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37th Cycle

Reduction in Photovoltaic Energy Curtailment by implementation of EVs Smart Charging and Blockchain Technology

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Overview

- The current issues of climate change and air pollution are pushing the electricity sector to move towards the deployment of renewable energy sources. However, shifting from traditional to renewable energy resources like solar energy introduces new aspects and challenges. Weather dependency and the need for expensive storage infrastructure to cope with power fluctuations appear among the main aspects for effectively using solar energy. When storage cannot be used, in the presence of high diffusion of renewable energy it could be necessary to resort to energy curtailment in the peak hours of production.
- In the last years, solar energy exploited in photovoltaic (PV) plants had a noteworthy increase, even though in absolute terms the total energy produced from PV plants is still relatively low with respect to the global energy needs. However, in some systems the diffusion of PV plants has been so high to make the PV production higher than the demand in some time periods. When the excess of local production is so high to cause power flows in the grid with possible violation of the grid constraints (e.g., maximum loading of lines and transformers, and node voltage magnitude limits and local energy storage is not available, the grid operator tends to curtail some the energy generated by PV plants to avoid overloading lines and transformers or creating over voltages in some nodes.
- In this research, the proposed methodology tends to help the reduction of energy curtailment in the peak production hours of photovoltaic panels by controlling the charging power of electric vehicles connected to the grid without reaching the line loading limits and without exceeding the voltage magnitude limits in the nodes of the grid.

Addressed research questions/problems

- ✓ A co-simulation framework based MATLAB fuzzy logic Tool Box and PandaPower has been developed (Fig 1). The experimental network is IEEE 13 Bus Feeder 3 phase (Fig 2). It has been assumed that maximum 26 electric vehicles (EVs) connect to the grid (node 634) and all are equipped with 30 kWh batteries. Every EV is connected to the grid with 7 kW chargers by default. There are two photovoltaic (PV) power plants connected to nodes 633 and 680 with peak power generation of 1 MW each (every phase generates 1 MW). EVs remain at charging point with minimum of 4 hours and maximum of 6 hours.

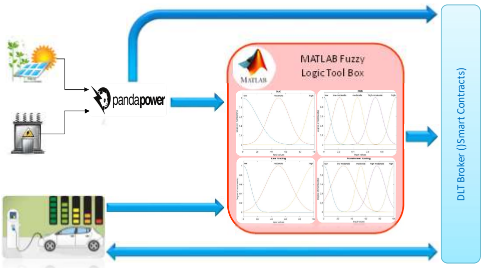


Fig 1.

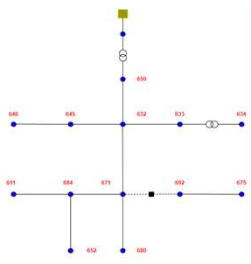


Fig 2.

- ✓ The proposed strategy controls the EV charging by increasing the charging power of the EVs in selected time steps with respect to the minimum EV charging considered, through the determination of the *fuzzy weights* that are generated for defined grid parameters. The avoidance of PV energy curtailment is obtained by changing the net power in the grid nodes close to the PV system location, in such a way that the line loadings and the node voltage magnitude limits are not violated in the entire grid. The simulation cases shown on the IEEE 13-node system indicate that violations of the grid limits may occur if the EVs are managed with uncontrolled charging, while the proposed controlled EV charging leads to a remarkably better situation.
- ✓ The results shown can be seen as the contribution of smart EV charging to the improvement of the system operation also in the absence of specific programmes targeted at increasing the PV plant diffusion. On the same line, the EV charging strategy considered can be applied as a contribution of the EV charging side to demand response programmes.
- ✓ For the practical applications, a key point is that a satisfactory forecasting of the generation and demand power curves needs to be available for constructing an effective daily EV charging strategy.
- ✓ EVs owners would be satisfied with the experience of charging their EV on the basis of the proposed methodology, since EVs charge at higher rates and it takes less amount of time to get charged.

Submitted and published works

❖ S. Saadatmandi, G. Chicco, A. Favenza, "Exploiting Blockchain for Smart Charging of Electric Vehicles: A Proof of Stake Algorithm", BLOckchain for Renewables INtegration (BLORIN 2022), Palermo, 2-3 September 2022 (accepted and presented)
❖ S. Saadatmandi, G. Chicco, F. Giordano, "Reducing the Curtailment of Photovoltaic Energy Production through Smart Electric Vehicle Charging", 2022 114th AEIT International Annual Conference, Rome, 3-5 October 2022 (accepted)

Novelties

- **Reduction of photovoltaic energy curtailment through smart charging of EVs**: By increasing charging power of the chosen EVs in each round, not only the excess amount of energy generated by PVs injected into the grid would be consumed, but also the batteries will get charged at higher rate, thus EVs get charged with less amount of time.
- **More clean energy generation**: Reduction of curtailment and satisfying grid contraints will result in the exploitation of more renewable energy inside the grid. which will help to move towards cleaner environment.
- **Introduction of Distributed Ledger Technology to smart charging of electric vehicles**: We benefit from the decentralization feature of Blockchain, which leads to saving time and money due to the elmination of third parties.
- **Proof of Stake Algorithm based on fuzzy logic**: validators are chosen according to their fuzzy weights assigned to them, since in this work, the stakes are considered as wealth and they are distributed fairly among all the members of network. Therefore, it is less likely to encounter the «nothing at the stake» problem like in the original algorithm.

Proposed Methodology and Results

Every minute, fuzzy weights would be generated based on four main parameters:

a) State of Charge (SoC) of EVs b) Transformer c)Loading d) RES production Line Loading

The parameters are getting produced according to fuzzy rules already defined in MATLAB Fuzzy Logic Tool Box. Some of these rules are shown below

If (SoC is moderate) and (Transformer loading is high-moderate) and (RES is moderate) and (Line loading is high) then (fuzzy weight is low)

If (SoC is low) and (Transformer loading is high-moderate) and (RES is moderate) and (Line loading is low) then (fuzzy weight is medium)

If (SoC is low) and (Transformer loading is moderate) and (RES is high) and (Line loading is low) then (fuzzy weight is high)

After the assignment of a fuzzy weight to each EV. In the grid In our methodology, stakes are considered as fuzzy weights rather than wealth in original PoS algorithm, thus they are distributed fairly among all the members of the network. Those EVs with fuzzy weights greater than average of all weights in the grid would be selected as validators to forge their blocks and gain their profits. Chosen EVs are allowed to increase their charging power 7 kW to 22 kW. By augmenting charging power the excess energy injected to grid by RES would be consumed.

The PV peak power curtailment (which occurs at a given time step), denoting with $P_{\mathrm{PV}}^{(k)}$ the peak power of the PV system in Case k: $P_{\mathrm{PV,cur}}^{(k)} = P_{\mathrm{PV}}^{\mathrm{ref}} - P_{\mathrm{PV}}^{(k)}$

The PV energy curtailed during the day, denoting with $W_{\mathrm{PV}}^{(k)}$ the PV energy generated in Case k:

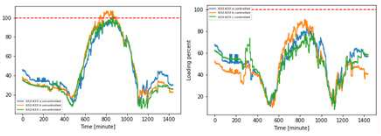
$$W_{\mathrm{PV,cur}}^{(k)} = W_{\mathrm{PV}}^{\mathrm{ref}} - W_{\mathrm{PV}}^{(k)}$$

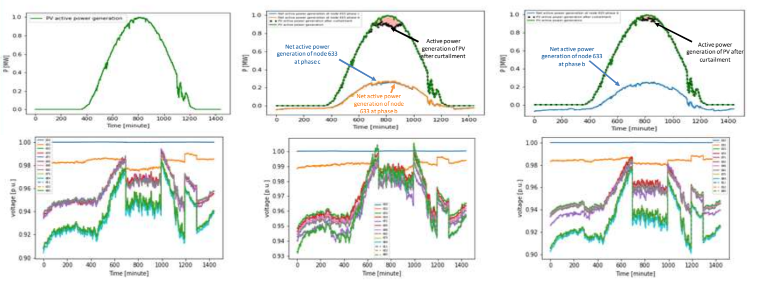
In the first case (reference case) we have the network without any constraints. In the second case the network with constraint in the absence of EVs is evaluated. And for the last case we have our grid at the presence of both EVs and constraints. The following are the results of the current research in three case studies.

Reference Case (case 1)
- P_{PV}^{ref} = 1 MW at timestep 819
- W_{PV}^{ref} = 24.42 MWh

Case 2
- P_{PV}^{2} = 983 kW at timestep 866
- $P_{PV,cur}^{2}$ = 144 kW
- W_{PV}^{2} = 23.653 MWh
- $W_{PV,cur}^{2}$ = 767 kWh

Case 3
- P_{PV}^{3} = 995 kW at timestep 844
- $P_{PV,cur}^{3}$ = 72 kW
- W_{PV}^{3} = 24.239 MWh
- $W_{PV,cur}^{3}$ = 181 kWh





Future Work

- ➢ The simiulation will be carried out on the basis of IEEE 123 Bus System. Thus, the method can be evaluated in a more enlarged scale.
- ➢ Adding different types of chargers with a wide range of powers to the the exprimental grid.
- ➢ Considering a wide variety of charging stations such as home chargers, fleets, public, ...
- ➢ Improving fuzzy logic membership functions based on statistical data to acheive more accurate results.
- ➢ Deploying the method on an open source blockchain framework
- ➢ Implemention of the whole idea on the small scale reality-based situation

List of attended classes

- ❑ 01DOARV – Electrical demand management (23/09/2022,25)
- ❑ 01NDLRV – Italian Language Level I (14/09/2022, 0)
- ❑ 01UNVRV – Navigating the hiring process: CV, tests, interview (25/03/2022, 2)
- ❑ 01LEVRV – Power system economics (12/09/2022, 16)
- ❑ 02SFURV – Advanced scientific programming in MATLAB (3/06/2022, 30)
- ❑ 08IXTRV – Project management (14/02/2022, 5)
- ❑ 01RESRV – Public speaking (12/07/2022, 5)
- ❑ 02RHORV – The new Internet Society: entering the black-box of digital innovations (8/07/2022, 3)

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