POWER ELECTRONICS AS EFFICIENT INTERFACE OF COMBINED HEAT AND POWER (CHP) SYSTEMS

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ABSTRACT

For achieving the Government of India's mission "Power for All in 2012", distributed generation (DG) has been identified has one of the mechanism for ensuring supply of power in rural areas by way of setting up small generating units based on a variety of local fuel along with localized distribution. DG encompasses a wide range of prime mover technologies, such as internal combustion engines, gas turbines, microturbines, photo voltaic, fuel cells and wind power. Micro turbines are excellent power generator for use in combined heat and power (CHP) systems. Characteristically, power electronics is an efficient and important interface to the grid and this paper will first briefly discuss three different power electronic circuit configurations used in micro turbine. Next, parallel operation of power converters for applications to DG is presented. Finally, the harmonic current reduction and the impacts of filters in the operation of micro turbine are discussed.

I. INTRODUCTION

Power Electronics is one of the broadest growth areas of electrical technology. Today, electronics energy processing circuits are needed for every computer systems, every digital, industrial systems of all types, automobiles, home appliances, lamps and lighting equipment, motor controllers and just about every possible application of electricity. In recent years, the field of power electronics has experienced a large growth due to confluence of general factors. Revolutionary advances in semiconductor fabrication technology have made it possible significantly improve the voltage and current handling capability and the switching speed of power semiconductor devices, used in industrial and power system applications [1]. At one time, the growth was pushed by DG sources for interfacing with the grid.

The advent of small power generation systems together with advances in power electronics has meant that Distributed Energy is becoming a reality. Bring the power plant close to where the power is used means that utilizing the waste heat for heating and air conditioning is possible, there by raising the efficiency of energy resources, and also there is less reliance on the transmission and distribution network that enhances reliability [2].

In case of micro turbines to generate electrical power, whose original design contemplated the feeding of remote loads that could not be assisted by the distribution network of any utility [3]. However, the fact that these microturbines operate at very high speed and frequency (96,000 rpm and 1,600Hz) force the use of power electronics in order to have 480/240 V output at 50/60 Hz.

With new applications and hundreds of megawatts of Distributed and Cogeneration (DCG) capacity installed each year, the demand for power electronics in DG, inverters, variable frequency converters and static transfer switches is expected to continue to grow, increasing from $ 3.7 billion in 2006 to $ 7.6 billion in 2011, a compounded annual growth rate of 15.4% [4]. A growing percentage of newly installed DCG systems, including gas turbines and gensets, less than 5% of the system cost is electronic power conversion. In newer alternative technologies like microturbines power electronics may account for over 30% of the system costs. The world wide DCG power electronics market (million of $) by DCG product is shown in Fig. 1.

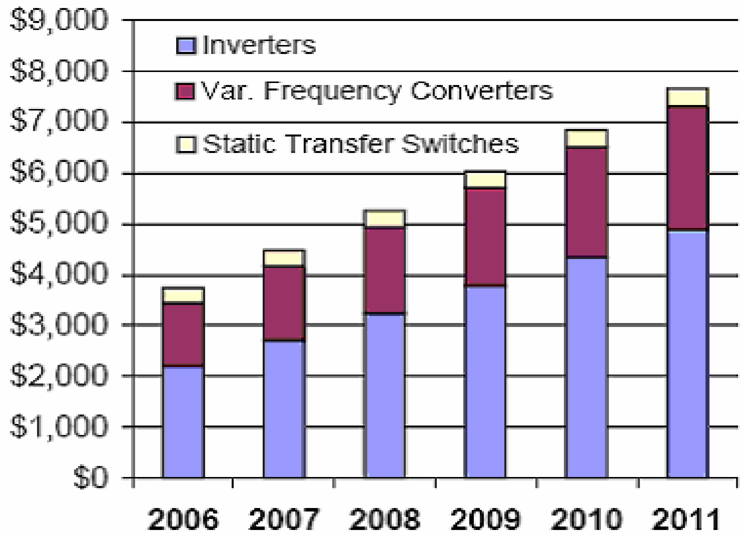

Fig. 1. World wide DCG power electronics market (million of $)

The industries that may develop cogeneration schemes are those that require steam as a part of the industrial processes such as paper mills, cement plants, sugar mills, petrochemical industries, steel mills, and refineries among others [3]. India, in, fact has great deal of potential in this regard and already emerged as a world leader in exploitation of renewable energy sources. India ranks first in biomass gasifiers (35MW), fourth in biomass based power generation (400MW), fifth in installed wind power capacity (1507 MW) and tenth in small hydel power capacity (1438 MW) and fourth in solar photovoltaic (50 MW). Also 19500 MW potential identified in India through biomass/cogeneration whereas 381.3 MW set up completed already [5]. This paper will first briefly discuss three different power electronic circuit configurations used in micro turbine in chapter II. Next, parallel operation of power converters for applications to DG is presented in chapter III. Finally, the harmonic current reduction and the impacts of filters in the operation of micro turbine are discussed in chapter IV and V.

II. MICROTURBINE POWER CONDITIONING SYSTEMS

A power conditioning system (PCS) generally composed of AC/DC rectification with the help of active (controlled solid state switches) or passive (diode) rectifiers and DC/AC inversion is required to interface the high-speed generator power output with the grid. Fig. 2 shows the schematic of a microturbine system [6].

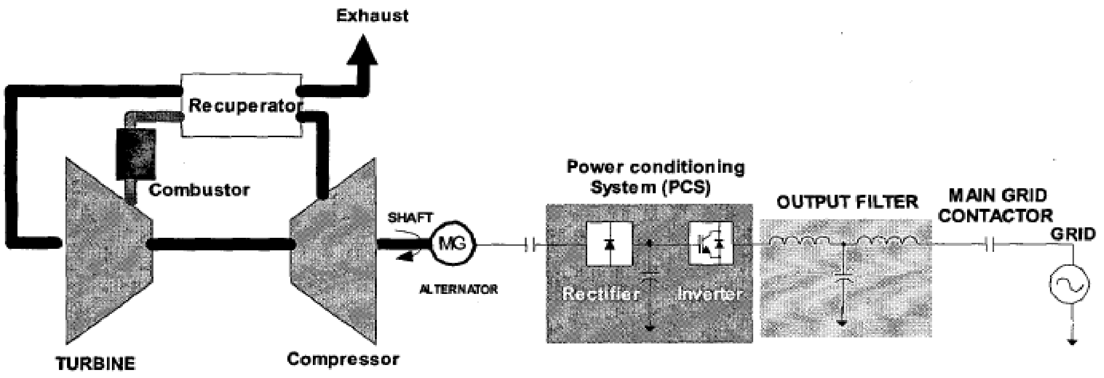

Fig. 2. Schematic diagram of microturbine system

The power converter can also be designed to provide valuable ancillary services to the power grid or microgrid. These services may include voltage support, sag support, static voltanp-reative (VAR) compensation, load following, backup supply and/or start-up power for the microturbine or other local microturbines [7]. Voltage support is common for grid independent operation while load following is used for grid connected operation. The availability of backup supply and start-up power varies not only by microturbine manufacturer but also by what options may be purchased with the microturbine. There are basically two types of static frequency changers: direct and indirect. The direct frequency changers are known as cycloconverters; they convert an ac supply of variable frequency to utility frequency. This section briefly explains three different configurations of PCS, namely, dc link converter, high frequency link converter and cycloconverter which are suggested by R.H. Staunton, et.al [7].

A. DC link converter

The dc link converter is the most common power converter topology for microturbine application. Figure 3 and 4 shows a microturbine generator feeding power to an active rectifier circuit and a passive rectifier followed by a dc link and inverter circuit.

The high frequency power from the generator must be converted to dc before the inverter can reconstruct a three-phase voltage supply at lower frequency required for grid connection. A controller manages the operation of the active rectifier and inverter circuitry by ensuring that functions such as voltage following, current following, phase matching; harmonic suppression, etc. are performed reliably and at high efficiency. The controller may be mostly on-board, pc-based, a processor linked to a pc, etc., depending on constraints and factors such as desired microturbine packaging, desired versatility, type of available features, and the sophistication/maturity of the system design.

The dc link consists of a capacitor to keep the input voltage to the inverter constant and to smooth the ripples in the rectified output voltage. The dc link voltage cannot reverse; it is a constant, so this is a voltage-source drive [8].

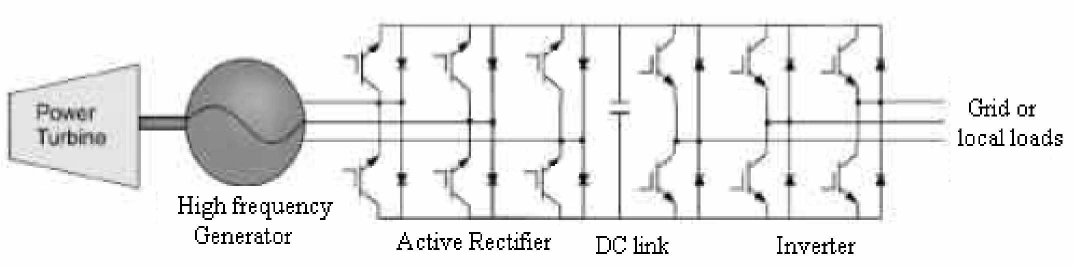

Fig. 3. Simplified diagram of a dc link converter using active rectifier

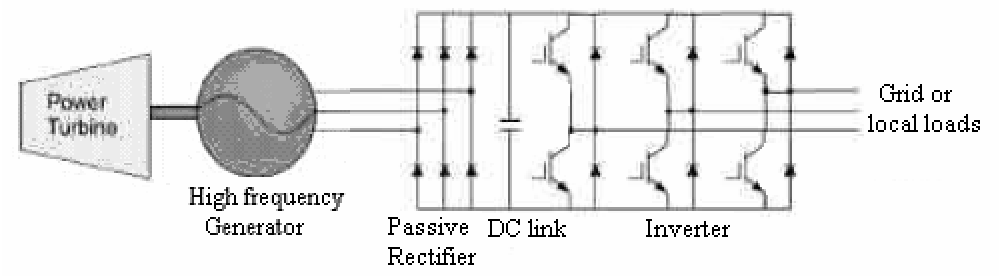

Fig. 4. Simplified diagram of a dc link converter using passive rectifier

B. High Frequency link converter

Another type of power conversion circuit that is of high interest is the high frequency link converter (HFLC). Fig. 5 shows a microturbine generator feeding 3-phase power to a rectifier and the dc is then fed to a high frequency, single-phase inverter so that a compact, high frequency transformer can be used. The secondary of the transformer feeds an ac/ac converter that takes the single phase, high frequency voltage to produce a 3-phase voltage at a frequency and phase needed to make a direct connection to the grid.

Although the HFLC requires a higher part count, the circuit provides several advantages including:

- The use of a transformer for robust isolation
- The high frequency inverter permits the use of compact, high-frequency transformers
- The use of a transformer permits the easy addition of other isolated loads and supplies via additional windings and taps
- The circuit eliminates the need for static transfer switches, which is normally used to mitigate the variations and interruptions in the utility voltages [9]
- Ancillary services can be provided with control software changes and additional hardware
- Adding additional hardware is easier.

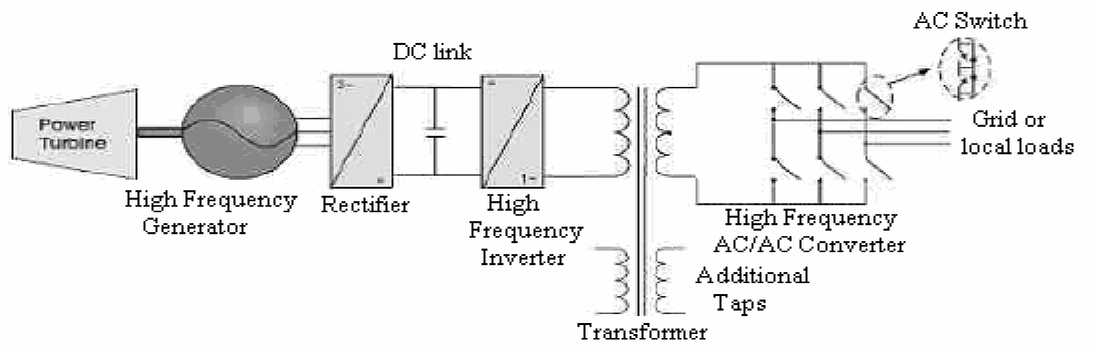

Fig. 5. Simplified diagram of a high frequency link converter.

C. Cycloconverter

A cycloconverter or a matrix converter could be used to connect the microturbine generator to the grid instead of using a rectifier and an inverter. These converters, as shown in Fig. 6, directly convert ac voltages at one frequency to ac voltages at another frequency with variable magnitude. The disadvantages of these converters are that they have double the number of switches compared to the dc link approach and they do not have a dc or ac link to store energy. Without energy storage in the converter, any fluctuations at either side of the converter will directly influence the other side. In addition to this, it is not possible to connect a battery or any other power source to these converters unlike the dc link converter or the HFLC.

A cycloconverter can still be used for microturbines with the high frequency link inverter. Instead of converting the generator voltage to dc and then to high frequency ac, a cycloconverter can directly convert the three-phase ac voltage to single-phase high frequency ac voltage.

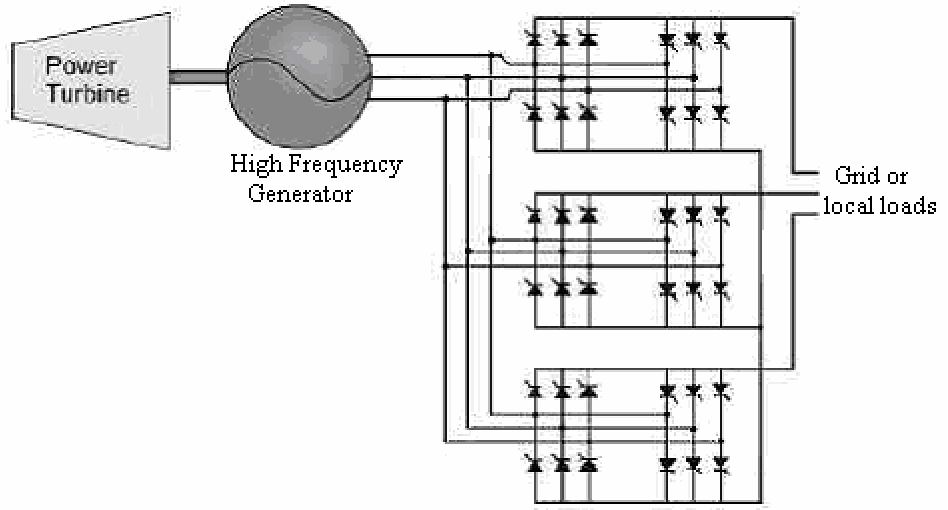

Fig. 6 Simplified diagram of cycloconverter in CHP systems

III. PARALLEL OPERATION OF POWER CONVERTERS IN CHP APPLICATIONS

Distributed Generation Systems have mainly been used as a standby power source for critical businesses. For example, most hospitals and office buildings had stand-by diesel generation as an emergency power source for use only during outages. However, the diesel generators were not inherently cost-effective, and produce noise and exhaust that would be objectionable on anything except for an emergency basis. Meanwhile, recently, the use of Distributed Energy Systems (DES) under the 500 kW level is rapidly increasing due to recent technology improvements in small generators, power electronics, and energy storage devices. Efficient clean fossil-fuels technologies such as micro-turbines and fuel cells, and environmentally friendly renewable energy technologies such as solar/photovoltaics, small wind and hydro are increasingly used for new distributed generation systems. These DES are applied to a standalone, a standby, a grid-interconnected, a cogeneration,

peak shavings, etc. and have a lot of benefits such as environmental-friendly and modular electric generation, increased reliability, high power quality,
uninterruptible service, cost savings, on-site generation, expandability, etc [10].

In the fields of power electronics, many researchers have suggested technical solutions which would permit to connect more generators on the network in good conditions and to perform a good voltage regulation. In Ref. [10], the author has discussed different operating modes (standby mode, standalone, and peak shaving) of power converters and proposed a hybrid power system which combines several DES.

A. Standby mode

In a standby mode shown in Fig. 7, a generator set serves as a UPS system operating during mains failures. It is used to increase the reliability of the energy supply and to enhance the overall performance of the system. The static switch SW 1 is closed in normal operation and SW 2 is open, while in case of mains failures or excessive voltage drop detection SW 1 is open and SW 2 is simultaneously closed. In this case, control techniques of DES are very similar to those of UPS. If a transient load increases, the output voltage has relatively large drops due to the internal impedance of the inverter and filter stage, which frequently result in malfunction of sensitive load.

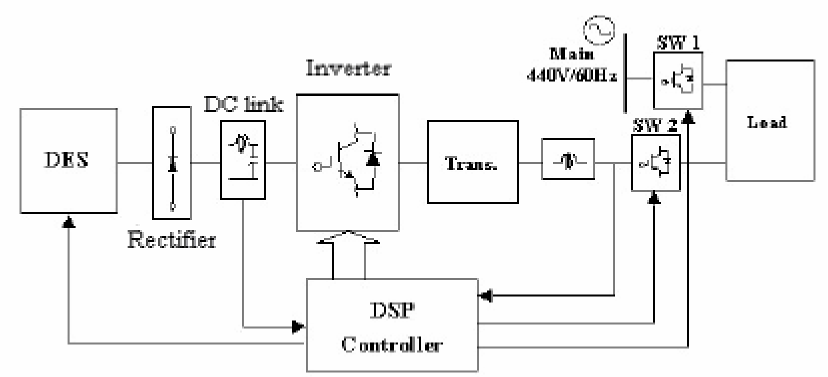

Fig. 7. DES in standby mode

B. Peak shaving mode

DES can serve as a peak shaving or interconnection with the grid to feed power back to mains which is shown in Fig. 8. In both modes, the generator is connected in parallel with the main grids.

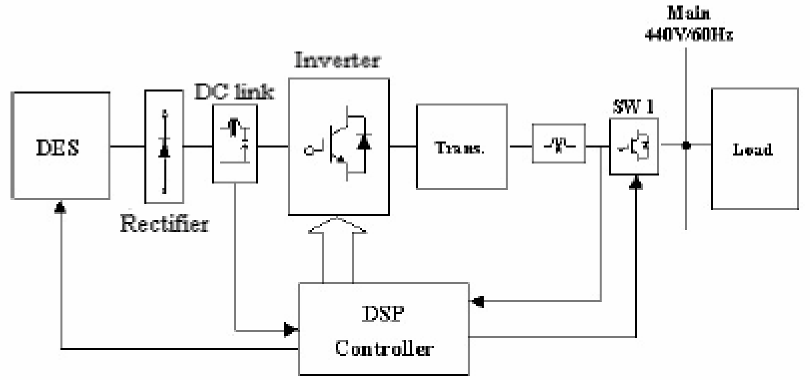

Fig. 8. DES in peak shaving mode

In a peak shaving mode, this generator is running as few as several hundred hours annually because the SW 1 is only closed during the limited periods. Meanwhile, in an interconnection with the grid, SW 1 is always closed and this system provides the grid with continuous electric power. In addition, the converter connected in parallel to the mains can serve also as a source of reactive power and higher harmonic current components.

C. Standalone mode

In a standalone DCS system shown in Fig. 9, the generator is directly connected to the load lines without being connected to the mains and it will operate independently. In this case, the operations of this system are similar to a standby mode, and it serves continuously unlike a standby mode and a peak shaving mode.

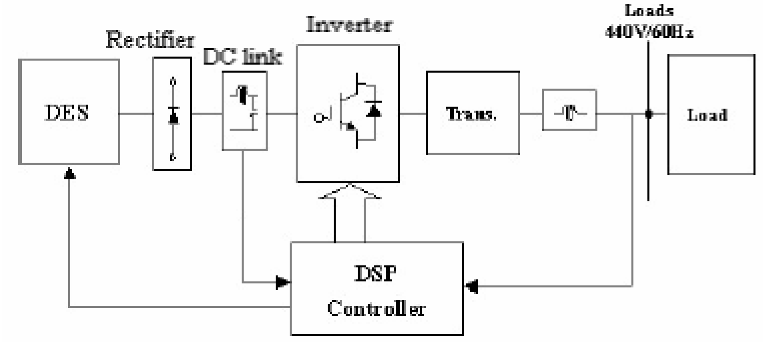

Fig. 9. DES in standalone mode

In the above modes, the digital signal processor (DSP) controller monitors multiple system variables on a real time basis and executes control routines to optimize the operation of the individual subsystems in response to measured variables. It also provides all necessary functions to sense output voltages, current, and power, to operate protections, and to give reference signals to regulators. The output power of the converter is controlled according to the reference signal of the control unit. As described above, in order to compensate for reactive power and higher harmonic components or to improve power factor, the active power and reactive power should be controlled independently.

D. Parallel operation of DES

The new configuration is proposed by Ali Keyhan, et.al [10] for various applications in Fig. 10. This figure shows a block diagram of the hybrid power system which combines several distributed energy sources into one system for a standalone mode or feeding it back to the utility mains. The hybrid power system should be developed to maximize the benefits of each power generating sources while minimizing the distinct disadvantages of each power source. Each generator consists of a generator, an input filter, an AC/AC power converter, an output filter, an isolation transformer, a control unit (DSP), two static switches (SW 1, SW 2) and output sensors (V, I, P). Each distributed generation system also is connected to utility mains and load lines by fast-acting static power switches in order to rapidly change a standalone mode or a parallel mode with mains. In case that some generators supply extra power with the mains, SW 1 is closed and SW 2 is open. In a standalone mode, SW 1 is open and SW 2 is closed. When the loads need more electric power, both SW 1 and SW 2 are closed, and during malfunctions of any generator both SW 1 and SW 2 are turned off. The characteristic of this system can be used as several modes by one system combined with several distributed energy resources. That is, some generator can be used for a standalone AC system, and another for a grid-interconnection.

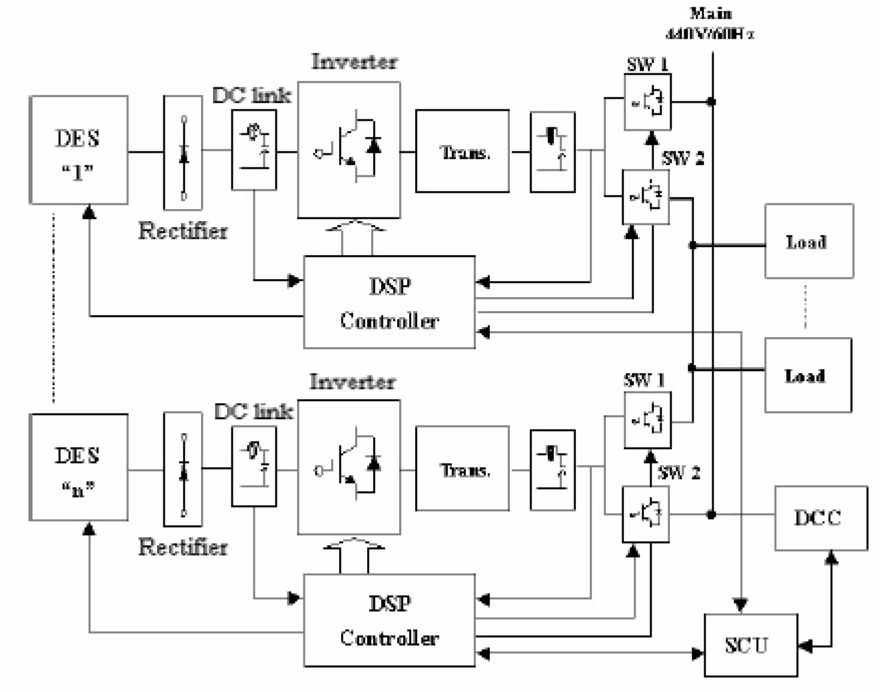

Fig. 10. Block diagram of hybrid power system

The DSP controller provides all necessary functions to sense output voltages, current, and power, to operate protections, to give reference signals to regulators, and to receive control reference signals from a Supervisory Control Unit (SCU). Moreover, SCU communicates with each DSP controller and Distributed Control Center (DCC), which is a remote central computer, via LAN/modem or radio link to allow interactive control of DES and data collection from those on a real time basis or as a pre-programmed data transfer.

IV. POWER QUALITY ISSUES CHP SYSTEMS

To bridge the frequency gap between the generator output and the requirement of the load/grid, a power electronic frequency changer should be inserted between them. Up to now, this frequency changer usually takes the form of an SCR-based cycloconverter, or a diode rectifier-PWM inverter pair. The first difficulty encountered for a PWM rectifier to be used in this scheme is that the rectifier will have to operate at a very low carrier ratio, because of the limited switching frequency of power semiconductor devices. This brings highly distorted input currents, sometimes more distorted than those generated by a diode rectifier. Application of an LCL filter can enhance harmonic filtering, but is not a good solution in this case since the switching frequency is too close to the fundamental frequency, leaving virtually no room for a good filter design [11].

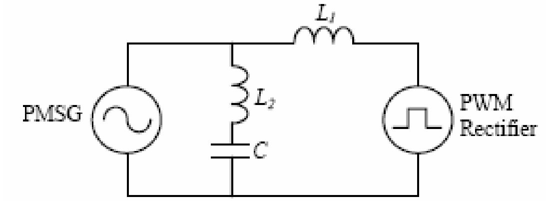

Fig. 11. Per-phase equivalent circuit of Notch filter

The author of this research paper [11] also proposed a modified SPWM scheme to eliminate the 3rd order harmonic and its multiples from the current spectrum and an LC-resonance based notch filter (shown in Fig. 11) to remove the remaining most significant harmonic component.

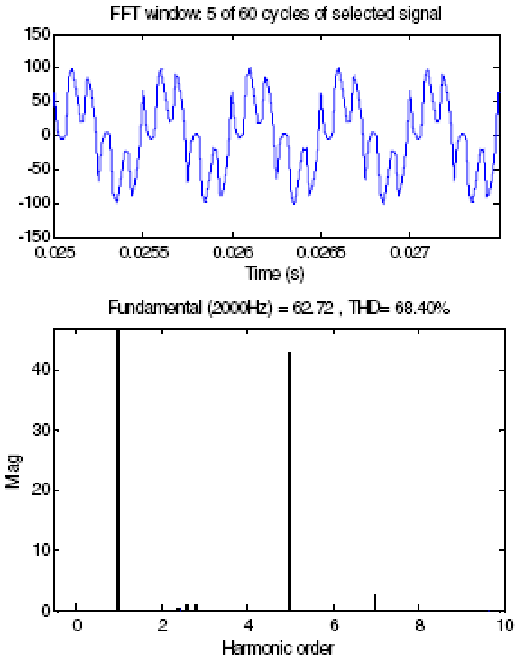

Fig. 12. Input current of the notch filter

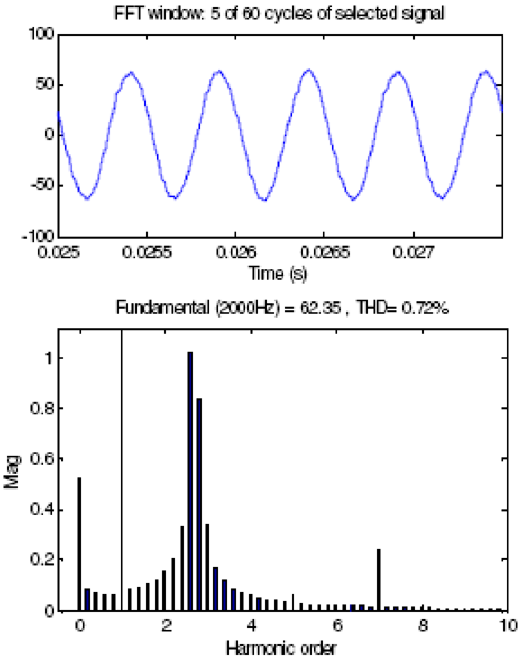

Fig. 13. Output current of the notch filter

Shown in Fig.12 and Fig.13 are the input (rectifier-side) and the output (generator-side) currents of the added notch filter, respectively. Introduction of the notch filter reduces the input impedance (seen from the rectifier side) for the 5th order harmonic; therefore the THD% on the rectifier side becomes a little higher. However, with the notch filter totally bypassing the 5th order harmonic current, the generator side current is nearly sinusoidal, with all the remaining harmonic components under 1% in amplitude with respective to the fundamental component. Besides, by comparing the fundamental currents in these two figures, it is found that the added notch filter has virtually no impact on the fundamental current flow.

V. EFFICIENCY COMPARISON OF POWER CONDITIONING SYSTEMS IN MICROTURBINE

The efficiency of two power conditioning systems for a microturbine application is studied in Ref. [6]. One PCS composes of a passive (diode) rectifier, a boost converter and an inverter. The other composes of an active (controlled solid state switches) rectifier and an inverter. The authors focused on semiconductor devices losses with the help of Saber modeling and simulation. They concluded that both PCS topologies have competitive efficiencies, while the topology with active filter has a little higher efficiency at heavy load as shown in Fig. 14.

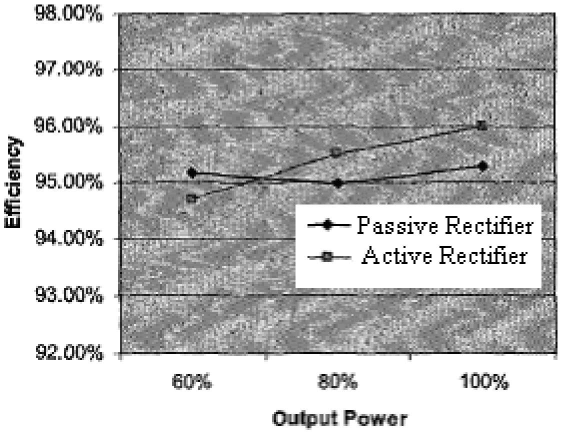

Fig. 14. Efficiency comparison between two PCS topologies

VI. CONCLUSION

Three important issues are of concern using the power electronic interface: reliability, efficiency and price. In some applications a fourth issue, volume, is also very important. For the moment the price of power semiconductor devices is decreasing 2-5% every year [12]. This paper briefed the different configuration of power converter systems in the application of CHP systems. It shortly discussed the harmonic reduction in the microturbine by using notch filter and the efficiency comparison of power condition systems with active and passive filter. Provided the internet addresses for the manufacturers of microturbine and/or power conditioning systems in Appendix [7] (Table 1).

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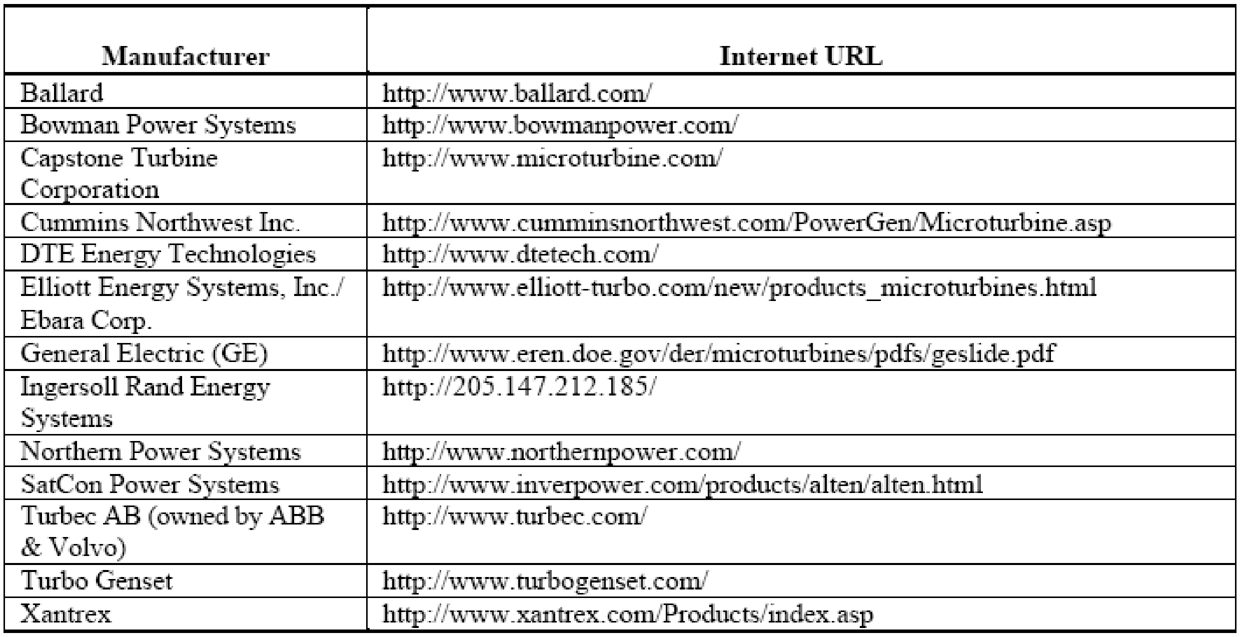
Appendix



Manufacturer	Internet URL
Ballard	http://www.ballard.com/
Bowman Power Systems	http://www.bowmanpower.com/
Capstone Turbine Corporation	http://www.microturbine.com/
Cummins Northwest Inc.	http://www.cumminsnorthwest.com/PowerGen/Microturbine.asp
DTE Energy Technologies	http://www.dtetech.com/
Elliott Energy Systems, Inc./ Ebara Corp.	http://www.elliott-turbo.com/new/products_microturbines.html
General Electric (GE)	http://www.eren.doe.gov/der/microturbines/pdfs/geslide.pdf
Ingersoll Rand Energy Systems	http://205.147.212.185/
Northern Power Systems	http://www.northernpower.com/
SatCon Power Systems	http://www.inverpower.com/products/alten/alten.html
Turbec AB (owned by ABB & Volvo)	http://www.turbec.com/
Turbo Genset	http://www.turbogenset.com/
Xantrex	http://www.xantrex.com/Products/index.asp