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IEEE P1547 Series of Standards for Interconnection

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T.S. Basso and R. DeBlasio

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IEEE P1547 Series of Standards for Interconnection

Thomas S. Basso, *Member, IEEE*, and Richard DeBlasio, *Senior Member*, *IEEE*

Abstract--The IEEE P1547 Standard For Interconnecting Distributed Resources With Electric Power Systems is the first in the P1547 series of planned interconnection standards, and additional standards are needed. There are major issues and obstacles to an orderly transition to the use and integration of distributed power resources with electric power systems. The lack of uniform national interconnection standards and tests for interconnection operation and certification—as well as the lack of uniform national building, electrical, and safety codes—is understood, and resolving this requires reasonable lead time to develop and promulgate consensus. The P1547 standard is a benchmark milestone for the IEEE standards consensus process and successfully demonstrates a model for ongoing success in the development of further national standards and for moving forward in modernizing our nation's electric power system.

Index Terms--certification; communications; dispersed storage and generation; distributed generation; distributed power; distributed resources; fuel cells; interconnection; monitoring and control; photovoltaic power systems; power distribution; power generation; power systems; regulation; standards; test.

I. Introduction

The use of distributed generation and, more generally, distributed resources (DR)—which includes distributed generation and energy storage systems—has the potential to provide more reliable and lower-cost energy for electricity customers as well as benefits for today's electric transmission and distribution (T&D) systems. This may prove to be particularly true for customer-sited generation. Further, increased interest in the use of DR is evolving as a result of the advent of competition in the electric power industry, the desire for customer choice, potential opportunities envisioned with the modernization of our T&D systems, and the advanced development of improved small, modular generation technologies such as fuel cells, photovoltaics, and microturbines. In addition, the potential environmental benefits of DR (for example, for renewable resources and combined heat and power systems) are substantial.

Although the application of distributed generation and storage can have many benefits, the technologies and operational concepts to properly integrate them into the existing power system must be developed to realize these benefits and avoid negative effects on reliability and safety. The electric distribution system traditionally was not designed to accommodate active generation and storage at the distribution level or, generally, at the sub-transmission level, and, especially, it was not designed to allow distributed generators to supply energy to other distribution customers. The technical issues involved in readily interconnecting and effectively integrating these types of DR applications with grid operations are significant.

Electricity regulation, zoning and permitting processes, and business practices developed under the framework of an electric industry based on central-station generation and ownership of generation facilities by a regulated monopoly can be barriers to the orderly development of market opportunities for DR in a restructured and modernized electric power industry. These barriers need to be identified and addressed through active participation in the development of solutions. Leadership and educational approaches are also needed to reduce these infrastructure barriers to the grid of the future.

The system integration and application issues related to DR interconnection are national issues that cut across a number of industries. There are federal, industry, and professional society leadership roles for bringing together the various stakeholders—manufacturers (e.g., manufacturers of electrical/electronics components and systems, photovoltaics, wind energy systems, fuel cells, gas turbines, and batteries), utilities, energy service companies, codes and standards organizations, state/federal regulators and legislators, and others—to address the technical, institutional, and regulatory barriers to interconnecting DR to modernized T&D systems. (See http://www.eere.energy.gov/distributedpower). In a discussion of national issues, it was suggested that there was a need for partnerships including industry and government to accomplish specific goal-oriented objectives such as developing uniform national technical interconnection consensus standards [1].

Standardized technical requirements tend to provide the framework for greater product and service quality, more interoperability, lower engineering and design costs, and streamlined installation, operation, and maintenance. They also help safeguard against hazards. In addition, uniform technical interconnection standards facilitate simplified contractual and other institutional interconnection agreements at the international, national, state, and local levels while facilitating industrial efficiency and robust commerce for DR in the increasingly competitive worldwide electric industry marketplace.

II. Background

IEEE—being a transnational technical professional society with a membership of more than 380,000 individual electrical, electronics, and computer engineers in 150 countries—oversees IEEE standards activities through its IEEE Standards Board Standards Association (IEEE SA). The IEEE SA pursues programs on an IEEE-wide basis that enhance globalization of IEEE standards to promote the development of electrotechnology and allied sciences and the application of those technologies. IEEE is a world leader in the development and

R. DeBlasio is with the National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, Colorado 80401 USA (e-mail: deblasid@tcplink.nrel.gov).

T. Basso is with the National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, Colorado 80401 USA (e-mail: thomas_basso@nrel.gov).

dissemination of voluntary, consensus-based standards involving today's leading-edge electro-technologies. IEEE has nearly 900 active standards, with 700 under development.

On June 25, 1998, the IEEE Standards Board, encouraged by IEEE members, decided that a serious standards effort needed to be launched to address the needs of members regarding distributed power systems on a national level. With that came an expansion of the responsibilities of IEEE Standards Coordinating Committee 21 (SCC21), which reports directly to the IEEE Standards Board and oversees all standards development activities for DR. The scope of SCC21 includes all distributed generation and energy storage, and its official title is IEEE SCC21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage. Its responsibilities include overseeing the development of standards in the areas of fuel cells, photovoltaics, dispersed generation, and energy storage and coordinating in those fields among the various IEEE societies and other affected organizations to ensure that all such IEEE standards are consistent and properly reflect the views of all applicable disciplines. In addition, SCC21 reviews all proposed IEEE standards in those fields before their submission to the IEEE SA for approval and coordinates submission to other organizations.

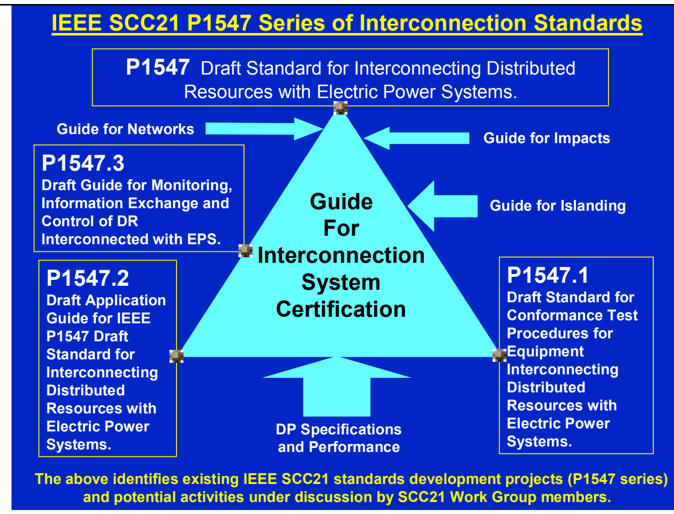
III. P1547 Series of Standards

The first organizational meeting of the expanded SCC21 was held in December 1998 and was hosted by the United States Department of Energy (US DOE) in Washington, DC. At that meeting, participants proposed an interconnection standards project. The interest to proceed was overwhelming, and it was determined that the document should indeed be an IEEE "standard" as opposed to a "guideline" or a "recommended practice." In March 1999, the IEEE Standards Board approved the project authorization request as submitted by SCC21 Chair and P1547 Sponsor Mr. R. DeBlasio. Additional IEEE interconnection standards project activities were first discussed at the January 2001 P1547 development meeting, and complementary projects were approved by IEEE and are now designated under the P1547 series of interconnection standards (Fig. 1).

Support for P1547 activities, from both the work group members and the electric power community at large, has been overwhelming. Members' organizations have sponsored a number of the P1547 meetings, and many meetings were sponsored by the US DOE/National Renewable Energy Laboratory (NREL) (e.g., see P1547 Minutes at http://grouper.ieee.org/groups/scc21/1547/1547_archives.html). It is estimated that the P1547 standard amounted to an approximately $4.5-million investment by the organizations and individuals supporting the P1547 meetings. These ongoing public/private partnerships, in conjunction with the IEEE consensus approach, are a large contributing factor to the success of P1547 development.

IV. Status of P1547 Series of Standards

The P1547 standard is targeted for IEEE publication in 2003. Since initiation of the P1547 project, the working group has grown to more than 350 members, with 100 attendees participating in meetings every other month for the first two years and then meeting three or four times per year for the next two years. Now, individual co-located meetings for the P1547.1,



P1547 Scope. This standard establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems (EPS). **Purpose**. This document provides a uniform standard for interconnection of DR with EPS. It provides requirements relevant to the performance, operation, testing, safety, and maintenance of the interconnection.

P1547.1 Scope. This standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that interconnection functions and equipment of a DR conform to IEEE (Draft) Standard P1547. **Purpose**. Interconnection equipment that connects DR to an EPS must meet the requirements specified in IEEE Standard 1547. Standardized test procedures are necessary to establish and verify compliance with those requirements. These test procedures must provide both repeatable results, independent of test location, and flexibility to accommodate a variety of DR technologies.

P1547.2 Scope. This guide provides technical background and application details to support the understanding of IEEE Standard 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. **Purpose**. This document facilitates the use of IEEE P1547 by characterizing the various forms of DR technologies and the associated interconnection issues. Additionally, the background and rationale of the technical requirements are discussed in terms of the operation of the DR interconnection with the EPS. Presented in the document are technical descriptions and schematics, applications guidance, and interconnection examples to enhance the use of IEEE Standard 1547.

P1547.3 Scope. This document provides guidelines for monitoring, information exchange, and control for DR interconnected with EPS. **Purpose**. This document facilitates the interoperability of one or more DR interconnected with EPS. It describes functionality, parameters, and methodologies for monitoring, information exchange, and control for the interconnected DR with, or associated with, EPS. DR include systems in the areas of fuel cells, photovoltaics, wind turbines, microturbines, and other distributed generators as well as distributed energy storage systems.

Fig. 1. IEEE SCC21 P1547 Series of Interconnection Standards

P1547.2, and P1547.3 work groups (WG) are proceeding on a regular basis. These complementary standards are in their formative stages of development, and those members wish to maintain accelerated schedules for development. They are targeting two to three years to have voting drafts completed.

V. History of P1547 Standard Development

Since the founding meeting in December 1998, P1547 participants have been very active and have provided numerous background documents, papers, draft materials, and presentations. An IEEE Web site and a list server for member e-mail exchanges were also developed.

The P1547 minutes include voluminous amounts of information. For the first six months of deliberations, P1547 members developed two complete versions of a work group resource document (see WGRD II dated June 6, 1999). After that, they provided addenda to the WGRD. In accordance with the P1547 WGRD draft outline/major topical headings, task forces were established to lead the drafting of topical information, which later evolved into draft clauses within the respective P1547 outline areas. Participants volunteered and contributed according to their choice and expertise. The WGRD was used as the basis for "P1547 Draft 1 – 9/21/99," which was somewhat skeletal in parts but was purposely written along the lines of providing mandatory requirements while minimizing guidance and alternative recommended practices.

A P1547 writing group was established, and it drafted ongoing revisions to the outline and specific clauses based on open and full work group review and feedback. A number of P1547 drafts evolved. These solidified and captured the overall P1547 work group's "consensus" deliberations and fleshed out the original, skeletal Draft 1 outline and clauses.

Around August 2000, drafts 4B to 5 evolved to a point at which the outline and its topical clauses were stabilizing. The group then instituted an approach for a standardized feedback and review format similar to the IEEE ballot comment format. This approach was designed to collect comments on individual clauses/sections and required recommended rewording and the rationale. At P1547 WG meetings, individuals had time to further express their feedback/rationale and answer questions from fellow participants. The overall P1547 draft document remained open for discussion and review, but it appeared the work group thought the standardized feedback and review format was appropriate and beneficial. However, that approach took some getting used to, and some individuals still don't understand it. Around January 2001 (and feedback on Draft 6) the P1547 WG decided that with the agreed-upon changes, P1547 Draft 7 should go to IEEE for formal ballot.

In March 2001, P1547 Draft 7 was voted on by the P1547 ballot group, which had 167 members. Following the 30-day voting period, there was a 91% return of ballots, which achieved the IEEE 75% return requirement. This was encouraging and showed the voters' determination and support for completing the standard. However, the IEEE requirement of 75% affirmation was not met; the draft received only 66% affirmative votes.

A combined P1547 WG and ballot group meeting was held in April 2001 to address the ballot results. Based on discussion and the ballot comments, it was decided to proceed with a recirculation ballot of a reworded P1547 Draft 7. The P1547 writing group then developed a reworded P1547 Draft 7. That was reviewed at another combined P1547 WG and ballot group meeting in June 2001. Based on feedback, P1547 Draft 8 was established.

P1547 Draft 8 underwent a recirculation ballot September–October 2001. The Draft 8 ballot resulted in an increase of ballots returns, reaching 96%, and an increase in affirmatives. But again, it had only 66% affirmatives, short of the 75% required to move forward.

Again, a P1547 combined WG and ballot group meeting was held in October 2001. The participants developed recommended wording changes and encouraged Chair DeBlasio to intensify efforts for balloting another reworded draft. However, it appeared that rewording might not be adequate to get beyond the 66% affirmation level.

During the next meeting, held in January 2002, P1547 Draft 8 and its ballot comments underwent a more pointed and focused review on a clause-by-clause basis. The first part of the P1547 Draft 8 review approach was to remove the information that was more appropriate for other standards or documents. That information included procedure requirements, application guidance, safety practices, and supporting information such as that needed for protocols, specific DR-electric power system applications, equipment-specific criteria (e.g., distributed generators or distribution transformers), type-specific utility grid configurations, operational aspects, and regulatory aspects. The material removed is being considered for recommendation under the P1547.1 testing project, the P1547.2 application guide to P1547 project, or the P1547.3 guide for monitoring/control project or for additional future standards projects or technical or regulatory review and study.

After the P1547 WG completed the clause-by-clause review of P1547 Draft 8, the resulting refined P1547 outline was again reviewed, this time for recommendations toward alignment with the idea that P1547 shall state the mandatory, minimum functional technical requirements that are universally needed to help ensure a technically sound interconnection, such as is stated in the P1547 introduction.

Also at the January 2002 meeting, it was announced that the P1547 writing group was being expanded to 25 individuals, maintaining the consensus balance that IEEE requires only for the ballot group. The P1547 expanded writing group held three meetings from February to May 2002 to write P1547 Draft 9. The establishment of P1547 Draft 9 involved significant changes from the previous draft. That meant the P1547 ballot pool would be newly formed, such that previous ballot members had to renew their commitment to ballot.

P1547 Draft 9 was sent by e-mail for comment by the P1547 WG and the past P1547 ballot group. The comments and recommended rewording that were received were compiled and distributed and discussed at the June 2002 P1547 WG meeting. The attendees at the June meeting provided and discussed additional comments and recommended rewording. At the June meeting, the expanded P1547 writing group participated in the open discussions and also directly interacted with individual attendees, discussing concerns and recommended rewording for the P1547 draft. Based on the writing group's final deliberations, they arrived at P1547 Draft 10.

During summer 2002, the P1547 ballot pool was reformed. It then comprised 230 individuals. P1547 Draft 10 was balloted August to September 2002. The Draft 10 ballot resulted in a 93% return of ballots and 90% affirmatives. That met the 75% requirement for returns and affirmation.

Then, according to IEEE ballot protocol, P1547 Draft 10 ballot comments were addressed. The P1547 expanded writing group established P1547 Draft 11, which included some changes to P1547 Draft 10 based on the ballot comments. The negative balloters were informed of the P1547 Draft 11 changes, were provided the P1547 expanded writing group's recommended responses to their negative ballot comments, and, based on that, had the opportunity to change their votes to affirmatives. However, not all of them agreed, so there remained unresolved negative ballot comments.

Again according to IEEE protocol, there was a recirculation ballot to everyone in the ballot group. That recirculation package included P1547 Draft 11 and the unresolved negative ballot comments. The 230 balloters then had the opportunity to change their previously cast votes based on the recirculation package information. The P1547 Draft 11 recirculation ballot resulted in an increase to 95% returns. The number of affirmatives also increased, now up to 91%.

Based on these results, the P1547 draft standard is proceeding to the IEEE Standards Board for consideration at the June 2003 meeting for approval as an IEEE publication. In the future, IEEE Std 1547 will be considered for submittal to the International Electrotechnical Commission.

VI. IEEE Standards – International Links

The following links between IEEE and the International Electrotechnical Commission (IEC) world standards development community should prove to have far-reaching influences on multinational technology development, trade, deployment, testing, and certification for all DR technologies.

The first link is that IEC and IEEE have agreed on a dual logo arrangement for IEC to adopt IEEE electronics, telecom, and power generation standards for international use.

At the working level, the IEEE consensus standards development P1547 activities have stimulated related world activities. In 2000, recognition of P1547 work influenced the establishment of IEC Joint Coordination Group for Decentralized Rural Electrification Systems (JCG DRES) standards development, including requirements for grid interconnection. With decentralized electrification projects being implemented in developing countries, there was a recognized need for standards to be developed and used as a reference for assessing the quality, acceptance, and operation of these electric systems. The JCG DRES convener is R. DeBlasio (chair of IEEE SCC21 and chair of IEC TC82 Photovoltaic Solar Energy Systems), with France undertaking the role of project leader. The JCG includes coordination among technical committees such as TC82, TC88 Wind Turbine Systems, and TC21 Secondary Cells and Batteries.

The recently revised IEC TC 8 System Aspects for Electrical Energy Supply has reestablished its scope to address the broadest system aspects of deregulation of the world's electric power industry: "to prepare the necessary standards framework and coordinate the development, in cooperation with other TCs/SCs, of the international standards needed to facilitate the functioning of electricity supply systems in open markets." Through SCC21 and P1547 officials' participation in coordination and support of TC8, the IEEE P1547 series of standards development information, issues, and results will be brought forward during the ongoing deliberations of the TC8 group.

The IEC activities related to DR interconnection are significant links to the world community for the IEEE standards development work. These links provide a venue for IEEE major leadership roles to satisfy the needs for facilitating international understanding, harmonizing requirements, and negotiating reciprocity of testing requirements and equipment/system certification. Further, these international links offer far-reaching influences for promoting world trade and facilitating technology deployment and application, such as by world organizations (e.g., the world bank) developing and investing in global energy projects.

VII. Moving Forward

DR and uniform interconnection standards offer much promise in helping to modernize and improve distribution system and related transmission system performance. When DR are properly designed, interconnected, and integrated with the grid, the potential benefits include reduced electric line loss; reduced T&D congestion; grid investment deferment and improved grid asset utilization; improved grid reliability; ancillary services such as voltage support or stability, VARs, contingency reserves, and black start capability; clean energy; lower-cost electricity; reduced price volatility; greater reliability and power quality; energy and load management; and combined heat and power synergies. In summary, those benefits tend toward the evolution of a modernized electric power system that has greater flexibility and energy security for the future.

However, there are major issues and obstacles to an orderly transition to the use and integration of DR. During P1547 development, there arose many specific examples that were not necessarily appropriate to be stated as universal mandatory requirements in the standard. Categories of those specific discussion items included design-specific, application-specific, and equipment-specific issues.

There were also concerns that were broader than simple technical issues. Some concerns seem more appropriately addressed external to a universal, mandatory requirements standards document and are perhaps more appropriate in a guide or special applications document. These include system impacts and analysis (e.g., is it necessary and when), penetration (e.g., ideal allowable aggregation), safety (e.g., functional versus operational modes), re-fitting of electric power systems (e.g., what to do), cost of electric power system re-fits (e.g., how and who pays), operation (e.g., which standard and who is in control), reliability (e.g., operational issues such as durability versus availability), federal/state implementation and impacts (e.g., rules), misunderstanding or misapplication (e.g., limited experience or knowledge), and user disagreement (e.g., not all utilities and distributed generators are alike). Even broader DR interconnection concerns and R&D issues that are not necessarily appropriate for a standard or perhaps not yet timely enough to be included in some form of a standard include after-sales service support and warranties, liability (e.g., distributed generation versus grid operators), fully commercialized and certified products, full-scale remote or unattended operation (e.g., autonomous versus semi-autonomous), fully integrated controls and protective relaying (e.g., design and location), comprehensive functionality of the interconnection package (e.g., always more to add), where to include the interconnection capabilities (e.g., "black box," generator control, etc.), standards for interface between the DER and the interconnection package (e.g., equipment manufacturing design standards), issues of scaling to different power levels, and lower interconnection system cost.

Further detailed standards and measures of success for DR will need to be based on initiating and conducting R&D on the key interface, interconnection, and communications and control technologies, including both hardware and software, for fully dispersed power system architectures. To quicken the realization of this success, consensus approaches tempered with reasoned solutions are required to remove barriers to DR for near-term markets by accelerating the development, adoption, and implementation of regulatory utility policies, technical standards, and local codes and permitting processes that will allow distributed power to compete fairly in the market without compromising consumer protection, environmental values, health, and safety. The development of IEEE standards, through partnerships of work group members, can continue to play a significant role.

State governments are moving forward to develop interconnection standard agreement rules and protocols and have attempted to include technical requirements. Such efforts are commendable, and often, the states' technical requirements and testing procedures are being referred back to IEEE for help with the foundation and to resolve issues and produce uniform national technical standards. The members of IEEE SCC21 P1547 are committed to addressing such tasks in open consensus forums. However, a lack of advanced interconnection technology hardware, software, tests, and system operational models of current and future electric power systems as well as consensus building needs to be taken into consideration. The IEEE SCC21 P1547 series of standards activities should be perceived as developing, living documents that will advance in time and in stages.

A complete interconnection infrastructure that includes a series of standards will require adopting uniform technical standards for interconnecting DR with the electric power system of today and of the future, developing and adopting testing and certification procedures for interconnection hardware and software, and accelerating the development of distributed power control and communication technology, equipment, and systems. Advancement and validation of industry-developed products such as distributed and electric power system architecture design criteria, characterization and certification tests, educational and training tools, technical standards, and models will require a central interface technologies characterization test and evaluation capability. This will be critical in the near term because validation will be necessary to establish the technical basis for advanced or additional requirements for other standards to be developed for interconnection with the modernized grid.

This paper has described some of the issues that were identified and considered and how the distributed generation community developed the P1547 interconnection standard through IEEE SCC21 activities. However, there are other issues not covered in IEEE standards—such as non-technical regulatory, business, and siting issues—that remain barriers to interconnection. The IEEE consensus style of open participation appears to be a model of what is needed in other areas of distributed generation and grid modernization development and deployment—along with education and commitment by all, including international stakeholders.

VIII. Acknowledgment

The authors gratefully acknowledge the dedication and contributions of the members of the IEEE P1547 working group and ballot groups who volunteer their expertise and time to the success of IEEE standards development.

IX. References

[1] N. R. Friedman and the staff of Resource Dynamics Corporation, "Distributed Energy Resources Interconnection Systems: Technology Review and Research Needs," National Renewable Energy Laboratory, Golden, CO, NREL/SR-560-32459, Sept. 2002.

X. Biographies

Richard DeBlasio (M'1966, SM'1980) is technology manager for the NREL/DOE Distributed Energy and Electricity Reliability (DEER) program, which includes Distribution and Interconnection R&D at the United States National Renewable Energy Laboratory (NREL). Before joining NREL in 1978, he was with the US Atomic Energy Commission in Washington, DC (1974–1978), and Underwriters Laboratories (1972–1974). He was also a member of the technical staff at Stanford University (1965–1972). He is an electrical engineer; a senior member of IEEE; an IEEE SA Standards Board member; chair of IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Distributed Power, and Energy Storage; and chair of international standards committees IEC TC82 and JCG DRES.

Thomas Basso (M'1980) is an engineer-scientist working at NREL for the NREL/DOE DEER program, under the NREL Distribution and Interconnection R&D area. Also at NREL, he has conducted outdoor accelerated weathering of photovoltaic (PV) modules and was NREL project leader for PV Management under the NREL/DOE PV Advanced R&D Project. Before NREL, he was a design engineer with a consulting engineering firm and with an OEM of air-cooled heat exchangers for the petrochemical, refinery, and utility industries. He was also a standards engineer for the American Society of Mechanical Engineers (ASME) and instructor in the Mechanical Engineering Department of Northeastern University. He serves as secretary for IEEE SCC21, P1547, P1547.2, and P1547.3 and is a member of IEC JCG DRES, IEC TC8, ASME, and the American Solar Energy Society.

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