



Distance Protection of Series Compensated Transmission Line

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Abstract— In order to meet the high demand for power transmission capacity, some power companies have installed series capacitor on power transmission line. This allows reduction in line impedance, thus resulting increased power transmission capacity. The protective distance relays use impedance measurement in order to determine the location and presence of faults. The introduction of the capacitance in series with the line reactance adds certain complexities. The paper presents series compensated transmission line model by using PSCAD/EMTDC. Upon extensive testing on different data set of fault cases with fault resistance and varying percentage compensation level, performance of the developed method ensures that the proposed scheme gives the apparent effects on various system parameters by changing series compensation level.

Keywords— distance protection; series compensation; PSCAD/EMTDC; voltage inversion; current inversion

I. INTRODUCTION

Series compensation plays the vital role in modern heavily loaded grid transmission lines. The series capacitor makes sense because it is simple and could be installed for 15 to 30% of the cost of installing a new line. Series compensation in modern power systems influences the power flow in particular network segment, reduces active power losses prevents system and sub synchronous oscillations, and connects more robustly different subsystems to stronger integrated network. The introduction of series compensation in existing networks requires not only extensive studies into the expected performance of the new system but also into the influence of its introduction on the operation of existing protection control and monitoring systems [1].

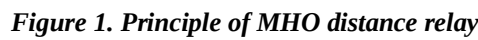
Series Compensation lines used series capacitor to cancel a portion of the inductive reactance of the line, and thereby improving the power transferring capability of the transmission line. To utilize the whole capacity of the series capacitor installation in a utility network, it is essential to understand the impact of series compensation on protection to design appropriate ways with necessary changes. Compensation in a transmission system is normally introduced for extra high voltage transmission line, which usually employs distance relay (Mho relay) for the protection purpose. A distance relay works on real time calculation of impedance of the line with real time measurements aided with types of fault information. Therefore, the position of fault with respect to the compensator (zone of fault) is required for a distance relay to accomplish its overall decision. Faulty phase selection also increases system stability and availability by allowing single pole tripping. This will improve the behavior of transient stability and reduces switching overvoltage in the system.

It is very difficult task to handle series compensated line during various abnormalities with relay settings. As it needs to develop adaptive feature like adaptive settings of relay, as the compensation level would change in the series compensated line. The introduction of the series capacitance in the lines adds many complexities to the effective performance of distance relay. The relay will try to look at the ratio of voltage and current to determine the distance to fault in order to decide if the fault is in its own zone or out of its protection zone. If it is known that the capacitor is always going to be part of fault loop, then reach setting of relay is possible [2].

II. DISTANCE PROTECTION OF TRANSMISSION LINE

Distance protection scheme is normally applied to protect long transmission lines. It acts as the main protection for overhead transmission lines and provides back-up protection to the adjoining parts of the network, such as bus bars, generators, transformers, motors, and further feeders. Distance protection is faster and more selective than overcurrent protection. It is also less susceptible to changes in the power system conditions. A further advantage of digital distance protection is that it can be easily adapted for a unit protection scheme, when applied with a communication link. Basically, a distance relay determines the impedance of the faulted portion of a transmission line from the measured voltages and currents at the relay location. The measured fault impedance is then compared with the set impedance of the transmission line to be protected. If the measured fault

High voltage transmission lines are generally equipped with distance protection. The basic idea of distance protection is shown in figure 1. The distance relay contains three distance measuring units it can be three separate units or one unit for the first and second zone with a timing unit to increase the delay of the former and a second unit for the third zone[4].



The figure consists of two parts. The top part is a graph titled "Setting Zones at Relay A". The vertical axis is labeled "Time (sec)" and has three marked points: T_1 , T_2 , and T_3 . The horizontal axis represents the setting zones. The 1st zone is represented by a blue solid line starting at T_1 and extending to the right. The 2nd zone is represented by a green solid line starting at T_2 and extending to the right. The 3rd zone is represented by an orange solid line starting at T_3 and extending to the right. Dotted lines show the continuation of these zones. The bottom part is a circuit diagram of a transmission line system. It shows three buses: A, B, and C. Between buses A and B, there is a transmission line with impedance Z_{AB} . Between buses B and C, there is a transmission line with impedance Z_{BC} . At bus A, there is a voltage transformer (VT) and a current transformer (CT) connected to a relay R_A . At bus B, there is a voltage transformer (VT) and a current transformer (CT) connected to a relay R_B . The load current I_L is indicated by an arrow pointing from bus A towards bus B.

The MHO distance relay uses three measuring distance units as shown in figure 4. In this figure we can see the different zones of protection setting in distance relay logic. Zone 1 set for 80% length of line Zone 2 for 50% length of line and Zone 3 protection for 20% length of line. This all settings are in R-X plan where impedance trajectory comes during faulty conditions.

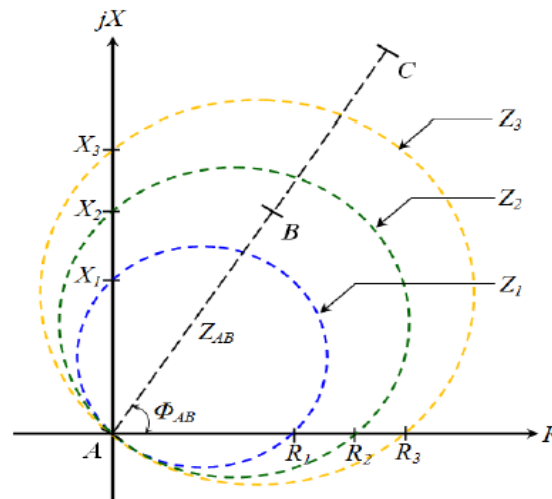


Figure 3. MHO circle

It is called mho relay because its characteristic is straight line on admittance diagram. The three unit of mho relay is used to protect as section of line. The first unit protects 80-90% of the line section that is high speed unit. The second unit protects rest of line plus 50% of adjacent line section. The third unit provides backup protection to adjacent line. The second and third unit operates after a pre-set timed delay usually 0.2 to 0.5 and 0.4 to 1 second respectively.

B. Impedance Seen by Distance Relay

Distance relays are designed to protect power systems against four basic types of faults L- G, LL-G, LL and three phase fault. In order to detect any of above faults each one of the zones of distance relays require six units. Three units for detecting faults between the phases and the remaining three units for detecting phase to earth faults. The setting of distance relays is always calculated on the basis of the positive sequence impedance. Table 1 indicates fault impedance calculation formulae for all of the fault types [5].

Table 1. Fault impedance calculation for different faults

Distance Element	Formula
Phase A	$Z_A = V_A / (I_A + 3kI_0)$
Phase B	$Z_B = V_B / (I_B + 3kI_0)$
Phase C	$Z_C = V_C / (I_C + 3kI_0)$
Phase A- Phase B	$Z_{AB} = V_{AB} / (I_A - I_B)$
Phase B- Phase C	$Z_{BC} = V_{BC} / (I_B - I_C)$
Phase C- Phase A	$Z_{CA} = V_{CA} / (I_C - I_A)$

Where, $k = (Z_0 - Z_1) / Z_1$, Z_0 and Z_1 are zero sequence and positive sequence impedances.

C. Proposed distance protection scheme

The main idea behind the proposed solution is to have a typical digital distance relay scheme with extra information received from other local and remote relay. The relay changes its setting or action based on the received information. The concept of adapting the relay performance based on information from other relays is receiving much more acceptance because the speed of data transfer has increased and the expense of communication systems has declined.

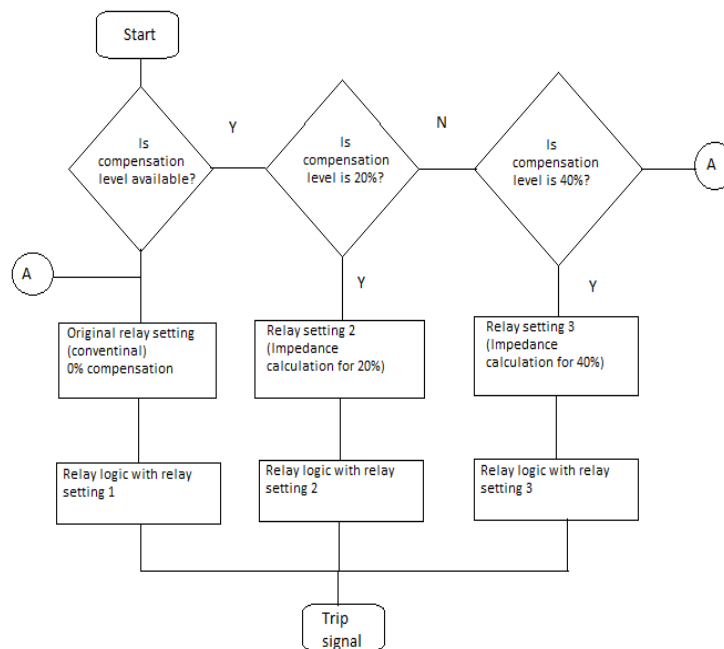


Figure 4. Sequence of proposed Adaptive Distance Protection Scheme

The proposed adaptive scheme is detailed in the figure 4. First checks to see whether the series compensation level is available. The steady state characteristics are modelled for the three compensation levels like 0%, 40% and 60%. Depending on the availability of the compensation level, the relay adapts its setting accordingly. Then the dynamic characteristics of the relay are obtained using Full Cycle Fourier Algorithm (FCF) to check the status of the particular relay. The capacitance to particular compensation level will be used for faulted line impedance computation, but will not be used in healthy line's impedance calculation. Whenever the required information is not available, the proposed scheme uses the default setting as a conventional relay without the capacitor in the distance computation [1].

III. VOLTAGE INVERSION AND CURRENT INVERSION

Voltage inversion is the phenomena that the relay sees the fault on the protected transmission line in the reverse direction or the change of 180 degree in the voltage phase angle. This can be explained in the below figure 5. Here a series compensated transmission line is shown, where the Series Capacitor (SC) is located in the substation. Now consider a fault occurring after capacitor bank.

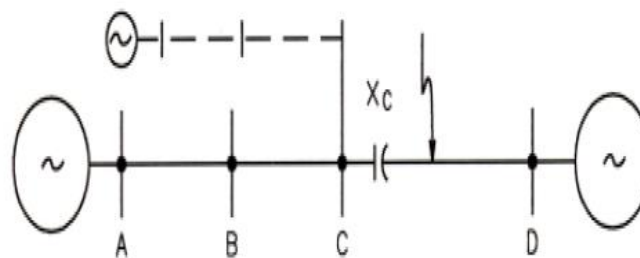


Figure 5. voltage inversion

Relay see an inverted or reverse voltage at the location of fault. In other word relay see this fault as a reverse fault. If the impedance from the relay to the fault is Capacitive rather than inductive then voltage inversion will occur. Voltage inversion may affect both directional and distance elements. Thus depending on the location of the fault, the relay sees a fault to be a forward or a reverse one. Now at a particular bus the condition for the voltage inversion assuming negligible resistance in the fault loops are as follows,

$$X_c > mX_L$$

$$X_c < mX_L + X_A$$

X_c is the line capacitance
 X_L is the inductive reactance
 m is the fault location in pu
 X_A is the reactance of source A

Conditions specify that the net impedance from bus C to fault location is capacitive and from bus A to Bus C is inductive so at bus C voltage reversal will occur [6].

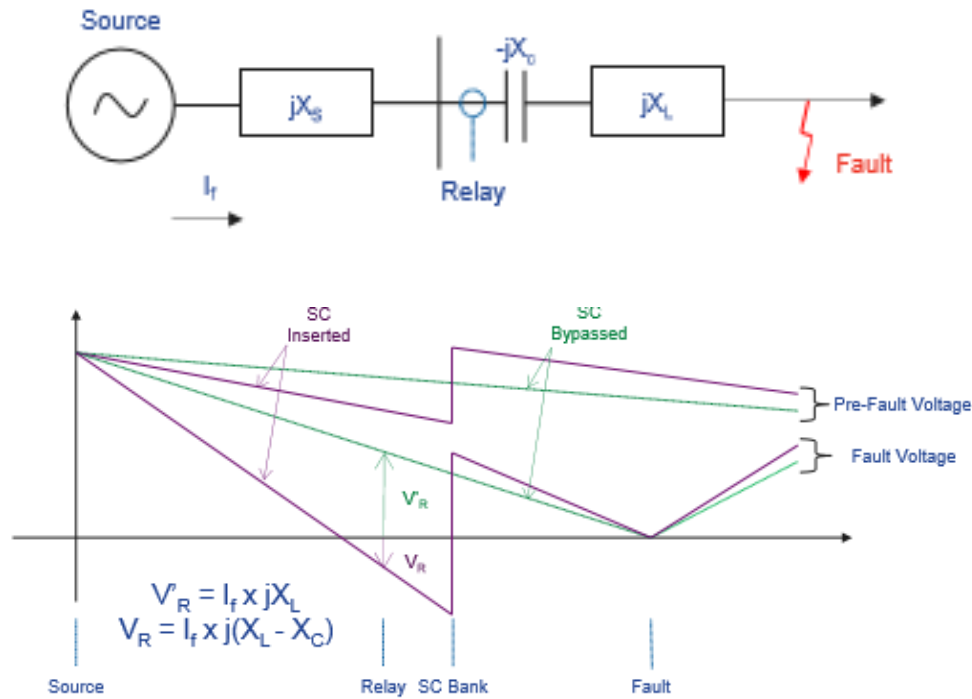
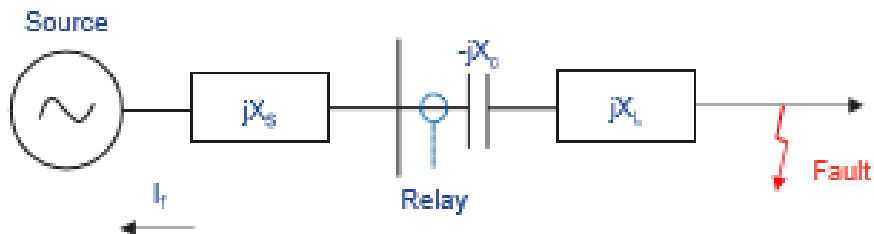


Figure 6. Voltage inversion during series compensation

With the SC bypassed, the voltage at the relay point, V_R , is equal to the voltage drop on the line and will lead fault current. If, With the SC inserted, it will increase due to lower overall impedance and the relay voltage, V_R , will be equal to the voltage drop across the combination of the line and SC reactance.

If $X_C > X_L$, the voltage at the relay point, V_R , will lag fault current. In this case the voltage at the relay point is inverted. Voltage inversion can lead to directional discrimination problems at the relay.



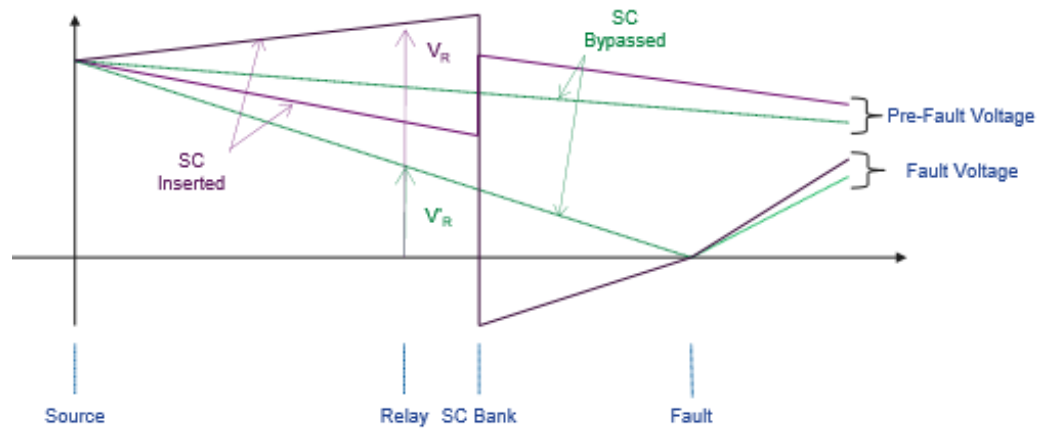


Figure 7. Current inversion during series compensation

A current inversion occurs in a series compensated transmission line, for an internal fault, the equivalent system at one side of the fault is capacitive and the equivalent system at another side of the fault is inductive. The current flows out of the line at one terminal, which is referred to as current out feed. In case of current inversion relay sees fault current in the reverse direction because of large capacitive reactance in the fault loop.

The voltage and current inversion cannot happen simultaneously. Current inversion may occur for the faults closer to the relay and for system having small source impedance. With the SC bypassed, fault current normally flows from the power source towards the fault point and fault current will lag source voltage.

IV. TRANSMISSION LINE MODEL

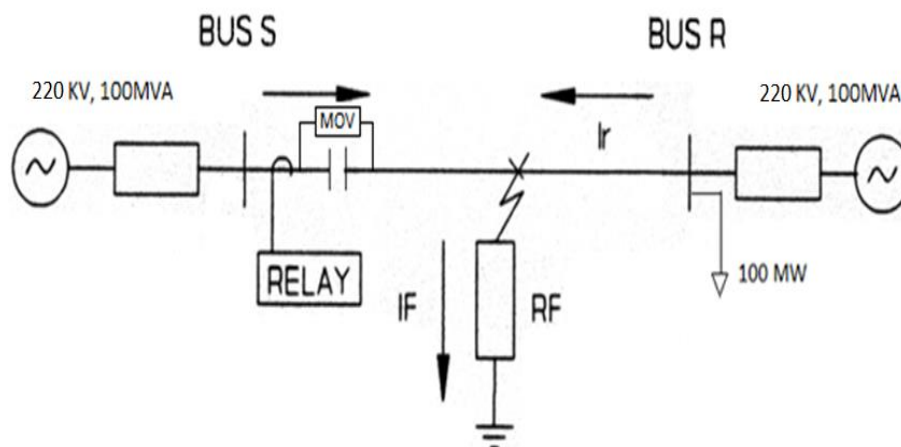


Figure 8. Single line diagram of system

Table 2. System parameters

Line length	300 km
Resistance of line	0.01273 Ω /km
Inductance of line	1.244 mH/km
Capacitance of line	12.74 nF/km
Source	220 KV, 100 MVA
Load	100 MW, 25 MVAR
Frequency	50 Hz

V. SIMULATION RESULTS

Here, fault applied at three different locations and it as follow: L1-at bus S, L2-at middle of the line and L3-at bus R. The series capacitor is located at location 1. For further analysis of the effects of series compensation on the operation of distance relay, we used three sorts of compensation level at 0%, 20%, and 40%. And we tested it for various fault resistance like 0.01, 10, 20, and 40 ohms respectively.

The fault applied at 0.2 sec and duration of fault is 0.06 sec with system frequency of 50Hz. To test the suggested scheme the simulation studies have been carried out under wide variation of fault resistance and fault locations for double line fault.

Table 3. Line to Line (B-C) fault analysis

Fault	R(Ω)	Location	Fault applied at 0.2 Second Relay operation in Second		
B-C	0.01	L1	0% Comp.	20% Comp.	40% Comp.
		L2	0.2082	0.2122	0.2122
		L3	0.2119	0.2168	0.2260
	10	L1	0.2193	0.2177	0.2269
		L2	0.2119	0.2113	0.2113
		L3	0.2193	0.2223	0.2223
	20	L1	0.2193	0.2260	0.2260
		L2	0.2107	0.2122	0.2131
		L3	0.2193	0.2269	0.2251
	40	L1	0.2217	0.2260	0.2260
		L2	0.2131	0.2131	0.2131
		L3	0.2205	0.2214	0.2214

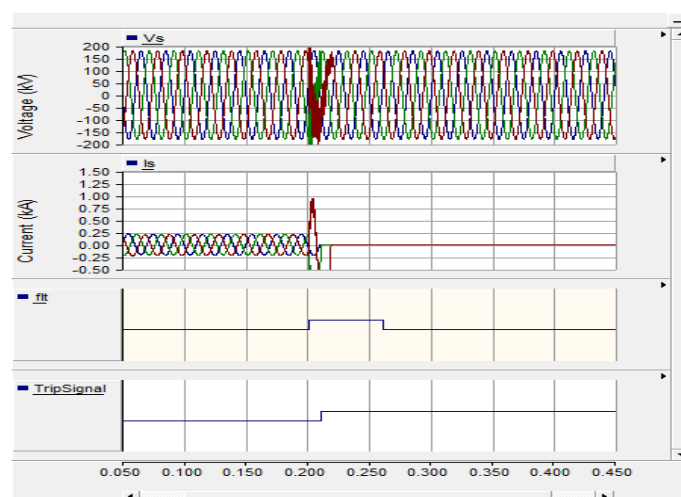


Figure 9. V&I waveform for L-L fault

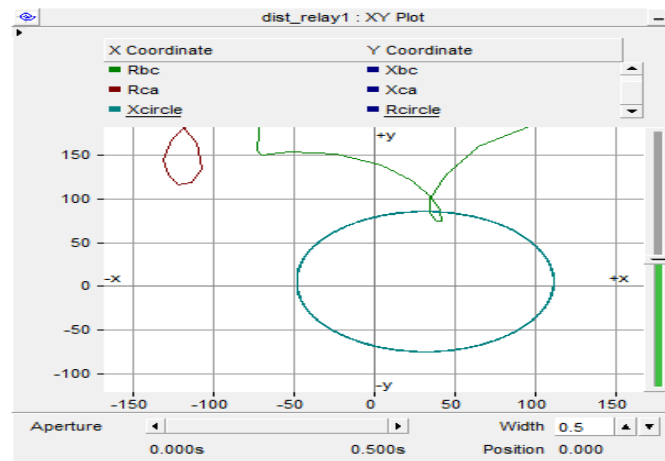


Figure 10. Fault at location L2, $R=0.01\Omega$, 0% comp.

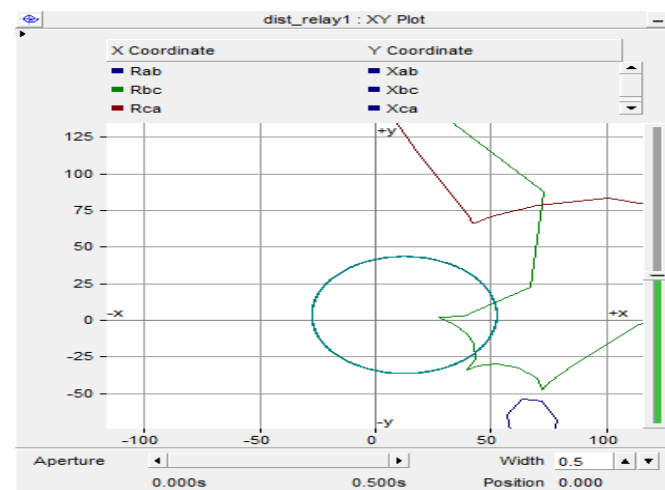


Figure 11. Fault at location L1, $R=10\Omega$, 40% Comp.

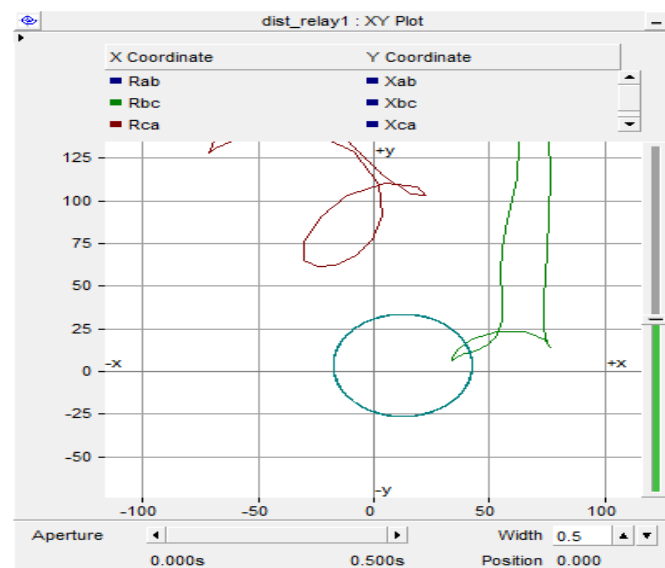


Figure 12. Fault at location L2, $R=10\Omega$, 40% Comp.

VI. CONCLUSION

This Project involved the usage of PSCAD Simulation for the fault detection of the Transmission Line. Here the simulation study is analyzed for line to line (B-C) faults. The Performance of the MHO relay is evaluated for different fault locations with various values of fault resistance. The RX plots show that the relay adapts its characteristic to trip itself in the respective Zones and for all the three compensation levels (0%, 20%, 40%), according to the information received on the system condition. For this we can say that when the fault occurs, the particular phase voltage drops and simultaneously the current of that phase is increased. Here, we can see that the relay issues the trip signal as fault occurs.

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