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Simulation of a Three-Phase Multilevel Unified Power Flow Controller UPFC

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Abstract: This work deals with the study and simulation of Unified Power Flow Control (UPFC) at its normal and abnormal conditions. The systems are modeled and simulated using MATLAB software. Shunt inverter or Static Compensator (STATCOM) is modeled as a 3-phase multipulse converter and the series inverter or SSSC has been constructed as a 3-phase, 3-level multilevel converter. Faults are set to the system to observe the operation of STATCOM and phase shift, ϕ of the SSSC is varied to observe the operation of SSSC. Simulations are carried out and the results obtained agreed with the theory of operation of the UPFC.

Key words: STATCOM, SSSC, UPFC, modelling

INTRODUCTION

Flexible Alternating Current Transmission System or FACTS uses power electronic based systems and others static equipment to provide control of one or more ac transmission system parameters to enhance controllability and increase power transfer capability. It was first introduced in 1980s by Narain G. Hingorani (Moore and Ashmole, 1995). Traditionally, power flow control is gained with the use of a phase shifter and mechanically changing tap setting of a transformer. However this method is not flexible enough to cope with the increasing needs. Following the trend of deregulating the electric power industry, a demand for flexible power load flow is becoming a technical need feasibly achievable by the innovative power electronics (Wang and Fang, 1999) thus the use of FACTS devices. This technology is based on the used of high voltage and high current power electronics devices in association with communication links and local automatic controllers.

UPFC concept was first proposed with objectives of controlling, simultaneously or selectively, all the parameters affecting power flow in the transmission line i.e., voltage, impedance and phase angle. It can also independently control both real and reactive power flow in the transmission line (Hingorani and Gyugyi, 2000) beside than that, it has the capabilities of improving transient stability, mitigating system oscillations and providing voltage support (Dong *et al*., 2002).

Since the introduction of the UPFC, many studies and investigation of its performance have been carried out either by simulation and hardware model. Zheng *et al*. (2000) reported the simulation model of UPFC with 12-pulse converters using Matlab and Simulink software has been developed. Static and dynamic characteristics of the developed UPFC simulation model in a power system are investigated under normal operating condition (i.e., no disturbance) and under severe disturbance. The developed model reflects precisely the operation characteristics of the practical devices. It shows that the UPFC can control the voltage and power flow of the system effectively.

Toufan and Annakkage (1998) investigate performance of a UPFC constructed by a back-to-back connection of a Hysteresis Current Forced (HCF) converter and a Pulse Width Modulated (PWM) inverter. The model has been developed at a component level and simulated using PSCAD/EMTDC software. From the investigation, the UPFC model can maintain an almost constant dc bus voltage and has the ability to pass the real power bidirectional. It has also been shown that using quadrate or in phase voltage injection, the UPFC can enhance the dynamic stability of the power systems effectively.

A current injection model of the UPFC is developed for transient stability (Meng and So, 2000). The effect of UPFC can be represented by an equivalent circuit with a shunt current source and a series connected voltage source. The series voltage source can be solved into in-phase and quadrature components with respect to the line current and the current injection model is obtained by replacing the voltage source with the current source. The controller of the UPFC is based on optimal control strategies in a Single-Machine Infinite-Bus (SMIB)

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system. The study proposed that the controller coordinates input signals to control the two components of the UPFC series voltage and the shunt compensation of the UPFC, in order to maintain the system bus voltage. The eigenvalue analysis and nonlinear results show that the proposed model and control method can significantly improve system dynamic performance.

New control approach combining the traditional control technique with an artificial intelligence technique such as Genetic Algorithm (GA) has been studied by Faried and Eldamaty (2004). The GA based UPFC is designed using eigenvalue shifting technique and the effectiveness of the new controller is demonstrated through time-domain simulations using Matlab. From the results, it shows that this new control approach give the UPFC more flexibility and increase capabilities in damping the power system oscillations when compared to the fixed power injection UPFC.

This research concentrates on the designing and developing a simulation model of a three phase UPFC using SimPowerSystem Blockest of Matlab/Simulink software. The shunt converter is developed using the traditional 6-pulse three-phase bridge topology, while the series converter is developed using multilevel, 3-level topology. The system is modeled as an open loop system. Results obtained from the simulation model are then compared with the theory of operation of the UPFC. Faults are set to the system to observe the operation of STATCOM and phase shift, ϕ of the SSSC is varied to observe the operation of SSSC. A good working simulation model has been obtained for the UPFC.

UNIFIED POWER FLOW CONTROLLER

UPFC consists of two switching power converters connected to each other back-to-back through a DC link capacitor as shown in Fig. 1. The converters are connected to the AC system by a shunt and series transformers. This arrangement functions as an ideal AC-to-AC power converter in which real power can freely flow in either direction between the two inverters.

The shunt inverter or STATCOM is connected to the system via a shunt transformer. It injects an almost sinusoidal controlled current of variable magnitude at the point of connection. STATCOM compensates reactive power flow in the transmission line and at the same time keeps the DC voltage constant across the DC link capacity or (i.e., regulates the active power flow between shunt and series converters).

The series converter or SSSC operates by adding a series voltage, ΔV of a variable magnitude and phase angle and thus forcing the power to flow to a desired value. This voltage addition has a controllable magnitude of range, δV ($0 \le \delta V \le \delta V_{max}$) and phase angle, ϕ ($0° \le \phi \le 360°$) and can be considered as asynchronous AC voltage source (Wang and Peng, 2004). It is connected to

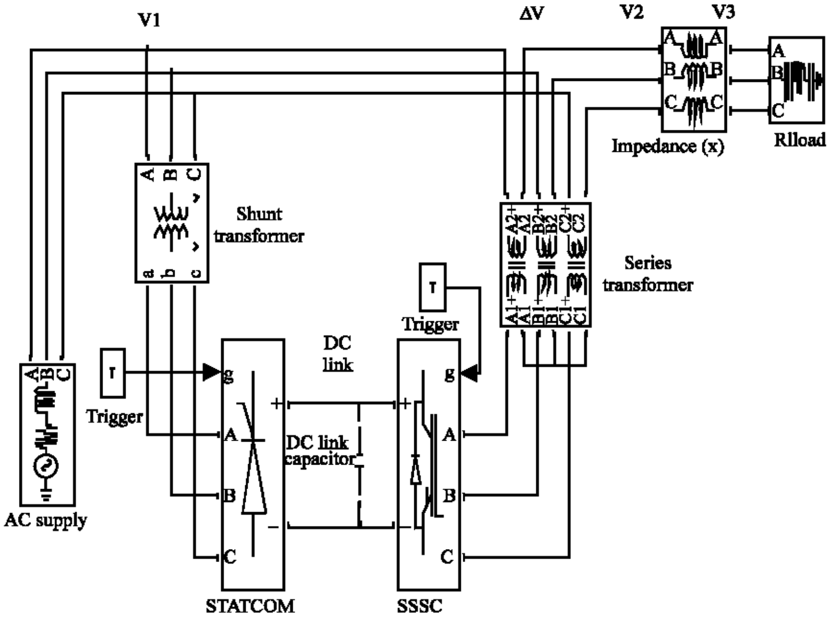
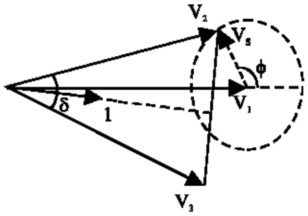


Fig. 1: Three-phase diagram of UPFC



$$P = \frac{V_2 V_3 \sin \delta}{X}$$

$$Q = \frac{V_2 (V_2 - V_3 \cos \delta)}{X}$$

Fig. 2: Vector diagram of system voltages

the system through a series transformer. Figure 2 shows the vector diagram of the voltages in the power system.

SYSTEM SIMULATION

The main interest in this study is to design and develop a simulation model of a three phase UPFC using SimPowerSystem Blockest of Matlab/Simulink software. The designing of the UPFC takes two steps. The shunt converter or STATCOM is designed first and then followed by the designing of the series converter or SSSC.

The STATCOM has been developed using the traditional 6-pulse, three-phase bridge topology, Which consists of two converters; rectifier and inverter, as shown in Fig. 3. The rectifier is constructed using diode and the inverter using thyristors. A capacitor connects the dc side of the rectifier and inverter and a shunt transformer connects both AC sides of the converters to the AC supply. Under normal operation, the rectifier will charge up the capacitor and when there is a voltage drop or sag occurs to the system such as a fault, the inverter operates and the capacitor gets discharged. As the charge in the capacitor depletes, the rectifier will operate and charge back the capacitor.

SSSC is developed based on the three-level multilevel structure using Insulated Gate Bipolar Transistors (IGBTs) as the power switches. Figure 3 shows the simulation model of the SSSC. By controlling the phase shift, ϕ, the angle of the output voltage of the SSSC, ΔV can be controlled and by varying the value of dc link capacitor voltage, V_{dc}, the magnitude of the output voltage of the SSSC, ΔV can be varied. This two parameters; phase shift, ϕ and DC link capacitor voltage, V_{dc}, provide the control of series voltage with variable magnitude and phase angle for the SSSC. By combining the STATCOM and the SSSC as in Fig. 4, a complete system of UPFC is constructed.

RESULTS AND DISCUSSION

The operation of the STATCOM is studied by applying two separate three phase solid faults at two separate times on the same transmission lines. The first fault occurs at time 0.5 to 0.7 sec for duration of 0.2 sec and the second fault occurs at time 1.2 to 1.3 sec for duration of 0.1 sec.

As shown from the Fig. 5, when a fault occurs, the voltage of the AC supply line drops and returns to normal after the fault is removed. The drop of sag value depends on fault and system impedances. A slight transient is noticed after the removal of fault.

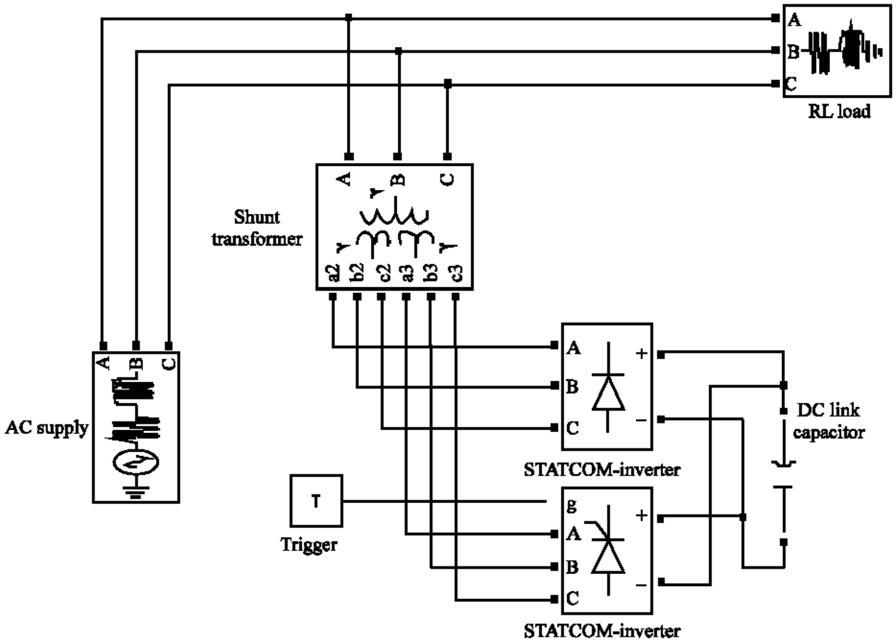


Fig. 3: Simulation model of STATCOM

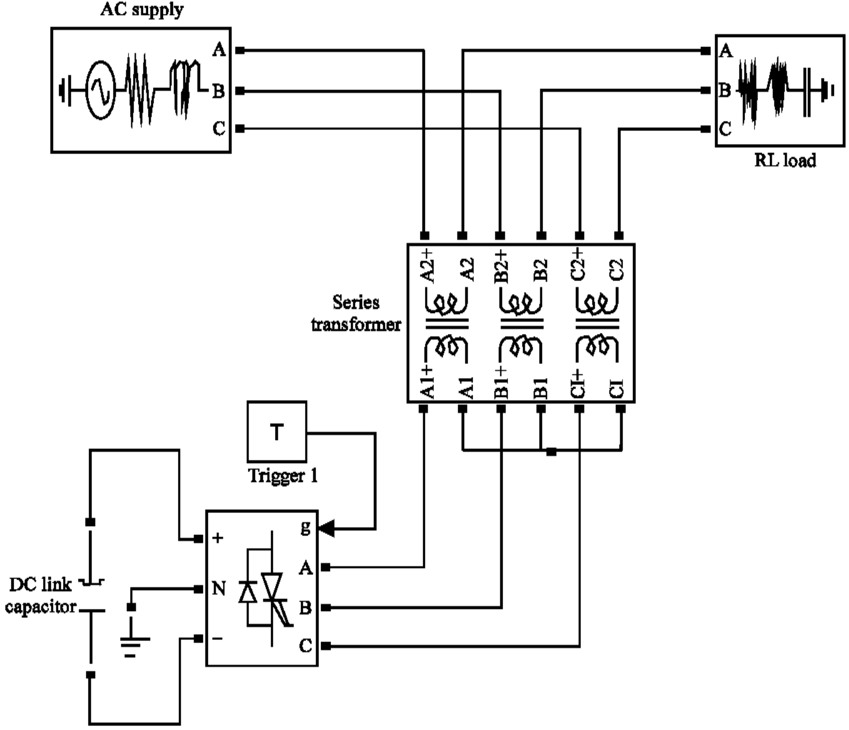


Fig. 4: Simulation model of SSSC

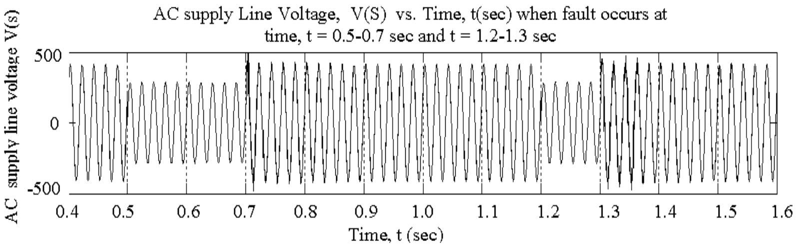


Fig. 5: AC supply line voltage

Figure 6 shows the AC current waveform of the inverter and rectifier. As shown, the current is of pulsed type due to the reason of the switching OFF and ON of the power devices when the converter operates. When faults occurred, the ac voltage of the supply lines will dropped, so, in order to mitigate the voltage drop, the inverter starts to operate. By using the DC link capacitor as power supply, the inverter discharges the capacitor to inject current to the AC supply. As the capacitor discharges and its voltage decreases, the rectifier starts to charge the capacitor back and injecting a reactive power into the AC system.

Figure 7 shows that during the duration of fault, the real power is absorbed by the STATCOM and the reactive power is generated by the STATCOM.

The SSSC operates by changing the phase shift, ϕ in order to change the angle of the output voltage of the SSSC, ΔV. Figure 8 shows the SSSC AC output line voltage for phase shift, ϕ equal to zero. When this voltage is added to the ac supply line voltage, a new V_2 is achieved. This way, the active power and reactive power can be controlled.

Figure 8 shows the line-to-neutral voltage and line-to-line voltage of the three-level neutral-point-clamped SSSC. It differs from the conventional two-level inverter as it is now has three voltage level i.e., +200V, 0V and -200V, as compared to the two-level where it only has two voltage level i.e., +200V and -200V. This zero voltage value is obtained by switching ON two power switches that are connected to the neutral point of the phase leg.

Figure 9 shows the voltage of V_1, V_2 and ΔV. In this case the voltage V_1 and V_2 are of different magnitude and in-phase to each other as the phase shift is zero.

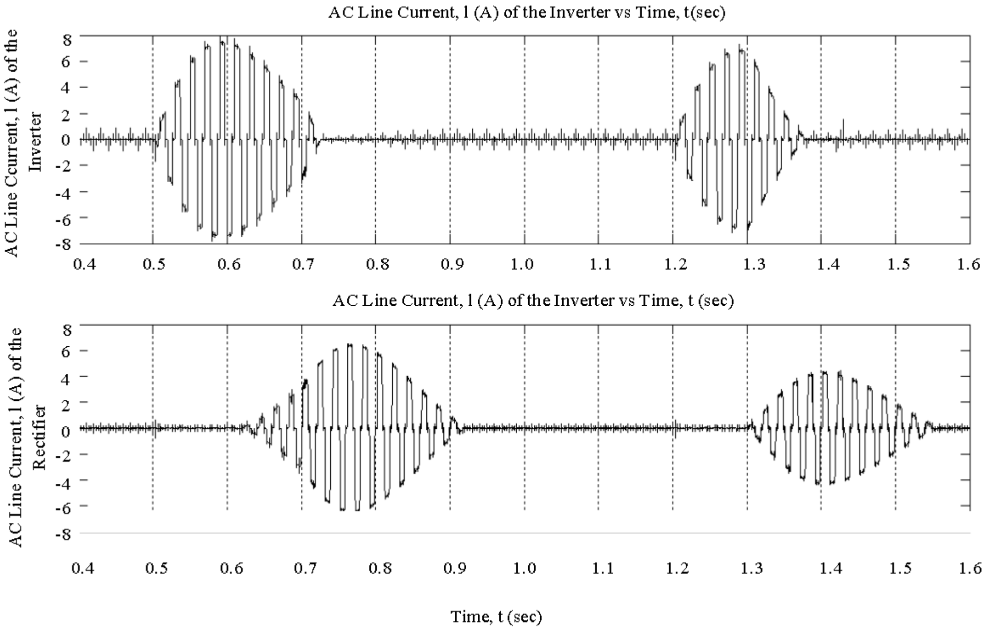


Fig. 6: AC line current of the rectifier (Top) AC line current of the inverter (Bottom)

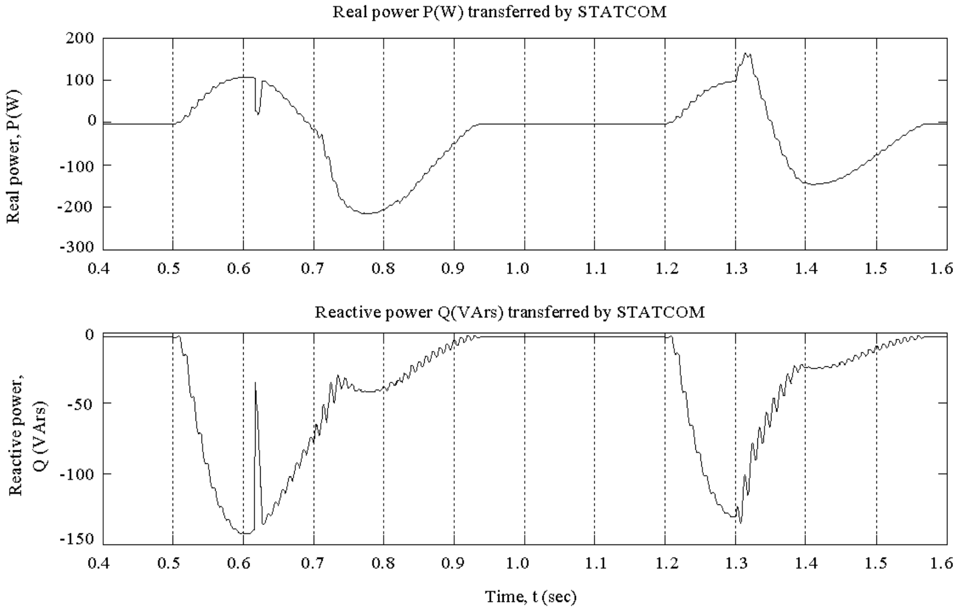


Fig. 7: Real power (top) and reactive power (bottom) of the STATCOM

The phase shift, ϕ is varied, but with the same magnitude of δV. As the phase shift, ϕ is varied, the voltage of the SSSC is also shifting. When this output voltage, ΔV is added to V_1, a new V_2 is obtained. If phase shift, ϕ leads, voltage, ΔV also leads and the resultant voltage, V_2 will has a leading phase shift and vice versa. This phase shift ϕ, also affects the amount of real power and reactive power transferred from the SSSC. This show by specifying certain value of phase shift ϕ, the control of power can be achieved.

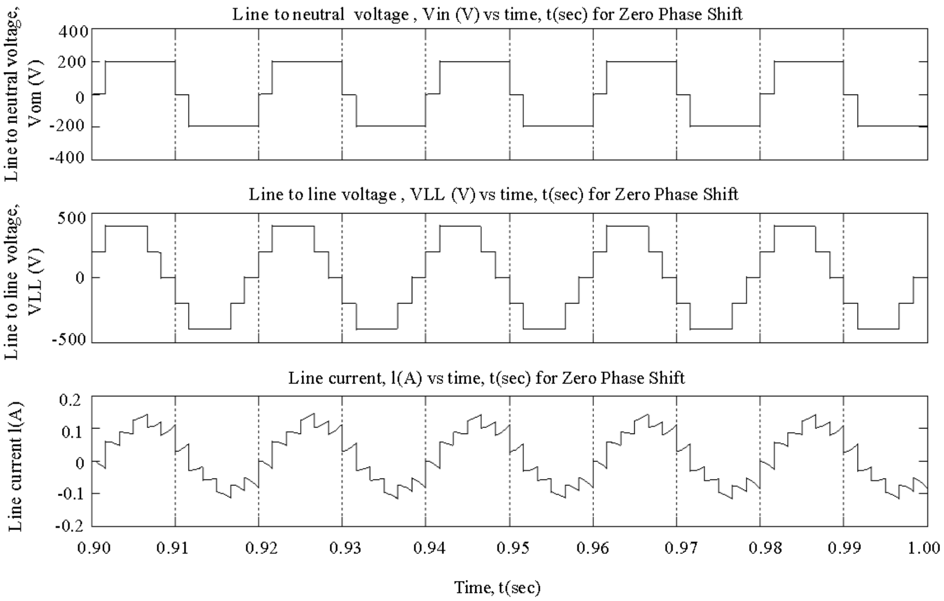


Fig. 8: SSSC line-to-neutral voltage (top), line-to-line voltage (middle) and line current (bottom)

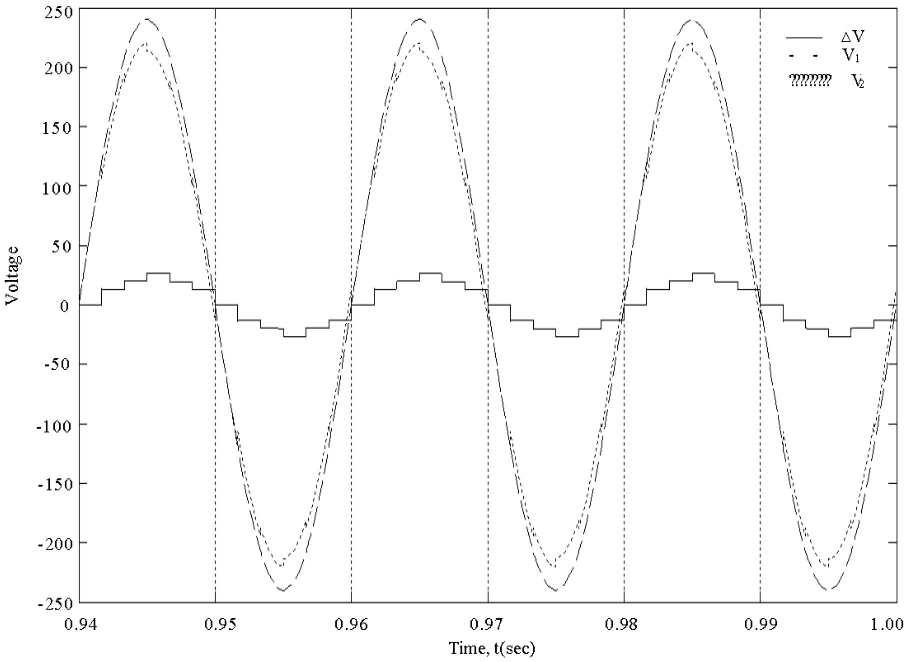


Fig. 9: Voltage ΔV, V_1 and V_2

CONCLUSION

Designing and developing a simulation model of a three phase UPFC using SimPower System Blockest is presented in this paper. The STATCOM is modeled based on the traditional 6-pulse three-phase bridge and the SSSC is modeled based on three-level multilevel structure. Simulation is carried out using a simple on and off switching of the switching devices. The control of power in the transmission system can be achieved by controlling the phase shift, ϕ of the SSSC. Simulations of normal and abnormal conditions have been carried out and the results obtained agreed with the theory of operation of the UPFC.

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