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Mitigation of Subsynchronous Resonance Oscillations Using Static Synchronous Series Compensator

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ABSTRACT

Subsynchronous Resonance (SSR) is a serious problem due to series capacitor placement in power system networks which causes uncontrolled oscillations in the mechanical system of a multi mass model [1]. Many models have been developed to mitigate these oscillations which generally occur during a three phase fault on the power system. In this paper IEEE second benchmark system [2] is investigated using MATLAB based on the Power System Block-set (PSB) in conjunction with Simulink. Here, this model is simulated without FACTS controllers and then the Static Synchronous Series Compensator (SSSC) is included in the model and the results are compared for their effectiveness in damping the SSR oscillations.
Keywords: FACTS, Sub synchronous Resonance, SSSC, Torsional Oscillations.

1. INTRODUCTION

Worldwide series capacitors have been extensively used for improving power transmission in long distance transmission lines. While it has been known that series capacitors can cause self excited oscillations at low frequencies (due to low X/R ratio) or at Sub synchronous frequencies (due to induction generator effect), the problem of self excited torsional frequency oscillations (due to torsional interactions) was first experienced at Mohave power station in U.S.A. in December 1970 and October 1971. The problem of self excitation due to torsional interaction is a serious problem and led to detailed analysis and study [5].

Subsynchronous resonance is electric power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system [1].

While steady state SSR problem is conveniently studied by the characterization of operating point stability based on small signal analysis, the study of the transient torques requires the consideration of nonlinear models. This is due to the fact that transient torques which can damage shafts arise from large disturbances such as faults and reinsertion of series capacitors.

There are two aspects of the SSR problem. These are: Self Excitation (also called as steady state SSR) Transient torques (also called as transient SSR). Since the inclusion of network transients is essential for the analysis of SSR, the simulation used in connection with transient stability evaluation is inadequate. Also it is necessary to model the torsional dynamics considering multi mass rotor representation with elastic shafts [2]. Thus, special purpose simulation programs become necessary.

For the purpose of analysis of SSR, IEEE SSR task force has prepared standard test cases [2-3]. The multi mass model turbine-generator and series compensated transmission system is as shown in the fig 1.

T his system consists of 6 masses coupled to the same shaft namely HP, IP, LPA, LPB, Generator and Exciter. These masses are connected to the transmission line viz. a 600 MVA, 22/500 kV transformer. Fig 2 shows the single line diagram of the First Benchmark system.

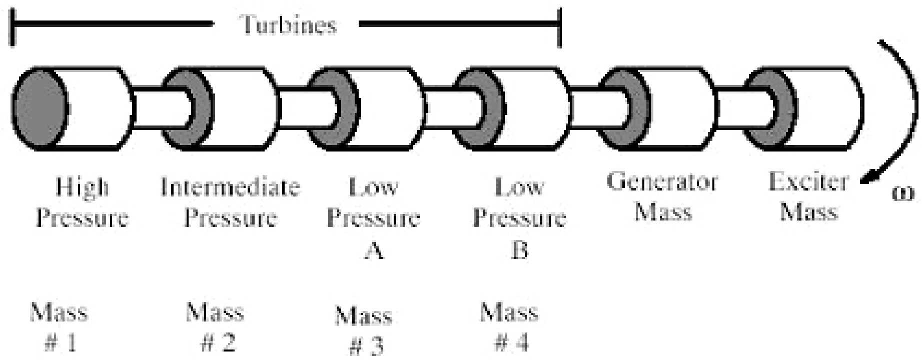

Fig 1: Block Diagram of the mechanical multi-mass system

This model (fig. 2) is developed in MATLAB and is simulated for analysis. In this research paper, a transmission system similar to IEEE Second benchmark system is developed in MATLAB including the Static Synchronous Series Compensator (SSSC) in parallel with the compensating series capacitor [4].

This model is as shown in fig 3. This model consists of multi mass model denoted as steam turbine generator, a transformer, breaker, transmission line parameters, series capacitor, and an infinite bus.

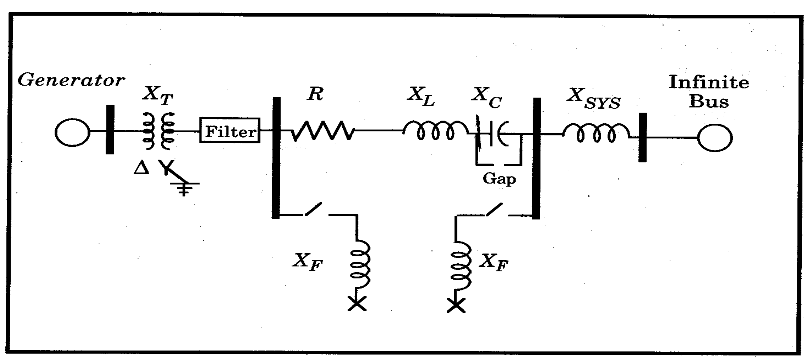

Fig 2: Single line diagram for IEEE First benchmark model for SSR analysis

A three phase fault is applied at the terminals of the breaker for a time period of 0.25 seconds with fault reactance is included [9]. Here the model is simulated without inserting any FACTS controller [7].

0 The simulation results for the above model are as shown in fig 4. As shown in the figure, the torque waveform between the Gen-LP turbines oscillates beyond the prescribed limits of 2pu and -2 pu and that between LP-HP turbines oscillates beyond the prescribed limits -1.0 and 1.0 during the fault period. This situation if repeated frequently may damage the shaft due to shaft fatigue [6]. This figure also shows the angular velocity variations of Generator, LP and HP turbines.

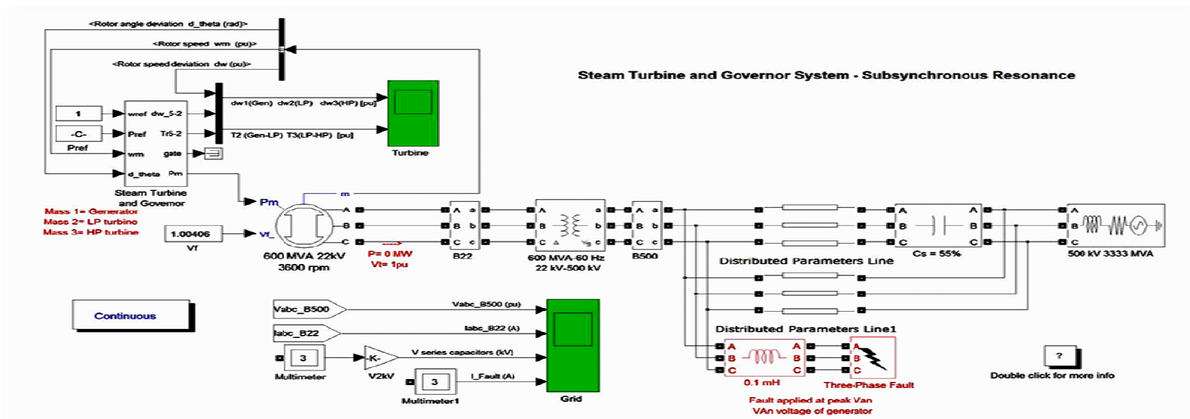

Fig 3: MATLAB Simulink model for IEEE First Benchmark System without SSSC

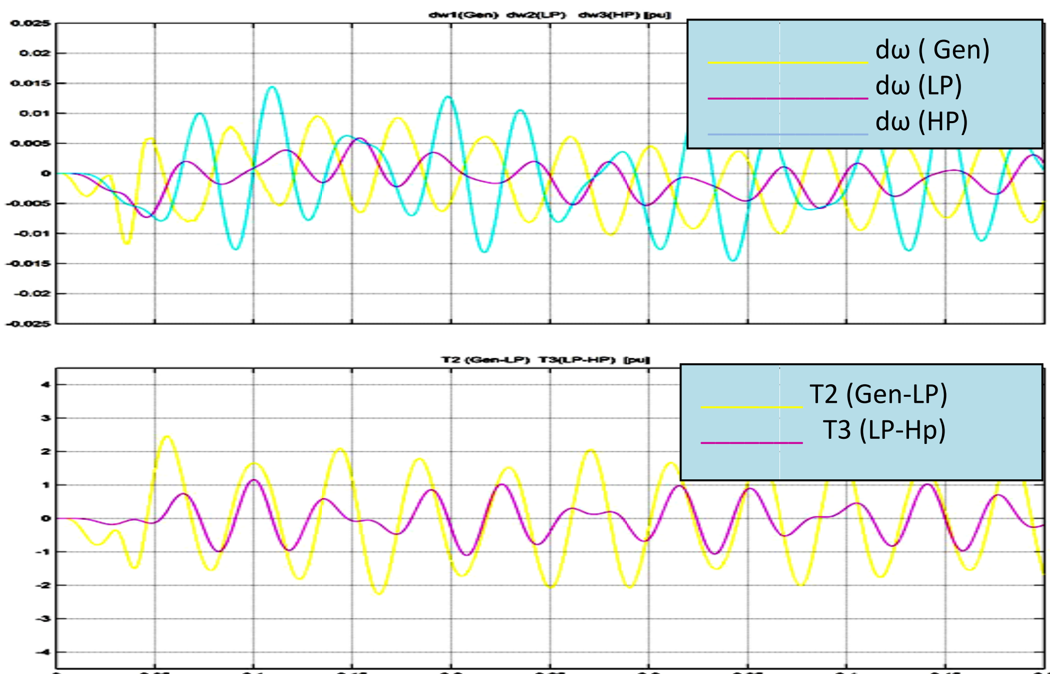

Fig 4: Generator, low pressure, high pressure turbine outputs with respect to time without SSSC

For minimizing these oscillations FACTS controllers like UPFC, SSSC, SVC and STATCOM can be included in parallel to the series capacitor.

The Static Synchronous Series Compensator (SSSC) is a series connected FACTS controller based on VSC and can be viewed as an advanced type of controlled series compensation, just as a STATCOM is an advanced SVC. A SSSC has several advantages over a TCSC such as (a) elimination of bulky passive components capacitors and reactors, (b) improved technical characteristics (c) symmetric capability in both inductive and capacitive operating modes (d) possibility of connecting an energy source on the DC side to exchange real power with the AC network.

The voltage-source converter-based series compensator, called Static Synchronous Series Compensator (SSSC), was proposed by Gyugyi in 1989 within the concept of using converter-based technology uniformly for shunt and series compensation, as well as for transmission angle control.

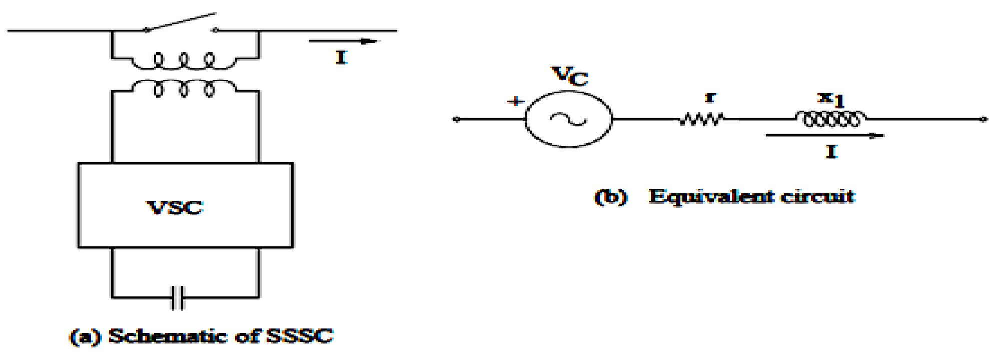

Fig 5. Schematic diagram of SSSC

2. OPERATING PRINCIPLE OF SVC

The basic operating principles of the SSSC can be explained with reference to the conventional series capacitive compensation of Figure 5.

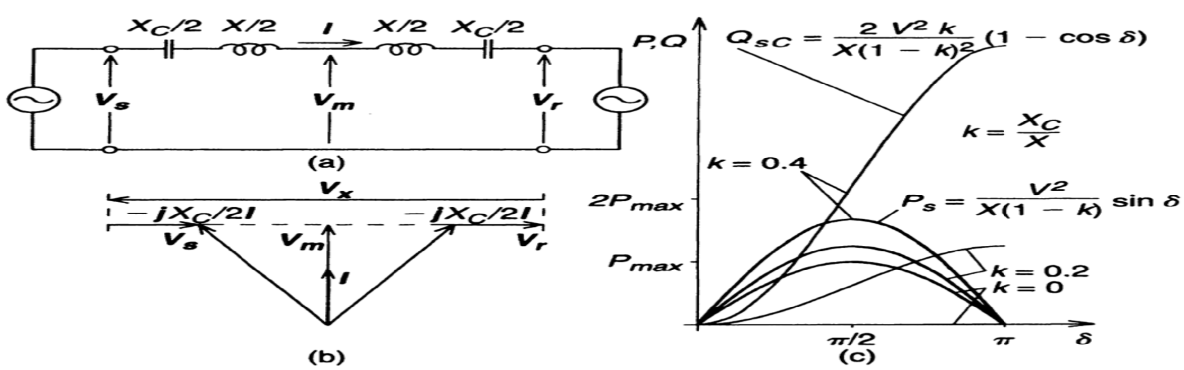

Fig 6. (a) Two machine power system with series capacitive compensation, (b) Corresponding phasor diagram, (c) Real power and series capacitor reactive power vs. angle characteristics

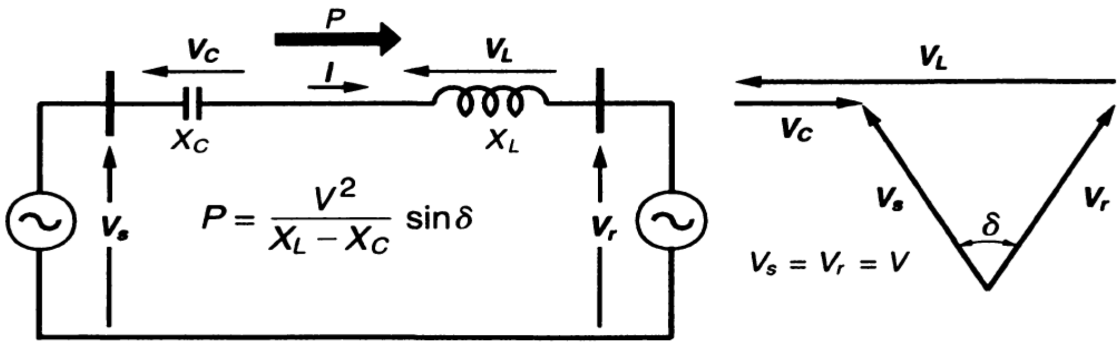

Fig 7. Basic two-machine system with a series capacitor compensated and associated phasor diagram.

SSSC is shown simplified in Figures 6 & 7 together with the relative voltage phasor diagram. The phasor diagram clearly shows that at a given line current the voltage across the series capacitor forces the opposite polarity voltage across the series line reactance to increase by the magnitude of the capacitor voltage.

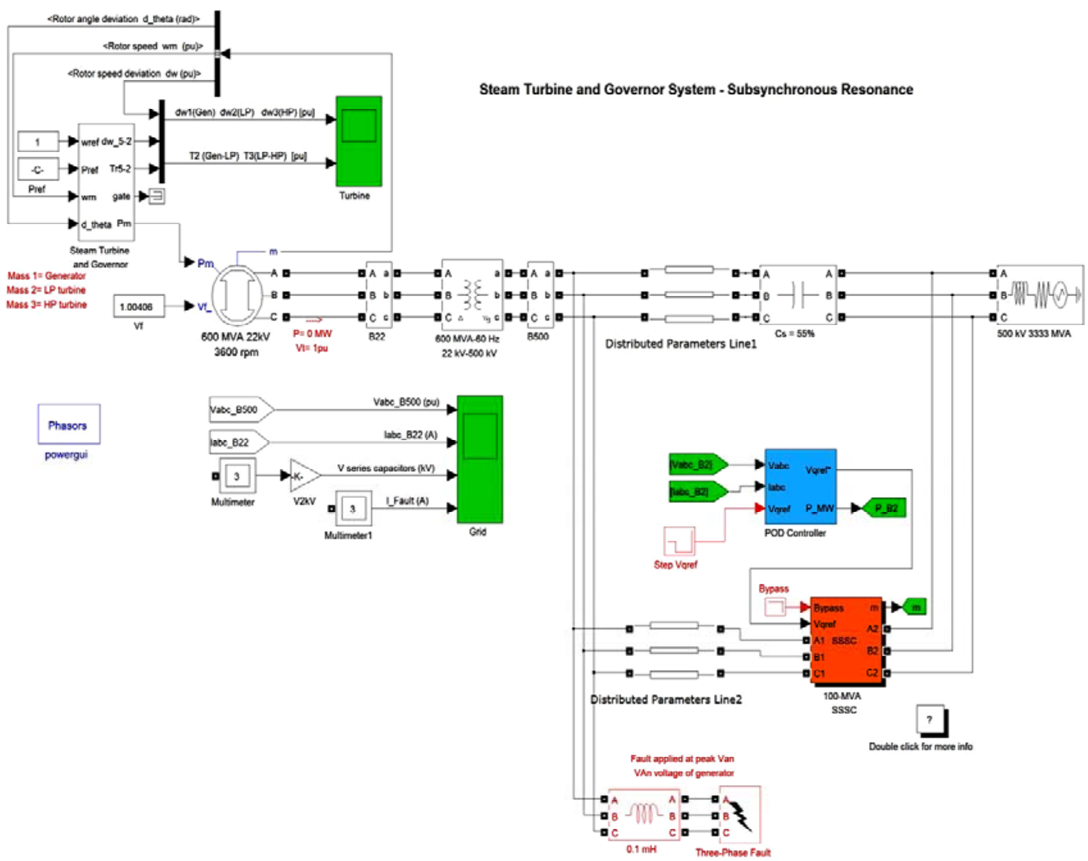

Fig 8. Second Benchmark model with static synchronous series compensator (sssc)

The simulation circuit for the IEEE second benchmark model in MATLAB is as shown in Fig 8. Here SSSC is included in the model.

Fig. 9 shows the simulation results of the above model. This figure clearly shows that the SSR oscillations between LP-HP turbines are gradually decreased and are made to lie within 1 p.u. This graph indicates that with inclusion of SSSC the SSR currents are reduced and hence the torque remains within the prescribed limits.

3. RESULTS

The simulation results are tabulated as shown in Table 1. It clearly indicates that the peak torque values and the speed deviations are gradually reduced with inclusion of SSSC when compared to the case of not including SSSC.

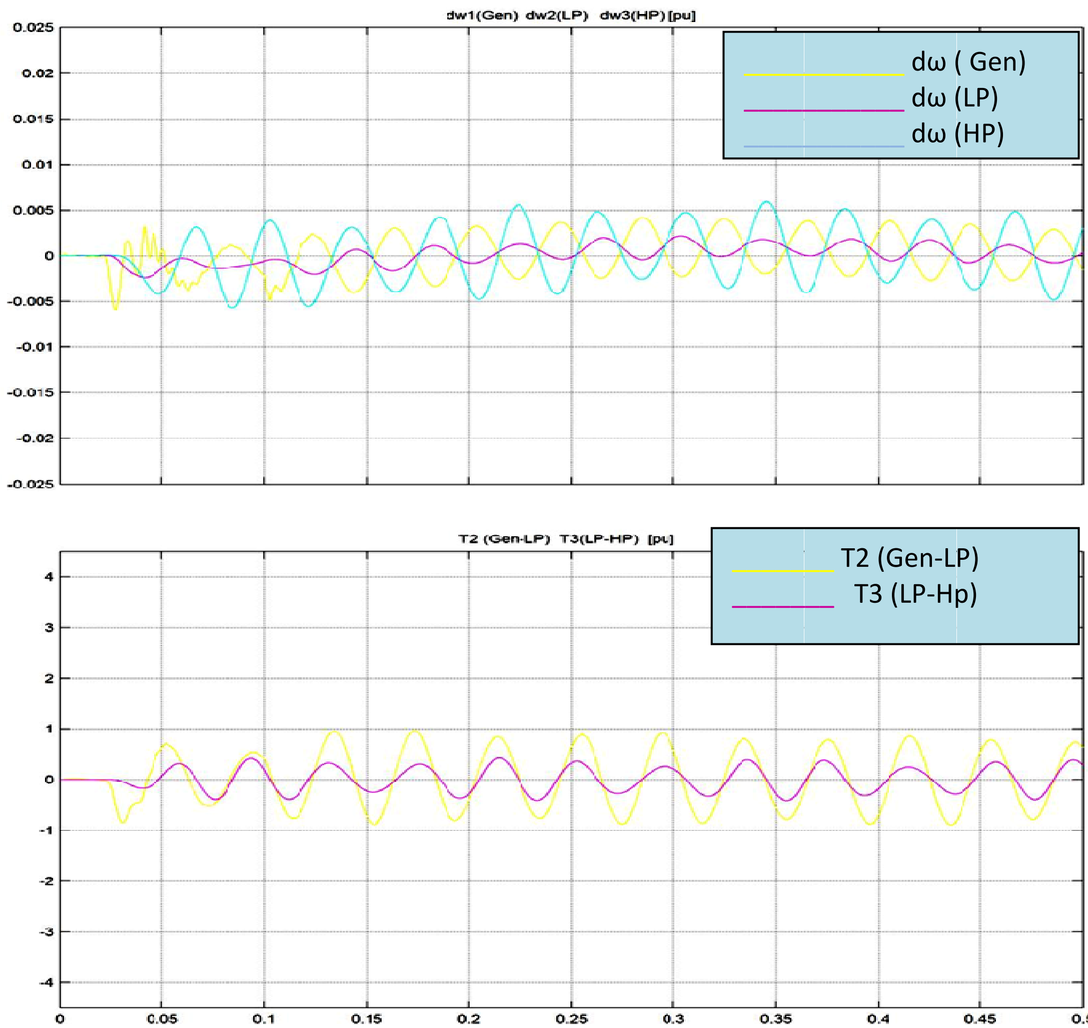

Fig 9. Generator, low pressure, high pressure turbine outputs with respect to time when SSSC included

Table 1. Peak Torques and speed deviations of the two cases

Case	**Gen-LP Torque (p.u.)**		**LP-HP Torque (p.u.)**		**dω (Gen) p.u.**		**dω (LP) pu**		**dω (HP) pu**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Without SSSC	**-2.4**	**2.5**	**-1.1**	**1.15**	**-0.012**	**0.0097**	**-0.0072**	**0.0058**	**-0.0145**	**0.0145**
With SSSC	**-0.89**	**0.97**	**-0.45**	**0.54**	**-0.006**	**0.008**	**-0.0025**	**0.0034**	**-0.0061**	**0.0062**

4. CONCLUSIONS

This paper illustrates the effectiveness of SSSC in damping the sub synchronous resonance oscillations observed in large multi mass model consisting various turbines, exciter and synchronous generator. Here, two cases are investigated i.e. without and with the inclusion of SSSC. These results clearly show that the without SSSC the oscillations in the mechanical system are between -2.4pu and 2.5 pu between generator-LP turbines and between -1.1pu and 1.15 between LP-HP turbines. With the inclusion of SSSC the oscillations were can reduced to -0.89pu and 0.97 between the turbine generator and -0.45 and 0.54 between LP-HP turbines. Also the change in angular velocity is also reduced which can be observed from graph and table 1. Hence the performance of the network is improved due to inclusion of SSSC.

Appendix

AC System Parameters:

System Voltage: 500 kV

System frequency: 50 Hz

1. Parameters of both the Transmission lines

(3 phase):

Resistance/km : 0.02 ohm,

Inductance/km : 0.9 H

Capacitance/km: 13 μF,

Length of Transmission Line: 200 km Capacitive reactance: 30% of inductive reactance.

2. Data of Synchronous Generator (3 phase, round rotor):

Nominal Power: 600MVA

L-L voltage: 22 kV

Reactances: Xd = 1.65, Xd′ = 0.25, Xd′′ = 0.2, Xq = 1.59, Xq′= 0.46, Xq′′=0.2

D- axis time constant : open circuit

q- axis time constant : open circuit

Time Constant:

Tdo′= 4.5 sec,Tdo′′= 0.04 sec,

Tqo′= 0.67 sec,Tqo′′= 0.09 sec

Stator resistance= 0.0045 pu

3. Power Transformer (Delta/Star):

Nominal Power: 600 MVA(3 phase)

Rated voltage: 22kV/500kV (Line-Line)

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