Solar Power Integration and the Pros and Cons of Building-Integrated PV (BIPV)

Solar power has long been thought of as a possible source of power for the buildings in which humankind work, play, and lives. The concept of powering our society from multiple energy sources is a relatively new but increasingly important focus area of power systems engineering. The engineering of power systems utilizing solar power is going to be vital for both industrialized and emerging countries in the coming decades, largely due to solar power being readily available in many parts of the world where there are limited resources to meet the power demands of human civilization. The present power grid structure that many countries use today was designed over a century ago, during a time when mankind was just learning the advantages of life with readily available electricity. Now that modern technologies have increased human civilization's dependency and demand for readily available electricity, it is imperative to utilize solar power as part of a power grid that utilizes multiple sources of power together to ease the burden of energy demand on one resource.

How can humankind harness the power of the sun to be used in a practical manner? We know that the power of the sun can be harnessed via photovoltaic panels, but it takes a large amount of photovoltaic panels to create the energy necessary to be the prime source of power for a building. In order to convert sunlight to useful electrical energy, the entire surface area of the photovoltaic panel needs to be completely exposed to direct sunlight. Traditionally, photovoltaic panels are either placed on the roof of the building which they are to power, or they are set up in large arrays in a rural setting where they are able to occupy land square footage. Depending on the size of the building and the energy requirements of the occupants of the building, there may be more demand than there is area to place solar panels.

This poses quite a problem for utilizing photovoltaic panels as a source of energy in urban areas where space is at a premium and the demand for energy is the largest. An answer to this problem is the concept of using building-integrated photovoltaic systems and building-applied photovoltaic systems. "A Building Integrated Photovoltaics (BIPV) system consists of integrating photovoltaics modules into the building envelope, such as the roof or the façade" (Strong 2011). Using this same concept, building-applied photovoltaic systems integrate photovoltaics modules into an already existing building. Simply put, BAPV is a retrofit added to a building that already exists or construction has already been completed.

By using photovoltaic material as part of the construction materials used in the construction of the building, building designers are essentially creating a scenario in which the building’s structural materials are able to generate electricity and curb the need for a traditional utility source. This essentially makes the building its own distributed generation resource which can be used in conjunction with a utility to meet the demands of occupants.

The concept of building-integrated photovoltaic systems has been around for roughly 35 years with development beginning in the late 1970s. The U.S. Department of Energy (DOE) began sponsoring projects and collaborating with the private industry sector to advance distributed PV systems by integrating photovoltaic materials with building materials (James et al. 2011). In the 1980s, the first prototype PV shingles were created but met with many technical challenges. It is only within the last two decades that PV material efficiency has increased to a point to be practical for commercialized use. The commercialization of innovative BIPV products in the United States began with the DOE program “Building Opportunities in the U.S. for Photovoltaics” (PV:BONUS) in 1993 (James et al. 2011). The objective of the PV:BONUS program was to develop technologies and business arrangements that would integrate photovoltaics into buildings cost-effectively (Eifert and Kiss 2000).

Several different types of new technologies emerged from the PV:BONUS projects which soon became commercially available. These include the following: AC photovoltaic module and curtain wall application, architectural PV glazing system, dispatchable PV peak-shaving system, PV-integrated modular homes, and rooftop BIPV standing-seam systems.

AC Photovoltaic Module and Curtain Wall Application was “a large-area PV module with a dedicated, integrally mounted, direct current (DC) to alternating-current (AC) power inverter” (Haley 2011).

The architectural PV glazing system was a large-area thin-film PV module, either opaque or semitransparent, with a high-absorptance metal pan behind the panel to heat air. Fans operated by the electricity produced by the PV modules drew the heated air into an air-to-water heat exchanger which heats water and reduces the energy required to heat water for the building to use (Haley 2011). When sunlight is hitting the PV modules, a great deal of heat is produced just as heat is produced when sunlight heats any surface. This heat decreases the operating efficiency of PV modules. With the fans drawing heat from the modules to heat the water, the modules are able to heat water, and produce more electricity for use in other loads.

A dispatchable PV peak-shaving system utilized a battery system to curb energy demand during peak demand periods, even if peak demand was not during a time of peak energy production (Haley 2011). This type of system was developed primarily for commercial use and saves on building utility costs when energy production rates are highest.

Building homes in a factory that featured a factory integrated PV system was the aim of the PV-Integrated Modular Homes. The idea was to reduce the overall cost of the home to offset the higher cost of including the PV system (Haley 2011). The savings of building the homes in a factory kept the overall cost of the home similar to that of a home that is built on site.

The rooftop photovoltaic system introduced the use of amorphous-silicon modules that either replace traditional asphalt shingles, or laminated onto metal standing-seam room modules (Haley 2011). This type of BIPV system was targeted for use in residential and light commercial applications.

After a positive experience with the first program of its kind, the DOE funded an additional program in 1997 which ran through the 2000s and came to be known as PV:BONUS two. PV:BONUS two included projects of the following categories: glazing products, roofing materials, PV/Thermal (PV/T) hybrid systems, and an “other” category consisting inverter technology fire retardancy investigations, and development of a “mini-grid” (Haley 2011). The projects undertaken in PV:BONUS two were to be completed in three phases that included a concept design and building planning phase, a product and business development phase, and a commercial product demonstration phase (Hayter and Martin 1998).

In 2005, the largest commercial solar facade in Europe, CIS Tower, was put into service. The building is wall cladded in 7,244 BAPV modules of which 4,898 80 W modules are live and generating 333,000 kWh of electricity for the building annually (Solarcentury.com).

As a result of the backing of the DOE, an environment which fostered open communication and business partnerships was created among PV manufacturers, building material suppliers, and architects. This open communication is still on going and works to address problems with BIPV technologies as well as bring new lower cost products into the market (James et al. 2011).

With building-integrated photovoltaics making large strides over the last two decades and the continued pushing of “green” initiatives, it is important to look at the required balance of system (BOS) components to support BIPV systems. There are two types of systems that need to be considered when discussing BIPV. One type of BIPV system is a stand-alone system and the other is a grid connected BIPV system. A complete BIPV system includes the following components: PV modules, a solar combiner box, an array disconnect, a charge controller and power storage system (for stand-alone systems), power conversion equipment (inverter), backup power supplies (if applicable), and a building power distribution system. Figure 1 illustrates the principal BOS components for a grid-connected BIPV System.

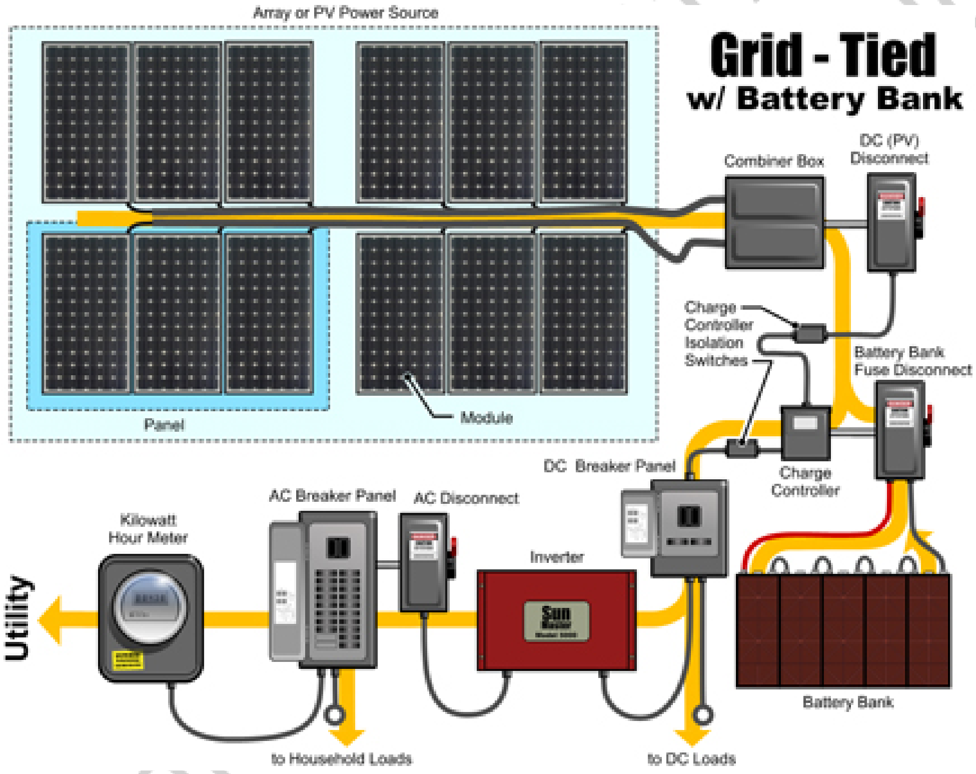
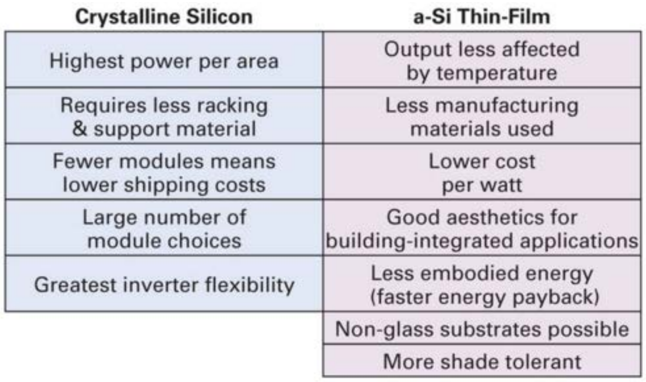


Figure 1. Balance of System components for a grid-connected BIPV System

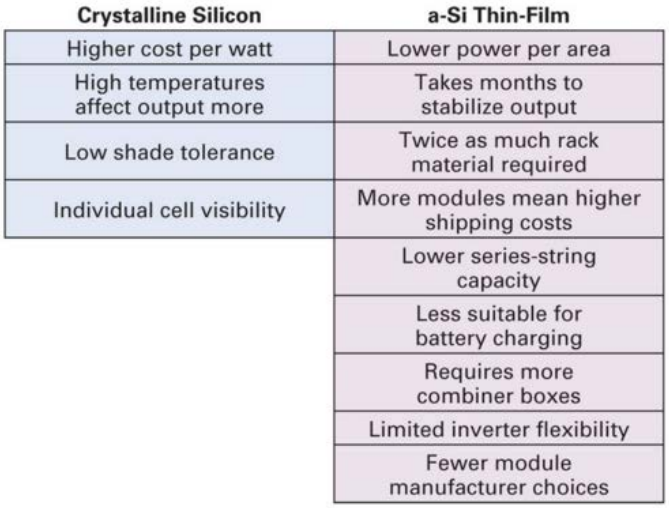
The PV modules used as building materials commercially available today come in two forms. Thick single or poly-crystalline silicon wafer based products are one option. A second building material type is thin-film amorphous silicon. Each have application specific advantages and disadvantages as detailed by Tables 1 and 2 below (Weliczko 2008).

Table 1. Advantages of Crystalline Silicon vs. a-Si Thin Film PV Modules



Crystalline Silicon	a-Si Thin-Film
Highest power per area	Output less affected by temperature
Requires less racking & support material	Less manufacturing materials used
Fewer modules means lower shipping costs	Lower cost per watt
Large number of module choices	Good aesthetics for building-integrated applications
Greatest inverter flexibility	Less embodied energy (faster energy payback)
	Non-glass substrates possible
	More shade tolerant

Table 2. Disadvantages of Crystalline Silicon vs. a-Si Thin Film PV Modules



Crystalline Silicon	a-Si Thin-Film
Higher cost per watt	Lower power per area
High temperatures affect output more	Takes months to stabilize output
Low shade tolerance	Twice as much rack material required
Individual cell visibility	More modules mean higher shipping costs
	Lower series-string capacity
	Less suitable for battery charging
	Requires more combiner boxes
	Limited inverter flexibility
	Fewer module manufacturer choices

From the advantages and disadvantages shown in tables 1 and 2 for crystalline silicon, it can be concluded that builders and BIPV customers would generally want to use c-Si solutions in light commercial or residential roofing applications where surface area space is at a premium and shading is at a minimum. Conversely, a-Si Thin Film technologies would best be applied in large commercial and high-rise applications, especially in urban areas. This is due to many factors including better aesthetics, lower costs per watt, and being more shade tolerant. These characteristics make a-Si Thin Film technologies more suitable to be used on the facades of buildings where more shading is probable as a function of the time of day and season. Using a-Si Thin Film photovoltaics on the façade of a large building would also make up for the disadvantage of having a lower power per area by using more modules than would be possible by only using roof mounted PV.

In large BIPV applications, a combiner box is installed between the PV modules and the power conditioner. It allows for the connection of several strings of PV modules in parallel (Schneider-electric.com 2015). These combiner boxes also may contain fusing for individual series strings of PV modules as well as lightning surge arrestors. This serves as a first line of disconnect, if there is a fault condition with a string of PV modules or the PV array is damaged from weather. PV arrays must have a disconnecting means to isolate the inverter from the PV power source, according to the National Electric Code, section 690.15. Overcurrent protection must be included if there are three or more PV array strings (Regello 2012). For large commercial applications, this is typically a DC rated four pole insulated case circuit breaker which comes before the battery system (if applicable).

In stand-alone BIPV systems, it is essential to incorporate a battery system with a charge controller into the system. The battery system is utilized to provide power to loads during time in which sun light is unavailable. It can also be utilized as a means of voltage regulation. Figure 2 below illustrates the flow of current generated by a stand-alone PV distributed generation system. In both types of BIPV systems, it is necessary to regulate the power into and out of the battery storage bank (Strong 2011). The most common batteries found in BIPV systems are either lead-acid (Pb-acid) or nickel cadmium (NiCad) (Architectural Energy Corporation). Lead-acid battery systems are typically much less expensive than NiCad, but NiCad batteries have a longer life expectancy. To charge the battery system, charge controllers block reverse current from the battery system and prevent battery overcharge (wholesalesolar.com). Charge controllers can manage the power generated by PV modules by deciding whether or not to store energy in the battery system or bypass it to prevent overcharging. If a battery system is bypassed or does not exist in the BIPV system, the generated power is sent to an inverter.

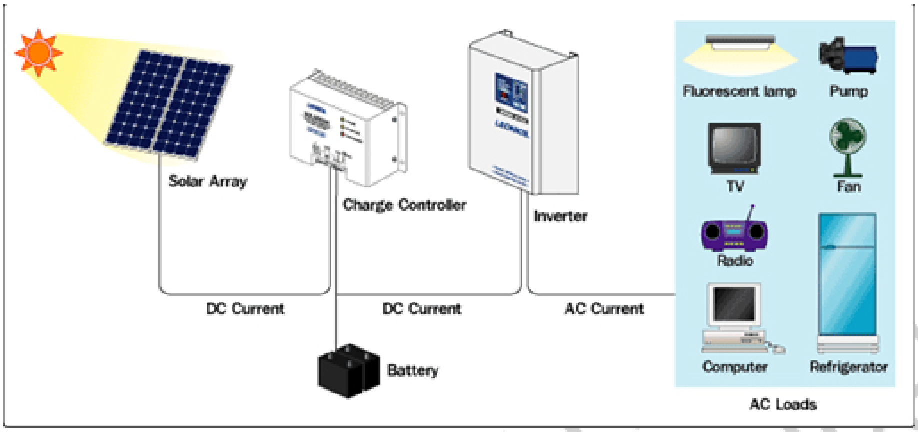


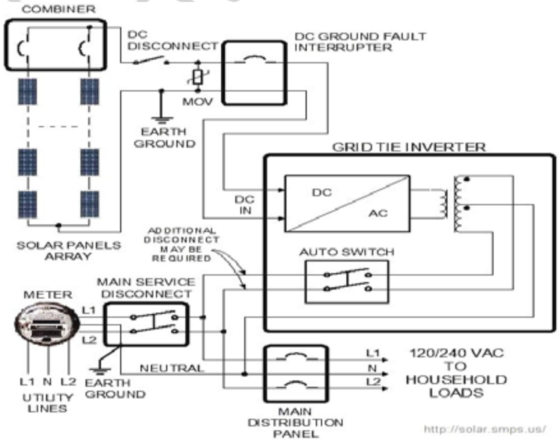
Figure 2. Current flow in a stand-alone PV distributed generation system

The most integral part BOS component to BIPV systems is the power inverter. The majority of loads that are used today in society are made to utilize alternating current. Photovoltaic modules only produce direct current. Since this is the case, the direct current needs to be power conditioned to be transformed into a usable form for typical loads. There are two types of inverters that can be utilized in a BIPV system.

The first type of inverter is a DC to DC inverter. A DC to DC inverter is used as a means of maximum power point tracking (MMPT). MMPT is a way to account for the non-linear complexities introduced by a dynamic environment in order to produce the greatest power generating efficiency out of a solar array. An MMPT algorithm allows for the monitoring of a solar array's current-voltage, or I-V curve, and tracks the point on the curve that will produce the most power. The inverter controller utilizes one of several maximum power point tracking algorithms in order to optimize the power delivered to the load. Maximum power point tracking is especially useful in BIPV applications that have façades that are wrapped with PV modules. Shading of façade-mounted PV modules offer more variations and complexities based on the time of day and solar irradiance. By tracking the point of maximum power using a DC to DC converter, BIPV systems can continue to generate power efficiently, even through dynamic environmental conditions. DC to DC inverters also offer a level of voltage regulation for the output of the system. As the battery system's stored energy decreases, the battery voltage decreases as well. This under voltage condition could cause loads malfunction. DC voltage regulation is especially useful in systems that use the DC current to feed loads directly such as battery chargers, DC pumps, and DC fed appliances.

The second and most critical type of inverter used in BIPV systems is a DC to AC inverter. This type of inverter is used in both stand-alone and gird connected BIPV systems. Once the PV modules generate direct current, it is necessary to either store the energy for future use, use the energy immediately, or sell excess energy to the utility. In applications with a battery system, the finite capacity of the battery bank may be less than the amount of energy being produced by the BIPV array. The excess energy could be used immediately with a DC panelboard to power DC loads. When considering a BIPV system, the only time there will not be an AC to DC inverter is when the system is exclusive to serving DC Loads.

In grid connected BIPV systems, a DC to AC inverter is not only able to transform the generated DC into an output that conforms to utility power quality standards, but also control utility interconnection. In the event that the utility suffers a power outage, the DC to AC inverter should automatically disconnect the BIPV system from the utility source. A schematic diagram of a small BIPV system with a grid connection (tie) inverter is shown in figure 3. It is highly recommended that continuously grid connected BIPV systems utilize an inverter with automatic paralleling controls with anti-islanding protection. Islanding is a condition in which the BIPV array is still paralleled with the utility even though the utility may be experiencing an outage. The result is that the BIPV array will try to supply power to the remaining grid connected loads. This may place extreme strain that the BIPV system was not designed to support and cause unnecessary damage to the system.



http://solar.smps.us/

Figure 3: Small Grid Connected PV System Schematic with Anti-Islanding Disconnect

The grid connected system, establishes a two-way flow of electricity. In this scheme, the utility can be used as both a backup power source and a place to sell excess electricity. Selling electricity to the utility is desirable to BIPV system owners because the highest demand for utilities comes during the afternoon, which is the peak time of PV power production. Not only does this utilize excess BIPV generated electricity effectively, but also gives BIPV owners net metering credit towards their utility bill. In the U.S., section 1251 of the EPAct of 2005 states that utility customers that generate electricity with an eligible on-site generating facility and deliver electricity to local distribution facilities are able to have the amount of energy put onto the grid credited as an offset to their electric bill for that billing period. Having a grid connected BIPV system is advantageous because it essentially allows for using the utility as an infinite place to store energy in the form of a bill credit (ferc.gov). The BIPV system owner would then be able to use a single meter after their building's AC distribution panel(s) which meters both their imported and exported electricity. This allows the utility to charge or pay for the difference in electricity.

For BIPV owners, there is also another scheme of being paid for supplying the utilities with energy produced. Feed-in tariff programs are performance based in the sense that they encourage a long term contract between BIPV system owners and utilities which pays a higher rate per kWh for supplying electricity from the solar array (eia.gov). The reason is the aforementioned fact that PV arrays typically generate their maximum electrical output during peak demand hours of the day for utilities. With the utilities putting less stress on their distribution equipment during peak demand times, they are able to increase the lifespan of equipment and use less non-renewable resources for electricity production.

With the U.S. federal government implementing policy and regulation that encourages distributed generation with renewable resources, the question becomes, "Is it worth it to go solar?" In order to decide whether or not the implementation of building-integrated photovoltaic is economically feasible for a given project, all aspects of photovoltaic balance of system economics must be evaluated as well as any federal or local government incentives that may be available.

Key elements of concern when evaluating the possibility of implementing BIPV within a building project include environmental considerations (the average solar irradiance of the area, temperature), building demand schedule (hours of operation), and the availability of a secondary power source or energy storage system. It would make little to no sense to use if the building in question or future site plan is observed to be shaded most of the day, or the typical demand is only during the night. Another challenge facing BIPV systems is the fact that they are mounted directly to building surfaces, thus leaving no space underneath the modules for cooling (James et al. 2011). This cooling problem, unless addressed by technological advances, will result in performance losses that could impact the economic feasibility of BIPV systems.

One technology that needs further development in order to become a viable option is to harvest the heat from BIPV systems for use as a heating source for the inside of the building. This would create a solar combined heat and power (SCHP) system, but this type of technology for large scale applications is still under active research and development and has implementation issues still to be addressed, according to the Strategic Environmental Research and Development Program (SERDP).

With the global market being in a constant state of evolution and many variable system configurations available, statistics on present installation, equipment, and operation and management prices are not “one size fits all” and readily available. Current economic trends do show progression toward photovoltaic products becoming more competitively priced in addition to becoming more efficient. In fact, data has shown that “costs for PV-generated electricity have decreased nearly 96% over the past 30 years,” (Architectural Energy Corporation). With the development of less expensive thin-film PV technologies, the unit costs of PV modules for BIPV systems have become more economically feasible (Architectural Energy Corporation). According to the Architectural Energy Corporation, in terms of the cost of the raw building materials for a building’s façade, photovoltaics rank second after polished stone per square foot. Unpolished stone, glass wall systems, and stainless steel all rank as less expensive building materials (Architectural Energy Corporation). Although PV building materials rank on the higher side of construction materials, an economic advantage is realized due to the fact that the other materials will not generate anything useful through the life of their installation and are only for aesthetics. The PV modules can serve in both functions, being both aesthetically pleasing and produce an energy cost savings; thus, offsetting the building material cost.

Installation costs can widely vary based on several factors. In BIPV applications, again the cost of installation will be offset by the need to install a construction material, whether it is PV modules or traditional construction materials. Additional costs may be incurred based on the size of the PV modules used and intricacies of the installation. PV modules that are smaller may take more time to install, resulting in a higher installation cost from the contractor (James et al. 2011). In stand-alone BIPV systems, the need for an energy storage system by way of batteries also adds a substantial amount to the equipment, installation, and lifecycle costs.

According to the Architectural Energy Corporation, “Economic trends indicate that the price of BIPVs will continue to decrease while the efficiency of PV-generated electricity will continue to increase” (Architectural Energy Corporation). As this trend continues over time, the hope is that within the next few decades, the cost of using PV based systems will be comparable or cheaper per kWh than the cost of traditional utility electricity. Although there is a large interest in BIPV from public policy makers, solar energy stakeholders, and scientists in research and development, BIPV systems account for a very small fraction of globally installed distributed generation systems (James et al. 2011). Solar projects and BIPV still has a long way to go before it can be considered as “taking off”. With more technological advances on the horizon, in addition to the development of standard practices, BIPV systems will likely become a more prominent part of the distributed generation as a supplementary energy source, in the decades to come.

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