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Design and Implementation of Fuzzy Controlled SMES for Enhancing the Transient Stability

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***Abstract*: For the enhancement of the transient stability of an electric power system, this paper presents superconducting magnetic energy storage (SMES) of fuzzy logic-controlled and its execution. And comparison is made between a traditional PI controlled SMES and this new controller. Also, a relative analysis amid the fuzzy controlled SMES and fuzzy controlled braking resistor (BR) is made. Simulation results show that the anticipated fuzzy controlled SMES gives easy and efficient way of improving transient stability of electric power systems than that of the PI controller.**

***Keywords:* Superconducting Magnetic Energy Storage (SMES), Braking resistor (BR), Fuzzy Logic controller (FLC), Proportional Integral (PI), Transient Stability Improvement.**

I. INTRODUCTION

Exhaustive advancement among the power electronics with superconductivity have given power transmission in addition to distribution industry with (SMES) units, as the effective dispatching examine of the BPA 30-MJ unit[1], SMES system is considered in power system applications, like controlling frequency, AGC, UPSs etc. Depending on the power system requirements the true power can be absorbed or delivered from the low loss superconducting magnetic inductor. For this purpose the delay angle is used. This method gives vast chances to precede transient stability of power system due to advanced high speed electronic switches. The thyristors controlled SMES unit is also such a device. Demonstrating the use of SMES unit for power system transient stability improvement has been reported by many articles. Based on proper control strategy the efficiency of SMES on power system stabilization depends.

Previous methods [2]-[6] show that there are many methods for controlling SMES unit, Still the main problem is willpower for the efficient method for switching method. So the new efficient controlling methods are going on.

In embedded control with in sequence processing, with numerous applications.

Fuzzy logic has the huge investigative methodology. Fuzzy logic looks like human choice building with its ability to work from assessed information and find exact arrangements. The controlling technique of displaying human dialect has a few points of interest, for example, easy sum estimation, more strength, absence of a require to find the transfer function of the system, suitability for nonlinear systems, and so on. Accordingly, by considering these perspectives, this paper shows how a fuzzy logic switching of the thyristors controlled SMES to enhance the transient stability of an electric power system. To show how well this fuzzy controlled SMES unit has to be ability for enhancing the transient stability it is compared with a proportional-integral (PI) SMES method.

II. MODELLING OF SYSTEM

In this paper fig. 1 shows the model of simulation for enhancing the transient stability, it has synchronous generator (SG) fed to an infinite bus with a transformer and double circuit transmission line. CB indicates a circuit breaker, when a dynamic period occurs for the efficient of power balance of a synchronous generator can be controlled, generator terminal bus will be placed with the SMES unit.

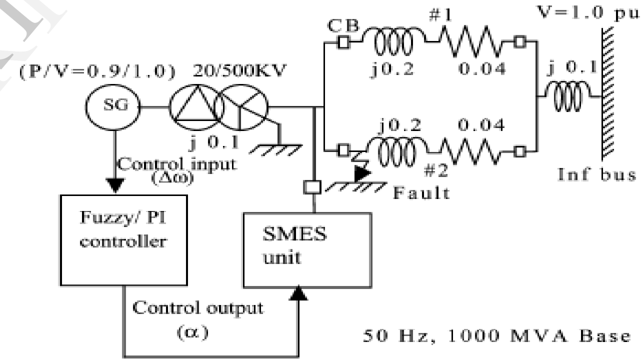


Fig. 1. Power system model

Fig.2 and fig.3.shows automatic voltage regulator (AVR) and governor (GOV) control system models, has added in this present work and also the parameters of generators are tabulated in table I.

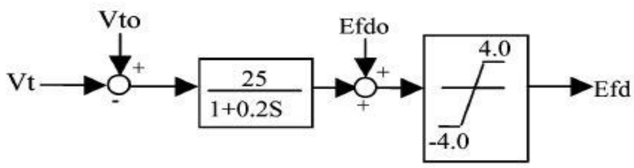


Fig. 2. Automatic Voltage Regulator model

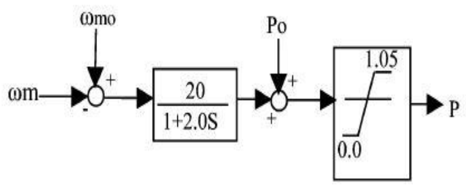


Fig.3. Governor Model

TABLE-I
PI CONTROLLER PARAMETERS

MVA	1000
r_a [pu]	0.003
x_a [pu]	0.13
X_d [pu]	1.79
X_q [pu]	1.71
X'_d [pu]	0.169
X'_q [pu]	0.228
X''_d [pu]	0.135
X''_q [pu]	0.20
X_0 [pu]	0.13
T'do [sec]	4.30
T'qo [sec]	0.85
T''do [sec]	0.032
T''qo [sec]	0.05
H [sec]	2.894

III. CONSTRUCTION OF SMES

Fig. 4 depicts the probable SMES unit having a Y-Δ 500 KayV/5KayV transformer, an ac/dc bridge-converter of thyristors controlled, and a superconducting coil or inductor with 0.5 H.

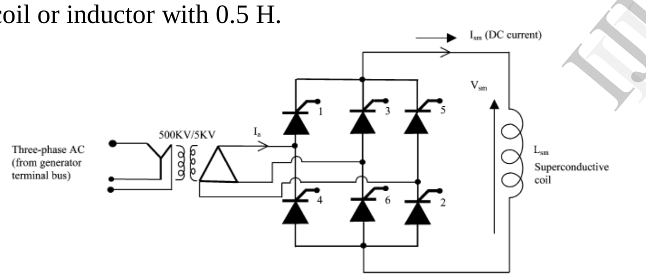


Fig. 4 SMES unit with six-pulse bridge ac/dc thyristors controlled converter.

The superconducting coil experiences +Ve or -Ve voltage by the converter. The Charge and discharge are easily controlled by simply varying the delay angle (α) of the thyristors,. If α <90, the converter acts as a rectifier (i.e. charging). And the converter acts as an inverter (i.e. is discharging) if α >90. As a result, depending on the load requirement the power system sends to or absorbs from. At steady state SMES doesn't consume any active or reactive power.

When SMES unit is at starting charge, the V_{bridge} is kept steady at a suitable +Ve value. The current through inductor rises tremendously and the inductor starts storing energy. At a point when the current of inductor reaches its appraised value, it is held at consistent by bringing down the inductor voltage to zero. To maintain stability the SMES unit has to be attached to the power system. It is important near select current through inductor such that the greatest suitable energy ingestion levels with the most extreme passable energy dis-charge.

The DC side voltage of the converters is given as

$$V_{sm} = V_{sm} \cos\alpha \qquad (1)$$

Where V_{smo} is the bridge maximum DC voltage on no load.

The V and I of super conductor are related by

$$I_{sm} = \frac{1}{L_{sm}} \int_{t_0}^{t} V_{sm} d\tau + I_{sm} \qquad (2)$$

Where I_{smo} is the initial current of the inductor.

The active power absorbed or delivered by the SMES is given by

$$P_{sm} = V_{sm} I_{sm} \qquad (3)$$

The bridge current in not reversible whereas the bridge output power is reversible. If output power is +Ve is positive, the power system sends power to the SMES unit. And if it is -Ve, power system absorbs power from the SMES unit.

The expression for the energy of the super-conducting inductor at any instant is given as

$$W_{sm} = W_{sm0} + \int_{t_o}^{t} P_{sm} d\tau \qquad (4)$$

Where $W_{sm} = (1/2) L_{sm} I_{sm\alpha}^2$ is the initial energy in the inductor

Assumptions to be made for the modeling of SMES following are :

1).To eliminate the effect of the ripple of the DC current Superconducting coil should possess large inductance.
2) Superconducting coil Resistance is kept very small.
3).Negligible voltage drop in the converter.
4).The harmonic power is negligibly small.

IV. DESIGNING OF FLC

The drawback of PI controller is that which has failed in respond to sudden changes in the error signal ε, for the reason that it is only able of demonstrating the immediate value of the error signal lacking consideration, the transformation of the increase and decrease of the error, by numerical terms, the derivative of the error is denoted as Δε.

The fuzzy logic controller (FLC) [13] dissimilar to the crispy-logic during Boolean theory to use just two logic levels (0 to 1), is an extension of logic which concedes unending logic levels (from 0 to 1), to take care of an issue that has vulnerabilities or uncertain circumstances. Once more, a fuzzy control is a methodology control which is focused around fuzzy logic and be ordinarily portrayed by "IF-THEN" runs by show. The configuration of the anticipated FLC is portrayed within the accompanying.

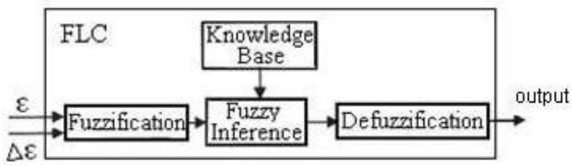


Fig.5.fundamental demonstration of FLC

The determination of the output control signal is done in an inference engine with a rule base having if-then rules in the form of "IF ε is .... AND Δε is ...., THEN output is ...."
With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of-error Δε.

A. FUZZIFICATION

Fuzzification methodology comprises with discovering fitting membership functions to depict crisp information. For the outline of the anticipated FLC, departure of pace of synchronous generator and firing angle of thyristors are chosen as the input & output, individually. Triangular membership functions are indicated in Figure. 4. In which the phonetic variables N, Z, and P stand for negative, zero and positive, separately. The membership functions are controlled by the experimentation method so as to get the better framework execution. The mathematical statement of the triangular membership capacity use to focus the evaluation of membership in which the estimation of evaluation of membership, is 1 and 0 be the estimation of the input variable.

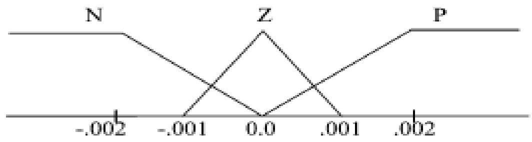


Fig.6. Membership functions of $\Delta\omega$ (pu) for SMES.

B. FUZZY RULE BASE

The main part of a fuzzy controller is the rule base as the control technique is used for controlling the closed-loop system is put away as an issue of control rules,particular gimmick of this anticipated fuzzy controller which is extremely is basic configuration containing two variables. The utilization of the single–input single–output(SISO) changeable make the fuzzy controller exceptionally direct. Fig. 6 demonstrates the membership functions for the output variable comprising of three singleton fuzzy sets Little, intermediate, and Enormous. The organize rules of the anticipated controller be resolved from the perspective of commonsense system operation and by experimentation and are demonstrated.

Triangular membership functions are shown in Fig.6, in which the linguistic variables N, Z, and P stand for negative zero, and positive, respectively. The membership functions have been resolute by the trial and error method in arrange to get the good system presentation.

C. FUZZY INFERENCE

The essential working principle of the deduction motor is it induces, i.e. it finds a sensible solution. Really, the surmising motor is a system which utilizes the rule base and the input data of the controller to make the determination. The finish of the derivation motor is the fuzzy output of the controller, which therefore turns into the input to the defuzzification interface. For the derivation system of the anticipated FLC, Mamdani's-technique[10] is used. A fuzzy rule normally has an IF-THEN arrangement as takes after: IF IS And IS THEN where and are fuzzy input variables, is the fuzzy output variable, is the rule number, is the aggregate number of rules and be fuzzy subsets in the creation of talks , and , individually. Consequently, as indicated by Mamdani, the level of similarity, of every fuzzy rule is as per the following: where also be the estimations of the evaluation of membership.

D. DEFUZZIFICATION

In the previous operation, the fuzzy finish of the induction motor is defuzzified, i.e. It is changed to a crisp signal. The last signal is the last result of the FLC, which is obviously, the crisp direct signal to the procedure. The inside of-range system is the most well-known and rather basic defuzzification strategy which is actualized to focus the yield crispy worth. Which has accompanying statement: where is the crispy yield work and is now characterized in the past area. To perceive how compelling the fuzzy controlled Fell system in enhancing the stability and its execution is contrasted with traditional PI controller Fell System plan.

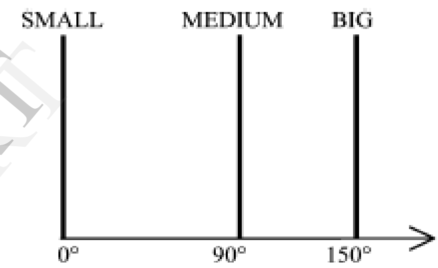


Fig.7 Membership functions of α (degree) for SMES.

Fig. 7 shows the membership functions which are having output variables small, medium, big of three singletons, rule base is prepared with trial-and-error technique Table II.

TABLE-II
SMES WITH FUZZY RULE

Δω (pu)	α (degree)
N	BIG
Z	MEDIUM
P	SMALL

V. PI CONTROLLER

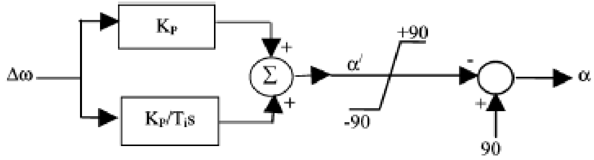


Fig.8. Block diagram of PI controller

TABLE-III
PI CONTROLLER PARAMETER

K_p	T_i
180.0	0.2

VI. SIMULATION AND RESULTS

Fig.9. Single Machine Connected to the infinite bus With

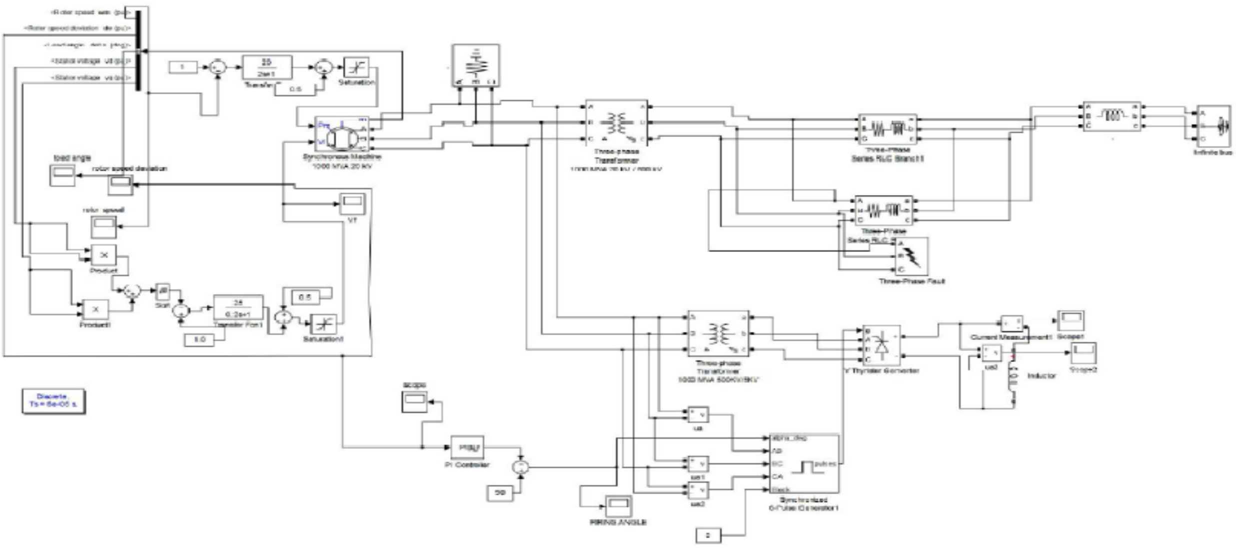
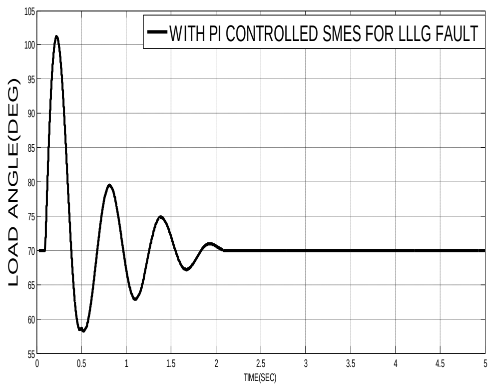
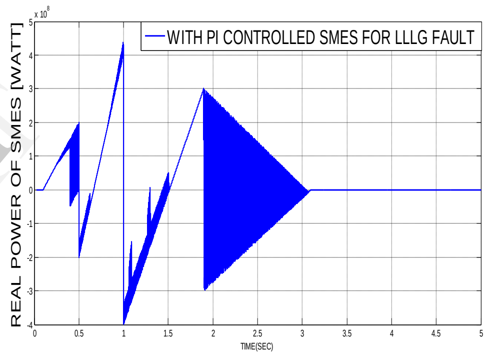


Fig.9. Single machine Connected to the infinite bus with proportional integral controller





The below figure 10 shows the Simulink model of Single Machine Connected To Infinite Bus with Fuzzy Controlled SMES for The Fuzzy Controller .The Deviation of Rotor Speed is taken as input and firing angle is taken as output.

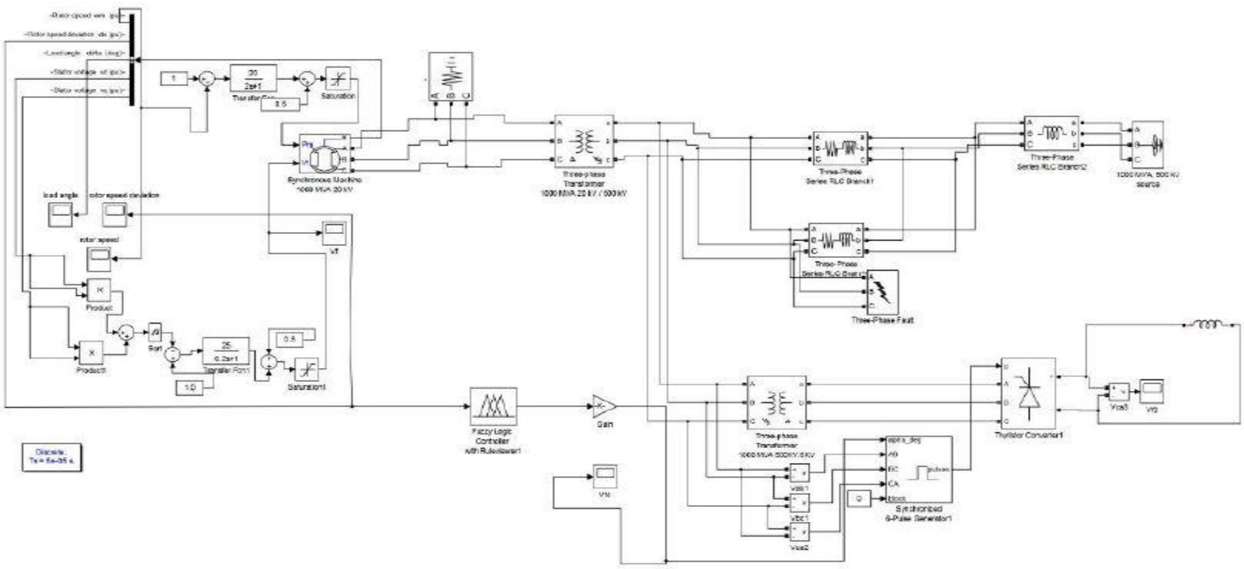
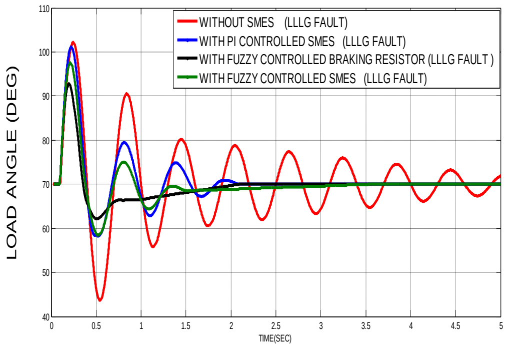
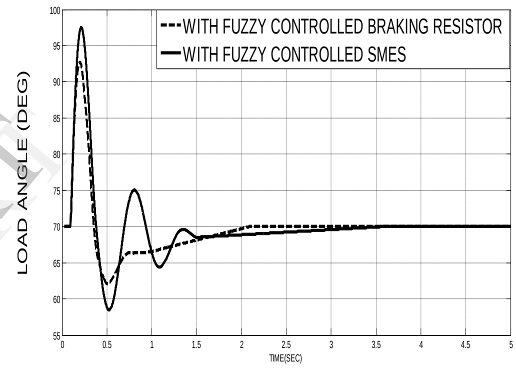
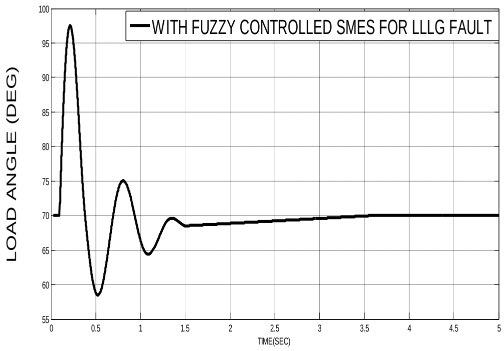
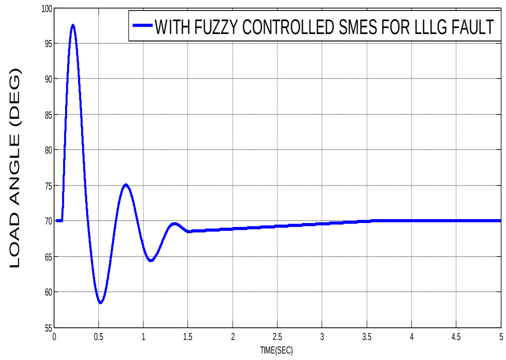


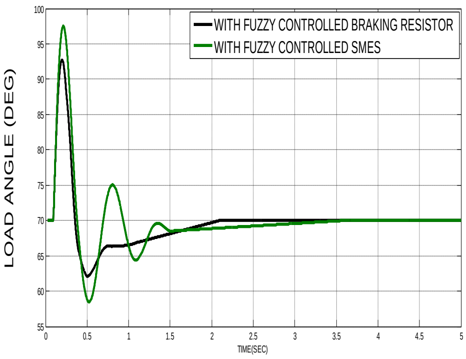
Fig.10. Single Machine Connected To Infinite Bus with Fuzzy Controlled SMES

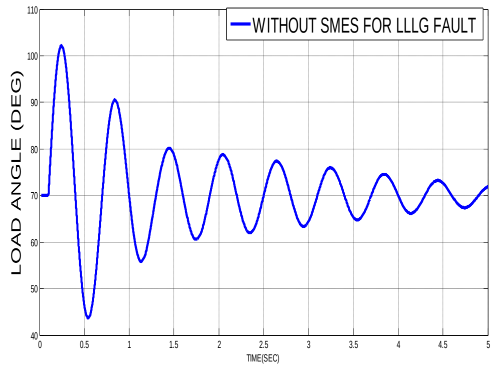


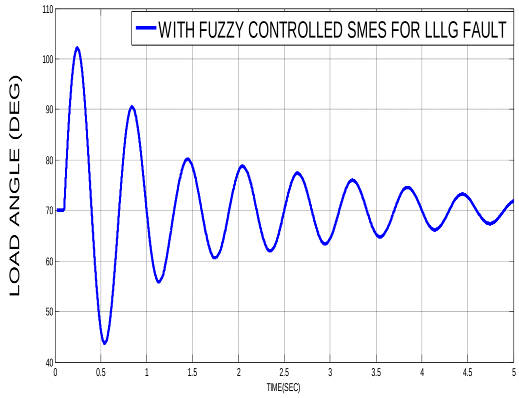


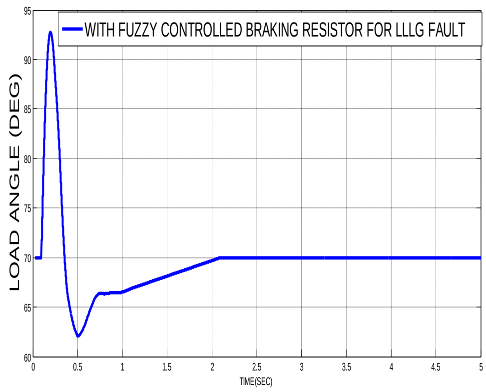




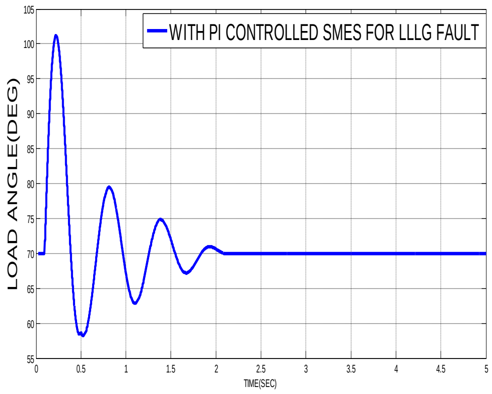


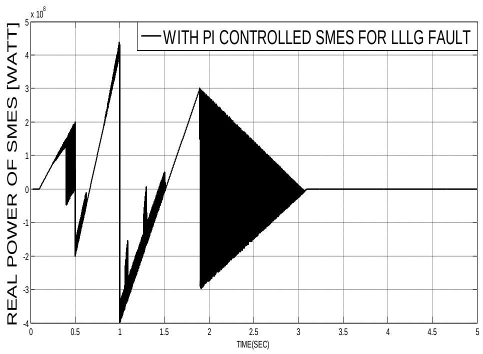


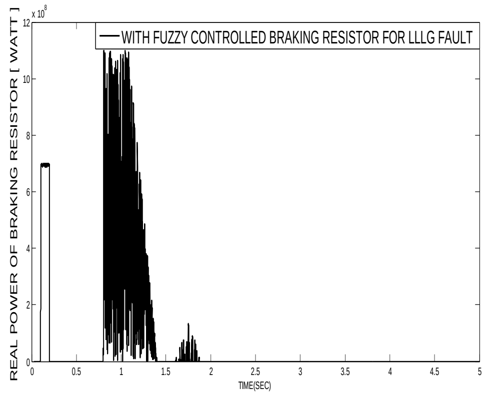

WITH FUZZY CONTROLLED SMES FOR LLLG FAULT
LOAD ANGLE (DEG)
TIME(SEC)


WITH FUZZY CONTROLLED BRAKING RESISTOR FOR LLLG FAULT
LOAD ANGLE (DEG)
TIME(SEC)

V


WITH PI CONTROLLED SMES FOR LLLG FAULT
LOAD ANGLE(DEG)
TIME(SEC)


WITH PI CONTROLLED SMES FOR LLLG FAULT
REAL POWER OF SMES [WATT]
TIME(SEC)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REAL POWER OF BRAKING RESISTOR [WATT]
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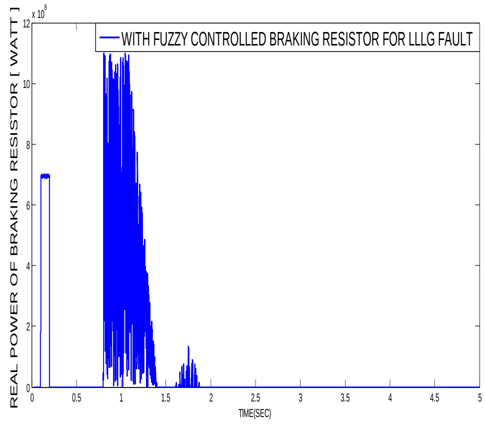
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REAL POWER OF BRAKING RESISTOR [WATT]
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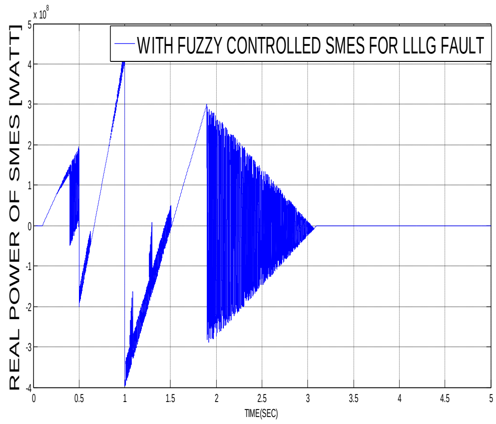
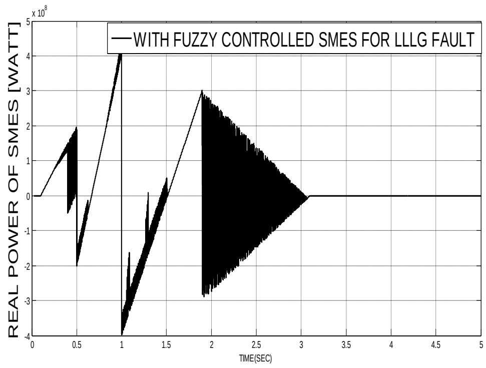
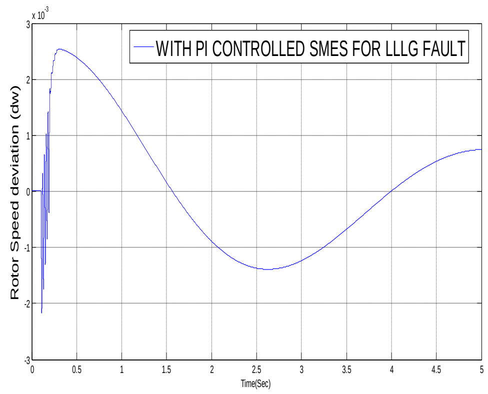
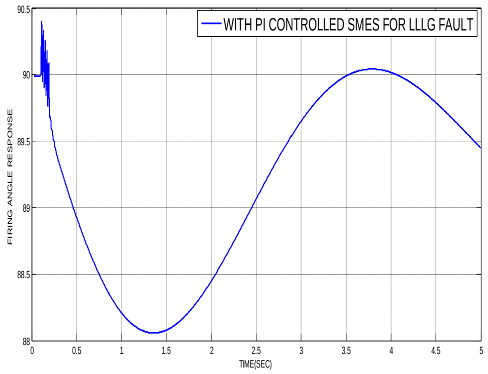
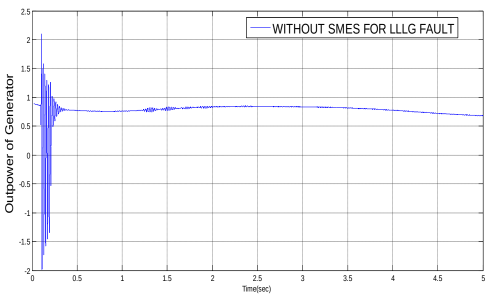

WITH FUZZY CONTROLLED SMES FOR LLLG FAULT
REAL POWER OF SMES [WATT]
TIME(SEC)


WITH FUZZY CONTROLLED SMES FOR LLLG FAULT
REAL POWER OF SMES [WATT]
TIME(SEC)







VII. CONCLUSION

In this paper for enhancing the transient stability, a fuzzy controlled switching of thyristors is proposed for the 3LG balanced faults. For enhancing the transient stability the proposed methodology is efficient, which are shown by the simulation results. Additionally, the presentation of fuzzy controlled SMES have more efficiency than of PI controlled SMES. Also, it is initiated to the presentation of SMES is best one than BR, since for perspective of a speedier course of action, for decreasing the first swing of the transient, BR is better one when compared with SMES. So at last, it can be accomplished that the projected FLC SMES approach is advanced of fuzzy logic-controlled BR method, which shows a extremely easy with efficient way of transient stability improvement of an electric power system.

NAME OF FAULT	With fuzzy controlled SMES	With PI controlled SMES	With fuzzy controlled BR	Without controller
3LG	0.4147	0.7037	0.4953	1.0639

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