Smart Energy Buildings: PV Integration and Grid Sensitivity for the Case of Vietnam

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Abstract: The Vietnamese government is pushing for higher implementation of distributed photovoltaic (PV) generation through various policies. Due to the decreasing trend in feed-in tariff (FIT) prices, self- consumption of energy is an increasingly viable option. The increased PV penetration in the distribution grid also leads to changes in the voltage profile on the distribution line, which needs to be regulated. The paper discusses a study where an energy management system (EMS) is implemented for a commercial building in Hanoi after modelling the respective generating units. As a next step in the study, the self-consumption behaviour of the building is analyzed and the voltage regulation for a sample distribution grid in Vietnam is implemented.

1 INTRODUCTION

1.1 Status and Objectives of Renewable Energy Integration in Vietnam and Germany

In Vietnam, solar power is an increasingly attractive electricity generating option for the country. Recent reduction in investing cost, quick construction and incentive policies from the government are accelerating the development of PV power in total capacity, number of projects and penetration rate.

Regarding solar power development in the urban areas of Vietnam, rooftop PV systems have been booming recently, especially at locations with high solar irradiation. Compared to rooftop systems, PV facade systems, although they have great potential, do not get enough attention.

In Hanoi, by October 2020, 1,138 rooftop solar power projects were installed, interconnected and brought into operation with total capacity reaching 12 MWp, Vietnam Electricity Group Hanoi [EVN Hanoi] (2021). By comparison, 1,672 customers installed rooftop PV systems in Da Nang city, comprising a total capacity of 20 MWp (by the end of August 2020) as mentioned by Lam, Ky, Hieu and Hieu (2021). However, the highest total installed capacity was seen in Ho Chi Minh City with 365 MWp by the end of August 2021 (Vietnam Electricity, 2021).

Noteworthy, most of the rooftop PV projects in cities of Vietnam have less than 15 kWp in capacity. In Hanoi, among 1,138 projects, only 79 projects have the capacity of over 20 kWp. The number of projects which have capacity higher than 100 kWp is 12, most of which are concentrated in Thanh Tri and Dong Anh districts and are mainly located on the roofs of large factories (EVN Hanoi, 2021).

Additionally, in Vietnam, although the integration of the distributed PV rooftop systems might promise many technical and economic benefits, these systems are mainly invested, installed, operated with the purpose of self-consumption and selling surplus electricity to the grid. Self-consumption is the share of locally generated electricity that is consumed in house as defined by Luthander, Widén, Nilsson and Palm (2015). Most of these systems do not adopt energy storage devices or only integrate small capacity lead-acid batteries providing a small amount of energy for power outages. This means that, surplus PV electricity, which has uncertain and intermittent characteristics, is injected into grid without caring for its impacts on power quality as well as the distribution system operation. The impacts might be more serious

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when a higher share of distributed PV generation participates in the existing low voltage (LV) grid.

Germany aims at a climate-neutral system in 2050. For the electrical energy consumption, the share of renewable generation in 2019 was about 42% and the milestone for 2030 is set to 65% according to the Federal Ministry for Economic Affairs and Energy [BMWi] (2019), the objectives are currently updated. According to a scenario developed by Fraunhofer Cluster of Excellence 'Integrated Energy Systems' [CINES] (2020), the installed PV capacity has to increase by a factor of 4 from today to 200-300 GW in 2050 to achieve the political objectives. The power demand will increase due to sector coupling technologies, amongst others with electric vehicles and decentralized heat pumps for residential purposes (Fraunhofer CINES, 2020, p. 12). A high share of the overall PV in Germany is residential and commercial PV rooftop systems with a strong tendency in a combination with battery systems to foster PV self-consumption. In 2020, 184,000 PV systems with a capacity of 4.8 GWp were registered according to the Bundesverband Solarwirtschaft e.V. [BSW Solar] (2021). Moreover, the number of installed home storage systems increased by 88,000 to overall 272,000 as a result leading to 50% of the new installed PV (capacity up to 10 kWp) combined with a battery storage (capacity 7 kWh on average) (BSW Solar, 2021 (2)). These trends mark potential challenges for the distribution grid and, at the same time, opportunities for energy management to mitigate them.

1.2 Load Development in Urban Areas Related to Space Cooling or Heating

Apart from PV rooftop together with battery systems and electric vehicles, the increased use of cooling systems in southern countries and electrical heating systems (e.g. heat pumps) in northern countries will define the future power demand. The International Energy Agency [IEA] (2018, p. 36) expects the cooling degree days, a measure of potential space cooling demand, to increase worldwide by roughly 25% from 2016 to 2050. Furthermore, (IEA, 2018, p. 37) describes cooling mainly as challenge in urban areas, partially because temperatures are generally higher in urban areas than in the surrounding countryside (so-called heat island effect), and cooling demand often coincides with the peak load of urban grids. In (IEA, 2018, p. 33) as well as Ershad, Pietzcker, Ueckerdt and Luderer (2020) and in Sultan and Glusenkamp (2021); cooling systems as well as heat pumps together with thermal storage are seen also as technologies that can effectively be used in demand side management concepts thus potentially mitigating load peaks in urban distribution grids.

1.3 Challenges for the Distribution Grid

As in Paatero and Lund (2007) and in Lavalliere, Abdelsalam and Makram (2015), in some cases PV can help with load shaving. However, peak loads of residential customers usually do not happen at peak hours of PV output. With the Vietnamese government not renewing the support mechanisms for grid-tied PV, the development of grid-tied solar power has been stalled. The use of a battery system provides a key solution in this regard by storing the excess energy generated by the PV system during the day for use at night and continuing the use of installed rooftop PV which cannot be fed into the grid due to the rules. In contrast to the booming growth of rooftop PV, facade PV integrated into buildings is still limited in Vietnam. Until now, there is no literature focusing on the generation profile and energy yield from facade integrated PV systems in the urban areas of Vietnam.

The participation of PV systems in the distribution grids can affect the voltage profile along the power line. Additionally, according to Walling, Saint, Dugan, Burke and Kojovic (2008) and Matkar, Dheer, Vijay, Doolla (2017), since integration of PV systems can contribute to the change in the voltage profile, they can affect the operation of voltage regulators such as voltage regulator (VR), static compensator (SC) and on-load tap changer (OLTC). At high PV penetration, the voltage at the point of common coupling (PCC) can increase, resulting in the OLTC control to reduce voltage across the line. If a group of PV systems is disconnected or suffers a sudden reduction in the power output, a voltage drop may occur, which would trigger the protective relays.

In summary, Vietnam is pursuing the sustainable development policy by adopting PV systems in urban areas. The study mentioned in this paper therefore addresses and aims to solve the above-mentioned challenges by: a) investigating the benefits of facade integrated PV in addition to rooftop solar in Vietnam for a commercial building, followed by implementing an energy management system and evaluating the self-consumption behaviour of this building and b) controlling the negative effects of increasing PV penetration on the distribution grid voltage profile through reactive power control.

The rest of the paper is organized as follows: Section 2 describes the state of the art and on-going related research on facade PV integration towards the context of Vietnam. Objectives and first results of the study are presented in Section 3. Our conclusions and further research steps in this study are summarized in Section 4.

2 STATE OF THE ART AND ONGOING RESEARCH

2.1 Facade Integrated PV

This section shows some works in the area of PV-building integrated systems.

As indicated in Bot, Aelenei, Gomes and Santos Silva (2021), a Building Integrated Photovoltaic Thermal (BIPV) system developed for electrical generation and for heating recovery purposes as well showed that the needs for separate cooling and heating are reduced compared to the configuration without a BIPV thermal system. Another interesting investigation is managed by Brito, Freitas, Guimarães, Catita and Redweik (2017). Outcomes in this study revealed that, even though, the facade systems received less solar radiation in comparison to rooftop type systems they have the potential to increase the power generation for the load and are able to spread the peak PV production throughout the day, especially for the early and late hours.

PV-HoWoSan (Niedermeyer and Funtan (2019)), is a project whose objective is the evaluation of PV facade and rooftop systems in multi-storey residential buildings. The goal of the project is to develop a standardized procedure for design of PV facade systems, which works in terms of building physics and is safe in several respects.

In the project, a Python software tool was developed for calculating the PV generation from rooftop and facade systems and calculating the degree of self-consumption of a residential multi-storey building. For calculating the PV generation consideration to the building characteristics (number of floors, apartments, facade orientation) and the irradiation data for the specific city the building is located in is given (Axaopoulos, 2011). The tool can therefore be used for PV related studies for a building in any city for which the irradiation data is available. The exemplary building configuration (results in Figure 1 and Figure 2) in the city of Frankfurt consists of 25 floors and 7 apartments per floor. The building has an installed rooftop power of 75 kWp and facade integrated PV systems (maximum 31 kWp per floor). The PV facade system is analyzed for four different shares of facade covering: 7% density (installed power of 2.2 kWp), 25% density (7.8 kWp), 50% density (15.5 kWp) and 75% density (23.3 kWp) per floor. The PV facade is implemented on the south, west and east side of the building. Additionally, a second implementation of the same configuration with a 20 kWh battery storage system was considered.

For the city of Frankfurt, for the exemplary building, the Python tool can also calculate the total load per apartment according to the Verein Deutscher Ingenieure [VDI] 4655 (2019) in Germany. The VDI 4655 provides a guideline on calculating the typical load for a building in Germany based on the season, weather conditions and day of the week data.

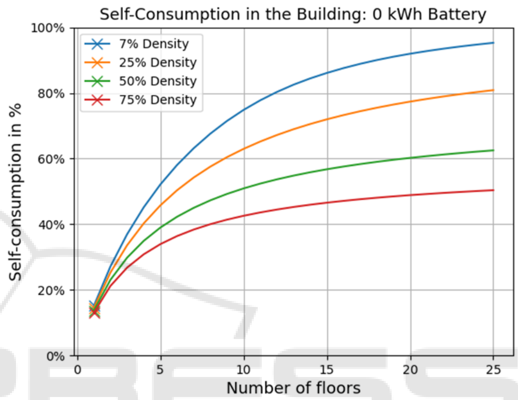

Figure 1: Percentage of self-consumption for the system when there is no storage system depending on the facade share covered with PV modules (Density).

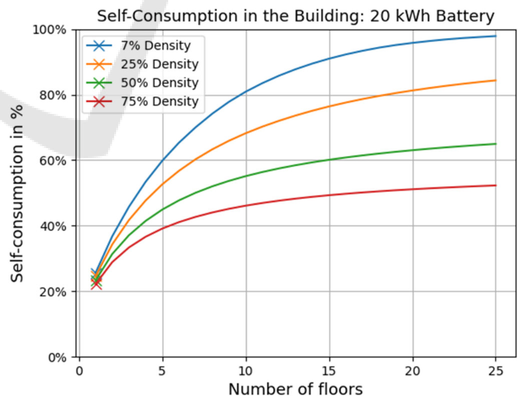

Figure 2: Percentage of self-consumption with a 20 kWh battery system for the entire building depending on the facade share covered with PV modules (Density).

Figure 1 and Figure 2 present that the self-consumption has a saturation tendency because there is more surplus generated with increasing PV covered facade. Comparing these two figures shows that the

Table 1: Retail electricity price for households and commercial customers (MOIT, 2019(2)) and new proposed FIT price.

Customers	Classification	Electricity Price (exclusive of 10% VAT)		Rooftop PV system capacity	FIT price	
		VND/kWh	€ ct/kWh		VND/kWh	€ ct/kWh
Households	Level 1: 0-50 kWh/month	1,678	6.40	Less than 20 kWp (most PV systems in households have the capacity of less than 20 kWp)	1,582.16	6.03
	Level 2: 51-100 kWh/month	1,734	6.61			
	Level 3: 101-200 kWh/month	2,014	7.68			
	Level 4: 201-300 kWh/month	2,536	9.67			
	Level 5: 301-400 kWh/month	2,834	10.81			
	Level 6: 401 kWh/month or more	2,927	11.16			
Commercial customers (from 6 kV to 22 kV)	Peak hours	4,400	16.78	20-100 kWp	1468.82	5.60
	Normal hours	2,629	10.02			
	Off-peak hours	1,547	5.90			
Commercial customers (< 6 kV)	Peak hours	4,587	17.49	From 100 kWp to 1250 kWp	1362.41	5.19
	Normal hours	2,666	10.16			
	Off-peak hours	1,622	6.18			
Note: EURO/VND exchange rate on Nov. 25, 2021 = 26,227.96 (State Bank of Vietnam)						

presence of one battery for the building already increases the self-consumption to approximately 90% up to the 15-floor. For the first floor (marked in both graphs), the self-consumption increases to 25% in comparison with the case without battery.

2.2 Status of Electricity Pricing in the Country of Vietnam

In Vietnam, the electricity price is different among residential, commercial and industrial customers Regarding electricity price for households, there are six level of prices applying to different amount of electricity consumption. The retail electricity price for commercial customers depends on voltage level and time of consumption with peak hours (9:30-11:30am and 5:00-8:00pm, not including Sunday), off-peak hours (10:00pm-4:00am) and other periods for normal hours (Table 1).

Regarding rooftop PV feed-in tariff in Vietnam, the price of 2,086 VND/kWh (7.95 € ct /kWh) (FIT1) has been expired since 2019-06-30 (Prime Minister [PM] (2019)) and Ministry of Industry and Trade [MOIT] (2019)). After that, a new policy (FIT2) was issued on 2020-04-06 (PM, 2020). The FIT price for rooftop solar systems was reduced to 1,943 VND/kWh (7.41 € ct/kWh). However, the FIT2 price has officially expired on 2020-12-31 and currently a new draft FIT price has been submitted to the Prime Minister. The draft still proposes a fixed price, but it is expected to decrease by 18-27% depending on the project capacity and project type (Table 1).

While the average price of retail electricity in Vietnam has recently increased, the FIT price tends to reduce and is lower than the lowest retail price. This builds a barrier for using the FIT mechanism. However, it could encourage households having PV systems to increase self-consumption.

2.3 Hybrid Storage Systems: Stationary and Mobile Batteries, Thermal Storage (Cooling)

In Huang, Hsu, Wang, Tang, Wang, Dong, Lee, Yeh, Dong, Wu, Sia, Li and Lee (2019), deployment of PV systems increased the necessity of creating new storage technologies for either self-consumption or control strategies. A PV system for self-consumption, comprising the PV modules, inverter and loads, a stationary battery and a thermal storage is proposed. In case of PV surplus, first, the battery is charged and then the thermal hot water storage system. This hybrid storage system is found to be more economically viable compared to exporting electricity to the grid.

In Niedermeyer, Dreher, Degner and Heckmann (2020) pooled electrical vehicles are used as frequency control reserves, and the relation between power variation and voltage change in LV grids are analyzed. From a pool of electric vehicle (EV), control reserves are provided in accordance with the regulations of the Frequency Restoration Reserves (FRR) without violation of the voltage bands in the LV feeder.

2.4 Voltage Management

Several papers demonstrate strategies for controlling the voltage in the power system. As mentioned by Li, Disfani, Pecenak, Mohajeryami and Kleissl (2018), traditionally, the OLTCs and voltage regulators are employed to address voltage issues in the distribution system. OLTCs always consider a voltage drop along feeder lines and rule-based control techniques have proven to lack scalability and cannot be applied to feeders with multiple OLTCs. Mainly due to the increase in PV penetration in the medium or low voltage grid, there is a rise in voltage at the PCC. According to Phochai, Ongsakul and Mitra (2014) strategies such as limitation of active power feed-in and fixed power factor method are first suggested where remote control utility is not possible. Dynamic control techniques are preferred because they do not curtail the active power from PV generation unless voltage control needs to be implemented.

In Geibel, Degner, Seibel, Bülo, Tschendel, Pfalzgraf, Boldt, Müller, Sutter and Hug (2013) voltage control strategies in low voltage grids with high PV penetration are explored. New voltage control strategies were developed and applied in active, intelligent LV networks utilizing reactive power control capabilities of PV inverters and OLTC functionalities of secondary substations. The grid voltages are dynamically regulated to ensure that the voltage limits are adhered to. The developed components were field tested in a German LV grid near Kassel. As part of the implementation, the smart secondary substation with an OLTC transformer (630kVA, 20/0,4kV, ± 3x 2%) controlled the reactive power provision of three independent PV systems (Geibel et al., 2013).

3 FIRST RESULTS FROM THE PV VIETNAM PROJECT

Driven by political incentives, such as the Vietnamese government's commitment to energy availability there is already an increased operation of grid connected PV systems in the distribution grid in Vietnam as presented by Do, Burke, Nguyen, Overland, Suryadi, Swandaru and Yurnaidi (2021). The study presented in this paper contributes a system study considering rooftop and facade integrated PV to observe the potential for self-consumption for a commercial building in Hanoi, Vietnam. The usage of mobile (electric vehicles) and stationary batteries and thermal storage (cooling) to avoid peak load situations is implemented. The consideration of peak/ off-peak tariffs can provide insights into the economic viability of such systems and the potential of grid-interactive buildings for load and voltage management in distribution grids.

A first step in this work is the calculation of the PV-energy yields for an identical building at the city of Hanoi and Frankfurt for rooftop and south, east and west oriented facade PV systems. A building area of 625 m^2 with 10 floors was chosen and the Python tool developed in the PV HoWoSan project (Niedermeyer and Funtan (2019)) was adapted for both cities. For the city of Hanoi an optimal tilt angle of 10° and for Frankfurt an optimal tilt angle of 30° were considered for the rooftop PV systems. Table 2 presents the energy yields of the rooftop and facade PV systems (in kWh/kWp) and the percentage generation of the facades as a share of the rooftop generation for each of the two respective cities:

Table 2: Energy yields in the city of Hanoi and Frankfurt for rooftop and south, east and west facade and ratio of energy yield of facades with respect to the rooftop PV system.

	Hanoi	Frankfurt
Roof-top	1317 kWh/kWp, (x)	949 kWh/kWp, (y)
South	722 kWh/kWp, 55%x	640 kWh/kWp, 67%y
East	685 kWh/kWp, 52%x	517 kWh/kWp, 55%y
West	811 kWh/kWp, 62%x	541 kWh/kWp, 57%y

The same building for the cities of Hanoi and Frankfurt is considered and shadowing effects are ignored. The energy yield contributions are higher for the city of Hanoi. However, the percentage of energy yield for the facades with respect to the rooftop generation is higher for the city of Frankfurt. This is due to the differences between the optimal tilt angles of the rooftop in the respective city and the vertical facade systems.

This next step in the study includes the assessment of the PV generation profile in Hanoi (World Bank Group (2018)) and the typical load profile of a commercial building (10 floors and 625 m^2 rooftop area) and the simulation of a simple EMS involving stationary batteries, EV and thermal storage (cooling systems). The load data is obtained from Electrical Power University [EPU] (2016). The EMS functions based on a peak-shaving process.

The EMS comprises the peak shaving functionality. For reducing total costs, the charging and discharging of the storage systems will be done according to the peak/off-peak time. As an example, Figure 3 and Figure 4 indicate flowchart diagrams of the cold water storage/ cooling system charge and discharge procedures.

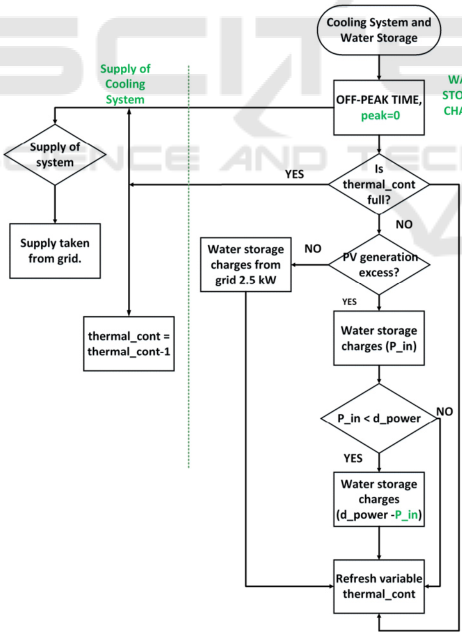

Figure 3: Flowchart diagram for the cooling system operation in the off-peak time.

Figure 3 indicates the flowchart diagram of the cooling system at the off-peak time. The objective of this approach is to charge the water storage to the maximum capacity to prepare for the peak-times and therefore to unload the grid. In this example, the charging power is chosen as 25% of the discharge power (d_power). This discharge power corresponds to the supply power that the cooling system needs for operating. In off-peak time, the grid can supply power to the cooling system and is able as well to charge the water storage. At the peak-times, as in Figure 4, the goal is to discharge the water storage first to provide the power supply to the cooling system thereby avoiding the import of power from the grid. Thus, the EMS can help to mitigate peak load in the grid, if necessary.

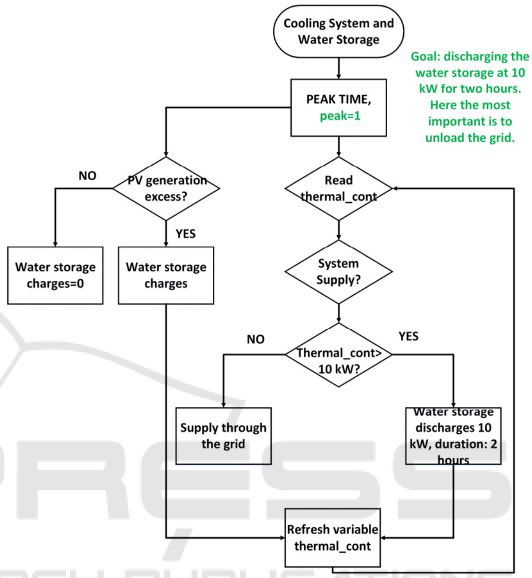

Figure 4: Flowchart diagram for the cooling system operation in the peak time.

4 CONCLUSIONS AND FURTHER WORK

This study is in the field of integration of distributed PV generation in urban areas in Vietnam. Because of the ambitious political objectives of the Vietnamese government, this topic is very important for the sustainable development strategy of Vietnam.

This study presented in this paper is a first investigation into the potential use of PV facade systems for energy yield in Vietnam. A case for increased PV facade implementation and self-consumption is made through the calculation of the irradiation data, modelling of generating units and initial implementation of energy management. Investigations on self-consumption are motivated by the proposed decreasing FIT prices while retail electricity prices are increasing.

This project has considered irradiation data for Hanoi and calculated the PV generation for rooftop and facade installations for an exemplary commercial building. An energy management concept is developed after modelling of the generating units such as a stationary battery, EV battery and the cooling system as thermal storage. Actual load values are considered for the calculations of the EMS. Further steps in the project are: a) further development of the EMS for the assessment of the self- consumption behaviour, b) analysis of the resulting electricity costs after implementing such an EMS using time-of-use pricing mechanism and c) development of voltage control strategies for the Vietnamese distribution grid with high PV penetration through modelling of the grid and implementation of control.

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