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Request for Comments

RFC-EITCI-SESG-SMART-PV-CONCEPTS-STD-VER-0.5

Reference Standard for the Smart AI Assisted Photovoltaic Systems
Conceptual Framework (Definitions, Architectures, Use Cases)

EITCI INSTITUTE SMART ENERGY STANDARDS GROUP

EITCI-SMART-PV-SESG

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This is a Request for Comments draft for standardization of AI assisted smart PV systems.
Please provide your comments and/or extensions at sesg@eitci.org until 31st OCT 2023.
Standardization activity of EITCI & ESN, under a funding of the H2020 StandICT program.

1. Introduction

The draft standards for the Smart AI Assisted Photovoltaic Systems – Conceptual Framework (Definitions, Architectures, Use Cases) aim to combine recent progress in Artificial Intelligence with improving performance of PV installations on many planes.

Some of these account for automated management of solar energy generated in grid-connected photovoltaic (PV) systems along with their operation-and-maintenance (O&M) and their smart on-grid integration control, other related to AI assisted methods in solar cells design and manufacturing (for optimized efficiency), while other relate to AI aided mapping of solar irradiation in low-data available regions.

The standardization effort in AI assisted smart PV aligns with the strategy of the European Union joining Digital and Green agendas as two major pillars for the COVID-19 economic recovery in the EU and is a part of the EU funded standardization action under the H2020 StandICT programme coordinated by the author and hosted by the Smart Energy Standards Group of the European Information Technologies Certification Institute (EITCI SESG) in cooperation with the European Solar Network.

The reference standard aim to contribute to one of the four primary objectives of the European Green Deal, i.e. to achieve a fully integrated, interconnected and digitalized EU energy market by increasing research oriented towards technical reference standardization aimed at consolidation of the expert community and the technology uptake.

Key-words: Smart PV, AI, Photovoltaics, Smart grids, Smart metering, Smart energy, MPPT

2. Definitions

A grid-connected PV system is generating electricity from the solar irradiation while being interconnected to the utility electric power grid. It generally consists of solar panels (PV modules), inverters, power conditioning units and grid connection equipment. Such PV systems range from small residential and commercial rooftop installations to large industrial-scale solar power-plants. Unlike stand-alone (off-grid) PV power systems, a grid-connected system usually does not include integrated batteries.

Thus whenever the solar irradiation conditions admit it, the grid-connected PV system automatically supplies the excess power beyond consumption by the connected load, to the utility electric grid, turning a consumer into a prosumer, thus transforming the energy market to a highly distributed model and introducing a dual concept of Distributed / Renewable Energy Sources (DES/RES).

2.1. Smart PV

Increasing automation of the PV solar power generated in-grid feeding control, operative optimization and maintenance has been recently dubbed smart PV, although in terms of in-grid feeding control it is mainly based on the developments of the smart grid achievements. The paper studies progress on research results in this area enabling undertaking and advancing international standardization efforts regarding PV systems grid-integration, as well as pronounces the need for extending these technical reference standards towards Artificial Intelligence assisted smart control over PV systems in solar power plants, PV integrated industrial buildings and the prosumer residential homes PV installations. A progress towards AI assisted PV in Deep Machine Learning and Neural Network models trained on a feedback loop of operational parameters for O&M and the in-grid (smart grid) power feeding is expected to contribute to the solar energy uptake parallelly to continuously impressive PV modules efficiency-to-cost ratios growth.

2.2. AI assisted smart PV architectures

Magnitude of various PV modules and inverters equipment producers develop their own systems of automated O&M and control processes. Many solar modules producers embed electronics into PV modules. Such systems (smart modules) enable maximum power point tracking (MPPT) along with monitoring of performance data for fault detection at a module level. Some of these systems make use of power optimizers to maximize generated power outputs.

With recent PV advancements the related electronics with a proper analytical software can compensate e.g. for shadows falling partially on a section of a solar module causing drop of electrical output of one or more strings of cells, but not zeroing the output of the entire module. A smart PV system should automatically control all its sophisticated operation parameters, including central or module-level MPPT, discover, diagnose and neutralize faults, hence improving its total efficiency, lowering O&M costs and increasing revenues. Main features of smart PV systems are automation, digitization and intelligence, optimally based on latest developments in AI applications (neural-networks big data learning comprising constant feedback input of all operational parameters of PV systems and their on-grid interconnection to AI enabled management system). The initiated effort aims at supporting international standardization work at a higher level of abstraction for the state of the art framework standard for deep learning neural networks AI assisted smart control over PV systems in solar power plants, PV integrated industrial buildings and the prosumer residential homes PV installations.

It should be noted that a lot fundamental processes and devices involved in smart grids is already present for decades in electronics and primarily involves well known circuitry, which doesn't have much to do with AI algorithms and machine learning. Mainly the electronic circuitry involves feed-back loops that lead to the self-regulation and balancing in purely electrical effects. However it is also known that implementing some device level AI and ML enabled data processing can by high increase efficiency of electronic control for better overall performance of such AI assisted PV module.

Furthermore the proposed standards in smart PV focus on a higher abstraction level applications for AI. These will include systems that manage consumption of the electrical energy precisely when it is dominantly produced from renewables (at renewables efficiency peak) not only in the scale of the PV installation, but in the grid. So that the AI algorithmics can make informed decisions on e.g. when to charge the electric car so that the energy consumed is most optimally produced.

2.3. AI assisted smart PV standardization context

Under the StandICT H2020 supported effort, researched multitudes of possible solutions and architectures are currently evaluated in order to propose a European framework of Smart PV reference standards under a newly organized Standards Developing Workgroup hosted by the European IT Certification Institute jointly with the European Solar Network. The project is tasked by the StandICT programme to conceive 2 Request for Comments standards drafts that will be iterated among WG experts and disseminated to other international SDOs active in the area of Smart Grids and Smart Metering standards with a focus on the solar power. The newly proposed Smart PV standard aims at systemizing conceptual architecture and implementation specification to define compatibility requirements between interfaces of PV modules and their associated electronic equipment control systems with inclusion of AI and cloud technologies. It aims in filling gaps in general smart-grid uniform communication standards mainly pursued by international SDOs in this field.

3. The context of the EU Rolling Plan 2020 for digital smart grids standards

The relevance of this research and standardization effort is in a direct correspondence with the EU Rolling-Plan 2020 for smart energy standardization overviewing the needs for digital standards in support of the EU policy for Smart Grids and Smart Metering in focus on the PV solar energy. Accordingly with the EU Rolling-Plan 2020 ICT standards in energy are expected to cover smart grid management, grid-balancing and interfacing with millions of new renewable sources in particular optimizing efficiency in complex processes of renewable energy systems control. These standards mainly focus on uniform communication and cybersecurity protocols (providing plug & play compatibility for new devices entering the grid, from renewable sources to electric cars or other smart devices and IoT enhancing smart homes, buildings or cities of the future).

The current dynamic EU energy transformation is driven by two main factors: the energy systems becoming clean (i.e. environmentally neutral accordingly with goals of the EU climate and energy framework and the European Green Deal strategy of the European Commission) based on renewable and consumer-centric sources, primarily in a form of the solar power, and the ongoing digital/smart transformation of the energy and electrical grid sectors. The first factor is due to the EU energy policy encouraging stakeholders to adapt to an increasing number of means of generating electricity from a variety of renewable energy sources with minimizing environmental impact (clean energy transformation).

The key policy milestones for this transformation are the EU's energy and climate targets for 2030 which emphasize Europe's leading role in the global fight against climate change. These 2030 EU climate and energy framework targets include at least 40% EU domestic reduction in greenhouse gas emissions compared to 1990 (with an increased ambition to 55% reduction as a part of the European Green Deal of September 2020), at least 32% share of renewable energy consumed in the EU, at least 32,5% improvement of energy efficiency and an electricity interconnection targeted at 15%. In this context both the PV systems and the electricity networks are of key importance. In 2012 electricity represented 22% of the EU's energy consumption with renewables accounting for a share of 24% of gross production (with ca. 3% increase on 2011, while reaching as high as 30.2% in 2016 and expected to grow up to 55% in 2030, correspondingly with the 2030 energy and climate goals and the Paris Agreement). As 2020 marked a hallmark achievement in the EU – for the first time the electricity generation mix has been dominated by renewables (at 39% share, exceeding by 4% the combined fossil fuels at 36% of electricity generation – as confirmed by the Directorate-General for Energy of the European Commission Communication of 9th April 2021) and the solar energy steadily increasing its stake (to 5.2% on the EU-27 level, and almost up to 10% in Italy, Greece, Germany and Spain), the smart PV based contribution to its efficiency is becoming even more so important. Furthermore the consumer position in the energy value chain has considerably changed. The energy consumer can now easily become a prosumer, deploying grid-connected renewable energy source (e.g. a PV system DES/RES), feeding the surplus of the generated energy into the utility grid. For this end with smart optimization of energy efficiency the digital and energy technologies need to overlap taking advantage of most recent developments in big data enabled AI control methods, smart homes and cities applications, energy intelligent products, the IoT, 5G networks, etc. It is for a reason that the EU COVID-19 strategic response is summarized in prioritizing two pillars: the single energy market and the digital single market combined as strongly interdependent and being both critical to the policy of the EU. This is where the second factor of EU energy transformation through smart (AI assisted) digitization is pronounced, with digital and AI holding a potential to further support uptake of the solar power. The current proposal targets a specific sector of this outlined in-demand technical standards of smart PV systems assisted by feedback loop trained neural networks based AI. An important concept for the proposed standards is defining a common cloud-based platform specification for distributed Smart PV operational data aggregation that will enable NN deep-learning not only on individual operative systems but also on the whole ecosystem of AI enabled Smart PV devices (with properly addressed security and privacy issues).

4. The current progress in related smart energy and smart grids standardization

In October of 2014 the CEN/CENELEC/ETSI's Smart Grid Coordination Group (SG-CG) successfully completed requirements of the EC M/490 mandate, with industry representatives confirming their will to take over and implement the results of the Expert-Group-1 work on the first iteration of the

Smart Grid standards. Consequently, EG1 of the Smart Grids Task Force assessed in 2016 the interoperability, standards and functionalities applied in the large scale roll out of smart-energy metering in Member States and in particular the status of implementation of the required standardized interfaces, along with EC recommended functionalities related to the provision of information to consumers (summarizing report was published in October of 2015). Further coordination of standardization efforts related to Smart Meters was due to the Smart Meters Coordination Group (SM-CG) established under the M/441 mandate. The SM-CG has returned the reference architecture (TR-50572) and an overview of technical requirements, continuing to liaise with its successor CG-SEG (since end of 2016, the CEN-CENELEC-ETSI Smart Energy Grid Coordination Group took over and cooperates with the EC-SGTF). In September 2017 EC issued a proposal for a regulation on ENISA on Cybersecurity certification (Cybersecurity Act) as a voluntary mechanism framework enabling creation of individual EU-wide certification schemes (with a scheme indicating a specific product/service, an assurance level and a standard for evaluation). Such schemes are now developed to verify security properties of digital energy systems. The EC fostered conceiving a common interoperability language SAREF - a standard of ETSI and OneM2M. The CEN-CENELEC-ETSI is endowed to further align SAREF with the data models developed at ISO and IEC. These are initial steps to enable smart-energy grid and its adaptive demand-response operation mode. The standards of the discussed research will mainly provide an added value as extensions of the CENELEC / IEC-TC CLC/TC-82 (Solar photovoltaic energy systems) and the CLC/TC-57 (Power systems management and associated information exchange) for power systems control equipment and systems including EMS (Energy Management Systems) and SCADA (Supervisory Control And Data Acquisition). Furthermore they will also build on CLC/TC-57 in providing amendments to the ENs on (Communication networks and systems for power utility automation – EN-61850), along with Application integration at electric utilities (prEN-61968), energy management system application program interface (EMS-API) (prEN-61970) and on Power systems management and associated information exchange (EN-62351). The added value will also address the CEN-CENELEC-ETSI Coordination Group on Smart Energy Grids, CG-SEG (incl. the M/490 and its iteration) and EN-IEC-61850 (Distributed Energy Resources).

5. Concepts, architectures and use-cases of AI assisted smart PV

Solar energy has many important advantages, but also few important drawbacks.

Among the advantages, it is a highly efficient energy source, which significantly advanced technologically in the recent years. It is a low cost and highly scalable, environmental friendly technology of energy generation.

The main drawbacks of PV are cost/energy ratios (still improving and in 2020 historically becoming the cheapest energy source on Earth, however in highly solar irradiated geographic areas only), intermittence of power supply and not linearly fluctuating power output. Solutions for the areas of problems haunting PV are under significant development correspondingly with new materials and nano-engineering of the solar cells designs and fabrication methods, battery storage (or smart grid integration enabling input of PV generated surplus power to be consumed somewhere else) and electronic control equipment stabilizing electric output (smart hybrid converters and other devices).

Furthermore facing the above problems many different optimization techniques were considered and implemented for PV modules and installations, mainly based on standard statistic techniques combined with numerical and analytical methods. Many of the these optimization techniques were also implemented by PV installations (or even PV modules) integrated electronic circuitry embedded in inverters, hybrid inverters, microinverters and alike. The better the optimization performance the higher the efficiency and power output stability of the optimized PV system which partially mitigates the main drawbacks of the PV technology, especially if it is interconnected to a smart power grid.

Most of the PV optimization techniques considered were however classical and the recent development in Artificial Intelligence and Machine Learning can bring important added value in terms of better optimization of the PV modules and installations operations, hence further limiting the disadvantages of the electric solar energy. The main areas in which AI can improve the PV performance are in:

- Solar cells designs and production phase:
  - Basic modeling of solar cells (materials, design and production technologies to devise new structures and designs, in terms of e.g. optimization of multi-junction cells, that haven't been considered yet but might surpass the efficiency of the current top solar cell designs),
- Planning of optimal solar cells systems deployments:
  - Forecasting and modeling of meteorological data for weather dependent insolation patterns, shading, etc. (AI assisted automated insolation analytics and interactive maps for smart PV deployments)
  - Optimal sizing of photovoltaic systems based upon AI assisted modeling
- Optimization of solar cells operation in power systems:
  - AI assisted optimization of electricity generation in solar modules within grid-connected PV systems (machine learning upgraded electronic circuitry for improved MPPT, fluctuations stabilization, etc.)
  - AI for PV performance loss rate determination and power forecasting on a level of single solar cells, solar modules as well as whole installations, from private residential PV setups, up to large scale PV power plants
  - Advanced automation and optimization of Operation and Maintenance (O&M) of PV installations (both small and large scale) and their smart on-grid integration, including AI assisted PV powerplants predictive management (using AI and machine learning to learn patterns in the electric fluctuations to be able to predict failures and support operations in terms of prevention in a right time rather then mitigating failures that have already occurred)
  - AI enabled concentrator PV (CPV) learned productivity under variable solar conditions
  - AI assisted optimization of smart distributed PV integration with power grids towards interconnected and digitalized energy market - towards energy production with consumers changed into prosumers by local power generation enabling PV, complemented with AI to optimize all integration processes
    - AI for increasing the smart grid awareness

- Machine learning methods to improve on the statistical based power grids net-load forecasting with enhanced behind-the-meter PV visibility (including various models, e.g. based on recurrent neural networks for ahead in time net-load prediction under high intermittent solar penetration in power grids)
- AI for demand response potentials with high penetration of behind-the-meter solar with storage
- AI assisted PV integrated smart grid connectivity tracking in real-time with various machine learning methods for state and events tracking
- AI algorithms for managing PV penetrated smart grids in a way to optimize intermittence of solar power with power storage control
- AI assisted carbon intensity awareness in the grid power production for the smart PV operation integrated with intelligent energy efficiency control
- AI assisted integration of smart meters data to increase renewable energy penetration in different parts of the power grid (data mining and machine learning on vast amounts of bidirectional smart electricity meters data to improve over time operation parameters and physical restructuring of the power grid, towards a future of implementing automatically reconfigurable network topologies of electric power grids)
- AI assisted tokenization of virtual energy market (involvement of blockchain technology and smart contracts to securely tokenize prosumers generated surplus PV energy amounts, that physically enter the power grid but virtually enter a new generation of a distributed energy market with AI assisted algorithms for auctions of the energy selling/purchasing, so that the prosumers can gain on the transactions regarding their generated energy or possibly get it back from the grid for free in different locations and time)

The approaches that can be used with applying AI to smart PV systems are vast and include among others:

- Machine learning (with many variants including, supervised learning with classification and regression, as well as unsupervised learning with dimensionality reduction, clustering and association, deep learning and reinforced learning, quantum machine learning)
- Neural networks (with many variants, including e.g. convolutional NNs, recurrent and feedforwarded NNs, generative adversarial NNs, quantum NNs)
- Autonomous multi-agent systems (including particle swarm optimization)
- Fuzzy logic (including quantum computational model based AI)
- Expert systems (with knowledge bases and inference systems)
- Evolutionary and genetic algorithms

A technical discussion of advantages of new AI enabled methods over conventional statistical methods will be discussed. An important aspect of the technical referencing of AI assisted smart PV is not focusing on the theory of artificial intelligence and machine learning, but on practical AI applications in methods that are either ready to apply to PV operations or need only industrial level research and development.