Trends of power electronics on renewable energy systems

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Abstract

The paper focuses on the power electronics used in renewable energy systems and especially in wind and photovoltaic (PV) applications. During the last years there was a broad development in the field of power electronics which led to more efficient systems and reduction of the cost per installed kW. The inverters became more efficient and reached efficiencies in excess of 98%, while commercial solar modules reached almost 17% efficiency. Furthermore, the wind turbines use inverters of improved efficiency, reliability and regulation capabilities. In this paper the recent trends of power electronics topologies used in such systems are presented

1.Introduction –

Photovoltaic and wind energy systems The Kyoto agreement renewed interest in renewable energy systems worldwide. Many renewable energy technologies today are well developed, reliable, and cost competitive with conventional generators. The cost of renewable energy technologies is on a falling trend and is expected to fall further as demand and production increases [1], [4]. There are many renewable energy sources such as biomass, solar, wind, mini-hydro, and tidal power [6]. Power electronics find applications in most RES technologies, solar and wind energy systems being the most important applications. During the last years, there is a constant effort to improve each part of a photovoltaic (PV) and wind turbine (WT) application.

The efficiency of commercial PV modules now exceeds 17%, inverters have reached almost 99% European efficiency and there are new topologies found which make WTs more efficient and flexible in their operation. Due to the increased demand, each manufacturer is trying to find new concepts in order to achieve better system yield, which results in increased economic returns for the investor. Most of the systems used in such applications produce DC current, so inverters are required to convert this power to AC, which is needed in most applications and definitely for grid connection. There are two types of PV systems: stand alone and grid connected. The first is used on remote locations, where the utility grid is not present. The grid connected systems inject power and energy directly to the utility grid. These systems have different structure and the inverters which are used have different methods to synchronize and produce clean AC power

Power Electronics for PV applications

The PV modules and the power electronics that convert the produced electric power by the PV modules are the basic parts of a PV installation. The PV modules comprise several solar cells which convert the energy of the sunlight directly into electricity, and are connected in a proper way (typically in series), to provide desired levels of DC current and voltage. They produce electricity due to a quantummechanic process known as the "photovoltaic effect" [1]. A presentation of this conversion is shown on Figure 1a. There are many semiconductor materials suitable for solar cells manufacturing. The most commonly used are monocrystalline Si cells, polycrystalline Si cells and amorphous Si cells, although several other thin film technologies exist in the market. The efficiency of monocrystalline Si cells is almost 17%, for polycrystalline cells reaches almost 15%, while an efficiency of 10% is achieved in the case of amorphous Si PV cells. All PV modules have a typical current-voltage characteristic curve, used to make all necessary calculations, as shown on Figure 1b [4].

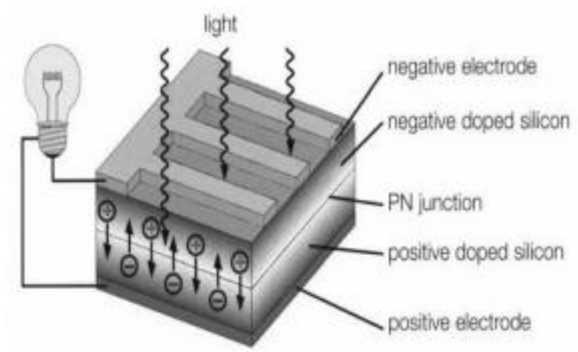

Figure 1a: Photovoltaic effect

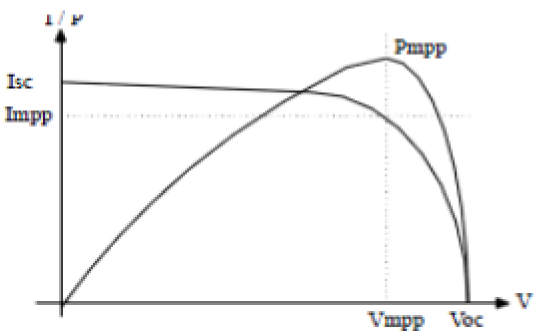

Figure 1b: PV module curve

Off-grid PV systems are used in cases, where the grid is not present and the use of batteries to store energy is required, in order to cover the demand during the night or whenever energy is needed. Blocking diodes are used to prevent the batteries to discharge on the modules during the night, while they also protect the batteries from short circuit. If more than one string is used, they also provide over-current protection of the strings in case of short circuits. Charge regulators control the charging of the batteries [1], [6]. In off-grid systems, there is the need to use dc voltage and current with stable characteristics, independent from irradiance fluctuations. Therefore, a DC – DC conversion topology is used. Switch mode DC – DC converters [1] are used to match the dc output of a PV generator to a variable load. Three different topologies are mostly used; step down converters, step up converters and a combination of these two. In Figure 2 simplified diagrams of these three topologies are presented

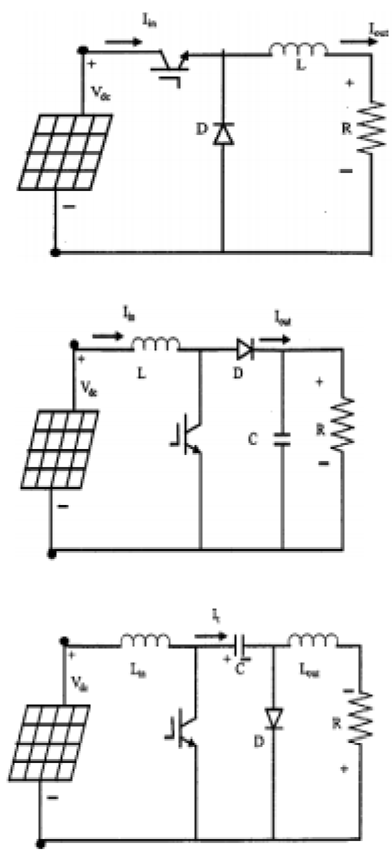

Figure 2: Simplified diagrams of DC/DC converter topologies

In order to maximize the performance of the string, in most charge regulators a maximum power point tracker (MPPT) controller is used. The MPPT applies heuristic algorithms to track the array voltage which results in maximum power, given a solar irradiance level. The efficiency of modern MPPTs is between 92-97%, getting a typical 20-45% power gain in winter and a 10-15% in summer. Actual gain can vary widely depending on temperature, battery state of charge, and other factors.

The MPPT is often performed via a high frequency DC to DC converter. Its input is the output of the solar panels strings. It converts the DC input to high frequency AC, and then back to a different DC voltage and current in order to match the panel voltage to that of the batteries. MPPTs operate at very high (audio range) frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with high efficiency and small volume transformers and other components. The design of high frequency circuits can be a very difficult task because of EMI/EMC considerations (e.g. problems with circuit parts that act as antennas, causing radio and TV interference). Noise isolation and suppression issues become very important

Inverters convert DC to AC. In off-grid systems, stand alone self-commutated inverters producing AC current without synchronisation with a reference signal are used. These inverters have the responsibility to produce AC voltage and current characteristics (sinusoidal 230V/50Hz) same as those of a typical grid in order to supply off-grid loads. Otherwise, the inverter is not suitable for most electronic devices [1]. Several different semiconductor devices such as MOSFETs and IGBTs are used. The first are used in units up to 3KW, because they have the advantage of low switching losses at higher frequencies. At higher voltages and powers IGBTs are used [2]. These inverters can be single phase or three phases. A common switching technique in order to eliminate higher frequencies is the SPWM method. A general layout of a single phase inverter with half bridge and full bridge topology is shown in figure 3a, b. In the half bridge topology, the two switches S1 and S2, the capacitors C1 and C2 are connected in series with the dc source (batteries). The center point between the two capacitors is at mid-potential. The voltage across each capacitor is VDC / 2. The switches S1 and S2 switch on and off periodically to produce the ac voltage. A filter (Lf and Cf) is used to reduce high switching frequency components and to produce sinusoidal output from the inverter

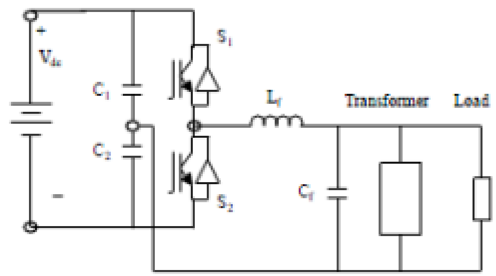

Figure 3a: Single phase half bridge inverter

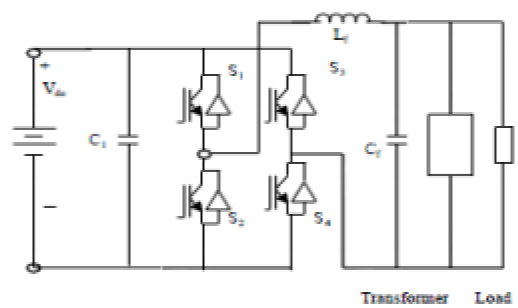

Figure 3: Single phase full bridge inverter

The output of the inverter is connected to the load through a transformer. The full bridge inverter has a similar function, but the output voltage is higher than the half bridge inverter. In figure 4 we can also see the layout of a three phase stand alone inverter

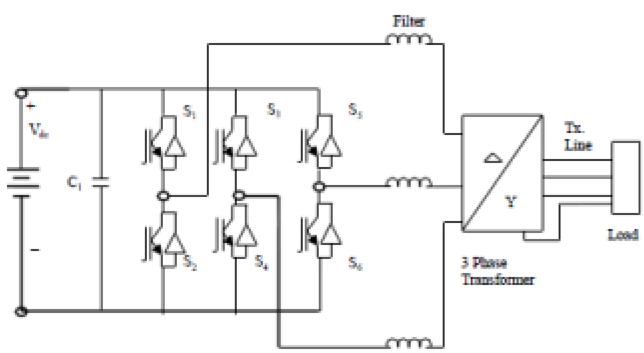

Figure 4: Three phase inverter

In grid-connected applications the energy is provided directly to the grid and the necessary parts are the PV modules and the inverters. This reduces the cost of the system and it also reduces the necessary maintenance, as the batteries are the most maintenance-demanding components. The inverters for grid connected applications may have different topology and operation than off-grid ones. They have to produce excellent quality sine wave output, follow the frequency and voltage of the grid and extract maximum power from the PV modules through the MPPT. The inverter input scans the I–V curve of the string until the maximum power point is found. [2], [1] The grid inverter always monitors the grid and the output voltage and frequency must be controlled. The most common modulation is the PWM modulation and operates at a range of 2 to 20 KHz [1]. Grid connected inverters are classified as voltage source inverters (VSI) and current source inverters (CSI). However, in PV applications VSI inverters are used. The layout of the VSI topology is shown in Figure 5

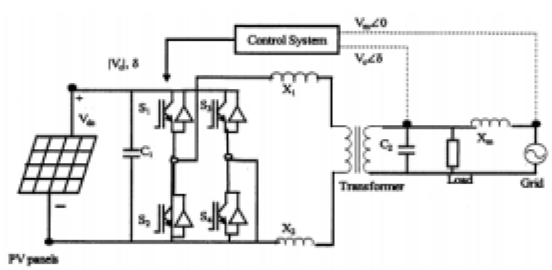

Figure 5: VSI inverter

During the years, the inverter topologies and the technology of power electronics has improved. Until some years ago, the common practice was to use central inverters for most PV applications. The PV modules were divided into series connections (called strings), each generating a sufficiently high voltage to avoid further amplification. Then all the strings were connected in parallel through string diodes in order to reach high power levels. The use of central inverter has many drawbacks such as MPPT power losses, losses from differentiations between the modules and high voltage DC cables from the PV panels to the inverter. In the beginning, line commutated inverters using thyristors were applied, characterized by poor harmonic performance. Today, the most popular inverter topology is the string inverter. One or two strings of crystalline modules are connected to each inverter which has its own MPP tracker and the power losses are significantly lower [11]. The use of more than one MPP trackers in the power plant is necessary in the case of different module orientation and shading. This maximizes each string's I-V curve power output [10]. From tests that have been performed on string inverters, the development through the years is obvious. According to [H. Haeberlin, BernerFachhochshule], the inverter efficiency in 1988 was in the order of 85.5 – 90%, in the mid 90's was increased to 90 – 92% and nowadays it has reached 98% [12]. The most popular string inverter is the transformerless one, because the transformers that operated at grid frequencies are bulky, expensive and cause losses. Furthermore, the transformers impose limitations in the control of grid current by the inverter. Especially at low load, the reactive power for the magnetization of the transformer leads to a lower power factor [10]. Another important factor that affects the system design optimization is the maximum input voltage (Vmax-in) of the inverters as well as their input voltage (Vin) bandwidth. These two characteristics (Vmax-in and Vin) are getting wider and still rise, a fact that allows the designer to perform more efficient and flexible combinations in order to achieve the desired power. The Vmax-in of the string inverters kept rising from 600V up to 900V in 2009, while the in 2010 inverters with Vmax-in=1000V allowing even bigger strings are already in the market. The higher the Vmax-in is, the less strings of more modules are used, so the losses are further decreased as less cables are used [11]

The IGBTs and MOSFETs with high pulsing frequencies provide improved power quality in compliance with the regulations of the utility grid. The high frequency used has led to the use of high frequency transformers with lower weight. This fact reduced the total weight of the inverters significantly (up to 20%). The today's string inverters vary from 22 - 65 kg.

Conclusion

In this paper the main trends of the power electronics used in PV and WT applications are presented. Due to the high demand for renewable energy sources applications, there is a continuing research for improving the total efficiency of these applications and by improving each electronic part included. As far as the PV systems are concerned the inverter's efficiency is continuously improving and ways to minimize the weight of the devices are tested so as to decrease transportation costs and ease the installation. Moreover, the power and voltage range of the string and central inverters is increased, so that more efficient and cheaper PV installations can be realized using a relatively low number of inverters. The power electronics for WT systems are subject to extensive R&D, especially about more efficient control concepts and even more efficient converters

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