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Evaluation of Fault Clearing Time in 9-Bus System for Numerical Protection

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Abstract: This paper present an approach for maintain system stability in case of power oscillation in power system network by using numerical relay for protection. Fault clearing time plays an important role for maintain system stability. Variation in load angles due any disturbance in huge interconnected network may cause power swing .By keeping fault clearing time as small as possible in case of, any large variation in load angles system stability can be enhance. Setting of fault clearing time is only possible in case of numerical relay haying very fast and accurate response. The proposed approach was tested for 3 phase fault in IEEE 9 bus system .Electromagnetic Transient program (EMPT) and Power System Computer Aided Design (PSCAD) were used for simulation purpose. The results show the variation in power swing with different fault clearing time.

Keywords: Critical Clearing Time (CCT), PSCAD/EMTDC, Transient Stability, IEEE 9-Bus system, Test system.

I. INTRODUCTION

Marinating system stability is most elaborate and challenging task in power system network after occurrence of any large disturbance. Such disturbance may be occurs due to 3 phase fault or by sudden large increment or removal of loads. During disturbance, the rotor of the generator swings around the final steady value and because of these rotor swings, variation in load angle has been seen. With variation in load angle current flowing through the lines also changes .Such current are very large in magnitude and produce power surges. In order to avoid over current damage to equipment due to heavy current and loss of system stability a rapid fault clearance is required in power system. The fault clearance signal to the circuit breaker is released from the protective relay. Relay sense the fault and it takes some time to close its contact. After closing the contact the operating mechanism of circuit breaker come into action and again it takes some time for final arc interruption. Hence the total fault -clearing time is therefore, made up of the relay time and breaker-interrupting time. The power system network shell remain stanble if the fault is cleared as soon as possible with minimum time duration .However ,if the fault is cleared after the particular time called critical clearing time which highest allowable value of clearing time for which the system remains to be stable within this time zone. However, if the fault is cleared after the CCT ,the power system is most likely to become unstable. Thus fault clearing time is very important factor for maintaining system stability. Smaller the fault clearing time, greater possibility to maintaining system stability or vice a versa. Since fault clearing time is time required by the relay as well as the time require by the circuit breaker. The relaying time varies according to the choose relay. The relaying time for electromagnetic relays can vary from one cycle to five cycle it means 20ms to 100ms.Static relay are more faster than electromagnetic relay it takes 20ms to 60ms. Numerical relays give very fast operation and their relaying time is within one cycle[1]. Since the relaying time of numerical relay is very less as compared to other available conversion relay, it is most preferable now a day. Fault clearing time is directly related to the variation in load angle. Larger the fault clearing time, large variation is seen in load angle.

In this paper concept review of swing question is discussed in section II. Overview of IEEE 9 bus system is explain in section III .Basic block diagrams of numerical relay is explain in section IV. Simulation model of the nine bus system is discussed in section V .Section VI shows the simulation result when 3 phase fault occurs with different fault clearing time. In section VII, conclusion is drawn.

II. SWING EQUATION CONCEPT REVIEW

During any disturbance rotor of synchronous machine will accelerate or de-accelerate with respect to synchronously rotating air gap mmf for adapting changing power transfer requirement and a relative motion begin. The equation explains the relative motion is popularly known as the swing equation. The swing equation express the relative motion of the machine rotor relating the inertia torque to the resultant of the Mechanical and electrical torque on the rotor [2].

$$M\frac{d^2\delta m}{dt^2} = Pm - Pe$$

Where M = Inertia constant of machine
δm = Mechanical power angle
Pm = Mechanical power supply to the generator

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Pe = Electrical power supply to the system

Swing equation in term of electrical power and the δ.

$$\delta = \frac{P}{2}\delta m$$

Where, P = No. of poles of a synchronous generator.

$$\frac{2}{P}M\frac{d^2\delta}{dt^2} = Pm - Pe$$

Swing equation in term of inertia constant H with power express in per unit is given by expression.

$$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = Pm - Pe$$

When δ express in electrical degree the swing equation become

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = Pm - Pe$$

From the above equation it is clear that when the Mechanical power supply is equal to the electrical power generator machine speeds are practically equal to the synchronous speed. The load angle δ of the machine in a system provides information about the system dynamic.

A plot of power angle (δ) and fault clearing time (t) is called the swing curve which is get from the numerical solution of the swing equation in the presence of large disturbance such as three phase short circuit or may be sudden loss of load.

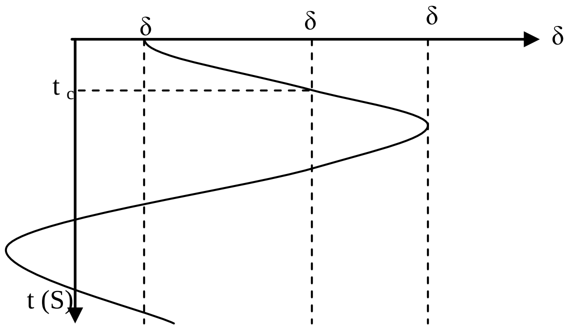

Fig. 1 Swing Curve for Stable System [4]

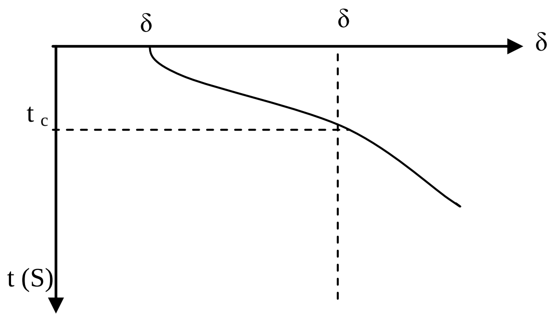

Fig. 2 Swing Curve for Unstable System [4]

RELATION BETWEEN CRITCAL CLEARING TIME (t_c) AND CRITCAL CLEARING ANGLE (δ_c).

For finding relation between critical clearing time and critical clearing angle again we solve non-linear swing equation. In this particular case generated electrical power Pe consider zero during three phase fault.

$$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = Pm - Pe$$

Pe = 0

$$\frac{Hd^2\delta}{\pi f dt^2} = Pm$$

$$\frac{d^2\delta}{dt^2} = \frac{\pi f Pm}{H}$$

Integrating both side

$$\frac{d\delta}{dt} = \frac{\pi f Pm}{H}\int_0^t dt$$

$$\frac{ds}{dt} = \frac{\pi f Pm\, t}{H}$$

Again integrating

$$\delta = \frac{\pi f}{H} Pm\, t^2 + \delta_0$$

If δ_c is the critical clearing angle, the corresponding critical clearing time is

$$t_c = \sqrt{\frac{2H(\delta c - \delta 0)}{\pi f Pm}}$$

Above equation show the relationship between the critical clearing time (t_c) and critical clearing (δ_c)[2].

III. NINE BUSES SYSTEM

The IEEE nine bus system consists three generators unit connected to bus number 1,2 and 3 respectively . Six transmission lines with specific line parameter and three steps up transformer connected between buses 1-4, 2-7 and 3-9 to each generator unit. Three load A, load B and load C connected to bus number5, 6 and 8 respectively. System frequency is 60 Hz. Data is taken from power system control and stability by Anderson and Fouad[3] The total generation is 313MW and total load is 312.5 MW.

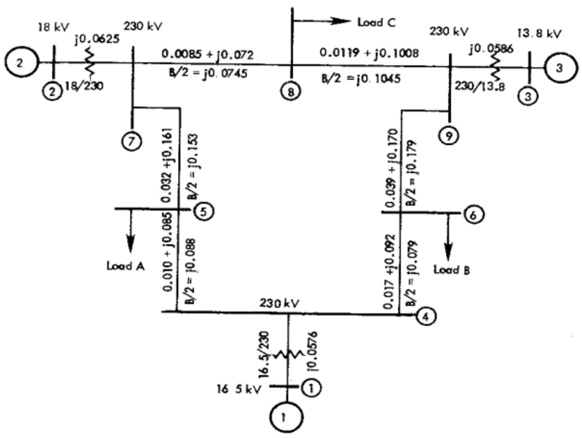

Fig. 3 Nine Bus System Impedance diagram [1]

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IV. NUMERICAL RELAY

Modern power system protection system are made with multifunction characteristic like protection ,control, monitoring and measuring .All such characteristic are available in numerical relay. The numerical relay is the latest development in the area of power system protection and it differs from all conventional protection system in design as well as operation method. This relay obtain sequential sample of the ac quantities in numeric data form through the data acquisition system(DAS) and processes the data numerically using a relaying algorithm to calculate the fault discriminate and make trip decisions.[1]

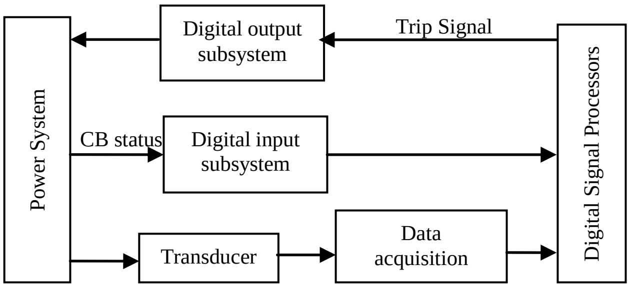

Fig. 4 Block diagram of Numerical Relay

V. SIMLATION MODEL OF TEST SYSTEM

The single line diagram of the simulated test system is shown in fig.(5).The IEEE 9 bus test system is simulated in PSCAD/EMPT [10]-[11].For this test system generation is parameter are given in appendix.Mostley data taken from power system control and stability by Anderson and Fouad[3].The total connected load of 9 bus system is ideally 315MW and generation is about 313MW.The system consists 6 transmission lines connecting the busbar of the test system and generator connected to network through step-up transformer at 230KV transmission voltage.In bus number 5 three phase to ground fault is created for 5 second near generator 1 and obtain the resopons for different fault clearing time.

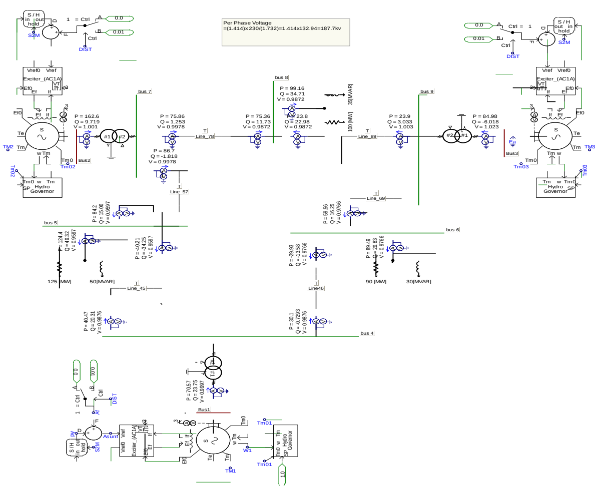

Fig. 5 Simulation Model of 9-Bus Systemin in PSCAD

VI. SIMULATION RESULTS

Case1- Three phase to ground fault is created in bus number 5 near generator 1at time 5.0 second for first case fault clearing time is 0.31 second. Variation in power, speed and load angle has been damped out nearly 15 second and system becomes stable.

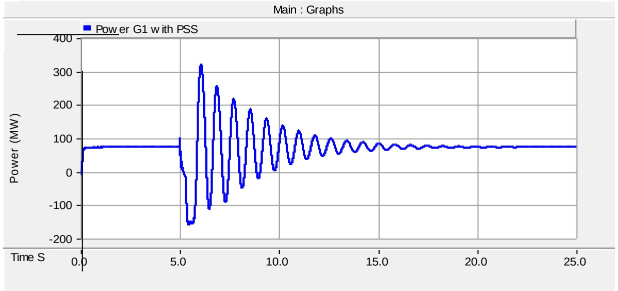

Fig. 6 Power Variation for FCC 0.31 second

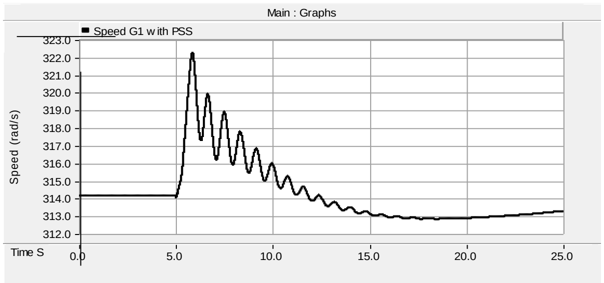

Fig. 7 Speed variation for FCC 0.31 second

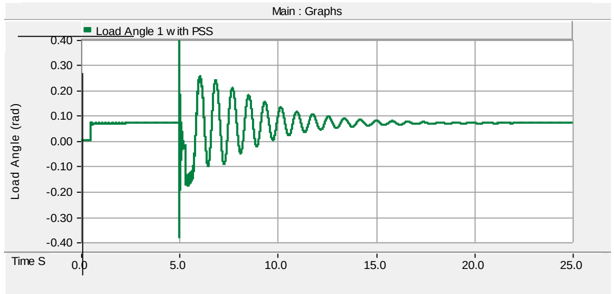

Fig. 8 Load Angle Variation for FCC 0.31 second

Case2-Now in second case increases the value of fault clearing time by .01 second. Due to small increment in fault clearing time not much variation is seen. Power, speed, and load angle variation is damped out approximately about 15 second and system becomes stable.

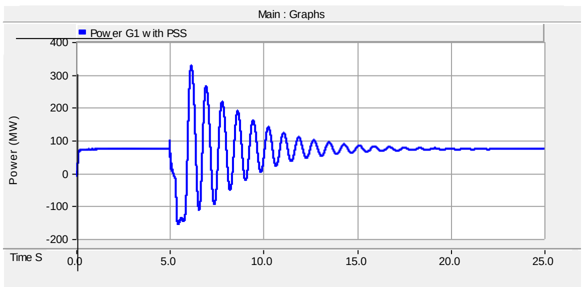

Fig. 9 Power Variation for FCC 0.32 second

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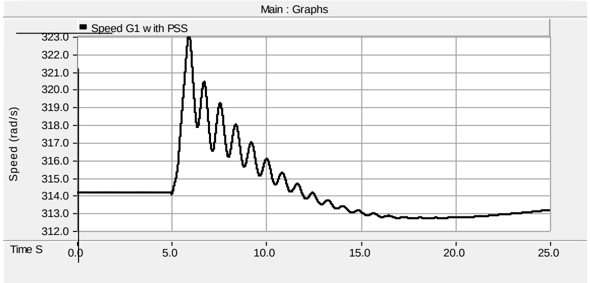

Fig. 10 Speed variation for FCC 0.32 second

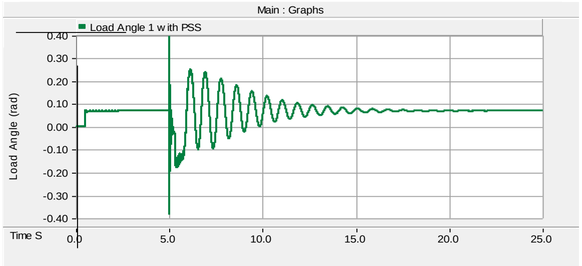

Fig. 11 Load angle variation for FCC 0.32 second

Case-3Again increases the fault clearing time by .296 second. Now the fault clearing time is .327 second. first overshoot observed in this case also same as the previous one and after 15 second system becomes stable.

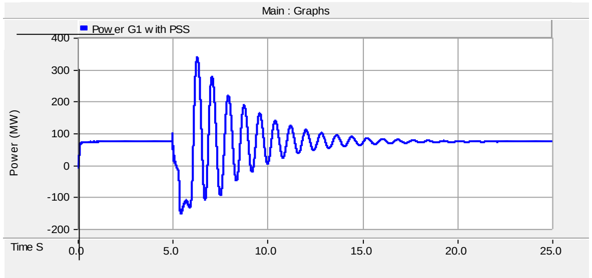

Fig. 12 Power variation for FCC 0.327 second

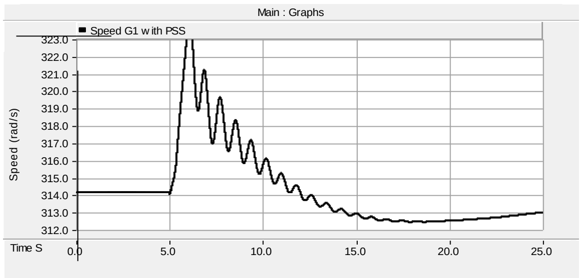

Fig. 13 Speed variation for FCC 0.327second

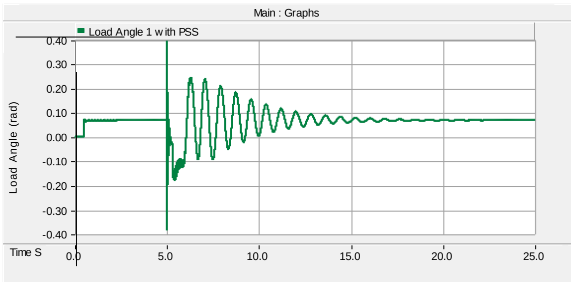

Fig. 14 Load angle for FCC 0.327

Case-4 Increaing the fault clearing time by.0002 second. Now the fault clearing time is 0 .3272 second. Variation in power, speed and load angle for generator 1 is damp out approximately about 18 second and system becomes stable.

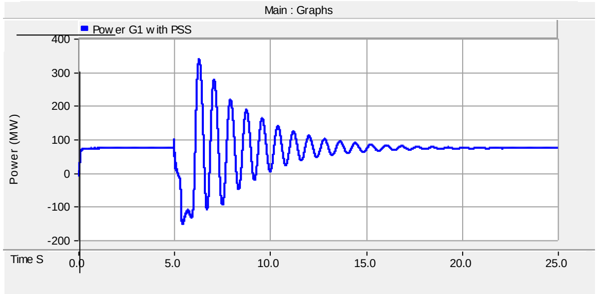

Fig. 15 Power variations for FCC 0.3272 second

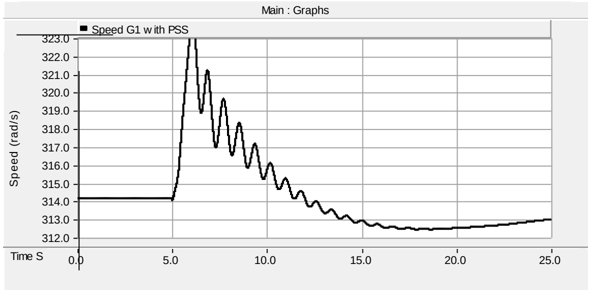

Fig. 16 Speed variation for FCC 0.3272 second

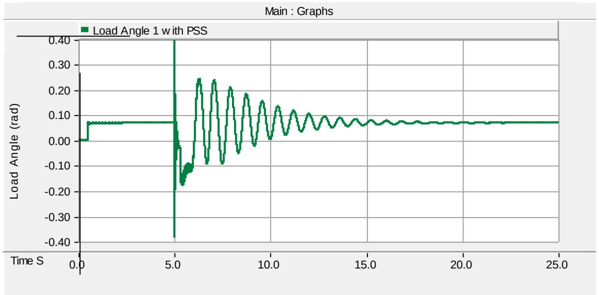

Fig. 17 Load angle variation for FCC 0.3272 second

Case-5 Fault clearing time is now increases by .00005 second .Now the fault clearing time is 0 .3272500. With this increment in fault clearing time speed, power and load angle variation for generator 1 for 3 phase fault has been damped out approximately15 second and system becomes stable.

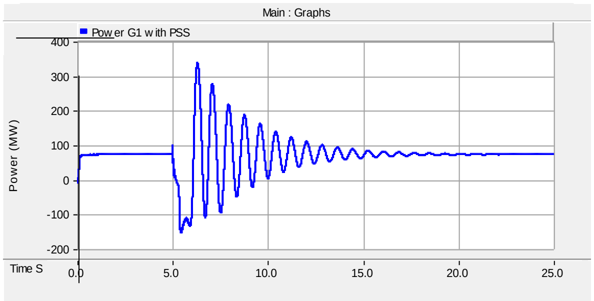

Fig. 18 Power variation for FCC 0.3272500 second

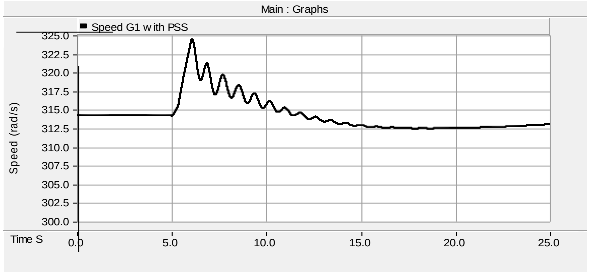

Fig. 19 Speed variation for FCC 0.3272500 second

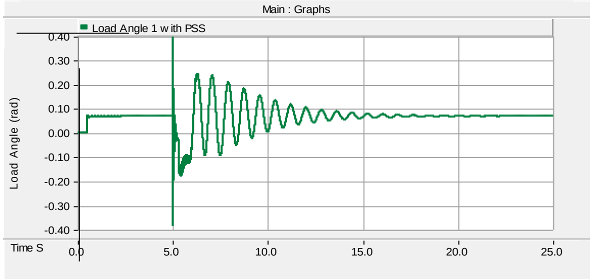

Fig. 20 Load angle for FCC 0.3272500 second

Case-6Finally increasing the fault clearing time by very small interval of .0000001 second. Now the operating time is 0.3272501second. From the waveform it is very clear that we observed very large variation in power, speed as well as in load angle and System become unstable.

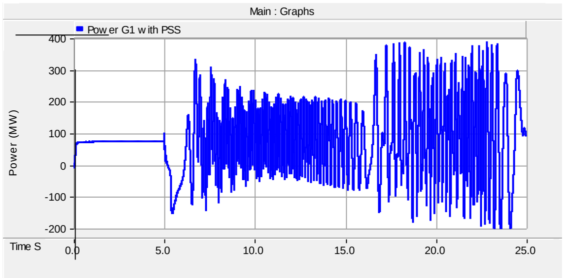

Fig. 21 Power variation for FCC 0.3272501 second

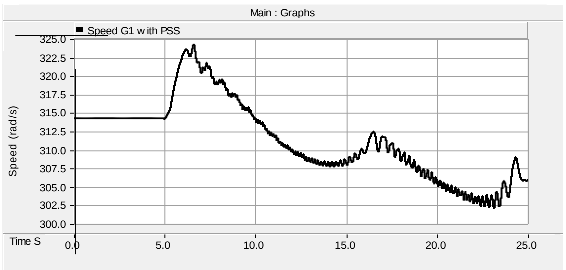

Fig. 22 Speed variation for FCC 0.3272501 second

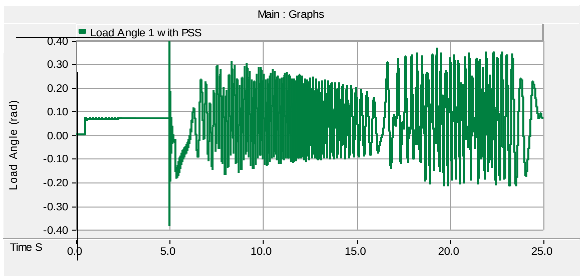

Fig. 23 Load angle for FCC 0.3272501 second

VII. CONCLUSION

System Responses are given for different fault clearing time. Fault is created near bus number 5 and it is cleared at different clearing time by opening the connecting line. For stable system overshoot patterns remain similer. And for unstable system large changes were observed in overshoot patterns. From the above response it is very clear that with very small increase in the value of fault clearing time system will move towards instability .As the fault clearing time is increases to .00000001 second system will become unstable .Large variation has been seen in the load angle with small increases in value of fault clearing time. Thus fault clearing time play a very important role for main ting system stability and this time can be make as small as possible with the help of numerical relay only because of its fast and aureate response.

APPENDIX

Generator data of IEEE 9 bus system

Parameter	G1	G2	G3
Operation mode	Swing	Voltage control	Voltage control
Rated MVA	80	220	110
KV	16.5	18	13.8
Power factor	0.90	0.85	0.85
Type	Hydro	Thermal	Thermal
Speed	1500	1500	1500
T'_{do}	5.6	5.6	5.6
T_{qo}	3.7	3.7	3.7

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