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Determining the Suitability of Using Charging Centers to Use Excess Power Generation from Solar PV

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Abstract

The amount of sunlight that strikes the earth's surface in 90 minutes is adequate to meet the energy requirement of the world for one full year. Solar photovoltaic (PV) technology is a safe, silent, and a non-polluting technology to convert solar energy to electricity. Grid-connected solar PV systems feeding low voltage networks are growing worldwide. As more PV systems are added to existing networks, they may be required to be curtailed to maintain the voltage stability of the grid. To avoid curtailment, several solutions are suggested in the literature. These include storing energy in battery banks, shifting loads to day-time, or converting electricity to other forms of energy. This study evaluates a solution to effectively use the surplus generation from solar PV within the distribution transformer service area, by establishing vehicle charging stations. The study attempts to determine the use of accumulated energy (rather than from individual generation sources) in charging centers for electric vehicles.

Keywords: Photovoltaic Systems, Smart Grids, Low-Voltage Systems, Voltage Stability

Introduction

Most countries have already developed programs to enhance power generation from solar PV to the electricity grid. PV impacts on the grid, and solutions to enhance the voltage

Solar PV Energy

Solar energy has been identified as a feasible alternative to fossil fuels [3]. Photovoltaic (PV) technology [4], and the concentrated solar power (CSP) [5] are the two technologies widely used to harness solar energy to produce electricity. PV technology is more widespread, structured as solar PV parks positioned on stability of the grid and power quality, are in progress. Most literature on this perspective is limited to the study of the PV generation through the use of probabilistic [1] and deterministic studies [2], but do not provide a comprehensive solution large for countries in the equatorial region where a amount of solar PV-based generation has to "hosted" during certain periods of the day. This paper presents a study on the possible use of EV charging centers as a variable load on distribution networks, to improve grid voltage stability.

Solar PV Energy

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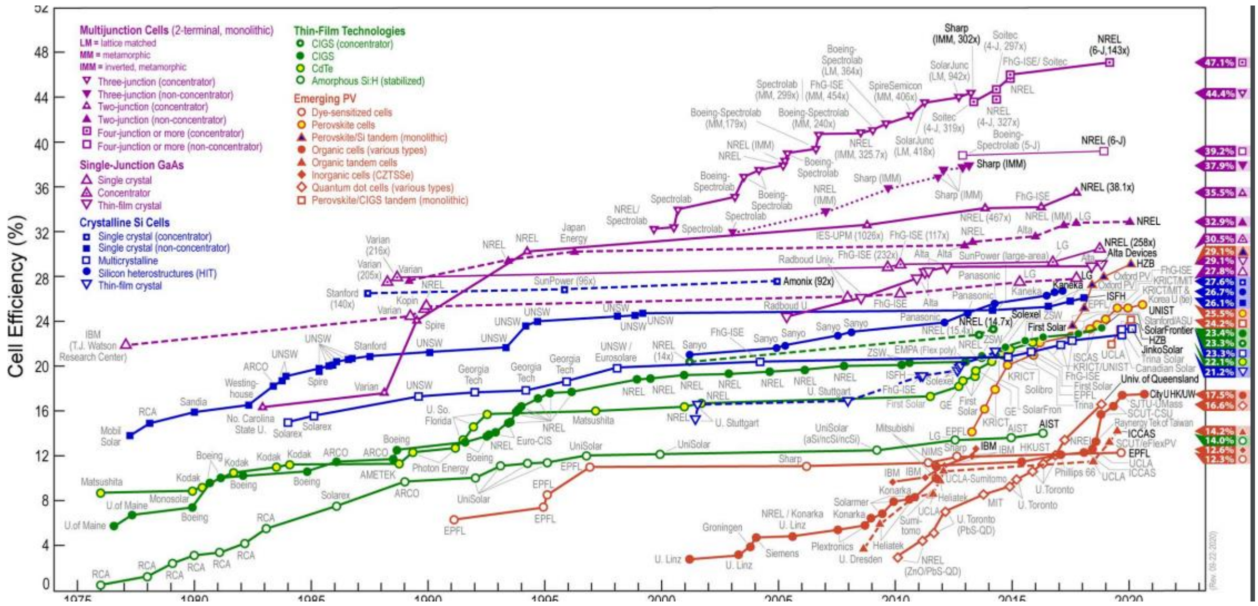
It most countries, government-initiated programs are currently active to increase the amount of electricity generated from solar PV systems. The modern PV cell technologies are highly developed have higher efficiency [6]. Figure 1 displays the pathway of development of different PV cell technologies and their efficiency, between 1975 to 2020. [7].

Figure 1: Energy Efficiency Pathway of PV Cells from 1975 to 2020



Stability Issue in Distribution Networks

Smart grid technologies provide options to integrate the renewable energy [8] into the power distribution system. However, the prevailing power quality, regulations, and models require to be retained or improved. The implemented solutions are required to be technically feasible with no adverse effects on the distribution system.

Among these considerations, the long-term voltage stability of a stressed distribution network [9] is of greatest concern. In the present distribution network arrangement, the grid absorbs the energy that is supplied, and if the PV production causes voltage and current limit in the grid to exceed the norms, the inverter is expected to curtail its output.

Several methods are used to store the energy from solar PV, which would otherwise be curtailed. (i) pumped hydro storage [10] (ii) compressed air energy storage [11] (iii) battery energy storage devices [12].

Status of Electric Vehicle Use

The concerns on environmental pollution, oil costs, and the depletion of oil reserves has caused increased use of electric vehicles (EVs) in place of conventional oil-powered vehicles. An EV is estimated to be capable of converting 90% of the input energy to motive power [13]. The world trend to adopt EVs as the primary automotive partners have increased, and has created hopes of EVs being capable to take over the world market in the near future [14].

The number of electric cars worldwide in the year 2019 surpassed 2.1 million, a 40% year-on-year increase [15]. The growth from 2017 to 2018 was 65% [16]. The electric vehicle stock in the global context is expected to increase continuously. The number of EVs worldwide, excluding two and three-wheelers, is expected to increase at an annual rate of 36% which can result in 245 million vehicles by the end of 2030 [15]. This is thirty times the EVs now in use.

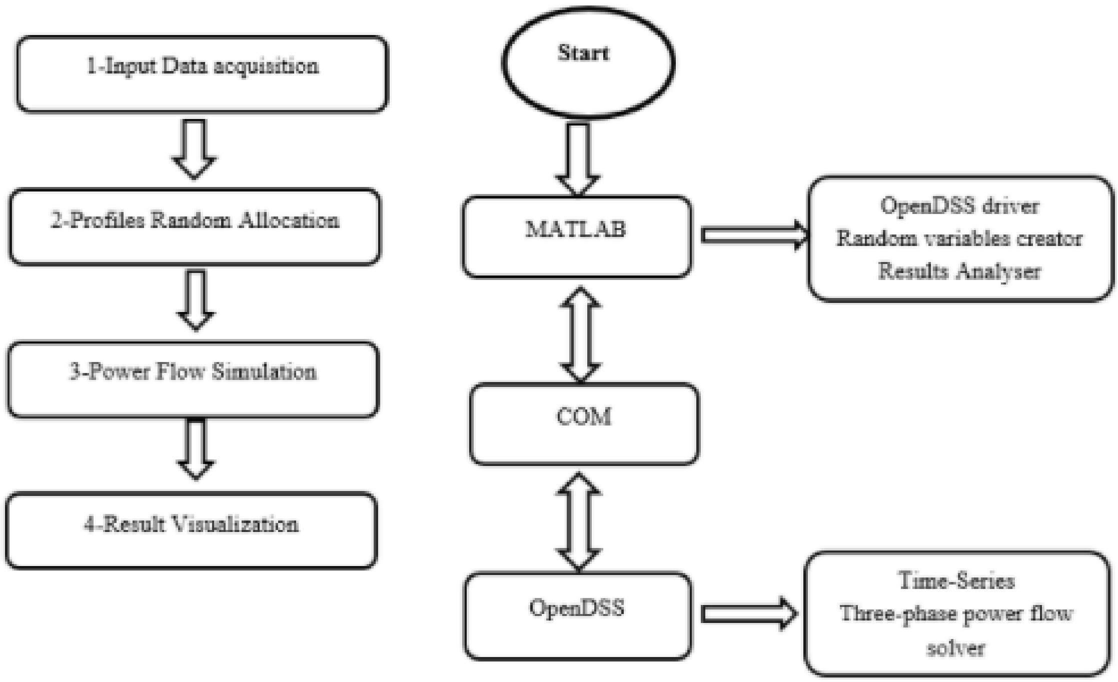
However, such an increasing trend, can create a major impact on power systems [17]. Battery charging will increase the electricity demand at night, and the balance between the demand and supply would be affected. The battery charging process of the EVs may coincide with the peak demand. Several studies have assessed the effect of EV battery charging on the grid demand, and the study of [18], presents a methodology to establish three charging regimes, namely uncontrolled, peak and off-peak time schemes.

Development of the Case Study

This study was undertaken to examine solutions to the emerging grid stability concerns by investigating the impact of solar

PV generation on power system voltage stability using a simulation model. Energy curtailed owing to grid code violation is used to charge EVs. The study uses a stochastic research methodology to simulate, using MATLAB, and Open-DSS software to analyze the energy saving. Figure 2 shows the flow diagram of the simulation.

Figure 2: System Operation Flowchart



The study was conducted by modelling 20 household solar PV systems on a distribution network. Each PV system was rated between 3 kW and 5 kW. Power output of each unit over a typical day were obtained from the actual recorded information about ac output of the respective inverter. Figure 3 shows the recorded power output of each solar PV system, in per unit of its rated capacity. Figure 4 shows the combined output of the 20 solar PV systems.

Figure 3: Individual Outputs on a Typical Day

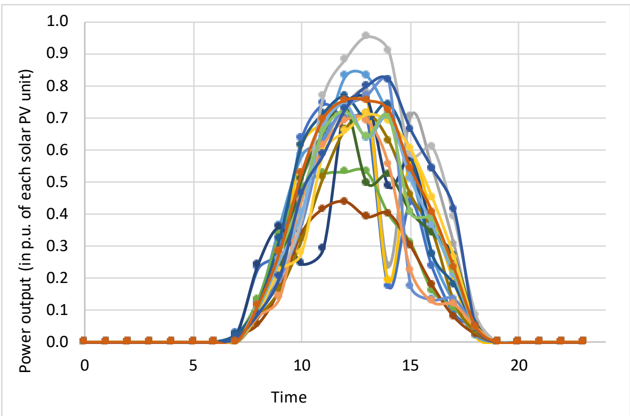
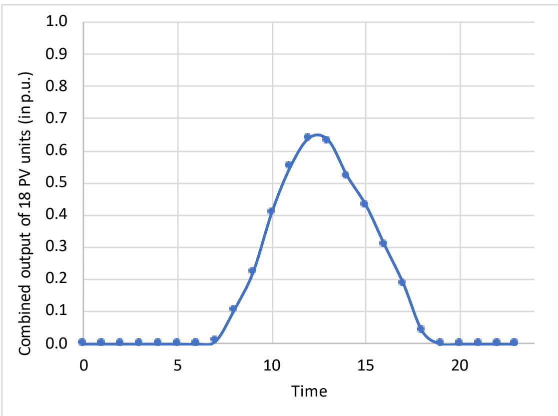


Figure 4: Combined Output on a Typical Day



These solar PV systems were placed in a distribution network (later shown in Figure 8), and the calculated voltages at the intended EV charging station is shown in Table 1.

Table 1: Results of Distribution Network Simulations with Increasing Solar PV Penetration.

Case	Number of PV Systems Added	Calculated Maximum Voltage (V)	Calculated Minimum Voltage (V)	Duration (HH:MM) over which the voltage limits in the distribution code are violated
01	10	243.3	219.3	14:00 to 16:05
02	12	244.0	219.3	12:15 to 16:10
03	15	245.3	219.3	10:02 to 17:30
04	18	249.2	219.3	09:20 to 18:05

Figure 5 shows the case II (see Table 1) of the simulation where the output of the system indicates a rule violation, exceeding of the maximum voltage level of 243 V, thus indicating the possibility of employing a consumption mechanism between 1200 h - 1600 h. The EV charging station will allow the grid voltage to be maintained at a continuously stable level, use the excess energy from solar PV systems.

Fig 5: Twelve (12) PV Systems Connected to the Network.

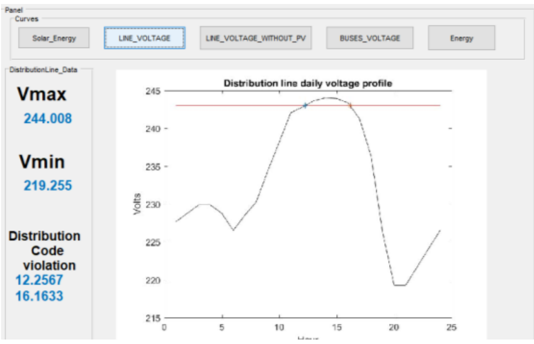
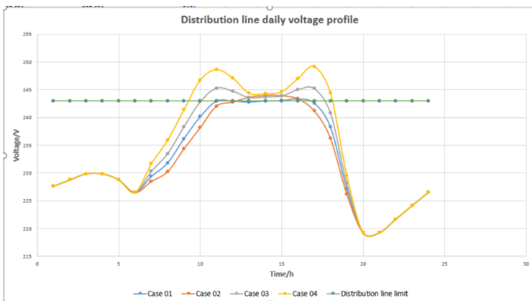


Fig 6: Output of 10,12,15 and 18 PV Systems Connected to the Network



To model the proposed EV station, commonly used EV charging systems were identified. These include both ac charging and dc fast charging. For ac charging two types of connectors were allowed: (i) 5-pin charger of 11 kW capacity at 230 V and 32A, (ii) 7-pin charger of 43 kW capacity at 230V/400V and 63A. The commonly used dc fast charger has 4 pins, with a rated capacity in the range 50-100 kW, at 500V and 125A.

The system should be able to determine the flow of energy according to the availability of PV output. Thus, the EV charging system in the parking areas is suggested to be implemented in the manner described in Figure 7, to ensure that the system can establish a proper progression of excess power, without causing the system to operate with limited capacity. The single line diagram of the system is as given in Figure 8.

Figure 7: Flow Diagram of the Control System

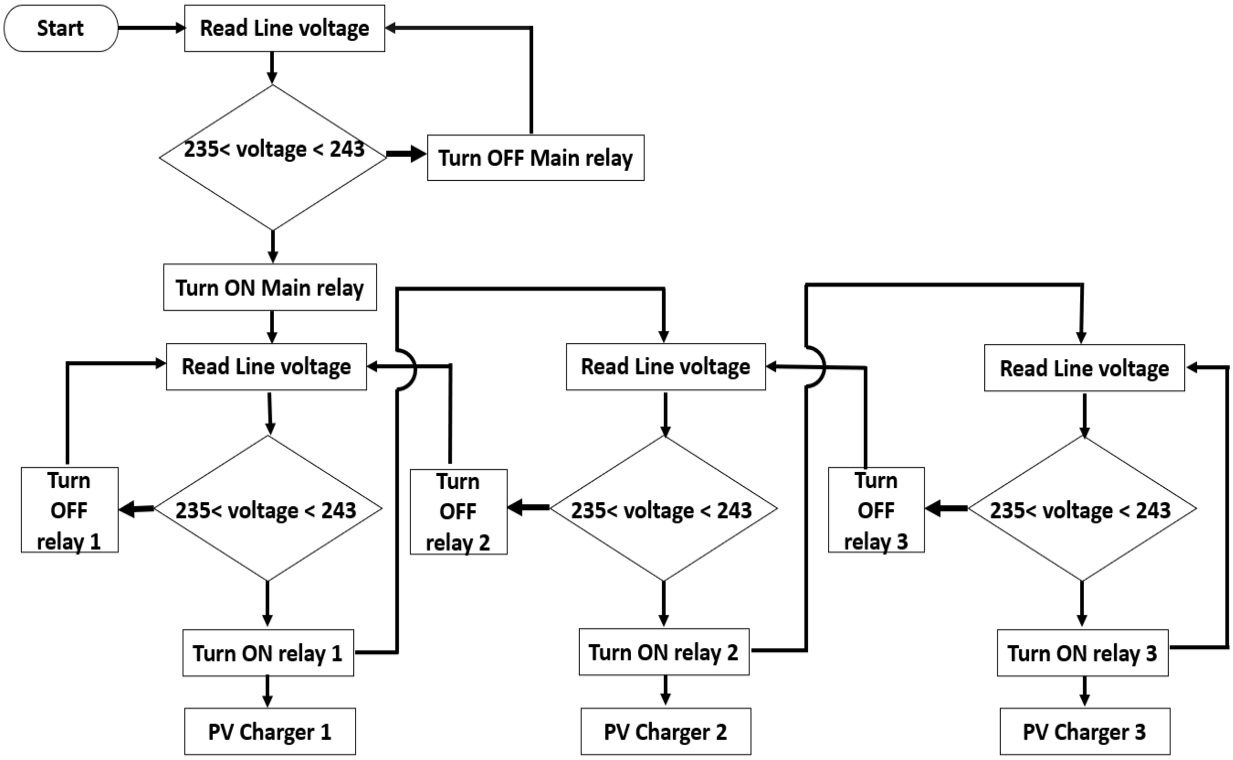
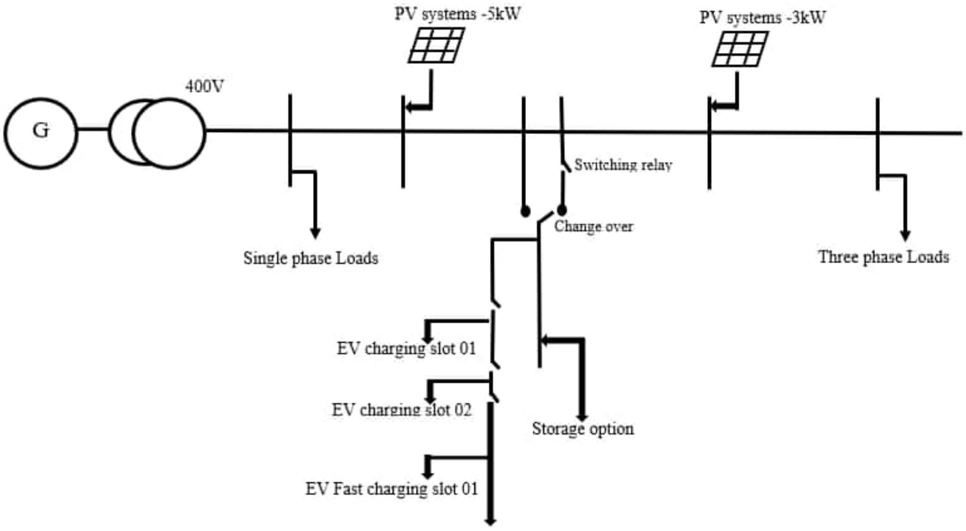


Figure 8: Single-Line Diagram of the System



As depicted in Figure 8, the system is built to provide a constant supply to the EV charging centre, with an innovative development in the power selection, where the excess energy produced by the solar PV systems will be used through the switching relay, whenever required and whenever it is possible. This mechanism allows the system to function on days with and without solar PV output. The system has been built to provide for three charging points, and the number of charging points that can be provided depends on the amount of energy obtained through solar PV. Hence, the value can either increase or decrease according to the capacity of the available solar PV systems in a given area.

The ability to adapt the system to provide charging facilities to EVs in a parking area were identified by simulation. Results were obtained by evaluating the system through its potential to maintain an excess amount of energy during the peak irradiation hours of a given day, indicated by voltage measurement.

Investment and Financial Viability

Table 2: ROI Calculation Sheet

No.	Item	Quantity	Price (USD)
1	63A 4P CB Level Dual Power Automatic Transfer Switch Mini Dual Power Generator Changeover Switch 50Hz/60Hz	1	200
2	50 kW Chademo and CCS EV Charging Station	1	10,000
3	Ocpp EV charger 3-phase 22 kW fast charging electric vehicle station	1	300
4	16A adjustable IEC 62196 Mode 2 charging 3 Phase 11kW EV Charger ac EV quick charger 220 V	1	300
5	AOASIS AOT-V09-M265M460 monitoring three phase voltage relay power	4	100
6	New electrical connection, cabling, panel, breakers, energy meter	-	1,000
	The total cost for the system as identified above is approximately		12,200
Other costs			
1	Maintenance cost		300
2	Charging center land rent (annually)		300
3	Worker annual salary		1,300
	Total other costs		1,900

The profit gained through charging	= USD 0.081 per kWh
Approximate energy delivered to charging per day	= 180 kWh
Number of fully functional days	= 300 (excluding the rainy days, other days with less sunlight)
Annual profit	= USD 0.081x180x300 = USD 4,374
Net annual profit	= USD 2,474
Return on investment	= Net income/Investment = 2,474 / 12,200 = 20.3%

Conclusion

The paper presented a solution to two significant emerging problems in present-day power systems – the increasing requirement to provide charging facilities for EVs, and the increasing penetration of solar PV that causes grid voltage instabilities during periods of peak irradiation.

This study was conducted with the motive of creating a futuristic pathway to provide a feasible solution to address both these problems. The increasing number of electric vehicles is no longer an assumption but a reality since most of the automobiles built in the present day are either hybrid or all-electric.

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