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Efficiency Increasing Strategies for Converters of Renewable Energy Sources

Ph. D. Thesis Booklet

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I. Introduction

Nowadays with the wide spreading of renewable energy sources the photovoltaic converters come into view increasingly. During the last decade the price of the photovoltaic modules has decreased significantly even so the renewable energy is still expensive. However, in case of higher power levels the costs of the investments can return in short time. At designing of photovoltaic converters the most critical point is the efficiency therefore during the last years several hardware and software solution were developed to increase it. During the developments we also have to take into account the strict prescription of the utility compatibility standards. To increase the efficiency of a grid connected photovoltaic converter several solutions were developed, the first group is the enhancement of maximal power point tracking methods, new main circuit arrangements and new switching loss decreasing control strategies for existing main circuits. My research work is connected to the last group. The main of my research was to develop new control strategies for existing main circuit arrangements, with which the existing power converters can transform the photovoltaic energy with higher efficiency meanwhile keeping the strict prescription of the utility compatibility standards. Additional aim was the check the efficiency of the newly developed control strategies with simulations and if possible with measurements on existing power converters.

II. Main aims of research work

In the introduction section I have mentioned that the switching loss decreasing methods can be divided into three groups. On the area of the maximal power point tracking methods many new methods are worked out so during my research I don't want to pay attention to this group in details. With new main circuit arrangements we can reach significant switching loss decrease, however, the cost of the developing and testing is quite big compared to the results. My research work is connected to the last group namely to the modulation technologies switching loss decreasing methods. The most spectacular efficiency increase can be reaching on this area, hence with the changing of the control software of the embedded processor the efficiency without extra cost can be increased. Thus, the main aim of my research was to develop new control strategies with which the traditional main circuit topology grid connected converters can work with higher efficiency keeping the strict prescriptions of the grid compatibility standards.

III. Methodological Summary

During the working-out of the theses the work was running on more threads. In first step in each thesis I have worked out and have deducted the equations or equation systems for the control. Especially in the first thesis I have got a quite complicated equation system which was solved in MATLAB environment. With the theoretical results I have made some simulation with MSIM 7.1 and with a self-made Borland C based simulation environment. After the successful simulations I have implemented the control methods on existing frequency converters and I have checked the efficiency of the control methods with measurements in real applications depending on the availability of the hardware. The measurements were done on the frequency converters of PROCON Drive System Ltd, Exendis-Deltronic Ltd and Hyundai Heavy Industry.

IV. Summary of scientific results

My research work is summarized in three theses. The main circuit topology of three phase grid connected photovoltaic converters can be divided into two groups. In the first case there is a Boost DC/DC converter between the inverter and the solar cells which fits the voltage of the solar cell to the voltage of the three phase inverter, in the opposite case the aforementioned Boost converter is not part of the photovoltaic system.

Thesis 1 is discussing the efficiency optimization of grid connected photovoltaic converters without Boost DC/DC converter using three state control (3SC). In this thesis I have worked out a new control strategy with which the grid connected photovoltaic converters with better efficiency can transform the photovoltaic energy into AC power. The controls strategy also keeps the strict prescription of the utility compatibility standards.

In Thesis 2 I have worked out a switching loss decreasing method for grid connected photovoltaic converters with internal Boost DC/DC converter. In this thesis I have developed a new control strategy which with the change of the DC link voltage (DLF) tries to decrease the switching loss of the power semiconductors of the inverter.

Thesis 3 is connected to the distributed energy generation of renewable energy sources. In this thesis I have worked out two switching loss decreasing methods (current trapezoidal control, resonant ZVS current trapezoidal control) for bidirectional galvanic isolated DC/DC converters.

During the workout of the theses I have always kept in my mind that the scientific results could be also used in industrial applications so the scientific results depending on the availability of the converters were verified with many measurements, as well. The measurements are proving that the scientific results of the theses can be also used in industrial applications and in different quality and performance parameters exceed the previous industrial solutions.

IV.1 Efficiency increasing method for three phase grid connected photovoltaic converters using three state control

[1,2,3,5,7,8,9,10,11,12]

IV.1.1 Background

In the first thesis I have worked out a new control strategy (3SC) for grid connected photovoltaic converters which with unchanged main circuit arrangement with the decreasing of the switching losses tries to increase the efficiency of the converter. The basic operation of 3SC control is introduced on a single phase double DC source inverter in which sinusoidal modulation is used. The simplified main circuit arrangement of the inverter can be seen in Figure 1, where ug is the grid voltage, ig is the grid current, Udc is the DC voltage of the solar cells and L is the inductance between the converter and the grid.

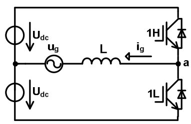

Figure 1, Simplified main circuit arrangement of single phase double DC source IGBT inverter

In case of grid connected photovoltaic converters the power factor must be greater than 0.95 and the grid current must be nearly sinusoidal (THD<5%). This also means that the waveform of the grid voltage and the grid current is almost the same and the phase angle between the voltage and the current is almost zero. In case of traditional sinusoidal modulation when the ug grid voltage is close to the positive peak than IGBT 1H is working with nearly 100% duty cycle. Around the negative peak of the grid voltage IGBT 1L have about 100% duty cycle, while at the zero crossing of the grid voltage IGBT 1H and 1L with nearly 50% duty cycle make the almost zero voltage of point „a”. Hence the phase difference between the grid voltage and the grid current is almost zero, at the zero crossing of the grid voltage the grid current – especially in case of small loads – is also small and it is cyclic changing with Tc switching period and with ΔIL current ripple around zero average (igAV) with positive and negative values (see Figure 2. upper curve). This cyclic current change is causing significant switching losses in the power semiconductors and iron losses in the filter chokes which will decrease the efficiency of the converter.

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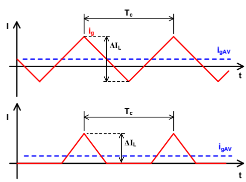

Figure 2, Current waveforms of continuous (upper) and discontinuous conduction

If we could change the cycle change at the current zero crossing so that it can change between positive and zero and negative and zero values (see Figure 2. lower curve), than the switching off losses of the power semiconductors would be lower because of the smaller current ripple the semiconductors are switched off at smaller currents. In case of discontinuous current conduction we can reach the same average current with smaller current ripple compared to continuous current conduction. With the aforementioned control strategy an additional advantage of the control will also appear, hence the smaller current ripple will also decrease the losses of the filter chokes.

I have used the 3SC control to transform the cyclic current change at the current zero crossing, which with discontinuous current mode (positive-zero and negative-zero current values) tries to reach smaller switching losses in the inverter. In case of 3SC control at the zero crossing of the grid voltage, IGBT 1H and 1L instead of 50% duty cycle will be switched in the direction of the current reference. If the current reference is positive than IGBT 1H if the current reference is negative IGBT 1L will be switched on. The solution seems very simple, however it is not at all, on one hand because of the non linear behavior on the other hand in case of three phase inverters the currents are not independent and the phase with discontinuous current conduction will affect to the other phases. Further problem arises in case of discontinuous current conduction at the current sampling which can be solved with the increasing of the performance of the embedded processor.

First I have investigated the 3SC control in case of 3P+N type grid connected photovoltaic converters where the neutral (N) wire of the grid was connected to the “middle point” of the DC link voltage. In this case the three phase inverter can be handled as three single phase converter and the 3SC control will be simpler. The simplified main circuit arrangement of the investigated converter can be seen in Figure 3, where uga, ugb és ugc are the grid voltages, Udc is the DC voltage of the solar cells, Udc1 and Udc2 are the half of the DC link voltage (it is assumed that the half voltages are controlled to be equal), N is the neutral wire of the grid and L is an inductor connected between the inverter and the grid.

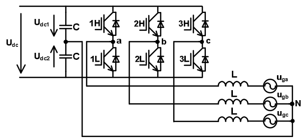

Figure 3, Simplified main circuit arrangement of three phase 3P+N type grid connected IGBT inverter

To verify the 3SC modulation in case of 3P+N type grid connected photovoltaic converters I have made some simulations in PSPICE simulation environment on a self-made 10kW nominal power three phase inverter model at 10% and at 35% of nominal load. After comparison the results of 3SC and traditional sinusoidal modulation noticed that in case of 3SC modulation the switching and above frequency currents are decreased resulting smaller losses in the filter chokes and better efficiency in the inverter. On an Exendis - Deltronic made 10kW nominal power photovoltaic converter I have checked the simulation results with measurements.

After the successful tests of 3P+N structure I have extended the 3SC control to 3P type grid connected photovoltaic converters which are widely spread in industrial applications. In first step I have investigated the operation principles of the three phase bridge IGBT inverter and after that I have determined the necessary equations and expressions for 3SC control in case of continuous and discontinuous current conduction mode. The simplified main circuit arrangement of the investigated 3P type grid connected inverter can be seen in Figure 4, where Udc is the internal DC link voltage, uga, ugb, ugc are the grid voltages, L is the inductor connected between the converter and the grid and ia, ib és ic are the grid currents.

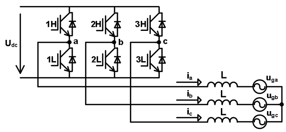

Figure 4, Main circuit arrangement of 3P type grid connected photovoltaic inverter

After the successful simulations of 3SC control on 3P structure I have investigated the control on a Hyundai Heavy Industries made 250kW nominal power photovoltaic inverter, which was able to work with 3SC modulation and with traditional Space vector modulation in d-q current control. The measurements have certified the switching loss decreasing properties of 3SC modulation. For industrial applications I have also worked out the 3SC-CMCC to decrease the distortion of the differential currents caused by the common mode current and the 3SC-RPHC to be able to inject harmonic current into te grid.

IV.1.2. Thesis 1

During my research work I have worked out a new switching loss decreasing modulation method which is named 3SC control. The fact that the switching loss of the three phase bridge topology grid connected photovoltaic converter without internal booster can be significantly decresed with 3SC modulation was verified with simulations and with measurements. The switching loss decrease is the most siginificant at low power which will result significant efficiency increase in the weighted efficiency.

I have verified with simulations that in case of three phase bridge topology grid connected photovoltaic converter with 3SC-CMCC control the distortion of the differential mode currents caused by the common mode currents can be decreased keeping the switching loss decresing property of the 3SC basic method. Furthermore, with simulations and with measurements I have verified that in case of three phase bridge topology grid connected photovoltaic converter with the 3SC-RPHC control method the switching loss decreasing property of the 3SC control automatically prevail depending on the reactive current.

IV.1.3 Experimental Results

The 3SC control and its auxiliary controls (CMCC and RPHC) are used in the photovoltaic converters of some foreign companies like Exendis and Hyundai.

IV.2 Efficiency increasing method for three phase grid connected photovoltaic converters using DC Link Floating

[4,5,6,13,14,15,16]

IV.2.1 Background

The 3SC control in my first thesis was used in case of such converters in which there were no Boost DC/DC converter between the solar cells and the three phase inverter. However most of the photovoltaic converters have internal Boost DC/DC converter, so in this thesis I will introduce a new control strategy which can be used in case of grid connected photovoltaic converters with internal Boost converter.

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The new DLF control strategy of this thesis was investigated on the following main circuit arrangement which can be seen in Figure 6.

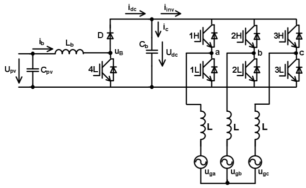

Figure 6, Main circuit arrangement for DLF control

In Figure 6 the Lb inductor the Cb capacitor the D diode and 4L IGBT are the Boost DC/DC converter, UPV is the DC voltage generated by the solar cells and CPV is the filter capacitor connected to the output of the solar cell. From point of view of currents ib is the current of the inductor of the Boost converter, idc is the current of the diode of the Boost converter, ic is the current of the Cb capacitor and iinv is the current of the inverter flowing from the DC link. IGBT 1H, 1L – 3H, 3L are the three phase bridge inverter and uga, ugb, ugc are the voltages of the ideal grid. The inverter is connected to the grid through the L inductor. The Cb capacitor because of the changing of the DC link voltage is much smaller than the usual DC link capacitor of photovoltaic converters in the same power range

The DLF control algorithm tries to reach the better efficiency with the changing of the internal DC link voltage. The DLF control depends on the Flat-top (two-phase) modulation and DLF is the extension of the two-phase modulation. In first step let's see the voltage vectors of a voltage source inverter in Figure 7. In Figure 7 with blue color the voltage vectors of the voltage source inverter, with red color the path of the maximal sinusoidal voltage vector and with dotted green line the path of the weighted blue vectors can be seen. On the dotted green line it is enough to switch only one leg of the inverter which will result smaller switching losses in the inverter. With dotted black line the path of the weighted black voltage vectors is showed. The DC link voltage of the black voltage vectors is smaller than the DC link voltage of the blue voltage vectors. The orange colored voltage vector is moving continuously on the locus of the red colored maximal sinusoidal voltage. In order to reach it we have to change continuously the DC link voltage. For example in point D the orange colored voltage vector is on the locus of the maximal sinusoidal output voltage and with the changing of the DC link voltage the amplitude of the blue voltage vectors had to be decreased to the amplitude of the black colored voltage vectors.

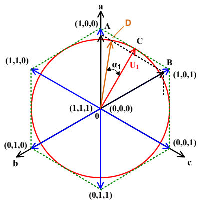

Figure 7, Voltage vectors of a voltage source inverter

Let's assume that we would like to make a voltage vector which is bounded by points A, B and 0 with the inverter. In this area the output voltage can be made with the weighting of voltage vectors A [a, b, c] = (1,0,0), B [a, b, c] = (1,0,1) and 0 [a, b, c] = (0,0,0 or 1,1,1). In case of voltage vectors, if in the name of the vector there is a "1" than it means that the upper IGBT of the inverter leg is switched on while in case of "0" the lower IGBT is switched on of the inverter leg. If the output voltage vector is on the A-B section than we can choose such switching profile in which only the IGBT-s of leg "c" are switched, hence in the other two phases with the switched-on IGBT-s we can ensure the output voltage vector. From point of view of switching losses point "C" has the best properties hence in this point only the IGBT-s of leg "c" must be switched and in phase "c" the current is also almost zero assuming unity power factor. In case of Flat-top modulation we choose the opportunity that we don't switch the IGBT when in that phase the current is maximal (hence in case of grid connected photovoltaic converters the power factor is close to one, practically this point is the same when the voltage is maximal in that phase). With this method the switching losses of the power semiconductors can be decreased. Fortunately in point C the output voltage path of the weighted voltage vectors (see dotted green line in Figure 7) - which depends on the DC link voltage - is equal to the maximal sinusoidal output voltage (see red line in Figure 7). If we could change the DC link voltage on such a way that the output voltage vector of the inverter follow the locus of the sinusoidal output voltage of the inverter, the advantages of point C from point of view of switching losses could be extended to the whole grid period which would result smaller switching losses in the inverter.

Theoretically we have to possibility to change the DC link voltage: floating with the inverter and floating with the Boost DC/DC converter.

In the first case let's assume that the Boost DC/DC converter tries to keep the solar cells in the maximal power point and the inverter is floating the DC link voltage. Hence because of the DC link floating the voltage in two phases of the inverter is the DC link voltage and in the third phase - where the IGBT is switched - the current is almost zero we cannot maintain the DC link voltage. We can draw the conclusion that with the inverter side DC link floating we cannot solve this application.

In the seconds case in contrast with the traditional control, where the Booster tries to keep the solar cell in the maximal power point and the inverter keep the constant DC voltage, we try to change the internal DC link voltage with the Boost DC/DC converter. There is other change in the control compared to the traditional control. In case of DLF modulation the Boost DC/DC converter regulates the inverter current in that phases where the current is high with the DC link voltage and the current of the third phase is controlled by the inverter. If DLF modulation is used than because of the DC link voltage change the stored energy in CB will also change which will be energized from the stored energy of CPV capacitor. Therefore we have to design the input filter of the Boost DC/DC converter on such a way that the low frequency voltage change of the capacitor would not be able to remove the solar cell from its maximal power point. In case of DLF modulation the internal DC link voltage, the Booster inductor current and the input current of the Boost DC/DC converter will have a 300Hz component which can be used for MPPT if our MPP sensors have good dynamic.

To verify the efficiency of the DLF modulation I have made some simulation in Borland C simulation environment on a 10kW inverter model with 16.5kHz switching frequency with 3% (1mH) grid inductor at nominal current in case of $\alpha 1 = 0°$, 20° and 30° floating angles. The simulations were successful and the DLF modulation is working properly in the 0°- 30° floating angle range with which we could reach 80% switching loss decrease compared to the space vector modulation.

IV.2.2 Thesis 2

During my research work I have worked out a new switching loss decresing method which is named DLF control. The fact that the switching loss of the three phase bridge topology grid connected photovoltaic inverter without internal booster can be significantly decreased with DLF control was verified with simulations. The decrease of switching loss can be changed with the duration of the floating. With the decreasing of the duration of the floating at borderline the DLF control is the same as the Flat-top modulation.

IV.2.3 Experimental Results

The DLF control is not ready to industrial applications yet, the control of the Boost DC/DC converter must be worked out which is not part of this thesis.

IV.3 Efficiency increasing method for bidirectional galvanic isolated DC/DC converter

[6,7,8]

IV.3.1 Background

Nowadays the distributed energy generation systems became increasingly more popular and are spreading widely on such areas where the centralized energy generation is not possible. Typical distributed energy generation applications are the energy systems of ranches and ships. The third thesis is dealing with this topic and it is connected to a European Green Yacht project. In the project the distributed energy generation of a 60m long sailing yacht (green yacht) had to be solved with Diesel-hybrid energy generation. The simplified main circuit schematic of the sailing yacht can be seen in Figure 8.

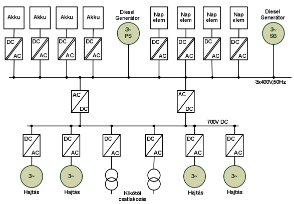

Figure 8, Main circuit diagram of the Green Yacht

The main parts of the energy generation system are: two Diesel generator – Sync generator compound, four independent battery pack with DC/AC converters and a photovoltaic inverter system. The sub systems are connected to a common 3x400V, 50Hz AC bus. The motion of the ship can be down with high power electrical or diesel drives. All electrical drives are able to operate in reverse power mode, as well. The shore power connections of the ship are also connected to the 700V DC bus.

The operational principle of the distributed energy generator system is the following: the power demand of the system is supported from the photovoltaic inverter system and with the power difference the batteries are continuously charged. Until it is possible the power demand of the power consumers are done from the batteries. If the stored energy of the batteries and the power of the photovoltaic system in not enough to keep the grid stable than the Diesel system will be also started. If there is no wind than the drive system of the ship can be operated from the Diesel generators and in green mode directly from the batteries. Additional benefit of the system is that in sailing mode due the bidirectional power converters the batteries of the ship can be charged using the kinetic energy of the ship. To prevent the presence of DC voltage of the solar cell or the battery on the AC grid due the damage of a power semiconductor the photovoltaic system must be galvanic isolated from the AC grid. The galvanic isolation can be done with grid frequency transformer or with a medium frequency transformer and a switched mode DC/DC converter. At the planning of the entire system very important issues were the modularity, the size and the weight of the entire system, so instead of the big size and big weight grid frequency transformer we decided that the medium frequency galvanic isolation will be used.

In the third thesis I have worked out a new control strategy with which the control of the galvanic isolated bidirectional switched mode DC/DC power converter can be done with optimal efficiency. In order to achieve the best possible efficiency I have chosen a resonant switched mode power supply topology and to reduce the size and the weight of the transformer I have also used current trapezoidal control at medium switching frequency.
The investigated main circuit arrangement of current trapezoidal control can be seen in Figure 9.

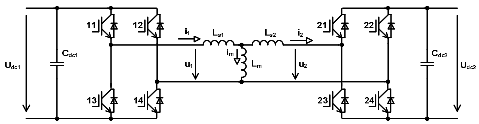

Figure 9, Main circuit arrangement of bidirectional galvanic isolated DC/DC converter

In Figure 9 IGBT 11-14 are the bridge inverter of the first side while IGBT 21-24 are the bridge inverter of the second side. The Cdc1 and Cdc2 capacitors or so high that their voltages are nearly constant in one switching period. Between the two inverters there is a 1:1 voltage ratio transformer which is represented by the Ls1 and Ls2 leakage inductances and the Lm magnetizing inductance. The current trapezoidal and the resonant current trapezoidal efficiency increasing control is also working with other voltage ratio transformers, however, for simplicity all control is worked out with 1:1 voltage ratio transformer. Without current trapezoidal control if the power is flowing from the first side to the second side of the converter than on the first side the transformer is driven by IGBT 11-14 from Udc1 voltage and on the second side the body diodes of IGBT 21-24 are rectifying the voltage of the transformer creating the Udc2 secondary side DC voltage. If the direction of the power flow is reversed than the transformer will be driven from the secondary side and the first side will rectify the transformer voltage.

If current trapezoidal control is not used than the current of the transformer will be nearly triangle waveform because of the relatively big magnetizing inductance of the transformer the peak of the im magnetizing current is much smaller than the current of the leakage inductance at nominal power. At the selection of the IGBT the peak value of i1 current and at the planning of the transformer the RMS value of the transformer current must be taken into account. During my research work I have worked out a new control strategy in which with the control of the load side IGBT the triangle waveform current of the transformer could be transformed to nearly square (trapezoid) waveform resulting smaller peak current in the semiconductors and smaller RMS current on the transformer. With the smaller transformer RMS current we could reach smaller and lighter transformer.

To verify the efficiency of the current trapezoidal control method I have made some simulations on a 60kW nominal power DC/DC converter model in PSPICE simulation environment.

The switching losses of the inverter can be decreased with connecting snubber capacitors (C11-14, C21-24) parallel to the IGBT resulting a zero voltage switch resonant converter while keeping the current trapezoidal control to reduce the size of the transformer The main circuit arrangement of the ZVS bridge inverter can be seen in Figure 10. In case of resonant ZVS main circuit the current trapezoidal control got more complicated.

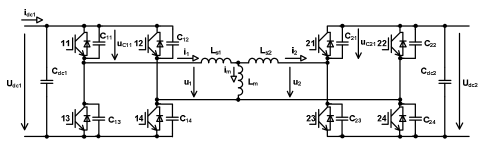

Figure 10, Main circuit arrangement of bidirectional galvanic isolated ZVS resonant DC/DC converter

During the research work of this thesis first I have investigated the basic working principles of the ZVS main circuit (see Figure 10) depending on the output load of the converter. To verify the theoretical principles and the resonant current trapezoidal control I have made some simulations on a 60kW nominal power converter model in PSPICE simulation environment. The main parameters of the resonant current trapezoidal control simulation were the followings: transformer leakage inductance Ls1=Ls2=95μH and snubber capacitors parallel to the IGBT C11=240nF. The simulations were than at nominal, at half nominal and at 1kW load. The simulations proved that the ZVS resonant current trapezoidal control is working properly in the whole load range and the switching losses of the inverter were also decreased.

IV.3.2 Thesis 3

During my research work I have worked out two new modulation strategies which are named current trapezoid and ZVS resonant current trapezoid control. The fact that the effective current of the transformer and the peak current of the semiconductors can be decreased significantly with current trapezoidal control in case of galvanic isolated bidirectional DC/DC converter was verified with simulation results and measurements. This will also result smaller transformer weight. The switching losses can be further decreased if with auxiliary snubber capacitors the DC/DC converter is transformed to resonant converter and the ZVS resonant current trapezoidal control is used.

IV.3.3 Experimental Results

The current trapezoidal control is already used in the 60kW nominal power bidirectional galvanic isolated ESI (Energy Storage Inverter) and SPCIIHy (Shore Power Converter Hybrid) converters of EXENDIS B.V. The resonant current trapezoidal control will be used in the ESI and SPCIIHy converter soon.

V. Own Publications connected to the research

This section contains the own publication list connected to the scientific results of the theses.

Journals:

[1] **Balogh Attila**, Varjasi István: Fotovillamos konverterek irányítása, Elektrotechnika 2006/6. pp:24-26.

[2] **Balogh Attila**, Varjasi István: Hatásfoknövelő irányítás hálózatra kapcsolt fotovillamos konverterekhez, Elektrotechnika 2008/5. pp:16-19.

[3] **Attila Balogh,** Eszter Varga, István Varjasi: 3 State Current Mode of a Grid Connected PV Converter, In International Journal of Electrical Power and Energy Systems Engineering Volume 1, Winter 2008. pp. 24-30. Paper 30040.

[4] **Attila Balogh,** Eszter Varga, István Varjasi: DC Link Floating for Grid Connected PV Converters, In International Journal of Electrical Power and Energy Systems Engineering Volume 1, Winter 2008. pp. 31-37. Paper 30287.

[5] **Attila Balogh**, István Varjasi: Discontinuous Current Mode of a Grid Connected PV Converter, Periodica Polytechnica, Budapest 2009. pp:1-9.

[6] **Attila Balogh**, István Varjasi: DLF Control for High Efficiency Grid Connected PV Converters, Periodica Polytechnica, Budapest 2009. pp:10-19.

Conference Proceedings:

[7] **Attila Balogh**, Zoltan Tamás Bilau, István Varjasi: New Control Method for High Efficiency Grid Connected PV Converters, In Proc. of International Workshop – Control and Information Technology (IWCIT 2007), Ostrava, Czech Republic, 2007. pp:173-177.

[8] **Attila Balogh**: 3 State Control of a Grid Connected PV Converter, In Proc. of Automation and Applied Computer Science Workshop (AACS 2007), Budapest, Hungary, 2007. pp:37-49.

[9] **Attila Balogh**, Zoltan Tamás Bilau, István Varjasi: High Efficiency Control of a Grid Connected PV Converter, In Proc. of Power and Energy Systems Conference (EuroPES 2007), Palma de Mallorca, Spain, 2007. pp:257-263.

[10] **Attila Balogh**, István Varjasi: Discontinuous Current Mode of a Grid Connected PV Converter, In Proc. of International Youth Conference on Energetics (IYCE 2007), Budapest, Hungary, 2007. pp:100-106.

[11] **Attila Balogh**, Eszter Varga, István Varjasi: 3SC for Grid Connected Converters, In Proc. of Power and Energy Systems Conference (EuroPES 2008), Corfu, Greece, 2008. pp:210-216.

[12] **Attila Balogh**, Eszter Varga, István Varjasi: 3 State Current Mode of a Grid Connected PV Converter, In Proc. Of International Conference on Electrical Power and Energy Systems (EPES2008), Paris, France, 2008. pp:131-137.

[13] **Attila Balogh**, Eszter Varga, István Varjasi: DC Link Floating for Grid Connected PV Converters, In Proc. Of International Conference on Electrical Power and Energy Systems (EPES2008), Paris, France, 2008. pp:123-131.

[14] **Attila Balogh**: DLF Control for Grid Connected PV Converters, In Proc. of Automation and Applied Computer Science Workshop (AACS2008), Budapest 2008. pp:67-79.

[15] **Attila Balogh**, István Varjasi: DC Link Floating for High Efficiency Grid Connected Photovoltaic Converters, European Control Conference, Budapest, Hungary, 2009. pp:1-7.

[16] **Attila Balogh**: DLF Control for High Efficiency Grid Connected Converters, In Proc. of Automation and Applied Computer Science Workshop (AACS 2009) Budapest, 2009. pp: 1-12.