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Dynamic Behavior and Current sharing Challenges in Multi Vendor Interop.

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Artesyn Embedded Technologies

Presentation Agenda

- Interop Objective
- Status Update
- Key Challenges
  - Current Sharing
  - Dynamic Response
- Solution Discussion
- Implementation Phase
- Next Steps
- Summary

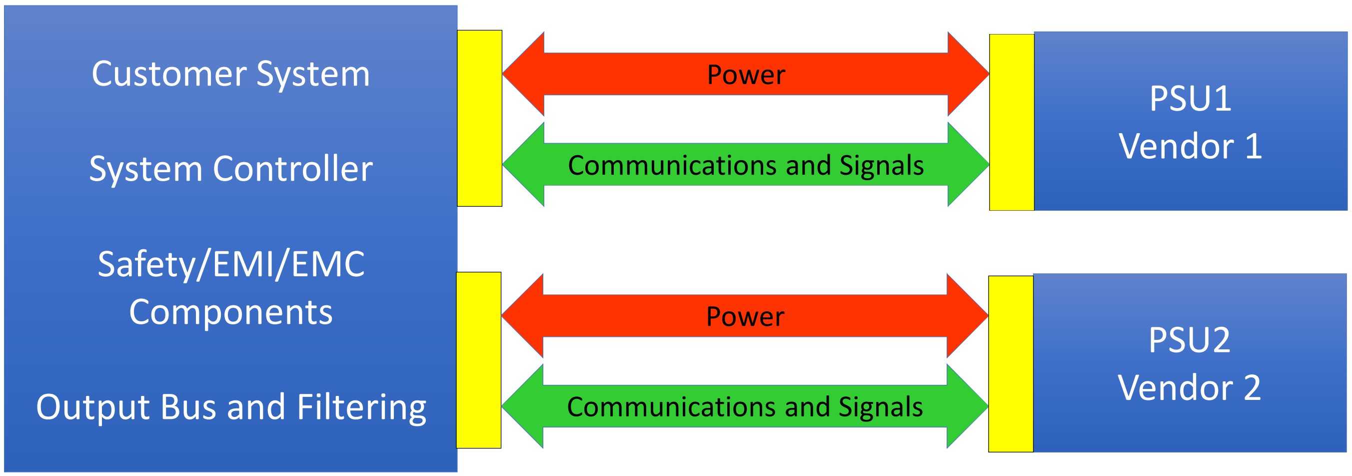
Power Interop Objective

- Interoperation (Interop): To allow PSUs and/or other components such as Power Shelf, BBU, etc., from different vendors to function compatibly in the same system together.
- True dual/multi-vendor sourcing

Key Challenges

- Different vendor design approaches to:
  - Current sharing
  - Communications protocol and other shared signals
  - Control functionality differences such as dynamic response, start-up and shut down timing, fault handling, etc.
  - Mechanical design
- System comprised of multiple components:
  - PSUs, Controller
  - Need to function compatibly in any combination

Shared Signals and Components



- Current Sharing, Remote Sense, and Digital Communications
- Filtering and protection components

Requirement Review

Current Sharing Control Method *

- PSU suppliers shall use a similar non-proprietary current sharing control method (e.g. single wire democratic active current sharing control, droop sharing control, etc.). The detailed parameters of the corresponding sharing control method shall be defined in the PSU specification (e.g. current sharing bus voltage versus current formula, adjustment range, etc.). Suppliers shall exchange their current sharing circuits.

Voltage Loop Bandwidth*

- PSUs from different suppliers shall have a similar voltage loop bandwidth.

Current Sharing Loop Bandwidth*

- PSUs from different suppliers shall have a similar current loop bandwidth.

- * Multi Vendor Interop – Facebook (May 2018)

Electrical Challenges

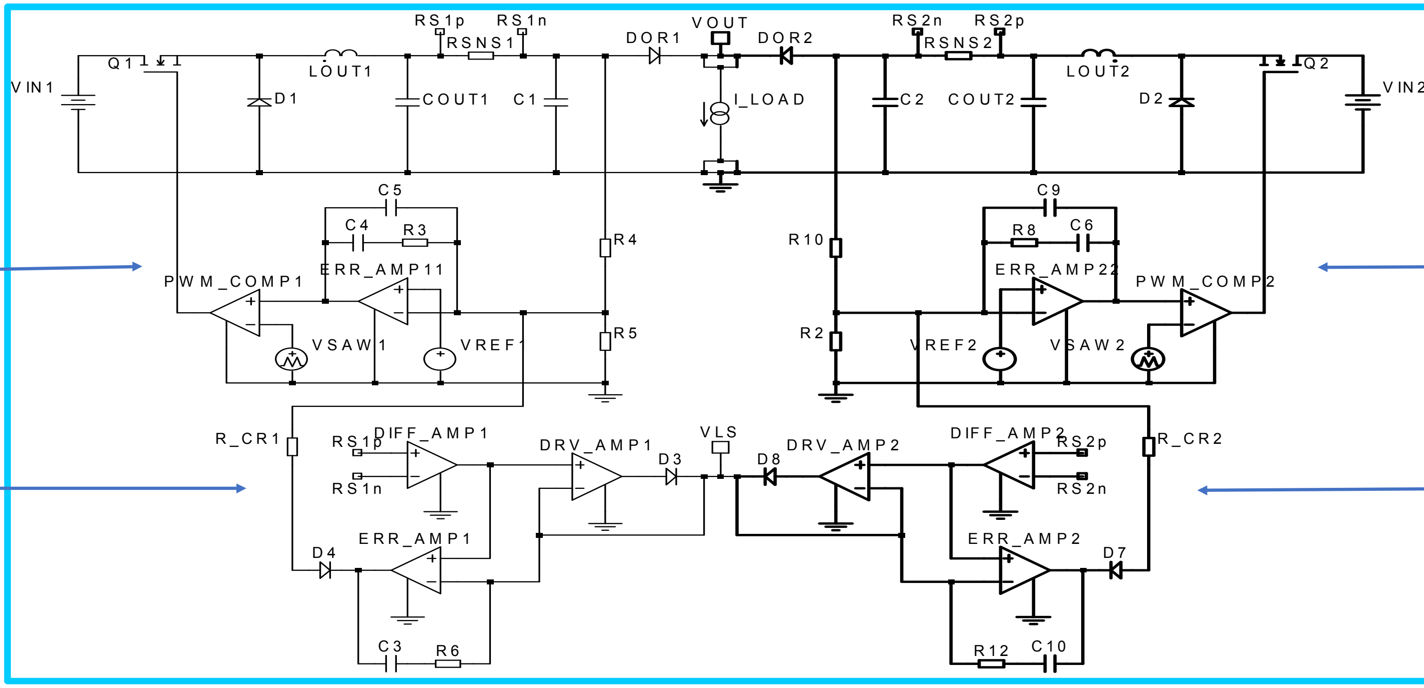
- Current Sharing
- Dynamic Response

Current Sharing and Dynamic Response

Current Share Circuit Overview

Vendor 1

Vendor 2



Voltage Loop

Voltage Loop

Current Share Loop

Current Share Loop

All need to work seamlessly together

Current Sharing Interoperability

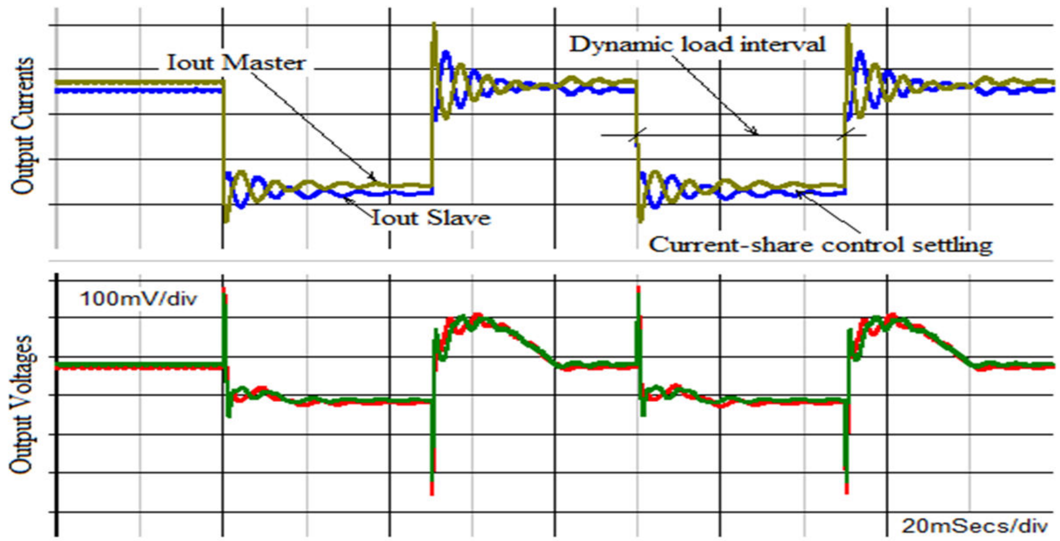
Possible Modes of Operation :

- Load Dynamic Change is slower than the Current Share Loop Bandwidth.
- Load Dynamic Change is faster than the Current Share Loop Bandwidth.
- Master PSU Voltage-loop response is slower than Slave PSU Voltage-loop response.
- Master PSU Voltage-loop response is faster than Slave PSU Voltage-loop response.

Current Sharing Interoperability

Possible Modes of Operation :

- Load Dynamic Change is slower than the Current Share Loop Bandwidth.

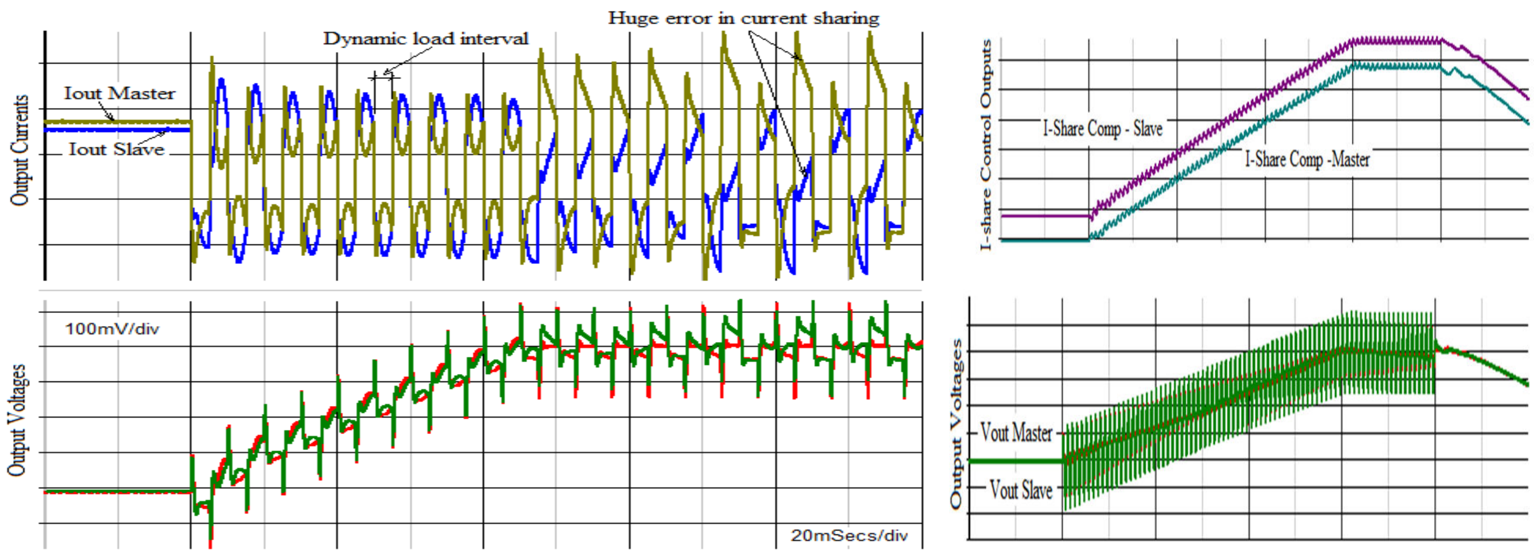


Dynamic load interval is slower than the current-share control settling time, the role reversal of the power converters quickly ends without causing problems at the converters' output.

Current Sharing Interoperability

Possible Modes of Operation :

- Load Dynamic Change is faster than the Current Share Loop Bandwidth.

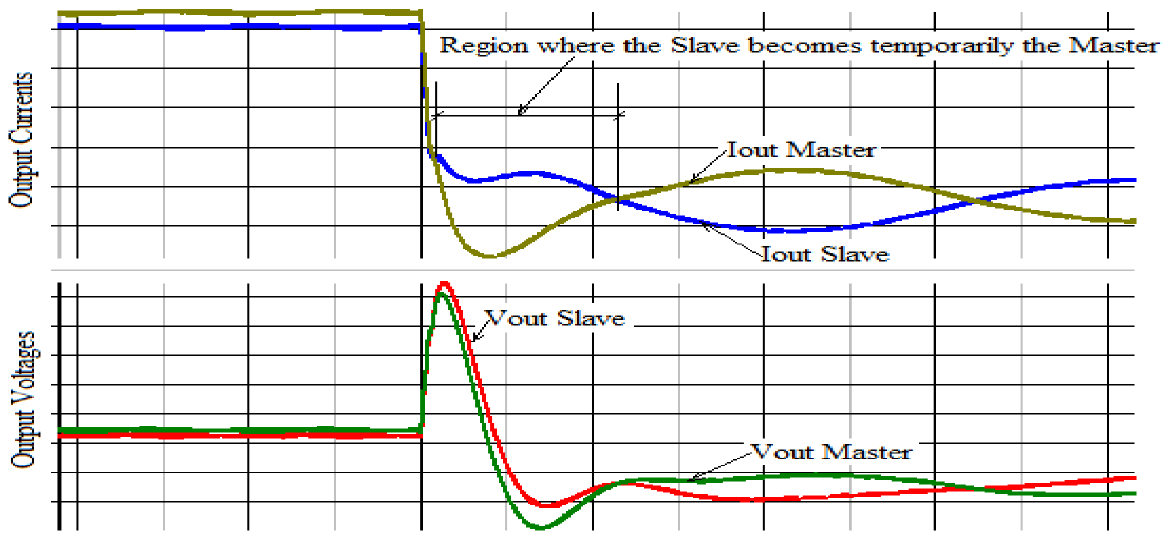


Instability in the current-share loop and desired sharing may not be achieved

Current Sharing Interoperability

Possible Modes of Operation :

- Master PSU Voltage-loop response is faster than Slave PSU Voltage-loop response.



Leading to Master/Slave role reversal and current oscillations before settling

Current Sharing Interoperability

Possible Modes of Operation :

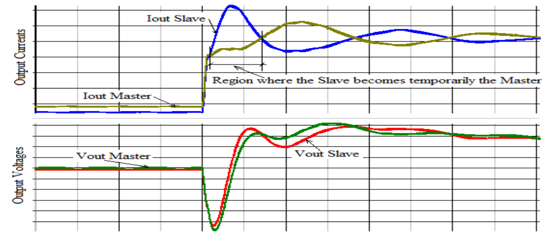
- Master PSU Voltage-loop response is slower than Slave PSU Voltage-loop response.

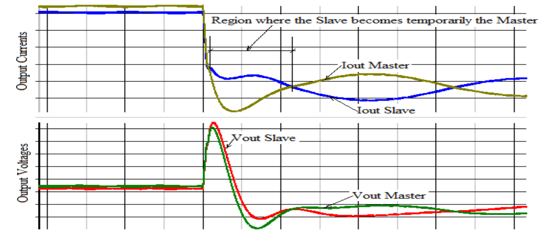
Leading to Master/Slave role reversal and current oscillations before settling

Analysis of Various Modes of Operation

Effects of different voltage-loop responses and dynamic-load frequency higher than current-share control bandwidth:

- Transition of master and slave roles
- Current share control on each PSU is 'On-and-Off'
- Current share keeps on adjusting the output voltage until it saturates to the capture range





Different voltage loop responses and dynamic load frequency higher than current share control leads to unstable operation.

Current Sharing/Dynamic Response Challenge

Other key Contributors:

- Current share interface circuit
- Current share capture range setting
- Current share signal vs. output current characteristic
- Vout temperature coefficient magnitude and direction (drift)
- Vout droop linearity (if droop sharing used)
- Remote sense offset compensation
- System distribution of bus resistances

Different Approaches and Set points compounding the challenge

Current Sharing/Dynamic Response Interoperability Recommendations

Master Slave Mode of Operation:

- The power supply with the highest output current automatically becomes the master and controls the share bus signal. All other PSU's become slaves, and the share bus signal causes them to increase their output voltages slightly until their output currents are almost equal to that of the master.
- A failed master power supply simply allows one of the slaves to become the master
- The PSU with the highest current (master) should be able to communicate with the PSU/'s with lower current/s (slave/s). The way to communicate is to have a common bus which is known as the ISHARE bus.
- Agree on Ishare signal level e.g. 5V
- Level of linearity to be defined
- Use Master Slave arbiter to account for the additional variation on parameters that are temperature-dependent, load-dependent, humidity, etc. after the unit-to-unit current-share calibration (trimming).
- Capture Range Setting to account for distribution impedance drop and other factors.

Current Sharing/Dynamic Response Interoperability Recommendations

Current Share bandwidth Loop:

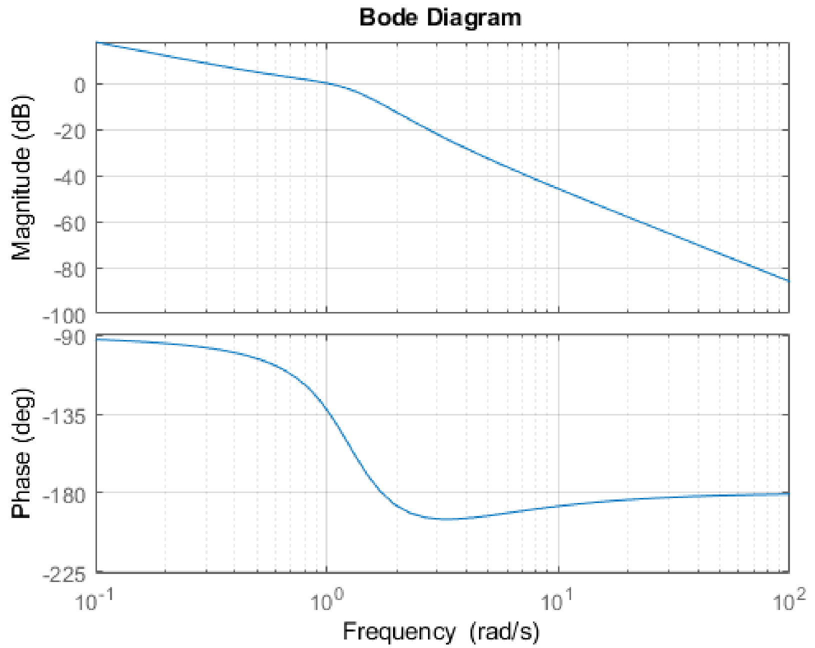
- 100-200 Hz bandwidth at full load
- Low Share loop bandwidth is preferred
- Share loop Margin >60 Degrees to ensure:
  - Best Performance for Hot Plug
  - Best Performance for AC loss and AC return
  - Best Performance for Hot Swap

If it can be agreed that the load dynamic change is slower than
the settling time of current-share loop response,
the majority of the issues and proprietary solutions can be avoided.

Current Sharing/Dynamic Response Interoperability Recommendations

Voltage Loop bandwidth:

- Sufficient to meet dynamic load requirements. Power supply response time to a step load reciprocal of the feedback loop bandwidth.
- Sufficient to meet phase margin particularly when using digital control which is limited by the sampling rate.



Interoperability Current Share/Dynamic Response Validation Phase

Alternate vendor sample requirements to carry out interoperability test program:

- Normal production level samples for test at proto stage
- PSU trimmed to max and min exit factory setting
- PSU trimmed to max and min capture range limit

Interoperability Current Share/Dynamic Response Validation Phase

Define and execute test program to ensure reliable interop for all conditions including:

- Steady state and dynamic conditions
- Start-up, shut down, hot swap
- Fault simulation
- Temperature effects
- Corner cases
- Role swaps

ATE Interop test program to be performed at each design phase

Current Sharing Illustration

Current Sharing Test Example:

- Testing is extensive must be automated

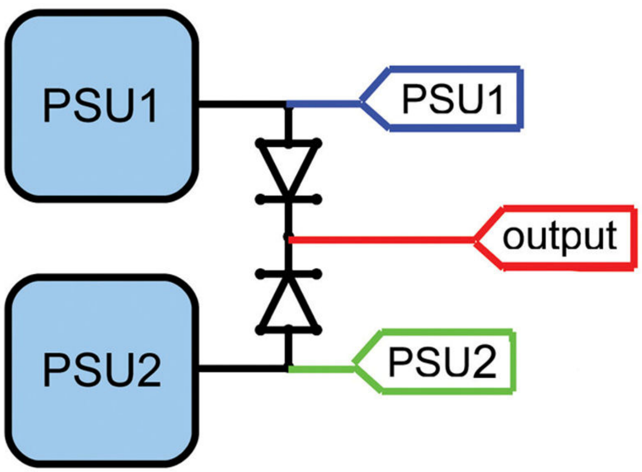


Table 2. Sharing Accuracy for 1+1 @ 230Vac (UUT1 trimmed 12.024V; UUT2 trimmed to 11.976V)

% Load	Load (A)	Bus Voltage (V)	Artesyn Load (A) UUT1	Artesyn Loading (A) UUT2	Total Load (A)	Ishare_V (V)	Accuracy (Artesyn - Artesyn) (A)	5% Limit	Remarks
0%	0.00	12.249	0.53	0.02	0.55	0.232	0.51	No requirement	
10%	4.13	12.230	2.89	1.62	4.51	0.664	1.27	2.06	PASS
20%	8.25	12.222	4.69	2.98	7.67	0.928	1.71	2.06	PASS
30%	12.38	12.215	7.22	5.63	12.85	1.271	1.59	2.06	PASS
40%	16.50	12.211	9.27	7.67	16.94	1.680	1.60	2.06	PASS
50%	20.63	12.207	11.34	9.75	21.09	2.089	1.59	2.06	PASS
60%	24.75	12.204	13.40	11.84	25.24	2.480	1.56	2.06	PASS
70%	28.88	12.201	15.56	13.80	29.36	2.884	1.76	2.06	PASS
80%	33.00	12.197	17.51	15.87	33.38	3.279	1.64	2.06	PASS
90%	37.13	12.195	19.51	17.89	37.40	3.685	1.62	2.06	PASS
100%	41.25	12.189	21.38	20.38	41.76	4.048	1.00	2.06	PASS

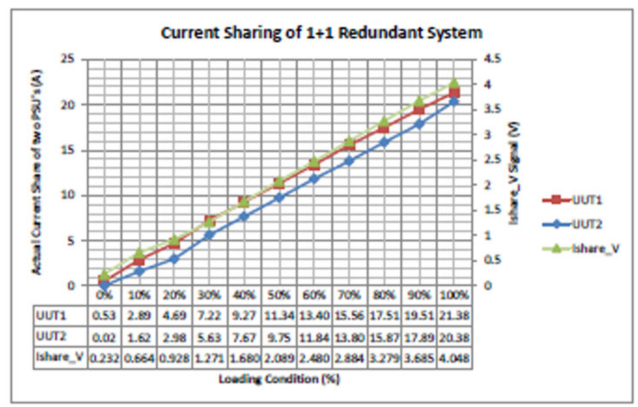


Figure 3. Current Sharing of Artesyn PSU's (Max and Min Vout Trim) in 1+1 Redundant System

Shared Agreement Needed

Agreement on Current Share/Dynamic response Parameters

- Current share circuit
- Current loop bandwidth
- Voltage loop bandwidth

Agreement on Mechanical

- Mechanical outline with tolerances, materials, feature definition such as mounting, airflow direction
- Connector definition including terminal assignments, short pin/long pin features, etc.

Agreement on Electrical

- Definition of signal and interface circuit for all shared control signals
- Definitions of output response and timing for start-up, shut down, dynamic and fault conditions
- LED Response (blinking rates, Intensity, wavelength)

Agreement on Digital Communications

- Communication architecture and spec
- Synchronization turn on/turn off sequence
- Firmware update compatibility requirements

Committee Agreement Required, Volunteers Wanted!

- Defined key objectives of multi vendor Interoperability
- Defined challenges of current share and dynamic response in multivendor Interoperability
- Discussed possible solutions of addressing
- Current sharing Challenges
- Dynamic response Issues
- Validating the solution
- Example

Thank You!

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