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DYNAMIC VOLTAGE RESTORER AND HYBRID ACTIVE POWER FILTER FOR POWER QUALITY IMPROVEMENT

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ABSTRACT

Power quality means maintaining the voltage, current and power within the rating as per the IEC standards and supplying it back to the consumers without any delay and interruption. But this has become a difficult task for the power industry. To improve power quality many Custom Power Device's (CPD) are used. Dynamic Voltage Restorer (DVR) is a CPD which is used to improve the voltage quality. Hybrid Active Power Filter (HAPF) is used to reduce current harmonics. In this paper DVR and HAPF are simulated for various conditions. A controller is proposed which gives voltage signals to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme. As a result, there is drastic improvement in voltage profile and also reduction in harmonics.

Keywords: power quality, custom power devices, dynamic voltage restorer, phase modulation technique, hybrid active power filter.

1. INTRODUCTION

The quality of power supplied to the consumers play a very important role in the working of various equipment which are connected on the consumer end. The power quality problems are classified as voltage imbalance, interruption, flicker, transient, distortion, harmonics, voltage sag and voltage swell. Voltage sag is the reduction in voltage magnitude from 0.1 to 0.9 p.u. of its nominal value and it lasts for 0.5 cycles to one minute. Voltage swell is the increase in voltage magnitude from 1.1 to 1.8 p.u. of its nominal value. Voltage sags even for a short duration leads to the damage of computer equipment, variable speed drives etc. (Dr A. Jaya Laxmi *et al*., 2010). CPD's are used to reduce power quality problems. CPD's can be either series or shunt compensators. Series compensators are connected in series with the load on the distribution side through a coupling transformer like Dynamic Voltage Restorer (DVR). Whereas shunt compensators are connected in parallel to the load like Active Filters (Sujin.P.R *et al.,* 2012). In this paper DVR and HAPF are simulated using MATLAB Simulink environment.

2. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic Voltage Restorer (DVR) is an important CPD used to reduce voltage sags and swells in the distribution network. DVR is a solid-state device that regulates the voltage on the load side by injecting the voltage into the system. DVR is usually installed between the source and the load at the Point of Common Coupling (PCC). DVR can reduce voltage sag and voltage swell. DVR can also limit fault current, reduce transients in the voltage and also compensate voltage harmonics (Dr A. Jaya Laxmi *et al.,* 2012). Figure-1 shows the basic block diagram of DVR.

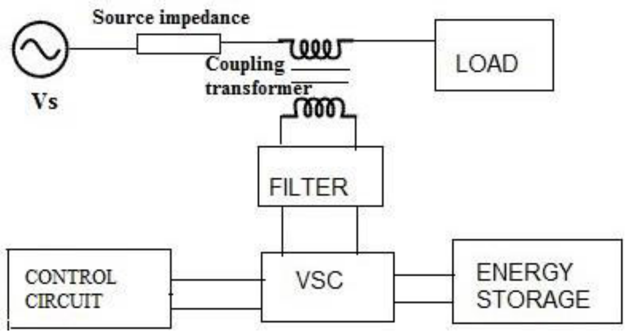

Figure-1. Block diagram of DVR.

DVR consists of a coupling transformer, harmonic filter, energy storage device, a Voltage Source Converter (VSC) and a control system for triggering the switches of VSC. The basic idea of a DVR is to inject voltage generated by the inverter to the bus through a coupling transformer. The injected voltage compensates for the reduction of voltage sags and swells. (R. Omar *et al.,* 2011). The equivalent circuit diagram of DVR is given in Figure-2.

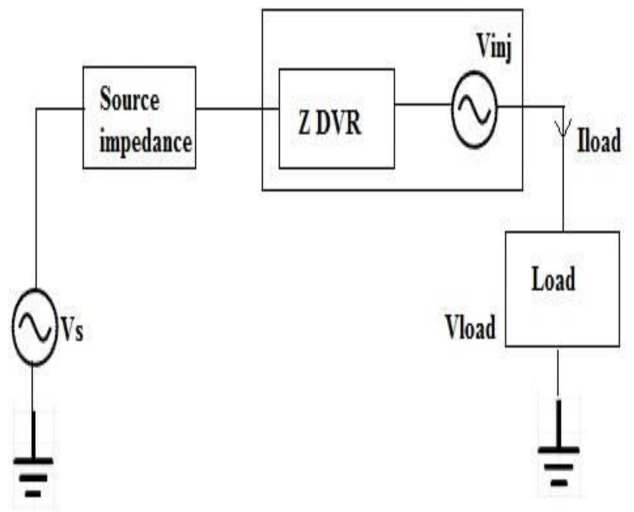

Figure-2. Equivalent circuit diagram of DVR.

When the system voltage drops from a specific value due to any fault, series voltage V_{DVR} is injected by the DVR through an injection transformer or coupling transformer such that the load voltage, V_{load} is maintained at the desired value.

$$V_{DVR} = V_{load} + Z_s * I_{load} - V_s \quad (1)$$

Where
V_{load} = Load voltage
Z_s = Source impedance
I_{load} = Load Current
V_s = Source voltage
Considering I_{load} as I_L, V_{load} as V_L, Zs as Z_{Th} and Vs as V_{Th}.
The load current I_L is given as

$$I_L = \frac{[P_L + j\,Q_L]}{V} \quad (2)$$

The equation (2) can be rewritten by considering V_L as reference
$V_{DVR}\angle\propto = V_L\angle 0 + Z_{Th}\angle(\beta - \theta) - V_{Th}\angle\delta$ (3)
Where ∝, β and δ are the angles of V_{DVR}, Z_{Th} and V_{Th} respectively. Θ is the power angle.

$$\theta = \tan^{-1}\frac{Q_L}{P_L} \quad (4)$$

The complex power injection of DVR is given as

$$S_{DVR} = V_{DVR}\, I_L{}^* \quad (5)$$

3. HYBRID ACTIVE POWER FILTER (HAPF)

Harmonic Filters are CPD's used to reduce harmonics. These filters are passive, active and Hybrid filters. Passive filters are basically LC filters which can be tuned to reduce a particular harmonic. Passive filters cannot reduce the random changes in load current and voltage. (A.Jaya Laxmi., *et al* 2007) These are simple in operation but are bulky and as the rating increases and the elements have resonance problem (Tirunagari Sridevi., *et al* 2015). Active filter consists of an inverter circuit to reduce the harmonics. These filters do not have resonance problem and have good response compared to passive filters. HAPF are a combination of active and passive filters (Hirofumi Akagi., 1996). Figure-3 shows the basic block diagram of a three-phase active filter.

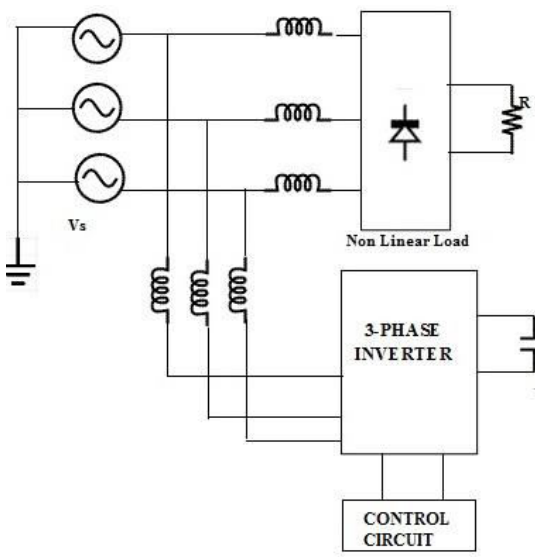

Figure-3. Three-phase active power filter.

In this paper, combination of 3-phase active filter and LC Passive filter, which is a HAPF is connected between source and load at the Point of Common Coupling (PCC) as shown in Figure-4.

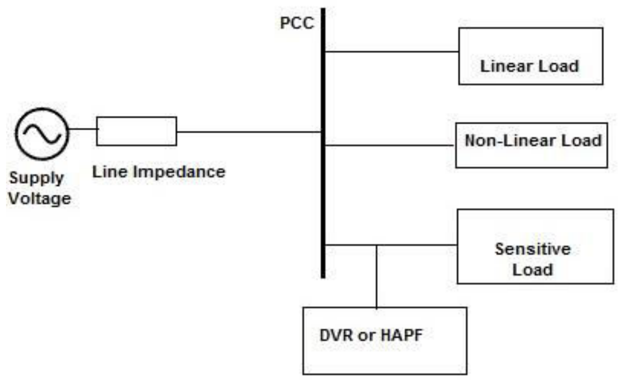

Figure-4. System across sensitive load.

4. PROPOSED CONTROL TECHNIQUE

The proposed controller uses error signal which is the difference between the actual value and the measured value to trigger the switches of inverter. It is based on feed forward technique which uses the above error signal to produce the gate pulses. The load values are sensed by the sequence analyzer and is then compared with the reference value. Pulse Width Modulation (PWM) technique is applied to the inverter to give the required voltages or currents to be added at the PCC. The control circuit is

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shown in Figure-5. Figure-6 shows the circuit of phase modulation.

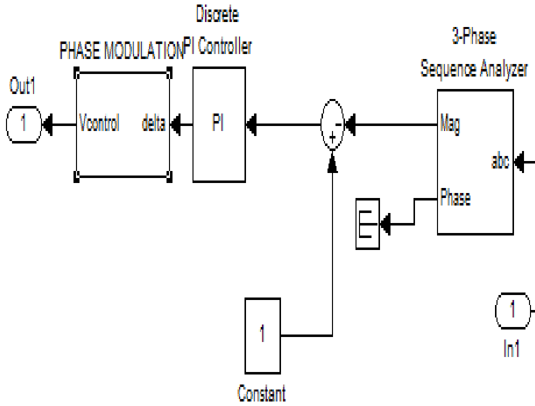

Figure-5. Control circuit.

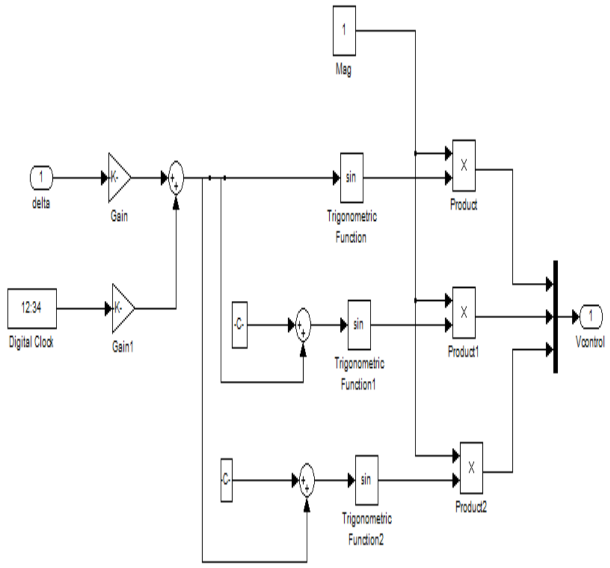

Figure-6. Phase modulation circuit.

5. SIMULATION RESULTS OF DVR

The test system of the DVR consists of 3-phase, 415V, 50Hz supply system. The output from supply unit feeds the primary of a 3-winding transformer. Two parallel feeders are drawn. DVR is connected in series to one of the feeder whereas the other feeder is kept as it is. The parameters are given in Table-1.

Table-1. Output of winding transformer.

Supply voltage	**3-phase, 415V**
Supply frequency	50 Hz
Inverter parameters	IGBT based 3 arms, 6 pulses
Carrier frequency	1080Hz
Sample time	5μsec

The system is analysed for voltage sag, voltage swell and both sag and swell conditions. Figure-7 shows the sag condition. Sag is created between 0.3 to 0.7 seconds and the magnitude reduces from 1 p.u. to 0.5 p.u. during this period. The THD value is 23.07%.

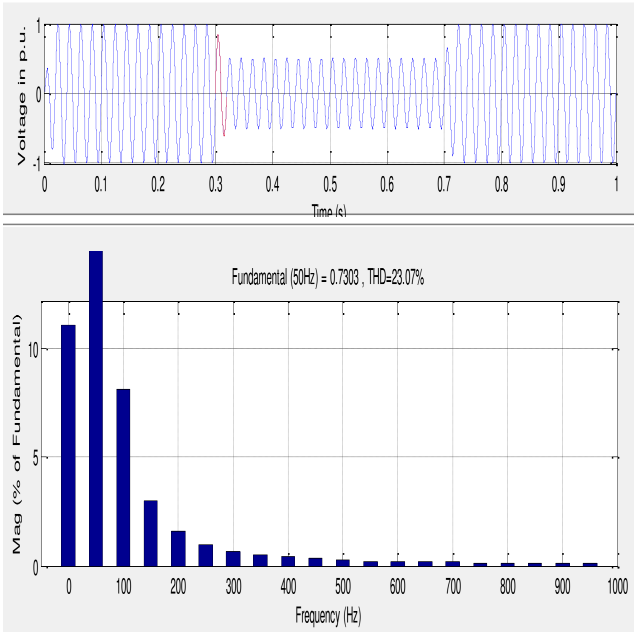

Figure-7. Load voltage and harmonic spectrum with voltage sag.

With DVR, the sag in the voltage is removed and the THD value reduces to 5.74% as shown in Figure. 8.

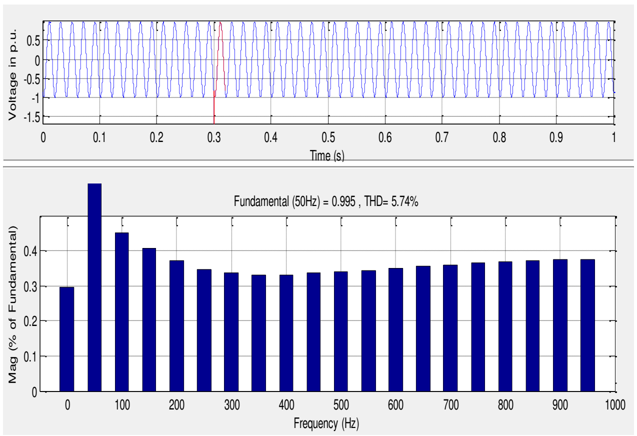

Figure-8. Output voltage and harmonic spectrum with DVR.

Figure-9 shows the load voltage with swell created during 0.3 to 0.7 sec. During the swell period voltage is increased from 1p.u. to 1.5p.u. Before compensation the THD value is 26.32%. With DVR voltage swell is compensated which is as shown in Figure-10. The THD value is reduced to 4.81%.

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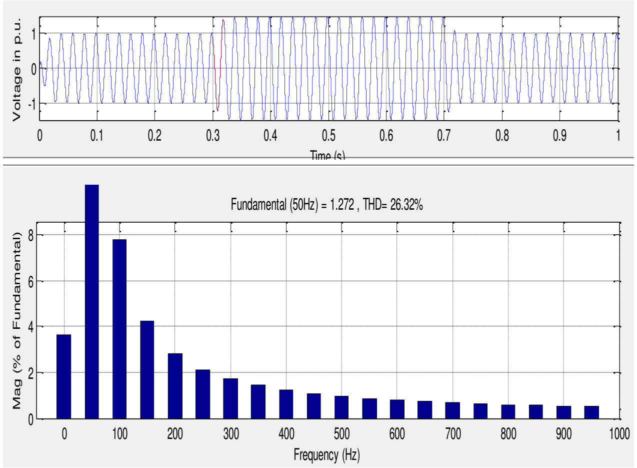

Figure-9. Load voltage and harmonic spectrum with swell.

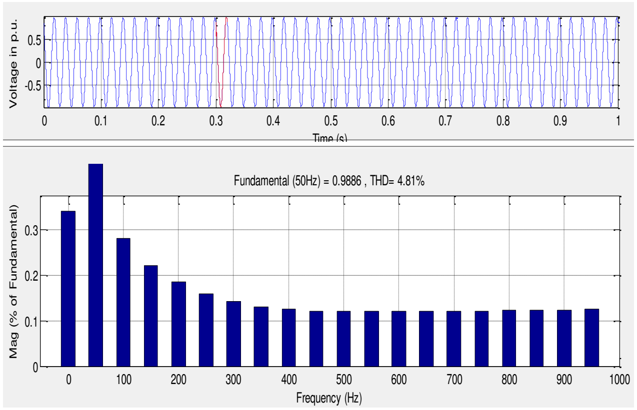

Figure-10. Output voltage and harmonic spectrum with DVR.

Figure-11 shows the voltage with both sag and swell. Sag is created between 0.1 to 0.3sec and swell is created between 0.5 to 0.7sec. Before compensation the THD value is 27.49%. But with DVR, voltage is improved and the THD value is reduced to 3.58% as shown in Figure-12.

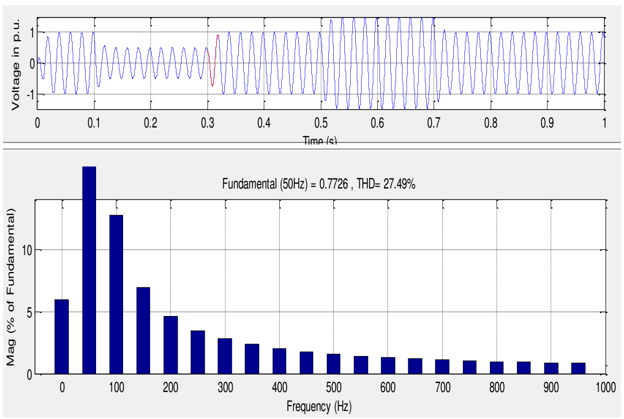

Figure-11. Load voltage and harmonic spectrum with sag and swell.

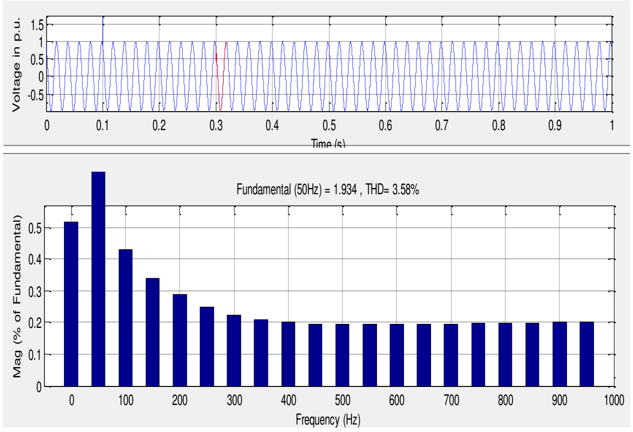

Figure-12. Output voltage and harmonic spectrum with DVR.

6. SIMULATION RESULTS OF HYBRID ACTIVE POWER FILTER

The system parameters taken for HAPF are given in Table-2.

Table-2. System parameter for HAPF.

Supply voltage	208 V
Supply frequency	50 Hz
Passive filter parameters	1.2 mH and 240 µF
Active filter parameters	3000 µF and 1 KΩ

The passive and active filters are designed with the parameters given in Table-2. With the proposed control method, simulation results are analysed for various combination of filters.

Figure-13 shows the source current without the controller. The THD value of the source current is 65.36%. With the combination of controller and passive filter, the THD value has reduced to 14.24% which is shown in Figure-14.

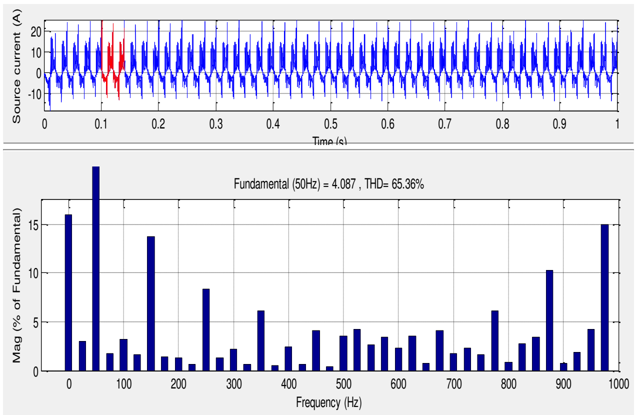

Figure-13. Source current and harmonic spectrum without controller.

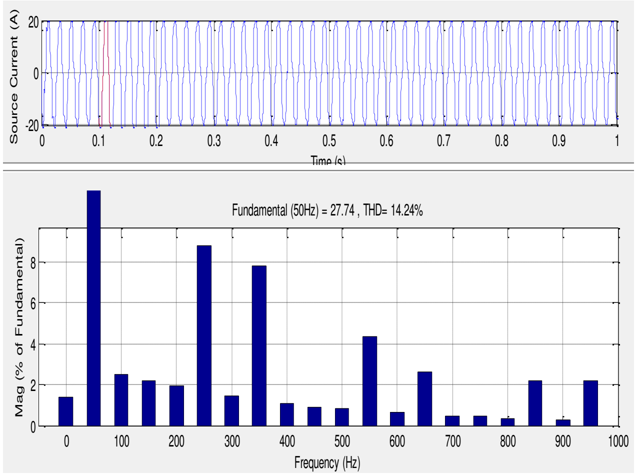

Figure-14. Source current and harmonic spectrum with passive filter.

Figure-15 shows the source current with active power filter. The THD value has reduced to 7.64%. Figure-16 shows the source current with hybrid active power filter. The THD has reduced to 4.89%.

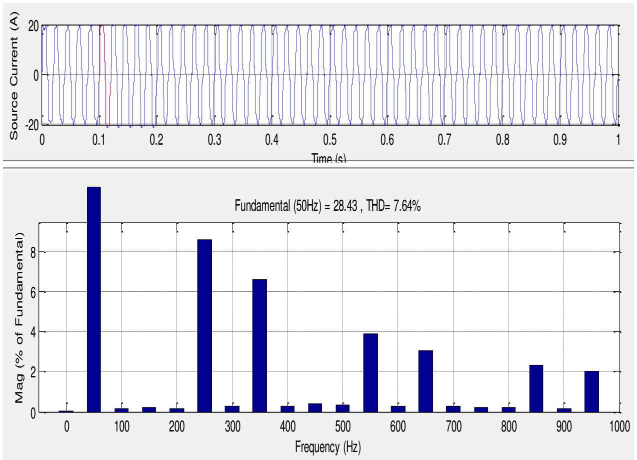

Figure-15. Source current and harmonic spectrum with active filter.

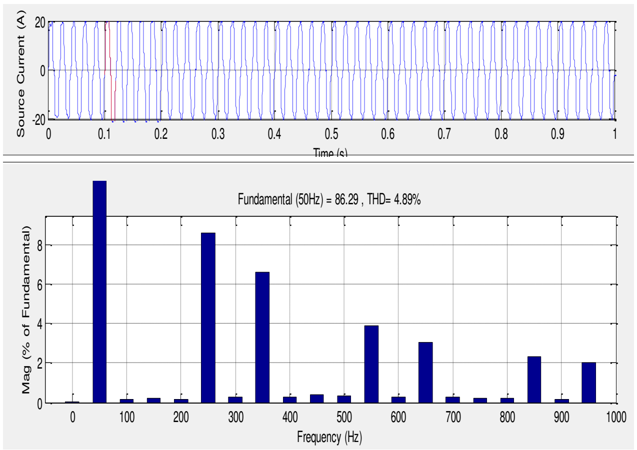

Figure-16. Source current and harmonic spectrum with hybrid active power filter.

Table-3. THD values with and without DVR.

% THD value	Sag condition	Swell condition	Sag and Swell condition
Without DVR	23.07%	26.32%	27.49%
With DVR	5.74%	4.81%	3.58%

Table-4. THD values for the filters.

	% THD value
Without HAPF	65.36%
With Passive Filter	14.24%
With Active Filter	7.64%
With HAPF	4.89%

7. CONCLUSIONS

DVR and HAPF circuits with the controller are built in MATLAB Simulink environment. DVR and the controller working is considered during voltage sag, voltage swell and both sag and swell conditions. As shown in table III the THD values have reduced using DVR. For sag, swell and sag, swell conditions the THD values are found to be 5.74%, 4.81% and 3.58% respectively.

HAPF working is analysed for different filter conditions. Table IV shows that the supply current THD values for various filter conditions. Without HAPF is 65.36%. With passive filter, the THD got reduced to 14.24%. By using active filter, the THD got further reduced to 7.64%. The combination of active and passive filter which is HAPF reduced the supply current THD value to 4.89%. With the help of these CPD's, both DVR and HAPF the voltage profile is improved and the current harmonics are maintained as per the IEEE standards.

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