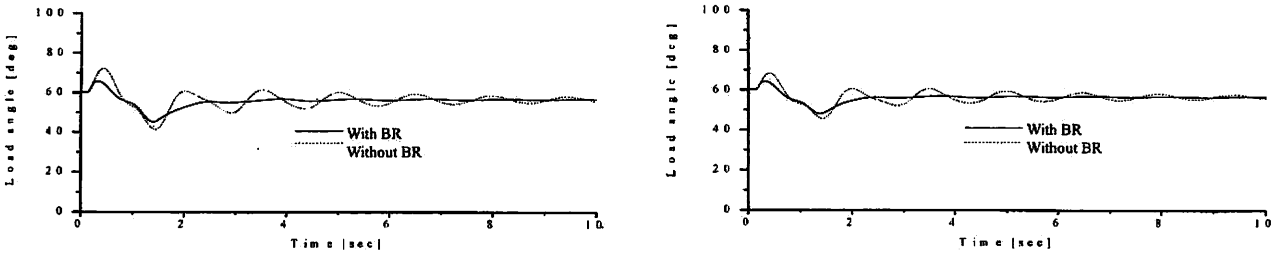


(c) 2LS fault (d) 1LG fault

Fig. 8. Load angle responses for generator 1 with fault at point F2

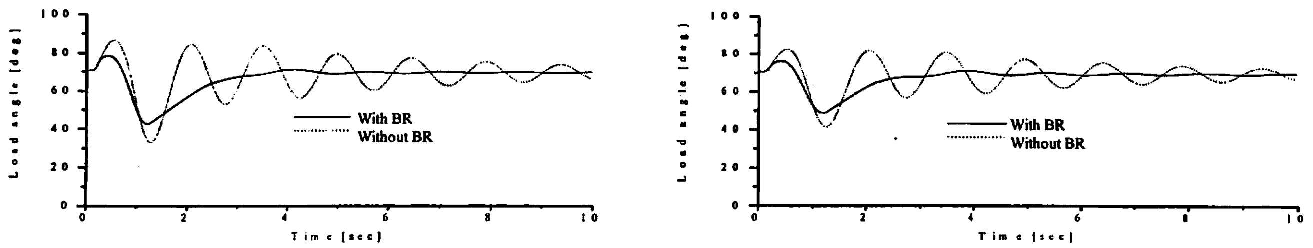


(a) 3LG fault (b) 2LG fault

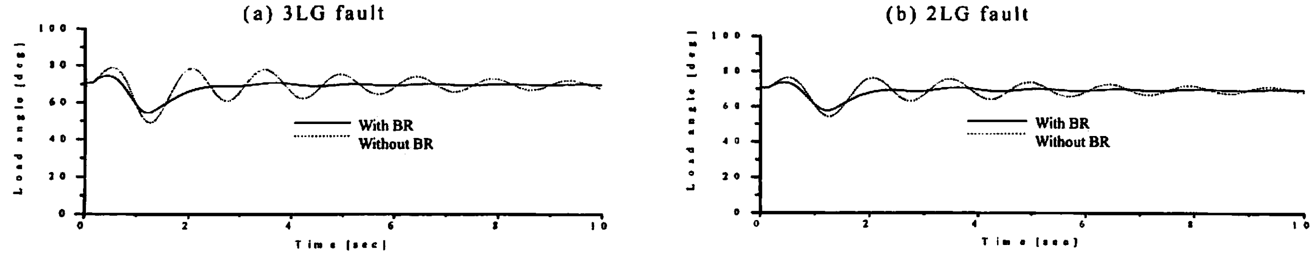


(c) 2LS fault (d) 1LG fault

Fig. 9. Load angle responses for generator 2 with fault at point F2

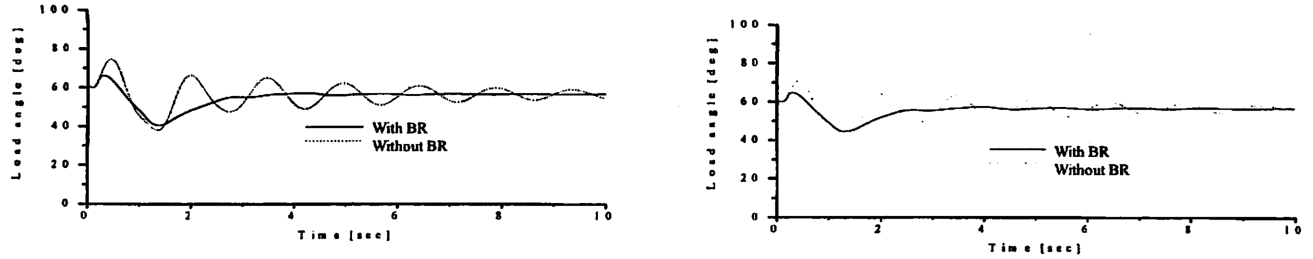


(a) 3LG fault (b) 2LG fault

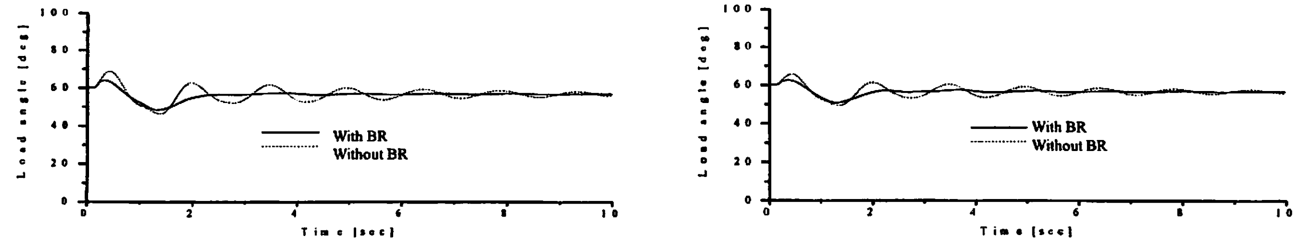


(c) 2LS fault (d) 1LG fault

Fig. 10. Load angle responses for generator 1 with fault at point F3



(a) 3LG fault (b) 2LG fault



(c) 2LS fault (d) 1LG fault

Fig. 11. Load angle responses for generator 2 with fault at point F3

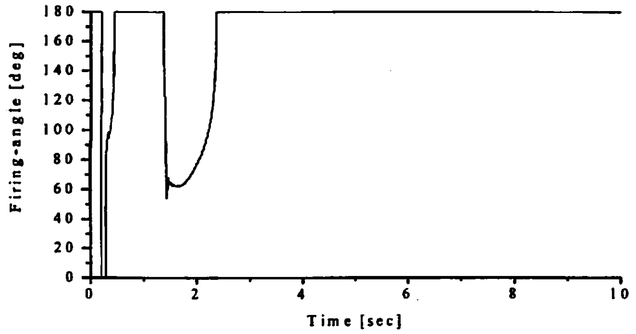


Fig. 12. Firing-angle response for BR 1

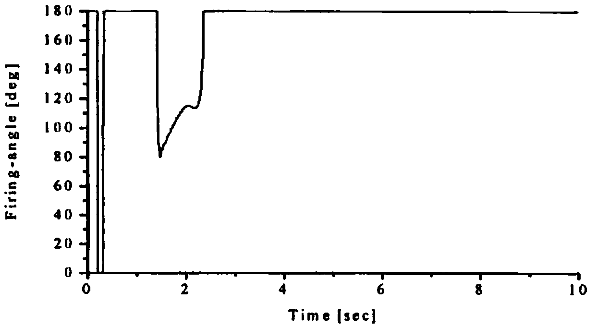


Fig. 13. Firing-angle response for BR 2

Finally, in Figs. 14 and 15, it is shown the responses of three-phase dissipated power through BR 1 and BR 2 respectively in case of 3LG fault at point F2. In the steady state of the power system, the power dissipation through BR is zero. Again, the amount of power to be dissipated through BR depends on the value of firing-angle. Therefore, it is observed in both figures that after some variations from 0.0 pu to about 2.0 pu (for BR 1) and 1.3 pu (for BR 2), the power dissipation becomes zero after about 2.4 sec and after that it is always zero upto 10.0 sec. This fact also indicates that the system is in stable condition after about 2.4 sec.

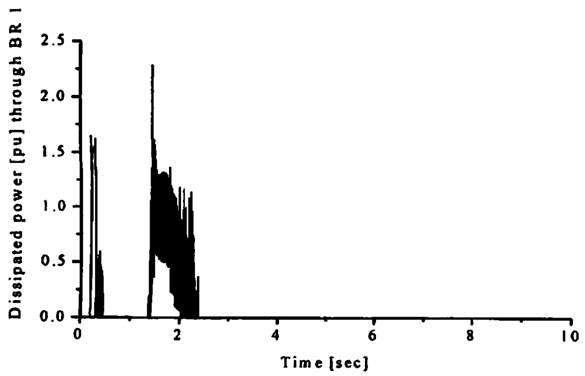


Fig. 14. Dissipated power response for BR 1

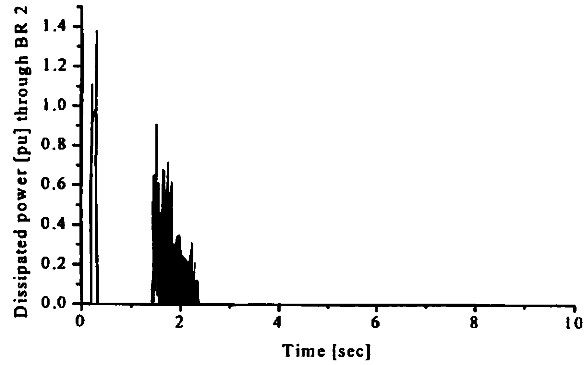


Fig. 15. Dissipated power response for BR 2

As a whole, from the point of view of the simulation results, one point is of paramount importance that the fuzzy controller can effectively enhance the transient stability by switching the braking resistor. Therefore, it can be concluded that the proposed fuzzy control scheme is an excellent and effective method to improve the transient stability for both balanced and unbalanced fault conditions.

VI. CONCLUSION

In this paper, a fuzzy logic controller has been proposed for the switching of the thyristor controlled braking resistor to improve the transient stability of a multi-machine power system. Simulation results clearly show the excellent performance and effectiveness of the proposed method. Therefore, it can be concluded that the proposed fuzzy logic controller provides an effective method of transient stability improvement under both balanced and unbalanced fault conditions.

VII. REFERENCES

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