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Enhancing the performance of building integrated photovoltaics

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Abstract

Recent research in Building Integrated Photovoltaics (BIPV) is reviewed with the emphases on a range of key systems whose improvement would be likely to lead to improved solar energy conversion efficiency and/or economic viability. These include invertors, concentrators and thermal management systems. Advances in techniques for specific aspects of systems design, installation and operation are also discussed.

Keywords: Photovoltaics; Buildings; Solar concentration; Inverters; Thermal management; Array sizing

1. Introduction

Building Integrated Photovoltaics (BIPV) is a PV application close to being capable of delivering electricity at less than the cost of grid electricity to end users in certain peak demand niche markets (Byrne et al., 1996; Masini and Frankl, 2002). BIPV adoption varies greatly, and within, by country depending upon climate, built environment, electricity industry structure, government polices, local product offerings, market stimulation mechanisms, consumer demand, existing industrial capabilities and the forms of tariff arrangement for grid-connected PV power generation (Green, 2003; Bakos et al., 2003; Watt et al., 1997; Imamura, 1993; Chambouleyron, 1996; Yordi and Gillett, 1997; Hass, 1997; Nieuwenhout et al. 2001). BIPV modularity results in short installation times, and the lack of moving parts reduces the need for maintenance (Yewdall et al., 2002). As Japan and some countries in Europe have low specific land use per capita (for the Netherlands, Japan, German and Switzerland, respectively, this is 2680, 3060, 4450, 6000 m^2 per capita compared with 37,040 m^2 per capita for the USA (Nordmann, 1997)) locating PV on buildings is preferable to specifically devoting land (Strong, 1996a). Grid-connected BIPV – the simplest such low-voltage residential system comprises a PV array and inverter – feed electricity directly to an electricity network operating in parallel with a conventional electric source and do not usually require/use batteries. The performance of a grid-connected system depends on PV efficiencies, local climate, the orientation and inclination of the PV array, load characteristics and the inverter performance (Kurokawa et al., 1997a,b; Simmons et al., 2000; Miguel et al., 2002).

The very extensive current research on photovoltaic cells has been reviewed extensively elsewhere (see, for example; Green, 2003, 2007; Van Kerchauer and Beaucamie, 2005; Kazmerski, 2006).

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Nomenclature

I	insolation (W m^{-2})	T	temperature of photovoltaic cell (K)
R	thermal resistance of photovoltaic cell (KW^{-1} m^2)	η	solar energy electrical conversion efficiency

2. Inverters

An inverter's efficiency in converting PV generated DC power into AC power determines the PV generated DC power required to supply a given AC load which in turn for specified PV array efficiency sets the PV array size. The performance of an inverter depends on its point of work, threshold of operation, grid connection system, inverter output waveform, harmonic distortion and frequency, PV efficiency, maximum power point tracker (MPPT) and transformer. The main functions of an inverter are waveshaping, regulation of output voltage and operation near peak power point (Kjar et al., 2005).

The three major types of inverter are sine wave, modified sine wave, and square wave inverter. The major advantage of a sine wave inverter is that most equipment available commercially is designed for sine wave operation. A modified sine wave inverter (which has a waveform more like a square wave, but with an extra step) will also operate with most equipment. Static inverters use power semiconductor switches which operate at the cut-off and saturation mode and therefore the output of the waveform is a square wave. A square wave inverter will only generally operate simple devices with universal motors but is much cheaper than the sine wave inverter. Using a power filter, the output square waveform can be converted to a sine waveform. An inverter equipped with a MPPT algorithm extracts maximum power from the PV by varying the input voltage to maintain maximum power point (MPP) voltage on the current–voltage curve as PV output varies with insolation and module temperature (Hussein et al., 1995; Hsiao and Chen, 2002; Takashima et al., 2000; Swiegers and Enslin, 1998; Kuo et al., 2001). The efficiency of an inverter depends on the fraction of its rated power at which it operates. A PV system operates at high-efficiency either when it has a sole inverter operating with a load large enough to maintain peak efficiency or is an interconnection of multiple string inverters, module-integrated inverters or master-slave configurations (Woyte et al., 2000). A sole inverter is supplied from several series-connected PV modules switched in parallel on a DC bus; it can be low-cost and provide high-efficiency but entails a complex DC installation. In a module-integrated inverter each PV module has its own individual inverter. Both string and module inverters are more expensive than a central inverter, however, they obviate the need for expensive DC wiring (Woyte et al., 2000). A master-slave configuration entails multiple inverters connected together; at low insolation, the whole string is connected to just a single inverter operating the inverter at its peak input power level, when insolation increases the PV array is divided progressively into smaller units, until every string inverter operates independently at or near its peak rated capacity. Master-slave inverters can give greater BIPV output (Marańda et al., 1998).

AC module-integrated inverters are located generally at the back of each module converting that module's DC output to AC power. The advantages of AC module-integrated inverters are: (i) low resistance losses in cables and connections; (ii) absence of a diode eliminates associated losses; (iii) excess energy can be supplied readily to the utility; (iv) safer than high-voltage DC PV systems; (v) flexibility, ease and low-cost of module installation; (vi) as each module is equipped with a maximum power point tracker, low mismatch losses at system level ensue; (vii) conduction losses and cable costs are low because of the high AC voltage and therefore low current; (viii) lower capital cost due to mass production economies; and (ix) the small size of one AC module lowers barriers to market entry (de Graaf and Weiden, 1994; Wills et al., 1996; de Haan et al., 1994; Yatsuki et al., 2001; Wills et al., 1997). The disadvantages of AC modules are: (i) increased heating of the inverter located at the back of the module; (ii) increased zero load dissipation compared to a conventional PV system; and (iii) for large PV systems, a central inverter system would be cheaper (de Graaf and Weiden, 1994; Wills et al., 1997).

Inverters are either line or self-commutated. Self-commutated inverters operate independently being activated solely by the input power source; an internal frequency generator provides the correct output frequency. Self-commutated inverters can be connected easily to the grid or any other power source which is tied to the inverter output and for a large PV system three-phase devices are used. Though line-commutated inverters have a lower cost, the AC electricity power quality and power factor are both poor. A PV inverter is either a 'voltage source' or a 'current source' inverter. In a current source inverter the DC source acts as a current source to the inverter (Longrigg, 1982) and needs fault-clearing devices. In the voltage source inverter, the inverter acts as an AC voltage source at its AC terminals (Longrigg, 1982). A PV array operates in the constant-voltage region of the I-V characteristics with this type of inverter for stable operation.

Inverter efficiency reaches its maximum usually above 90% efficiency for an input power level usually between 30% and 50% of its rated capacity. However, low efficiency ensues generally at input power levels below 10% of capacity (Rasmussen and Branz, 1981). When a BIPV module is shaded, the PV output current decreases significantly causing not only the particular module output power to drop but the series-connected PV output power also drops which