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Tie-Line Oscillation Control of An Interconnected Two Area System With Fixed Speed Wind Farm

T. Magesh
Associate Professor, R. M. K. Engineering College
Chennai-601206,India.
M. Gomathi
PG Student, R.M.K.Engineering College
Chennai-601206,India
Dr. C. Chellamuthu
Professor, R.M.K.Engineering College
Chennai-601206,India

Abstract

Wind power penetration is continuously increasing in many systems around the world in an effort to increase renewable energy with cost-effective solution in the energy production. This paper reviews modeling aspects of fixed speed induction generator and the design of controllers that can reduce the damping of the inter-area oscillation by modulating the active power flow in the tie-line of the power system. Inter-area oscillations in large interconnected systems are complex. So a controller is designed and tested on a four generator system traditionally used for inter-area oscillation damping.

Key Words: Wind farm, Induction generator, Tie-line oscillations, Two area system, Stability analysis, PSS, AVR

Introduction

In recent years, the growing environmental concerns and attempts to reduce dependency on fossil fuel resources are bringing renewable energy resources to the mainstream of the electric power sector. Among the various renewable resources, wind power is assumed to have the most favorable technical and economical prospects. As the wind power keeps on increasing, this change in power system operation and the potential impact on the stability of power system have received considerable attention. Considering the difference of WTG structure and dynamic performance with thermal plants, large penetration of wind power may change the load flow distribution and lead to a re-distribution of the system damping, which may affect the static stability. Under this circumstance, it is necessary and imperative to study the properties thoroughly in order to identify potential problems of wind power interconnection and to develop measures to mitigate these issues.

Two different power system are interconnected via a tie-line and the power deviations are decreased by designing and installing, wind turbine generator with fuzzy controller but the effect of oscillation in the tie-line is not considered.[1-3].

The feature of frequency regulation capability of the DFIG by incorporating an extra frequency control support function was tested on an interconnected two-area restructured power system. This extra frequency control support function is proposed with the DFIG which affects the rotational speed of the rotor in the event of frequency disturbance and reduces the frequency dip by releasing short term transient active power support [4]. The influence of wind power on the small signal stability of a power system is unstable when power produced in an area is exported over the weak tie-line. However, the system is stable for power import [5-6].SVC is used to increase the voltage stability limit with respect to the produced active power at the wind farm. But it fails to give more information about oscillation damping [7-8].The small signal stability characteristic of SCIG based wind farms is compared with traditional generators. So, from the perspective of security and stability, the dynamic reactive power compensation equipments should be equipped to SCIG based wind farms [9].

This paper reviews modeling aspects of fixed speed induction generator and the design of controllers using DIgSILENT power factory which reduces the damping of the inter-area oscillation by modulating the active power flow in the tie-line of the power system.Power System Stabilizer (PSS) and Automatic Voltage Regulator (AVR) are coordinated to improve the transient stability of generator in power system. The controller is tested on a four generator system used for inter-area oscillation damping.

Two Area System

Figure 1 shows the two area system which consist of four generators each of 900MVA. 967Mw load is connected to area 1and 1767Mw load is connected to area2.Both the areas are connected through tie-line.GEN11 in the area 2 is connected to swing bus.Electric utilities across regions are many times interconnected to allow for a variety of advantages. First, the fact that electric utilities benefit from its nature and the utilities can draw power from generator reserves from a different region in order to ensure reliable power and their loads. Interconnection allows regions to have access to cheap bulk energy by receiving power from different sources. Neighboring utilities also help others to maintain the overall system frequency and also help manage tie transfers between utility regions. The main advantages of interconnected power system are, possibility to use larger and more economical power plant,reduction in the necessary reseve capacity of the system and flexibility of building new power plant at favorable location.

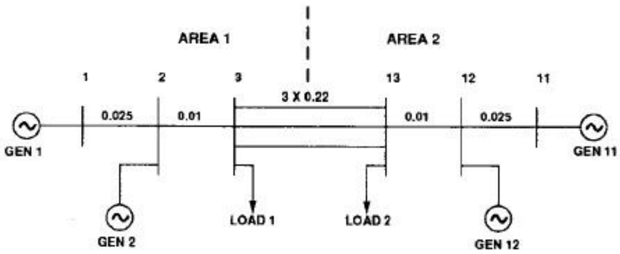

Figure 1: Two area system.

Model of A Constant-Speed Wind Turbine

Figure 2 depicts the general structure of a model of a constant-speed wind turbine. This general structure consists of models of the most important subsystems of this wind turbine type, namely, the rotor, the drive train and the generator, combined with a wind speed model.

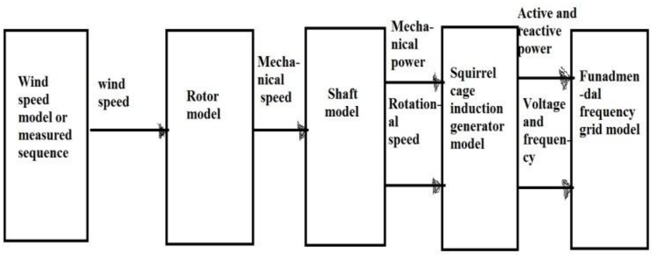

Figure 2: General Structure of Constant Speed Wind Turbine

Generator Model

The voltage equations of a squirrel cage induction generator in the d – q reference frame, using the generator convention, can be found in the literature (Kundur, 1994)

$$u_{ds} = -R_s i_{ds} - \omega_s \psi_{qs} + \frac{d\psi_{ds}}{dt} ------(1)$$

$$u_{qs} = -R_s i_{qs} + \omega_s \psi_{ds} + \frac{d\psi_{qs}}{dt} ------(2)$$

$$u_{dr} = 0 = -R_r i_{dr} - s\omega_s \psi_{qr} + \frac{d\psi_{dr}}{dt} --- (3)$$

$$u_{qr} = 0 = -R_r i_{qr} + s\omega_s \psi_{dr} + \frac{d\psi_{qr}}{dt} --- (4)$$

in which s is the slip, u is the voltage, i is the current, R is the resistance, and ψ is the flux. All quantities are in per unit. The subscripts d and q stand for direct and quadrature component, respectively, and the subscripts r and s for rotor and stator, respectively.

The slip is defined as follows:

$$s = 1 - \frac{p\omega_m}{2\omega_s}$$

in which p is the number of poles.

The flux linkagescan be calculated as

$$\psi_{ds} = -(L_{s\sigma} + L_m)i_{ds} - L_m i_{dr}$$
$$\psi_{qs} = -(L_{s\sigma} + L_m)i_{qs} - L_m i_{qr}$$
$$\psi_{dr} = -(L_{r\sigma} + L_m)i_{dr} - L_m i_{ds}$$
$$\psi_{qr} = -(L_{r\sigma} + L_m)i_{qr} - L_m i_{qs}$$

then voltage equation can be written as

$$u_{ds} = -R_s i_{ds} + \omega_s[(L_{s\sigma} + L_m)i_{qs} + L_m i_{qr}]$$
$$u_{qs} = -R_s i_{qs} - \omega_s[(L_{s\sigma} + L_m)i_{ds} + L_m i_{dr}]$$
$$u_{dr} = 0 = -R_r i_{dr} + s\omega_s[(L_{r\sigma} + L_m)i_{qr} + L_m i_{qs}] + \frac{d\psi_{dr}}{dt}$$

The electrical torque Te is

$$u_{qr} = 0 = -R_r i_{qr} - s\omega_s[(L_{r\sigma} + L_m)i_{dr} + L_m i_{ds}] + \frac{d\psi_{qr}}{dt}$$

given by

$$T_e = \psi_{qr} i_{dr} - \psi_{dr} i_{qr}$$

and the equation of the motion of the generator is:

$$\frac{d\omega_m}{dt} = \frac{1}{2H_m}(T_m - T_e)$$

The equations for active power generated, P, and the reactive power consumed Q, are:

$$P_s = u_{ds} i_{ds} + u_{qs} i_{qs}$$
$$Q_s = u_{qs} i_{ds} - u_{ds} i_{qs}$$

As the stator winding is connected to the grid, generator and grid canexchange active and reactive power only through the stator terminals. Therefore, the rotor is not taken into account.

Power System Stabilizer

In order to stabilize the inter area oscillation PSS is added to each of the generator in the two area system.PSS gives a signal to the excitation system, which produces electrical torque todamp out power oscillation.PSS comprise of an amplification block, washout block, lead-lag block and sensor time constant. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between the exciter input and the generator electrical torque. The signal washout block acts as a high pass filter with the time constant that allows the signal associated with the oscillation in rotor speed to pass unchanged. Structure of PSS is shown in Figure 3.Table 1 shows the values of PSS parameters.

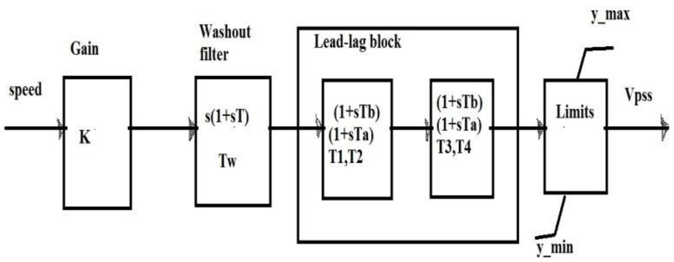

Figure 3: Structure of PSS

Table 1: Values For PSS Parameter.

Parameters	G1	G2	G3	G4
K	37.154	14.704	26.665	33.268
T1	2.0989	1.1687	2.81	0.65767
T2	0.2499	1.4871	2.6542	1.7089
T3	0.8845	0.73275	2.9059	1.7834
T4	0.6692	2.5904	0.2257	0.8669
TW	10	10	10	10
y_min	-0.2	-0.2	-0.2	-0.2
y_max	0.2	0.2	0.2	0.2

Automatic Voltage Regulator

The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a set level. A simple AVR system comprises four main components, namely amplifier, exciter, generator, and sensor. The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady-state error due to a step function to zero.The general block diagram of AVR is shown in Figure 4. Figure 4a shows the IEEE type AC4A excitation system which is used inDIgSILENTas AVR model and the values for AVR parameters are given in Table 2.

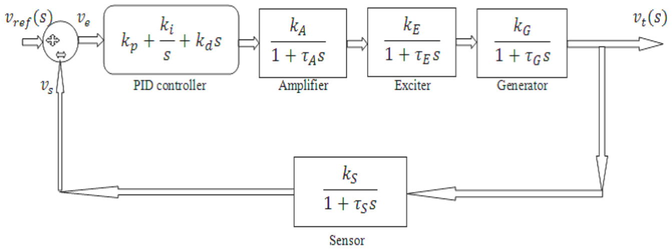

Figure 4: Generalblock diagram of the AVR

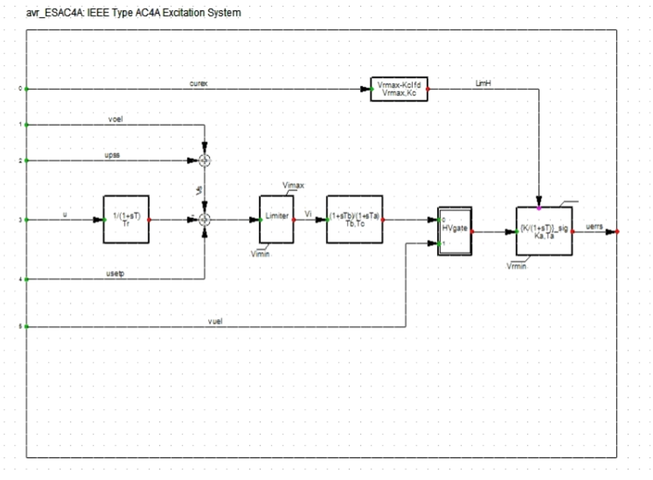

Figure 4a: AVR model in Dig SILENT

Table 2: Values for AVR Parameters

Parameters	Generators
Tr	0.01
Tb	0.05
Tc	0.1
Ka	100
Ta	0.01
Vmax controller	20
Vmin controller	-20
Vmax input	2
Vmin input	-2
Kc	0.2

Simulation and Results

An IEEE model of two area system is used for this study. It consist two area in which two generators are connected in each area. This two areas are inter connected through weak tie line. It has two modes of oscillation namely inter area oscillation and local mode oscillation.

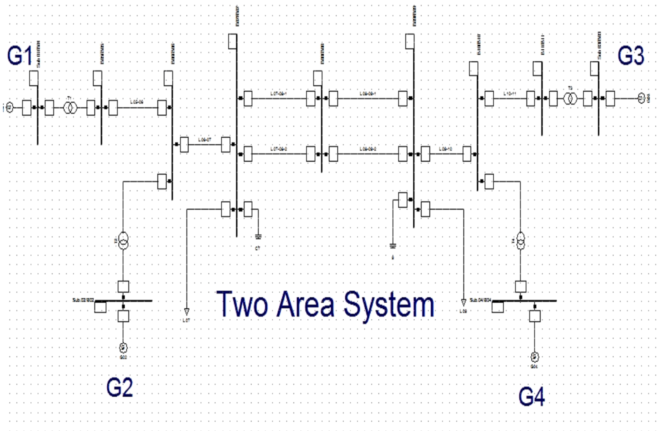

Figure 6: Two Area System

Table 3: Data For Two Area System

PARAMETERS	G1	G2	G3	G4
Nominal power	900 MVA	900 MVA	900 MVA	900 MVA
Nominal voltage	20 kv	20 kv	20 kv	20 kv
Power factor	0.8	0.8	0.8	0.8
Connection	YN	YN	YN	YN
Xd	1.8	1.8	1.8	1.8
Xq	1.7	1.7	1.7	1.7
X'd	0.3	0.3	0.3	0.3
X'q	0.55	0.55	0.55	0.55
X"d	0.25	0.25	0.25	0.25
X"q	0.25	0.25	0.25	0.25
Ra	0.0025	0.0025	0.0025	0.0025
T'd0	8.0 s	8.0 s	8.0 s	8.0 s
T'q0	0.4 s	0.4 s	0.4 s	0.4 s
T"d0	0.03 s	0.03 s	0.03 s	0.03 s
T"q0	0.05 s	0.05 s	0.05 s	0.05 s
Asat	0.015	0.015	0.015	0.015
Bsat	9.6	9.6	9.6	9.6
ψt1	0.9	0.9	0.9	0.9
H	6.5	6.5	6.175	6.175
Kd	0	0	0	0
Xl	0.2	0.2	0.2	0.2
	Load connected at bus 7 = 967 MW		Load connected at bus 9 = 1767 MW	

Oscillations related with a single generator are local modes and the oscillation related with group of generators are known as inter area oscillation. Inter area oscillations are large in interconnected system. Frequency range for local mode oscillation is between 0.7 to 2.0 Hz and for inter area oscillation is between 0.1 to 0.8 Hz. This oscillations are damped using PSS along with AVR which is implemented in all thefour generators.G3 in area2 is connected to the swing bus. Transient stability analysis is carried out and the tie-line power oscillation is simulated with and without

PSS. Figure 6 shows the Dig SILENT model of two area system and Table 3 gives the data for this system.

Simulation is carried out with and without wind farm and PSS in the two area system.

Simulation Result Without Wind Farm and PSS In The Two Area System

In steady state, active power is 200 MW. When fault is applied for theduration of 0.1 second, active power falls to 49 MW. After thefault is cleared, the tie line powerhas sustained oscillation with the frequency of 0.28Hz about the steady state value of 200 MW with an amplitude of 80 MW.

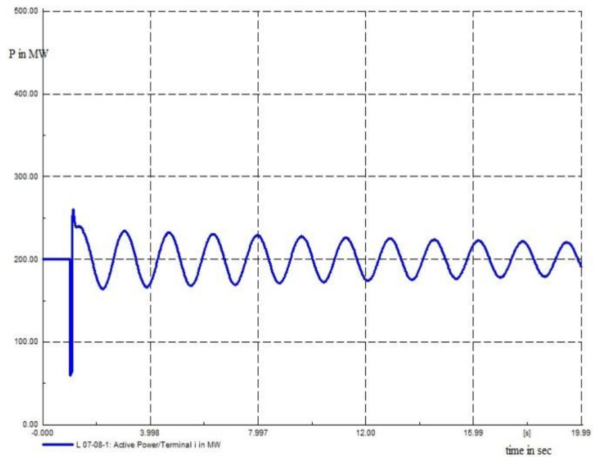

Figure 7: Wave Farm Without PSS And Wind Farm

Simulation result with PSS but without wind farm

In steady state, active power is 200 MW. When fault is applied for the duration of 0.1 second, active power falls to 49 MW. After the fault is cleared, the tie line power oscillates with the frequency of 0.166 Hz about the value of 200 MW and the oscillation decays after 2 cycles and reaches steady state value.

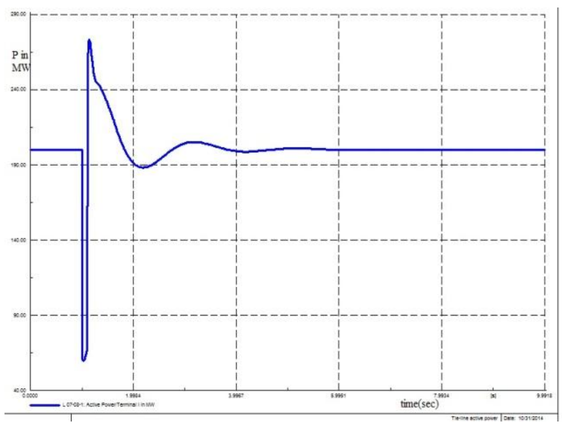

Figure 8: Waveform with PSS

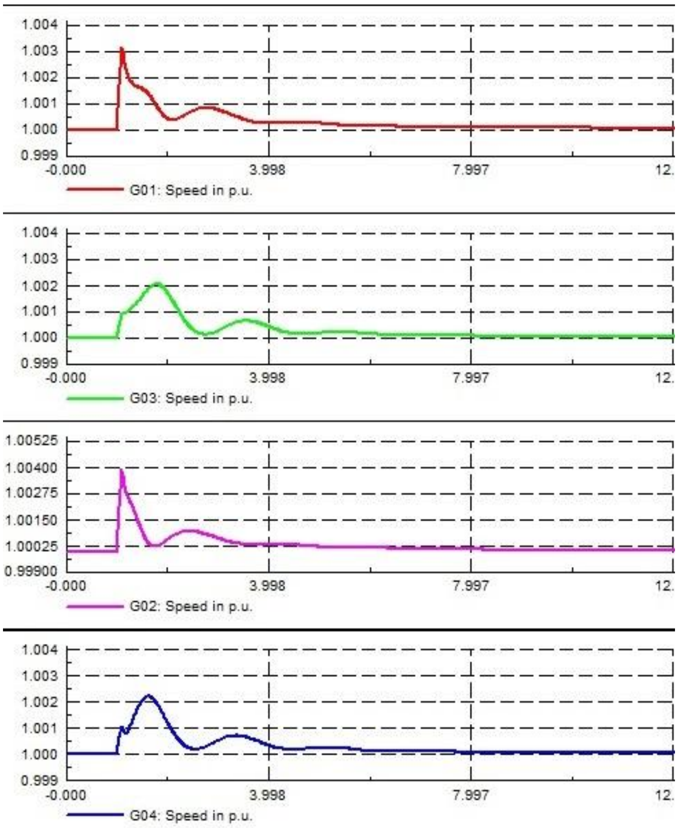

Figure 9: Rotor Speed of The Generators

The rotor speeds of the generators are shown in the Figure 9.Generators 1 and 2 have 1.003p.u peak value. Generators 3 and 4 have 1.002p.uas their peak values.

Two Area System Withwind Farm

In the two area system, wind farm is connected to busbar of area 2. This wind farm consist of 100 wind turbine. Each wind generator has 0.6 MW as their nominal active power and 0.69 kv as their rated voltage. Totally 60 MW is generated in wind farm which is connected to the busbar in area 2.When the wind farm is connected oscillations in the tie-line increases. This oscillations are damped by implementing PSS to increases the stability of the system.

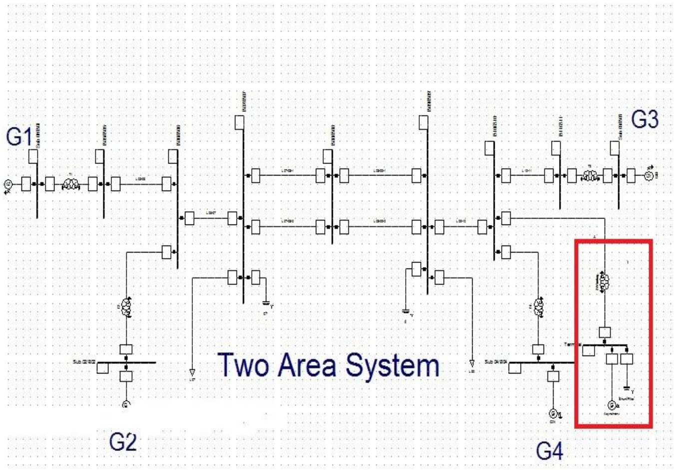

Figure 10: Two Area System With Wind Farm

Simulation result without PSS in the two area system

It is seen that the oscillation in the two area system is increased when wind farm is connected to system. This is due to the varying characteristic of the wind energy. In steady state, active power is 240MW.When fault is applied for the duration of 0.1 second, the active power falls to 30MW. After the fault is cleared ,the tie-line power oscillates with frequency of 0.66 Hz about the steady state value of 240 MW having peak to peak value of 140MW.These oscillations can be reduced by implementing PSS along with AVR in all the generators present in the system.

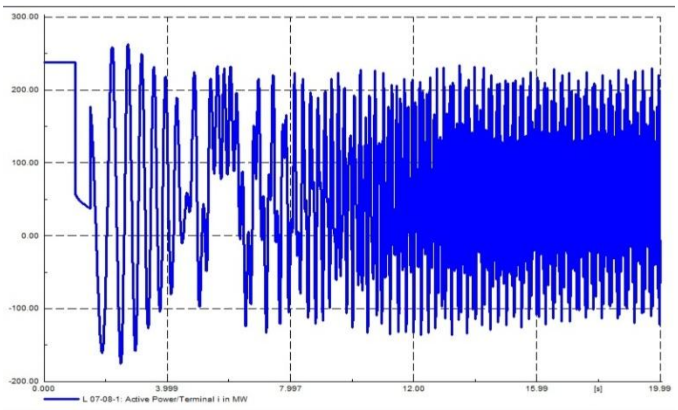

Figure 11: Wave Farm Without PSS

Simulation result with PSS and wind farm

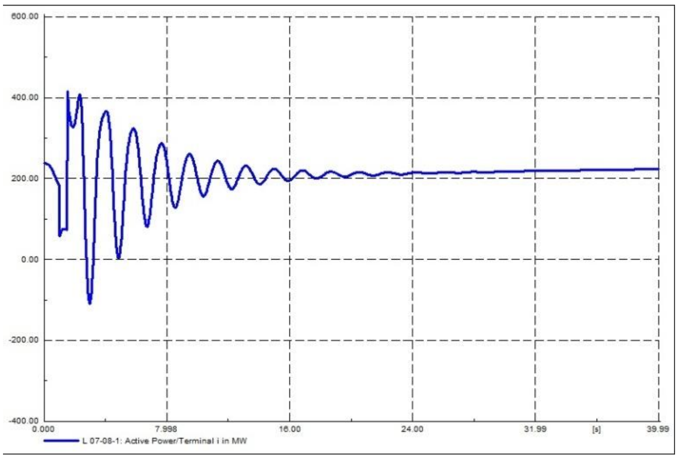

Figure 12: Wave form with PSS

In steady state, active power is 240 MW. When there is a sudden short circuit in the tie-line, active power falls to -100MW. After the fault is cleared decaying oscillation with frequency of 0.48 Hz about steady state value of 240, the peak to peak value of 400 MW, and decaysafter 10 cycles.These oscillations can be further damped by tuning the parameters of PSS and AVR manually. But tuning the parameters manually every time is difficult and so any optimization technique can be used for tuning the parameters.

Conclusion

To ensure reliable operation of power system, oscillation must in acceptable range. These oscillations affect the power system operation. In large power system, oscillation is undesirable and so some measures has to be taken to reduce this oscillation. Controllers are designed and installed in each generator to reduce the oscillation in the tie-line in the two area system. Further in the two area system with wind farm oscillations are damped by proper tuning of PSS and AVR parameters.

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