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Research Papers

VOLTAGE PROFILE IMPROVEMENT USING SERIES HYBRID ACTIVE FILTERS

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Abstract

The increase of nonlinear loads due to the proliferation of electronic equipment causes power quality in the power system to deteriorate. Harmonic current drawn from a supply by the nonlinear load results in the distortion of the supply voltage waveform at the point of common coupling (PCC) due to the source impedance. Both distorted current and voltage may cause end-user equipment to malfunction, conductors to overheat and may reduce the efficiency and life expectancy of the equipment connected at the PCC. An series active filter (SAF), typically consists of a three phase pulse width modulation (PWM) voltage source inverter, when this equipment is connected in series with the ac source impedance it is possible to improve the compensation characteristics of the passive filters in parallel connection.A three-phase series hybrid active filter(SHAF) topology is proposed in this project for improving the voltage profile in a distribution system. It is constituted by a series active filter and a passive filter connected in parallel with the load. The control strategy is based on the instantaneous reactive power theory, so that the voltage waveform injected by the active filter is able to compensate the reactive power and the load voltage harmonics and to balance asymmetrical loads. The proposed algorithm also improves the behavior of the series active filter with the introduction of passive filter. Hysteresis current control PWM method is used for producing switching signals for the switches of voltage source inverter. Simulations have been carried out on the MATLAB-Simulink platform with Non linear load and the results are presented and analysed. The proposed d-q theory effectively produced compensating reference voltage and hysteresis current control PWM method produced the required switching signals to control the switches effectively. The results show that the proposed topology of SHAF improved the voltage quality at the point of common coupling.

KEYWORDS:

Series Hybrid, Voltage Profile, electronic equipment, point of common coupling.

INTRODUCTION

Nowadays, the growth of the digital economy implies a widespread use of electronic equipment not only in the industrial and commercial sectors, but in the domestic environment too. Studies undertaken in different countries on the contribution of Information and Communication Technology (ICT) to the consumption of electricity conclude that office and telecommunication equipment used in the nonresidential sector represents about 3 or 4% of the annual consumption of electricity. This will not only bring about a greater demand for power, but in addition a higher level of Power Quality and

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Reliability (PQR), in quantities and time frames that have not been experienced before. It has been estimated that more than 30% of the power currently being drawn from the utility companies is now heading for sensitive equipment, and this is increasing. The electronic devices demand for higher PQR stems from the fact that semiconductor components require low-voltage direct current and are highly sensitive to short power interruptions, voltage surges and sags, harmonics, and other waveform distortions.

1.2 Causes For Voltage Problems:

1.2.1 Voltage Sag:

Voltage sag is an event where the line rms voltage decreases from the nominal line-voltage for a short period of time. Figure 1.1a shows an 80 percent sag with a duration of a few 60-Hz cycles. This type of variation can occur if a large load on the line experiences a line-to-ground fault, such as a short in a three-phase motor or a fault in a utility or plant feeder.









Fig 1.1b Voltage sag due to a single line-to-ground fault.

In Figure 1.2, we see a circuit with a line supplying an electric motor. Note that the line impedances cause a voltage drop when currents are drawn from the line. When the motor is energized, the motor current Im causes a voltage drop to other loads in the system at the point of common coupling (PCC). Figure 3.2b displays voltage sag due to a large motor starting, such as a pump or air-conditioner motor. Note that when an induction motor starts, it can draw very high currents until the rotor comes up to speed. This high current causes a significant voltage drop due to the impedance of the line.





Fig 1.2 Voltage sag caused by motor starting.



1.2.2 Voltage Swell:

A swell is the converse of the sag, and is a brief increase in the rms line voltage. Shown in Fig 1.3 is a voltage swell caused by a line-to-ground fault.

1.2.3 Impulsive Transient:

An impulsive "transient" is a brief, unidirectional variation in voltage, current, or both on a

power line. The most common sources of impulsive transients are lightning strikes (Figure 1.4). Impulsive transients due to lightning strikes



Maximum Harmonic Current Distortion in Percent of I_L Individual Harmonic Order (Odd Harmonics)						
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harm	onics are lir	nited to 25% of t	the odd harmoni	ic limits above.		
Current dis	tortions tha	t result in a dc o	offset, e.g., half-v	wave converters,	are not allo	wed.
*All power i actual I_{sc}/I_L	generation e	quipment is limi	ted to these valu	es of current dist	ortion, regar	dless of
Where $I_{SC} = ma$	ximum sho	rt-circuit curren	it at PCC. t (fundamental f	frequency comp	ment) at PC	c

Shown in table 1.1 are harmonic distortion limits found in IEEE 519 for current drawn by loads at the point of common coupling. The current harmonic distortion limits apply to limits of harmonics that loads should draw from the utility at the PCC. Note that the harmonic limits differ based on the I_{sc}/I_L rating, where I_{sc} is the maximum short-circuit current at the PCC, and I_L is the maximum demand load current at the PCC. IEEE Standard 1159 is entitled "IEEE Recommended Practice for Monitoring Electric Power Quality," and as its title suggests, this standard covers recommended methods of measuring power-quality events. Many different types of power-quality measurement devices exist and it is important for workers in different areas of power distribution, transmission, and processing to use the same language and measurement techniques.

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1.4.2 Voltage Standards in Middle- and Low-Voltage Distribution Networks:

In slow voltage changes in middle- and low-voltage distribution networks are the reason in the normal state, 95% of 10-minute mean values of measured r.m.s. voltage must be Un $\pm 10\%$ for each week.

Table 1.2 Values of individual harmonic voltages at the supply terminals for orders up to 25.

Odd harmonies				Even harmonies	
Not multiples of 3		Multiples of 3			
Order h	Relative voltage (%)	Order h	Relative voltage (%)	Order h	Relative voltage (%)
5	0	3	5	2	2
7	5	•	1.5	-1	
	3.5	1.5	0.5	6-24	0.5
1.25	23	21	0.5		
7	2				
9	1				
1.0	1.5				
2.25	1.5				

 Table 1.3 Voltage distortion limits.

Bus voltage at PCC	Individual voltage distortion (%)	Total voltage distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

Equipment subject to source voltage sags will respond in one of the following ways:

1.Restart with no damage—for example, home appliances.

2.Restart with some damage—for instance, computer with damage to functions that prevent a restart. 3.Require manual intervention to restart—such as motors in equipment where automatic restarting may be a hazard.

4. Will not restart—for example, the equipment is damaged due to voltage sag.





connected in series.

Fig 2.1 12-pulse converter. The bridges are Fig 2.2(a) The input current to each bridge, and the line current to the transformer.



Fig 2.2(b) The resultant line current from PWM.

3.1 Series Active Filter - Principle Operation:

The basic principle of APF is to produce specific harmonic current components that cancel the harmonic current components caused by the nonlinear load. Figure 3.1 shows the components of a typical APF system and their connections. The information regarding the harmonic currents and other system variables are passed to the compensation current/voltage reference signal estimator. The compensation reference signal from the estimator drives the overall system controller. This in turn provides the control for the gating signal generator. The output of the gating signal generator controls the power circuit via a suitable interface. Finally, the power circuit in the generalized block diagram can be connected in parallel, series or parallel/series configurations depending on the interfacing inductor/transformer used.



APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APF performances are independent of the power distribution system properties.

The series APF is connected in series with the distribution line through a matching transformer as shown in fig 3.2. VSI is used as the controlled source, thus the principle configuration of series APF is similar to shunt APF, except that the interfacing inductor is replaced with the interfacing transformer. The utilization of fast switching device in APF application causes switching frequency noise to appear in the compensated source current and interference with neighboring sensitive equipment. Technical limitations of conventional APFs mentioned above can be overcome with hybrid APF configurations. They are typically the combination of basic APFs and passive filters. Hybrid APFs, inheriting the advantages of both passive filters and APFs, provide improved performance and cost-effective solution. The idea behind this scheme is to simultaneously reduce the switching noise and electromagnetic interference.

Figure 3.3 shows the system configuration of hybrid series APF, in which the series APF is coupled to the distribution line by an interfacing transformer. The shunt passive filter consists of one or more single-tuned LC filters and/or a HPF. The hybrid series APF is controlled to act as a harmonic isolator between the source and nonlinear load by injection of a controlled harmonic voltage source.



Fig 3.3 Combination of series APF and shunt Fig. 3.4 Active Power Filter with the proposed control passive filter.

3.2.1.1 Synchronous-Reference-Frame (d-q) Theorem:

The performance of the active filter mainly depends on the methodology adopted to generate the reference current and the control strategy adopted to generate the gate pulses. We have so many methodologies to generate the reference current like Instantaneous Reactive-Power (p-q) theorem, Synchronous-detection theorem, Sine-Multiplication Theorem and Synchronous-Reference-Frame (d-q) Theorem. Among all of them d-q theorem having an advantage to implement.

The block diagram representation of the proposed control technique for the SAF is shown in Fig 3.4. The control strategy is implemented in three stages. In the first stage, the essential voltage signals are measured to gather accurate system information. In the second stage, compensating currents are derived based on synchronous reference D-Q theory. In the third stage, the gating signals for the solid-state devices are generated using HCPWM control method. There are several methods to extract the harmonic components from the detected three-phase waveforms. Among them, the so-called D-Q theory based on time domain has been widely applied to the harmonic extraction circuit of SAF. The detected three-phase voltage is transformed into the D-Q-0 co-ordinates as shown in Fig.3.4. Two first

order digital high pass filters (HPFs) with the same cut off frequency as 20 Hz extract the dc component V_{hd}^* , V_{hq}^* and V_0 which corresponds to the fundamental frequency in the coordinates.

The current reference for the voltage – source inverter is the sum of the current references from the three parts, as follows:

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 $I_{fd}^{*}(s) = K_v (G_h V_{hd}^{*} - V_d) + Preg \text{ or } (V_{dc}^{*} - V_{dc}) K$ (1) $I_{fq}^{*}(s) = K_{v}(G_{h}V_{hq}^{*} - V_{q})K$ (2) $I_{0}^{*}(s) = 1/3 (V_{a} + V_{b} + V_{c})K$ (3)

The obtained current reference is converted in to three phase current reference by inverse D-Qtransformation I_{fa}^* , I_{fb}^* , and I_{fc}^* . The three phase reference filter current is compared with the active filter compensating current extracted from ac system. Thus three phase filter currents Ifa, Ifb, and Ifc are produced. The obtained reference current is given to a HCPWM scheme, which is used to generate controlled gate signal for SAF.

3.2.2 Generation of firing signals for switching devices:

The aim of APF control is to generate appropriate gating signals for the switching devices based on the estimated compensation reference signals. The performance of an APF is affected significantly by the selection of control techniques. Therefore, the choice and implementation of the control technique is very important for the achievement of a satisfactory APF performance. A variety of control techniques, such as linear control digital deadbeat hysteresis control have been implemented for the APF applications. This section briefly describes the considered control techniques and their basic features.

3.2.2.1 Hysteresis Current Controller:

HCPWM controller derives the switching signals of the inverter power switches in a manner that reduces the current error. The switches are controlled asynchronously to ramp the current through the inductor up and down so that it follows the reference. The current ramping up and down between two limits is illustrated in Fig.3.6. When the current through the inductor exceeds the upper hysteresis limit a negative voltage is applied by the inverter to the inductor. This causes the current in the inductor to decrease. Once the current reaches the lower hysteresis limit, a positive voltage is applied by the inverter to the inductor and this causes the current to increase and the cycle repeats.



Fig 3.5 Hysteresis current controller block diagram. Fig 3.6 Hysteresis current controller operational

waveform.

The current controllers of the three phases are designed to operate independently. Each current controller determines the switching signals to the inverter. The switching logic for phase A is formulated as below;

If $ifa < (i*_{fa} - HB)$ upper switch is OFF and lower switch is ON. If $ifa < (i_{fa} + HB)$ upper switch is ON and lower switch is OFF.

In the same fashion, the switching of phase B and C devices are derived.

The DC side of the inverter is connected to a capacitor. The DC capacitor provides a constant DC voltage and the real power necessary to supply the losses of the system. In the steady state, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter. Thus, the DC capacitor voltage can be maintained at a reference value. However, when the load condition changes the real power balance between the mains

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and the load will be disturbed. The real power difference is to be compensated by the DC capacitor. This changes the DC capacitor voltage away from the reference voltage. A fuzzy logic controller is applied to maintain the constant voltage across the capacitor by minimizing the error between the capacitor voltage and the reference voltage.

Tuned Harmonic Order	$n = \frac{f_n}{c} = \sqrt{(X_c/X_L)}$	$f_{\underline{i}}$ =Fundamental Frequency
Quality Factor	J_1	$\omega = 2\pi f_1 = $ angular frequency
Band With	$Q=nX_L/R = X_c/(nR)$	\int_{n} = tuning frequency
Reactive Power <i>f</i> .	$B = f_n/Q$	n=Harmonic order
Active Derver et ($Q_{1} = \frac{V_{2}}{n_{0}}(n_{0} - 1)$	V-nominal line valtage
Active Power at J_1	$X_C X_C X_C$	X_{L} = inductor reactance at
	$P_c = \frac{Q_c}{2} \cdot n(n_2 - 1)$	fundamental frequency=L ω X. = Capacitor reactance at
	Q	fundamental
		frequency=1/Cw

 Table 3.1 Parameters of Single Tuned Filter.

At fundamental frequency, the resistance is, therefore, bypassed by the resonant LC circuit and losses are null. The quality factor of the C-type filter is still given by the ratio:

 $Q = (L * 2\pi f_n)/R.$

3.3.1 Fifth Order Single Tuned Filter design: Fundamental Frequency $(f_i) = 50$ Hz. Fifth order frequency $(f_s) = 250$ Hz. Quality Factor (Q) =75. Let the fifth order capacitor of capacitance $(C_s) = 30\mu$ F. We know that 5th order Frequency is given by

$$f_{5} = \frac{1}{2\pi\sqrt{L_{5}C_{5}}}$$

$$250 = \frac{1}{2\pi\sqrt{L_{5} * 30 * 10 * 10^{-6}}}$$

$$\frac{1}{2\pi\sqrt{L_5 * 30 * 10 * 10^{-6}}}$$

Now $Q = (L_5 * 2\pi f_5)/R$.

75 = $(13.509 * 10^{-3} * 2\pi * 250)/R$

R = 0.2829 fi.

3.3.2 Seventh Order Passive Filter Design:

Fundamental Frequency $(f_1) = 50$ Hz. Seventh order frequency $(f_2) = 350$ Hz.

Quality Factor (Q) =75. Let the seventh order capacitor of capacitance (C_7) =30µF. We know that 7th order Frequency is given by

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$$f_7 = \frac{1}{2\pi\sqrt{L_7 C_7}}$$

$$350 = \frac{1}{2\pi\sqrt{L_7 * 30 * 10 * 10^{-6}}}$$

$$L_7 = 6.8926 * 10^{-3} \text{ H.}$$
Now $Q = (L_7 * 2\pi f_7)/R.$

 $75 = (6.8926 * 10^{-3} * 2\pi + 250)/R$

R = 0.2021 fi.

By using the all above values the Single Tuned Passive filter is designed.

SIMULATION OF SERIES HYBRID ACTIVE FILTER USING MATLAB/SIMULINK DISCUSSION OF MATLAB-TOOLS OF SERIES HYBRID ACTIVE FILTER 4.1Simulation Of Test System:

The test system consists of 3 phase A.C Source, non linear diode rectifier bridge load as shown in fig 4.1.





4.1.1 Three-Phase A.C Voltage Source:

The A.C Voltage Source block is constructed from Simulink Library in each phase. The Voltage source are with the values of V=400V (RMS), f=50Hz in each phase with 120° phase shift. Source Inductance is connected in series with the Source with the value of 5mH in each phase.

4.1.2 Non-Linear Diode Rectifier Load:

Three Arm full bridge converter constructed by six diodes on D.C Side of the RC load collected from Sim poewer system elements in Simulink library.

The resistance of the diode=0.001 ohm. Load parameters are as follows, The Nominal Voltage=1000V (RMS). The Nominal Frequency=50Hz. Active Power=10KV. Capacitive Reactive Power=10000 VAR (negative).

4.2 Test System with Series Hybrid Active Filter:

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$$f_7 = \frac{1}{2\pi\sqrt{L_7 C_7}}$$

$$350 = \frac{1}{2\pi\sqrt{L_7 * 30 * 10 * 10^{-6}}}$$

$$L_7 = 6.8926 * 10^{-3} \text{ H.}$$
Now $Q = (L_7 * 2\pi f_7)/R.$

 $75 = (6.8926 * 10^{-3} * 2\pi + 250)/R$

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4.2 Test System with Series Hybrid Active Filter:



Fig 4.2 Test System with Series Active Filter.

The test system consists of series hybrid active filter consists of voltage source inverter pulse generator and coupling transformer.

4.2.1 Reference Current Generator:

Reference current generator consists of PI controller with proportional gain 0.1 and integral gain of 20 is connected with DQ subsystem which are brought from simulink library. In DQ sub system the signal is given from PI controller is given to sum2 which is brought from simulink library. The output of abc to dqo transformation is connected to mux and is given to the 2nd order filter with 75Hz frequency is connected to sum and the output of that sum is given to gain which is connected with sum2 and output of the sum is given to mux. The output of that mux is given to transformation, the output of the transformation is controller.



Fig 4.3 dq Subsystem.



4.2.2 Hysteresis Controller:

In Hysteresis Controller for a single phase the output taken from dq sub system is given to the gate pulse generator through a relay of switch on point +0.05 and OFF point at -0.05 is taken from functional lock of simpower system library, data conversion Boolean, logical operator NOT, and data type conversion Double which are taken from simpower system library. Similarly for remaining two phases.

4.3 Test System with Series Hybrid and Shunt Passive Filters:

To improve the performance of the Test System, Shunt Passive Filters are added. Among various types of Passive Filters here we are used Single Tuned Filter. The design of the filter is explained in the section 3.3.



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The Single Tuned Filter is designed to eliminate 5th and 7th order harmonics is shown in fig 4.6. The 5th order filter designed with elements Resistor of Resistance 0.2829 fi , Inductor of inductance 13.5094 mH in series with capacitor of capacitance 30 micro Farads. The 7th order filter designed with elements Resistor of 0.2021fi Inductor of inductance 6.89 mH in series with capacitor of capacitance 30 μ F.

4.4 Test System on Three Phase Fault:



Fig 4.7 Test System On Fault.

A fault is connected in parallel with the system. The fault resistance (R_on) of 0.001fi and Ground resistance of (R_g) of 0.00fi. Transition time is from one to two seconds. Snubber Resistance (R_p) of 1Mfi.

Three phase series RLC load is connected in addition to that of Non-Linear Load to estimate the Reactive power.

RLC Load Parameters are as follows,

Nominal Phase to phase Voltage (V_n) (RMS)=282.8V Nominal Frequency (f_n) =50Hz Active Power (P)=1KW Inductive Reactive Power (Q_L) =100VAR Capacitive Reactive Power (Q_C) =100VAR

RESULTSANDANALYSIS

This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy for the SAF to reduce the harmonics. Fig.4.2 shows the system used to carry out the analysis. The system consists of a three phase voltage source, and an uncontrolled rectifier with RL load. The active filter is connected to the system through an inductor Lf and Capacitor Cf. The Matlab/Simulink is used to simulate the test power system with and without the proposed SAF.Figs. 5.1 and 5.2 show the three phase source voltages and currents of test power system without Filters. It can be seen that the harmonic has severely disturbed the voltages as well as currents. Fig 5.3 shows the harmonic spectrum of phase a source voltage without filters. It can be found that the THD is 7.41 % and for current the THD is of 46.11% shown in fig 5.4 for proposed test system.



Fig 5.1 . Three phase supply voltages of test power system power system without filters



Fig 5.2 Three phase source currents of test power system without filters

	power system without mens	
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Fig 5.3 Harmonic spectrum of phase a source voltage current without Filters.







Fig 5.5 Three phase supply voltages of test power system Fig 5.6 Harmonic spectrum of phase-a source with SAF. voltage with SAF.

Figs. 5.5 show the three phase voltages of test power system with SAF. It could be found that the wave shapes of the voltages are in sinusoidal form with minimized harmonic distortions of 4.96%. The harmonic spectrum is shown in fig 5.6.



Fig 5.7 Three phase supply voltages of test power system Fig 5.8 Harmonic spectrum of phase-a source voltage with SAF and and passive filters. passive filterswith SAF

For a better improvement of THD we use Shunt Passive Filters. By including the passive filters the THD will decreases and reduces the ripples on source voltage wave forms which shown in fig 5.7 and the Harmonic spectrum of phase a is shown in fig 5.8



Fig 5.9 Voltage and Current levels at Fault Duration. Fig 5.10 Active Power and Reactive Power of

Filter during Fault.

Fig 5.9 shows the voltage and current waveforms of filter while the fault is taken place. During faulty condition the voltage level is increased and current levels decreased. Fig 5.10 shows the Active and Reactive power injected by the Shunt Active Filter during fault condition. It is to be noted that by the injection of Reactive power, the power is compensated even thought fault occurs. 12

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Table 5.1 comparison of THD in %

THD% Vsb Vsa Vsc Isa Isb Isc Without filters 7.41 7.41 7.40 46.11 46.12 46.11 With SAF 4.96 4.97 4.93 36.64 36.38 36.7 With SAF&SPF 2.85 2.91 2.87 9.74 10.19 9.82

Tables 5.2 show the THD analysis of supply currents and voltages with and without SAF. From the Table 5.2, with the combination of SAF and SPF, THD is very low compared to with SAF and without Filters.

CONCLUSION AND SCOPE FOR FUTURE ENHANCEMENT

6.1 CONCLUSIONS:

A series hybrid power filter topology constituted by a series active filter and a passive filter connected in parallel with the load is proposed for voltage mitigation. The control strategy is based on Synchronous reference frame (d-q) theory which effectively generated the required reference compensating voltages. The hysteresis current control method worked effectively in reducing THD in source voltage and current. The proposed control approach achieves the following targets.

1. The burden on source is reduced.

2. The compensation characteristics of the hybrid compensator do not depend on the system impedance. 3. The set hybrid filter and load presents a resistive behavior. This fact eliminates the risk of overload due to the current harmonics of nonlinear loads close to the compensated system.

4. This compensator can be applied to loads with random power variation as it is not affected by changes in the tuning frequency of the passive filter. Furthermore, the reactive power variation is compensated by the active filter under fault condition.

Therefore, with the proposed control algorithm, the active filter improves the harmonic compensation features of the passive filter and the power factor of the load.

6.2 SCOPE FOR FUTURE ENHANCEMENT:

The performance of series active filter can be simulated using different compensating current reference estimators such as instantaneous p-q theory, synchronous reference frame theorem, I $\cos \Phi$ algorithm etc.

Different gate signal generators can be implemented.

Different passive filters such as double tuned and high pass filters can be used for improving the performance of series active filter.

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