Title Of Project
"PVs in house and their impact on the power grid"

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Abstract

Due to environmental concerns, power system generation is shifting from traditional fossil-fuel resources to renewable energy such as wind, solar and geothermal. Some of these technologies are very location specific while others require high upfront costs. Photovoltaic (PV) generation has become the rising star of this pack, thanks to its versatility. It can be implemented with very little upfront costs, e.g., small solar home systems, or large solar power plants can be developed to generate MWs of power. In contrast with wind or tidal generation, PV can be deployed all around the globe, albeit with varying potentials. These merits have made PV the renewable energy technology with highest installed capacity around the globe. However, PV penetration into the grid comes with its drawbacks. The inverter-interfaced nature of the PV systems significantly impacts the power system operation from protection, power flow and stability perspectives. There must be strategies to mitigate these negative impacts so that PV penetration into the grid can continue [2].

Keywords
Solar Energy, PVs, licensing, renewable energy, effects, negative, positive, power grid
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1 Introduction

Increased demand in the grid necessitates development of new strategies for power generation. Preferably, clean energy sources are utilized to mitigate the environmental effects of fossil fuels. Renewable energy resources (RES) like wind and photovoltaic (PV) are substantially used for power generation as an alternative to the conventional ones. Carbon footprint of power generation is reduced as a result. In the current global scenario, PV has a greater installed capacity than any other RES such as hydro and wind. In Figure 1 shows the cumulative installed PV capacity in the world for the period of 2012-2018. PV modules have become the most common distributed energy resources (DER) at household level since other DERs like wind, geothermal, biogas are location-specific. PV, on the other hand, can be installed at every household to meet the energy demand of the house and sell excess energy to the grid when more energy is available. Such use of PV modules at residential level can reduce the power bills of the owner and also support the grid with local generation. The availability of PV panels and its financial reachability has encouraged household installations that can electrify rural areas. Accordingly, it is one of the fastest growing RES-based generation technologies. In addition, countries that are dependent on imported energy resources are looking at ways to increase their energy independence.

![Figure 1: Global stats of renewable generation](image)

However, there is a major drawback with PV systems as they are time dependent and maximum generation occurs at noon, which does not coincide with the peak demand hours. The transition from excess energy with little load to little generation with heavy load creates a peculiar profile called the duck curve. Optimal and coordinated operation of the alternate sources with thermal generation, wind or storage systems is significantly needed for balancing the load. Coordinated operation between different DERs, bulk thermal generation and loads require bi-directional communication. With the introduction of information and communication technologies (ICT) for monitoring and controlling has evolved the legacy power system as smart grid. A smart grid is an electrical power network integrated with different types and scales of generation sources along with ICT for enhanced monitoring and con-
control. Smart grids considerably improve the efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the power network.

Increased level of PV penetration in the distribution networks resulted in rise of power quality issues like voltage variations and reversal of power flow direction in the network. Several concerns related to power system stability such as oscillatory instability, small signal stability issues have severely impacted high levels of PV penetrations. These anomalies directly impact network equipment like load tap changers (LTCs), line voltage regulators (LVRs) and voltage-controlled capacitor banks, as they operate frequently to maintain the feeder voltages. Hence, higher levels of PV penetration shorten system life cycle shortens and increase maintenance costs.

This project analyzes the use of PVs at home and how they affect our lives and their impact on the power grid. Specifically in first chapter we analyzes the PVs modules. At first section 2.2 there is a presentation of solar energy exploitation and the structure, forms and modes of operation of the PVs modules [10]. Next in second chapter 3 we present the placement of PVs in the house based on [4] the law (licensing). In this section we will analyze you exactly what citizens need to do to get photovoltaics in their home. Finally 4 we provide the effects of the use of PVs. At first section 4.1 we present the positive effects of PVs [7] and in the second section 4.2 present the negative effects of the use of PVs [6] with the impact on the power grid peak.

Figure 2: PVs at home
2 Renewable Energy Sources

Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. [3]

In recent years the need for exploitation has become increasingly urgent alternative forms of energy. Because of the ever-increasing energy demand, combined with a decline in conventional fuel stocks and adverse effects on the environment from their widespread use worldwide interest in developing technologies to exploit renewable energy. This interest is reinforced by the fact that in many cases RES technology is not only economically feasible but also quite efficient.

2.1 RES power generation

The fact that electricity is the most user-friendly and friendly to him human form of energy, and that its production by Conventional (coal, oil) or even nuclear sources are becoming so more economical as the size of the production stations increases, led to development of modern interconnected Electrical Systems Energy (ESE). RES as well as heat generating plants - electricity, they are low power units and are scattered on different areas and locations. In addition, almost all of them efficient their exploitation requires their connection and parallel operation to a network of the ESE, which thus functions as a very high capacity warehouse. This is especially true for Wind and Solar power generation as well sea waves, for which control the rate of flow of the primary energy is impossible.

Several fundamental methods exist to convert other forms of energy into electrical...
energy. Utility-scale generation is achieved by rotating electric generators or by photovoltaic systems. A small proportion of electric power distributed by utilities is provided by batteries. Other forms of electricity generation used in niche applications include the triboelectric effect, the piezoelectric effect, the thermoelectric effect, and betavoltaics. [9]

Generators
Electric generators transform kinetic energy into electricity. This is the most used form for generating electricity and is based on Faraday's law. It can be seen experimentally by rotating a magnet within closed loops of conducting material (e.g. copper wire). Almost all commercial electrical generation is done using electromagnetic induction, in which mechanical energy forces a generator to rotate. [9]

Electrochemistry
Electrochemistry is the direct transformation of chemical energy into electricity, as in a battery. Electrochemical electricity generation is important in portable and mobile applications. Currently, most electrochemical power comes from batteries.[3] Primary cells, such as the common zinc-carbon batteries, act as power sources directly, but secondary cells (i.e. rechargeable batteries) are used for storage systems rather than primary generation systems. Open electrochemical systems, known as fuel cells, can be used to extract power either from natural fuels or from synthesized fuels. Osmotic power is a possibility at places where salt and fresh water merge. [9]

Photovoltaic effect
The photovoltaic effect is the transformation of light into electrical energy, as in solar cells. Photovoltaic panels convert sunlight directly to DC electricity. Power inverters can then convert that to AC electricity if needed. Although sunlight is free and abundant, solar power electricity is still usually more expensive to produce than large-scale mechanically generated power due to the cost of the panels. [9]

2.2 Solar Energy
Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.

It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

2.2.1 Exploitation of solar energy
Solar energy is exploited in a number of ways in two main categories. The first category consists of systems that convert solar energy into internal energy of building structures (passive solar systems) and the second, those that convert it to other forms of energy or use thermal fluid in motion (active solar systems). Active include
those that convert solar radiation into thermal fluid internal energy (thermocouple systems) and these converting sunlight directly into electricity (photovoltaic systems).

### 2.3 P/V Description

**Etymology**
The term "photovoltaic" comes from the Greek φῶς (phōs) meaning "light", and from "volt", the unit of electromotive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery (electrochemical cell). The term "photovoltaic" has been in use in English since 1849.

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. Specifically:

1. **Solar Cell**
   It collects sunlight. It is a properly machined thin-walled semiconductor. The solar radiation incident generates electrical voltage and with the proper connection to the load generates electricity. [10]

2. **PV Module**
   It consists of several PVs connected to each other and is the basic building block of the PV generator. The panels have a typical power of 20W-300W. Types of PV panels:
   - With regard to the degree of integration:
     1. Typical PV panels (glass-plate panels)
     2. Semi-permeable PV (Glass-Glass Crystal Frames)
   - With regard to their construction material:
     1. Crystalline silicon technology
     2. Thin film technology

3. **Strings**
   The PV modules are electrically connected to each other and the photovoltaic arrays are created.

4. **Charge Controller**
   An electronic device that controls the process of charging and discharging the battery and is able to isolate the battery from the power source in case of overcharging or overcharging.

5. **Inverter**
   Systems designed to deliver alternating current (AC), such as grid-connected applications need an inverter to convert the direct current (DC) from the solar
modules to AC. Grid connected inverters must supply AC electricity in sinusoidal form, synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage and disconnect from the grid if the grid voltage is turned off.

- DC-AC inverter
- AC-DC converter
- DC-DC converter

6. Battery
PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high. Common battery technologies used in today’s PV systems include the valve regulated lead-acid battery – a modified version of the conventional lead–acid battery, nickel–cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self discharge as well as low investment and maintenance costs, they are currently the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid batteries. Furthermore, as storage devices for PV systems are stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as, for example, in electric transportation. [10]

2.4 Scale of system
Photovoltaic systems are generally categorized into three distinct market segments: residential rooftop, commercial rooftop, and ground-mount utility-scale systems. Their capacities range from a few kilowatts to hundreds of megawatts. A typical residential system is around 10 kilowatts and mounted on a sloped roof, while commercial systems may reach a megawatt-scale and are generally installed on low-slope or even flat roofs. Although rooftop mounted systems are small and have a higher cost per watt than large utility-scale installations, they account for the largest share in the market. There is, however, a growing trend towards bigger utility-scale power plants, especially in the "sunbelt" region of the planet. [10]

- Utility-scale
Large utility-scale solar parks or farms are power stations and capable of providing an energy supply to large numbers of consumers. Generated electricity is fed into the transmission grid powered by central generation plants (grid-connected or grid-tied plant), or combined with one, or many, domestic electricity generators to feed into a small electrical grid (hybrid plant). In rare cases generated electricity is stored or used directly by island/standalone plant. PV systems are generally designed in order to ensure the highest energy yield for a given investment. Some large photovoltaic power stations such as Solar
Star, Waldpolenz Solar Park and Topaz Solar Farm cover tens or hundreds of hectares and have power outputs up to hundreds of megawatts. [10]

Figure 4: Perovo Solar Park in Ukraine

- **Rooftop, mobile, and portable**
  A small PV system is capable of providing enough AC electricity to power a single home, or an isolated device in the form of AC or DC electric. Military and civilian Earth observation satellites, street lights, construction and traffic signs, electric cars, solar-powered tents, and electric aircraft may contain integrated photovoltaic systems to provide a primary or auxiliary power source in the form of AC or DC power, depending on the design and power demands. Portable and mobile PV systems provide electrical power independent of utility connections, for "off the grid" operation. Such systems are so commonly used on recreational vehicles and boats that there are retailers specializing in these applications and products specifically targeted to them. Since recreational vehicles (RV) normally carry batteries and operate lighting and other systems on nominally 12-volt DC power, RV systems normally operate in a voltage range that can charge 12-volt batteries directly, so addition of a PV system requires only panels, a charge controller, and wiring. Solar systems on recreation vehicles are usually constrained in wattage by the physical size of the RV's roof space. Also there is a rooftop photovoltaic power station, or rooftop PV system, is a photovoltaic system that has its electricity-generating solar panels mounted on the rooftop of a residential or commercial building or structure. The various components of such a system include photovoltaic modules, mounting systems, cables, solar inverters and other electrical accessories. Rooftop mounted systems are small compared to ground-mounted photovoltaic power stations with capacities in the megawatt range. Rooftop PV systems on residential buildings typically feature a capacity of about 5 to 20 kilowatts (kW), while those mounted on commercial buildings often reach 100 kilowatts or more. [10]

- **Building-integrated photovoltaics**
  Building-integrated photovoltaics (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. They are increasingly being incorporated into the construction of new buildings as a principal or ancillary source of electrical power, although existing buildings may be retrofitted with similar technology. The advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost can be offset by reducing
the amount spent on building materials and labor that would normally be used to construct the part of the building that the BIPV modules replace. These advantages make BIPV one of the fastest growing segments of the photovoltaic industry. The term building-applied photovoltaics (BAPV) is sometimes used to refer to photovoltaics that are a retrofit – integrated into the building after construction is complete. Most building-integrated installations are actually BAPV. Some manufacturers and builders differentiate new construction BIPV from BAPV. [10]
3 Licensing of Photovoltaic Systems

The following section gives an overview of the licensing steps and lists some key points of the licensing process. A national target of renewable energy (RES) coverage of at least 40% of gross electricity consumption by 2020 is set. Please note here that Community law provides for the ability to revise the indicative targets for each technology every two years or earlier if necessary, and therefore future corrective moves may be made in this direction. Investments in photovoltaic systems are no longer subsidized to the initial installation and interconnection costs and thus a potential investor should have investigated the cost of the investment and the possibility of financing either from the banking system or by itself before starting the licensing process.

The following licensing categories are distinguished at this stage depending on the installation location and power of a Photovoltaic system. [4]

- Systems up to 10kWp on building roofs
- Photovoltaic Systems on Industrial Roofs
- Photovoltaic Systems in Parcels

3.1 Systems up to 10kWp on building roofs

From 1 July 2009 a program is in place for the installation of small photovoltaic systems in the residential building sector. This program provides incentives in the form of reinforcement of the generated solar kWh, so that the home consumer can depreciate the system he has installed and make a reasonable profit. It is for home consumers or small businesses wishing to install photovoltaic power up to 10 kWp on the roof or legally existing building, including verandas, facades and shades, as well as sheds, shelves and shades. For small businesses these should be up to 10 people and have a cycle works and total assets up to euro 2 million per year. To be part of the program, they must own the space where the photovoltaic system is installed. As of September 2010, the Program covers the whole territory.

The maximum power of photovoltaic systems under the Program is as follows:

- For the mainland, the islands interconnected, Crete 10 kWp
- Other Non-Interconnected Islands at 5 kWp

The following conditions must be met for apartment buildings.

- Have the other owners agree in writing, or photovoltaic to be installed on behalf of all owners (who in this case is represented by the manager).
- Only one system can be entered in each apartment building. If the terrace is communal and the owners of this place want to give it to another owner of the building who has no rights to the terrace, they can do it.
- If the system enters a veranda compartment roof, more than one system can obviously be entered into a single apartment building. All of the photovoltaic electricity generated is fed into the electricity grid and the domestic small-scale generator is charged 0.55 euro / kWh, a price guaranteed for 25 years. The
domestic small-scale power generator continues to buy electricity from PPC and pay it at the price it is still paying today (approximately 10-12 cents per kilowatt hour). In practice this means that PPC will install a new meter to record the generated energy. If, for example, the photovoltaic generates electricity at a cost of 300 euro for two months and the energy consumed at the building costs 100 euro, a credit account of 200 euro will be deposited by PPC in the bank account of the owner of the photovoltaic.

No license is required for the installation of household photovoltaics (with the exception of preserved buildings and traditional settlements requiring the approval of the Planning and Architectural Committee Control [PACC]). According to YAS36720 / 25-8-2010 “Approval of special conditions for installation of photovoltaic and solar panels systems on buildings and plots within design areas and on settlements” (Government Gazette 376 / 6-9-2010) no longer need a permit small-scale work by Town Planning, as it was until now precedent. Simply notify the PPC when you file a system connection to the network there. [4]

3.2 Home Producers

There are two prerequisites for joining the program:

- Have a PPC meter in its name (or in the shared one account of the building if the collective is selected installation).
- To cover part of the needs for hot water from renewables energy sources (eg solar water heater, biomass, geothermal heat pump)

A particularly important arrangement is that the home solar power producer is no longer considered a trader, in other words he is exempt from opening books at the tax office. As stated in the relevant joint ministerial decision, “there are no tax obligations for the photovoltaic system owner to distribute this energy to the grid”. In other words, any proceeds from the sale of energy by the domestic smallholder are not taxed. [4]

3.3 Small Business

In order to be included in the program, very small businesses should have previously received no other photovoltaic subsidy from national or Community programs. Any income from the sale of energy is not taxed, provided that the profits are shown in special tax-free reserve account. In the event of their distribution or capitalization, the current taxation on profits distributed shall apply. We note that the installation of photovoltaic power over 10 kWp on commercial-industrial roofs is subject to other rules and other incentives apply to these systems. [4]

3.4 Photovoltaic Systems on Industrial Roofs (> 10kWp)

Law 3851/2010 and Law 36720 / 25-8-2010 allow the installation of photovoltaic systems of any power on the roof or legally existing building, including verandas, facades and shades, as well as auxiliary areas of the building, such as warehouses and parking spaces. These systems do not require environmental authorization, and
systems up to 1 MWp do not require a production license or other verification decision. The systems (>1 MWp) require a production license from RAE (which is accompanied by two further licenses: the installation license and the operating license issued by the competent Region). [4]

For systems with power from 10 kWp to 100 kWp the only steps required are:

- The offer of connection terms by PPC
- The signing of the sale and purchase contract with HTSO

For systems with power from 100 kWp to 1,000 kWp (1 MWp) steps required are:

- The approval of small-scale construction work by Town Planning
- The offer of terms of connection by PPC
- The signing of the sale and purchase contract with HTSO

For systems with power greater than 1 MWp the steps required are:

- RAE issued a production license
- The permit of establishment from the Region
- The approval of small-scale construction work by Town Planning
- The offer of terms of connection by PPC
- The signing of the sale and purchase contract with HTSO and finally a license issued by the Region

The above applies only to the continental network, as autonomous island networks are considered saturated and there will be periodic custom arrangements for them. In any case, in non-interconnected islands, however, we are always talking about systems with less than 100 kWp.
4 Results of use of PV

In order to ascertain whether PV could help bring about household energy use efficiency and management, its contribution towards helping to modify household energy consumption behaviour was examined. Through the inclusion of questions bordering around whether the adopter’s installation had a monitoring metre attached, the location of the device and how frequently the monitor was viewed, this important aspect was analysed. The findings were positive and revealed that PV use can contribute to increased energy use awareness and in consequence reduce overall demand, improve supply and encourage de-consumption.

One reason behind the energy use management uncovered was the presence of a feedback metre on the inverter. This supports Keirstead’s finding. All but one of the adopters stated having a display monitor on their PV inverter. With most of the adopters’ inverter located inside the dwelling, there were more regular checks by the energy conserving and efficient households. The presence of an inverter monitor can influence the number of checks on a PV system which can in turn lead to more energy use conservation and efficiency of use. There was an almost five-fold increase in energy use monitoring and conservation following the introduction of PV. Therefore, the use of PV directly impacts on households and consumers energy demand and fosters interaction between the users and the system. This interaction is the direct result of PV output limitations.

Figure 7: Energy use and savings pre and post-PV

4.1 The hidden benefits of PV module power limitations

One of the most interesting discoveries of this study was that household PV adoption leads to increased energy use awareness and subsequently energy conservation and efficiency. An almost five fold increase in energy management was reported by the adopting households’ post-PV. They said the presence and location of the feedback
metre helped. Like smart metres, PV metre does not only provide useful information for adopters, it served to place control in the hands of the users in a way centrally-supplied electricity does not. This directly impacted household’s energy demand and fostered interaction between the users and the system. The energy management opportunity was therefore a function of the high costs of a sizable PV, the presence of an in-house metre and most essentially, the output limits of PV. It is this latter feature of PV that makes for its distinctiveness. Figure 8 details the energy-saving processes taken by the PV adopters and users.

![Figure 8: The PV efficiency cycle](image)

The continuous processes illustrated in Figure 7 above serves to indicate the crucial steps that PV-adopting households in urban Nigeria take to achieve energy use efficiency. Starting from Step 1 when the PV is installed, the PV electricity generating households start to notice the improvements to their energy demand which PV has enabled. This excitement stems from the fact that it may be the first time the users have had uninterrupted supply for a while, without the need to use alternative sources like fossil-based generators that require constant fuel purchases. This excitement, plus metre/monitor checks, draws the users closer to the workings of a PV unit.

Clockwise from point 1, at Step 2, PV design limitations start to bear on the users as they realise that they cannot use their PV for every appliance but mainly for essentials. Due to its non-dispatch design, the users then realise that they have to conserve power to allow the efficient running of the device. At this stage, energy use management becomes the sole prerogative of the PV adopters as they make sure that unnecessary plugging in of every household appliance is avoided and discouraged. Increased electricity and energy use awareness arises from the restrictive use of PV and prevents over consumption habit formation by households. This new energy use
awareness creates the “conditioning effect” resulting in behavioural changes (Step 3) which is the most important role of a PV module as it pertains to energy cost savings, efficiency and environmental sustainability.

It thus falls on the households to begin to search out other ways they can reduce consumption in order to make the device function more effectively and efficiently. This leads to greater awareness and the consideration and uptake of modern power saving household appliances and building technologies (Step 4). Also, other possible avenues to minimise energy consumption is sought. Here, energy efficiency ideas like purchasing more energy saving appliances and retrofitting the building for passive cooling and heating, to allow for natural airflow and solar gains to the dwelling, become more realistic. This is a form of climate change building adaptation that PV utilisation can stimulate. Some households would voluntarily make these building changes having had the opportunity to observe first-hand the energy dynamics of a PV unit. For other non-adopting households, the government (Step 5) can assist with support instruments (with particular emphasis on efficiency) to encourage PV adoption e.g. by mandating the building construction industry and private developers to incorporate low-carbon technologies in dwellings such as the German pioneered Passivhaus standard.

It should be noted that not in all cases is the PV cycle sequential as it appears on the diagram. For example, those individuals with high technical knowledge might bypass the energy awareness and conditioning phase (behavioural change) by deliberately installing their PV to be used with certain selected appliances in the home. They could include a PV controller or exclude power guzzling devices like multiple A/Cs from the unit to better manage the system. Nevertheless, their use of PV will still demand that they routinely check their energy consumption as solar radiation and daylight intensity varies daily and hourly. Notwithstanding, the point of the cycle is that most adopters will pass through the 4 initial phases and then decide if there is further need for additional adjustments such as more building retrofit works to accommodate the proper function of the solar panels.

Also the costs of power from wind and solar are already below those of conventional electricity generation in some parts of the world, as they have fallen sharply and will continue to do so. the electrical grid has been greatly expanded worldwide, and is ready to receive and distribute electricity from renewable sources. In addition, worldwide electricity prices came under strong pressure from renewable energy sources, that are, in part, enthusiastically embraced by consumers.

The 122 PW of sunlight reaching the Earth’s surface is plentiful—almost 10,000 times more than the 13 TW equivalent of average power consumed in 2005 by humans. This abundance leads to the suggestion that it will not be long before solar energy will become the world’s primary energy source. Additionally, solar electric generation has the highest power density (global mean of 170 W/m²) among renewable energies. Solar power is pollution-free during use, which enables it to cut down on pollution when it is substituted for other energy sources. For example, MIT estimated that 52,000 people per year die prematurely in the U.S. from coal-fired power plant pollution and all but one of these deaths could be prevented from using PV to replace coal. Production end-wastes and emissions are manageable using existing pollution controls. End-of-use recycling technologies are under development.
and policies are being produced that encourage recycling from producers. PV installations could ideally operate for 100 years or even more with little maintenance or intervention after their initial set-up, so after the initial capital cost of building any solar power plant, operating costs are extremely low compared to existing power technologies. Grid-connected solar electricity can be used locally thus reducing transmission/distribution losses (transmission losses in the US were approximately 7.2 per cent in 1995). Compared to fossil and nuclear energy sources, very little research money has been invested in the development of solar cells, so there is considerable room for improvement. Nevertheless, experimental high efficiency solar cells already have efficiencies of over 40 per cent in case of concentrating photovoltaic cells and efficiencies are rapidly rising while mass-production costs are rapidly falling. Finally it is worth adding that the presence of a home-mounted solar system can actually increase the value of a home.

4.2 The impact of rooftop PV on power grid

Concerning the impact of PVs on the electricity distribution network, we will deal with the South African region. The power output of a solar PV module is dependent on the intensity of the incident solar irradiance (sunlight), which is a fluctuating resource. The installation of large amounts of variable solar PV hence presents a challenge to the system operator and distribution utilities.

The electrical network has historically been designed and operated to supply loads via centrally installed and dispatched generation (in the South African context large scale coal based in Mpumalanga). These networks were designed to allow the unidirectional flow of power from the transmission grid to the end use customers via the distribution network. For the purposes we focus on a typical distribution network supplying domestic customers, and consider the impact that widespread rooftop PV could have on the distribution network.

The South African urban distribution network generally consists of an 11 kV medium voltage (MV) network supplying 400 V low voltage (LV) networks via MV/LV distribution transformers. The LV network consists of a three-phase backbone, with individual customers supplied with either three-phase or single-phase supplies, depending on the magnitude of load to be supplied. All power flows from the MV network to the LV network. These networks were designed to keep voltage drops within acceptable limits without overloading components.

When rooftop PV is connected to this distribution network, the generated power is consumed by the local loads in the customers’ facility. Any excess power is exported into the network where it is then consumed by other customer loads. The domestic demand typically peaks in the mornings and evenings, as linked to the time periods when consumers generally use the most appliances, such as lighting, electrical cooking, space heating and hot water heating. Solar PV only generates when the sun is shining, typically peaking at solar noon. The domestic load consumption at midday is relatively low, and may result in PV generated power flowing back into the utility network. There are a number of different commercial arrangements whereby customers can be compensated for the generated energy, such as feed-in tariffs (FITs) and the banking of energy, but these commercial aspects are not the focus of this article.
Reverse power flow in the distribution network can be problematic due to the resultant voltage rise. The distribution network has been designed and operated to curb the impacts of voltage drop, not voltage rise. The voltage control philosophy is such that during periods of low-loading the maximum voltages may already be close to the allowable limits. Local generation (causing a voltage rise) may then result in the maximum voltage limits being violated, leading to the failure or reduced efficiency of customer appliances. A South African domestic LV network is able to absorb significantly less generation as compared to the maximum amount of load that it can supply.

This is a concept that is not adequately appreciated, as the uninformed understandably assume that a customer can inject the same amount of power into the network as they can consume as a load. This is not the case in voltage limited networks, such as those that supply domestic customers.

LV customer loads vary considerably throughout the day and year, and the periods of maximum load occur when customer demand coincides. Maximum loading typically occurs on a cold winter evening due to increased cooking, hot water usage and space heating. These peak loading conditions might only occur for few hours in a year.

By comparison, most parts of South Africa have an abundance of sunny days, and it is common to have weeks of excellent sunshine whereby a solar PV installation will regularly generate maximum (or close to maximum) output during noon hours. The PV installations in a local area will peak at the same times. If the penetration of solar PV causes over-voltages (due to reverse power flow), such over-voltages may occur frequently, with serious ramifications for customers and the utility.

Another key consideration is the impact that cloud transients will have on the network. If a cloud passes over a residential neighbourhood and shades all of the PV panels in the area, then within a few seconds the PV output will drop drastically. The distribution network suddenly has to supply all of the power that was being supplied by the PV, resulting in a rapid change in voltage. This implies that with cloud shading, the voltages supplied to customers will vary. These frequent and rapid voltage changes may exceed maximum allowable limits, and could result in voltage flicker problems.

Voltage variations are a key constraint in establishing the maximum amount of PV that can be connected to a distribution network before technical limits are violated. The phase allocation (R, W, B or A, B, C) of loads and generators has a very significant impact on voltage variations, and is an important aspect that has historically been poorly managed by South African distributors. The phase allocation of single phase customer supplies is often such that there are considerable voltage imbalances in the three phase LV network.

If phase connections are not well managed then a scenario could arise whereby all the PV installations on a particular LV network are connected to the same phase. The resultant voltage rise would be in excess of three times the balanced scenario. The management of the phase allocations in the distribution networks is hence expected to be a key issue, and this is supported by experiences in other counties, such as Australia, where the installation of rooftop PV has seen an increase in the frequency
and severity of voltage imbalance problems.

At this point we should emphasize that the photovoltaic installation on the roof cannot have a negative impact on the grid. Rather it should be appreciated that uncontrolled widespread rooftop PV rollout (without adequate coordination and technical checks) runs the risk of voltage and power quality problems. The probability and severity of the problems will depend on historical planning practices, from reduced opportunities for better network management, from redefining relationships with home customers, from how well the network functions are optimized. [6]
5 Conclusion

Environmental concerns and energy independence considerations led nations around the world to turn to clean energy resources such as solar and wind. However, these generation technologies have very unique topologies and alter the grid operation substantially. Low inertia, unknown fault behaviors and intermittent power output can be named as some examples. Nevertheless, the benefits of these clean energy resources are plenty. This paper is evidence that a simple decision to install solar PV in order to improve power supply to a home can bring about a whole range of unforeseen positive behavioural changes and long-term benefits for the adopting households and society at large. However, PV output limits is frequently cited as a hindrance. While one cannot deny the existence of output limitations and capacity factor issues, there seem to be an understated usefulness of solar PV in this regard. After all, we didn’t forget the words of Daniel Matthews in the article "Why Solar Power Is Worth the Initial Investment" in July 2017 that "After many years of environmental campaigns against the burning of fossil fuels and utilizing nuclear energy to power our homes, the consensus is finally coming through that alternative energy is the way of the future. Of all the available methods for home and business owners alike, solar energy has come out on top of being the most resourceful, effective, and financially advantageous".
A  Acronyms and Abbreviations

PV  PhotoVoltaic
RES  Renewable Energy Sources
ESE  Electrical Systems Energy
RV  Recreational Vehicles
ICT  information and communication technologies
PPC  Public Power Corporation
e.g.  for example
HTSO  Operator of the Hellenic Electricity Transmission System
RAE  Regulator Authority Energy
PW  Peta 10 to 15 Watt
TW  Tera 10 to 12 Watt
References


