Alexander ABRAMOVITZ[1], Volodymyr YASKIV[2] , Keyue SMEDLEY[3]

Sami Shamoon College of Engineering (1), Ternopil Ivan Puluj National Technical University (2), University of California (3)

Power factor correction as the right step towards a safer environment

***Abstract**. Generation and transfer of electrical energy can severly degrade the environment. Tthe necessity of joint research in the field of high-frequency power converters with power factor correction to protect the environment from the electromagnetic pollution was discussed. Current state of law and research in several countries was presented. Pasive and active correctors and the idea of new topology for power factor correction wer described.*

***Streszczenie.** Działalność człowieka na polu wytwarzania energii elektrycznej powoduje znaczącą degradację środowiska naturalnego. Główny przedmiot zainteresowania przedstawiony w artykule dotyczy analizy wpływu współczynnika mocy na efektywność transferu energii elektrycznej od wytwórcy do końcowego odbiorcy. Przedstawiono stan prac legislacyjnych oraz badawczych w różnych krajach ze szczególnym uwzględnieniem Ukrainy. Opisano dwa typy korektorów, pasywny i aktywny oraz główne założenia dotyczące nowej, projektowanej topologii korektorów współczynnika mocy. (**Korekcja współczynnika mocy jako właściwy krok w kierunku bezpieczniejszego środowiska**).*

Keywords: Power Converter, Power Factor Correction , High-Frequency Magnetic Amplifier, One-Cycle Control.
Słowa kluczowe: przetworniki energii, korekcha współczynnika mocy, wzmacniacz magnetyczny.

Introduction and background

Today it is widely recognized that human activities make a strong environmental impact. Safe existence and well being of mankind and other life on our planet depend on quality, reliability and efficiency of our power systems. Pollution of coal and nuclear power generation plants is a major threat to the environment. Along with improving the efficiency of power generation and distribution systems the power consumption practices should be improved as well. Consumers are an essential part of any power system and play a major role in the game. Proper use of power and energy is consumers' liability.

Electronic systems are the fastest growing electrical energy consumer market. IT and Telecom systems are found everywhere in military installations, industrial plants, office environment and every household. Most of electronic systems relay on the utility for power. Though the power consumption of a single electronic appliance is quite low, the accumulative effect of electronic appliances makes a profound impact on the grid. It is estimated that about half of power generated in US is processed by some kind of electronic system. As a matter of fact, simple rectifier stages of the old generation electronic power supplies, industrial phase controlled rectifiers and even the fluorescent lighting are main contributors to the harmonic pollution of the utility. Harmonic currents injected into the utility cause high frequency interference problems, increased conduction losses and increase transformer core losses. Harmonics may also cause resonance and increased failure rate of capacitors due to isolation breakdown. These factors decrease the reliability and efficiency of power distribution system.

An extreme case of power quality failure is the notorious New York outage of 2003 when a major power outage struck simultaneously across dozens of cities in the eastern United States and Canada costing millions in damages. However, less damaging power quality disturbances may appear daily. Some of more common utility disturbance types of are the sags, swells, surges and interruptions. In our age, electrical and electronic equipment and especially IT and Telecom systems play an ever-growing role in governing of our society. Once a utility disturbance causes a mis-operation of the IT equipment, our society relies on in our daily lives, it can take a heavy toll on our personal as well as our business life. In extreme cases power quality failure can disrupt the civil order causing severe damages.

Power Factor (PF) is a measure of how efficiently electrical power is consumed. While the ideal PF is unity, in reality power factor of highly inductive or nonlinear loads is about 0.7 or even less. For these reasons, recent regulations in US and EU have made Power Factor Correctors (PFC) a mandatory utility interface stage of next generation power supplies. The task of an ideal PFC is to draw pure sinusoidal line current in phase with the line voltage as well as automatically regulate and protect the output. An ideal PFC system should operate with a unity power factor drawing no harmonic line current. As a result, the power generation plants and distribution systems can operate with lower rms currents, higher efficiency and, therefore, with fewer emissions and lower pollution footprint. Furthermore, a power supply with the PFC interface can tolerate and ride through sags, swells and surges and provide reliable power to operate the IT and Telecom equipment. PFC is also expected to provide protection functions as well as some hold-up time sufficient for systems' emergency data save and shut down during line voltage interruptions.

Hence, low power quality practices have a destabilizing environmental and economical effects whereas, high quality/low harmonic power consumption is beneficial to the environment and secure wellbeing of our society. To combat the issues of power quality, the industry requires new technological solutions. Scientists and researchers around the world are engaged in research of new theoretical approaches to PFC problem. Existing high quality power supplies attain their characteristics by rather complicated schemes. These are high-tech feedback systems which are costly to build. And, due to the sheer numbers of IT or Telecom consumers, power quality comes at a considerable cost. Commercial industries are striving to be competitive and thus are eager for better products. Hence, more research effort is required to develop simple, cheaper and reliable technological solutions which can provide good performance at affordable cost.

State of the art of the topic

a) Current State of the Technology

According to the operating principles PFC's can be classified as passive or active [1, 2].

Passive PFC relay on heavy filtering of the input current. The main advantage is that there is no pre-regulator stage. Such an approach can provide reasonably good quality current, very low EMI and also good reliability.

However, the passive elements of the filter are oversized and excessively bulky.

Active PFCs are designed around high frequency converters. Good quality of the input current is obtained by a pre-regulator stage, whereas, the second stage provides tight output voltage regulation. The two-stage schemes offer several advantages: sinusoidal line current and compliance with IEEE regulations; good performance under widely varying universal line voltage; isolation can be provided by the output stage; hold-up time can be provided by a proper choice of the first stage capacitor; easier design of the second stage. The main disadvantages of the two stage PFCs are: cascade connected scheme lowers the overall efficiency; overall increased size, weight and cost.

According to the shape of the input current Active PFC's may be further classified in two major groups: PFC with sinusoidal current and PFC with a near-sinusoidal input current.

Actually, IEEE regulations does not require an absolute zero harmonic content and unity power factor as these objectives would be very difficult to achieve. To be practical, both IEEE 519 and IEC 1000-3-2, permit a certain amount of distortion in the line current. Accordingly, several simple schemes of one stage PFC with reduced component count and a single control loop were proposed in literature. Mainly for low power range applications.

Some other PFCs with the near-sinusoidal current operate in the discontinuous conduction mode (DCM). As in DCM some converter topologies draw input current which shape crudely follows the line voltage. The practical meaning of this is that the input current may not be actively controlled and only a single voltage control loop is required. However, the near sinusoidal line current translates as some amount of distortion. This type of PFC is also limited by regulations to low power level. Moreover, due to relatively high input current ripple the EMI filter size, cost and weight are relatively large.

PFCs with active current shaping can achieve much better quality of the input current. This means lower distortion. These PFCs are generally designed using Boost converter in the continuous conduction mode. Boost power stage is perhaps the most popular converter used in a single phase PFCs due to its simplicity, low part count and inherent ability to generate a sinusoidal input current. However, when operated from the line voltage, the Boost converter generates high output voltage with significant output ripple. The high output voltage increases the switching losses of the semiconductor devices and penalizes the efficiency especially in low power applications. Snubbers can be used to improve the efficiency but also increase the circuits' complexity. Additional disadvantage of the Boost converter is the lack of isolation and inability to provide multiple outputs. These features make the Boost converter incompatible with the needs of IT and Telecom systems. As mentioned, the standard practice is to overcome these deficiencies is by introduction of an additional downstream converter/s. The resulting cascade connection of several power stages reduces the overall power supply efficiency whereas, the cost, weight, volume and heat dissipation are increased.

Clearly, the existent practices have to be improved and the quest for better technological solutions continues.

b) Current Status of Environmental Awareness and Research Activities in Participating Countries

US being the home for many world top universities take the leading role in research and development in the area of advanced power electronics and PFC. In general US public has a high sense of environmental awareness. Consequently, stringent power quality regulations were introduced in US and EU. US and EU industries comply with the regulations on power quality and cooperate to introduce the newest PFC systems available. One of the more advanced research centers on power factor correction systems is University of California, Irvine, Power Electronics Laboratory (UCIPEL). UCIPEL is a world leading center with years of industry oriented research experience and dozens of scientific publications in the area of AC-DC conversion.

Perhaps due to the communist legacy and social turbulence of post communism era Ukraine has low environmental awareness. Ukrainian legislators still see the environmental issues as matters of low priority and little attention is given to the power quality problems. Ukrainian industries are striving for survival and lack the will and the capital to invest in power quality. Regretfully, at present, Ukraine has no power quality regulations. However, as a future forecast, Ukraine industry will have no other choice but to renovate and join the world trend. Realizing the future trend, Power Electronic Laboratory of Ternopil State Ivan Pul'uj Technical University is joining PFC research to establish this new research field in Ukraine. TSIPTU has an extensive expirience with magamp circuits [3-6] which are an interesting alternative technology for PFC applications.

Israeli high learning institutions follow the power quality trend dictated by the US and EU. Power electronics research groups in major Israeli research universities are actively engaged in PFC research [7-10]. Israeli industry also endorsed the IEEE power quality regulations and is catching up on their implementation. Power Electronic Laboratory of Sami Shamoon College of Engineering has over a decade of experience in research and development of high power factor interface circuits.

Justificationof the project

It has been long recognized that power generation system is a key component of national security of any country. Power quality and proper power consumption also deserve to be recognized as factors of national security. Power quality directly affects the stability and reliability of power generation and distribution systems on which ordinary citizens, business and government of our society depends on in daily life. Power quality has an effect on amount of polluting emissions from power plants and, as a result, affects the environment, public health, and quality of life. Hence, issues of power quality have a far reaching economical and social influence. Technologies that increase power quality and reliability, contribute to safer environment, better public health, better public productivity and economical development. Secure economical wellbeing insures civil rest, political stability and help promoting world peace.

Organization of the project and implementation of the results

The joint research venture launches a study of a single stage PFC topology which can provide high quality utility interface, multiple isolated outputs and large voltage step-down as usually required by IT and Telecom systems. With an appropriate control scheme, the proposed converter can achieve both a sinusoidal input current and a constant regulated output voltage suitable for powering modern electronic systems.

The objectives of the proposed research are to form an international research team to promote the power quality and energy efficiency issues and to extend the existing knowledge on PFC systems. The aim of the joint research is to develop a simple, reliable, and cost effective power converter for IT and Telecom systems and to implement a viable prototype to be put into practice by commercial industries. The joint venture will also set the stage for international cooperation and provide training to international researchers via joint research activities and offer a wide public report of the technological advances.

This project is aimed to provide cheaper, economically viable solution to increase the power quality and, thus, reliability of IT and Telecom systems. The project is intended to design of a state of the art power converter with high quality input and output characteristics; prototyping of the proposed converter; testing and experimental verification of the proposed approach.

The innovation offered by this project is the incorporation of a utility interface stage and the output regulator stage into a single power stage. The new technological principle allows attaining several important features, usually provided by two cascade stages, by a single stage. In comparison with traditional technologies, the proposed converter possesses several advantages: high quality input characteristics with low harmonic content; universal line voltage input; multiple regulated output voltages compatible with the power demands of the IT and Telecom systems; high overall efficiency of the proposed converter is expected; robust power stage and control circuitry; circuit simplicity and overall reduced cost of power supply; low manufacture cost can facilitate wider use of high quality utility interface systems.

The PFC control circuits are implemented by a One Cycle Controller (OCC) [11-14]. OCC objectives are to draw the sinusoidal current from the source and keep the PFC output voltage at the predetermined DC level. The control circuit is comprised of an integrator with reset, a clock, two comparators, and two flip/flops along with a few linear and logical components to form current selection circuit, region selection circuit, and drive signal distributor. No multipliers, DSP, or software is necessary, resulting in a simple and reliable solution.

Compared to other control methods, the OCC-based current compensator is a very simple circuit. OCC is capable of obtaining fast dynamic response because the inner current control loop is embedded in the PWM modulator, which has a dynamic response at the speed of switching cycles. Consequently, the operation at wide line frequency range 0–2 kHz is achievable with low total harmonic distortion in the line current.

University of California, Irvine, Power Electronics Laboratory (UCIPEL) will provide project management, technical advisory, training, research facility and testing equipment for the project. UCIPEL will also provide education and research training of researchers from Israel and Ukraine. In addition, UCIPEL will also be responsable of prototyping and testing of the converter. Ukraine, Ternopil State Ivan Pul'uj Technical University, will perform design and implementation of the magnetic amplifier regulator part, construction of the experimental prototype and conduct the prototype testing. Israel, Sami Shamoon Colege, will perform comprehensive theoretical and simulation study of the proposed topology; design of the Power Factor Corrector stage and Control circuitry and assist in the experimental testing of the prototype converter.

UCIPEL has an extensive record of products been licensed and commercialized by industries. UCIPEL will take action to make sure that the final implementation of the research result passes many rigid industrial standards such as IEC, FCC, UL tests. With the required certifications obtained the research product can be easily adopted by commercial partners.

The investigators team will present the research results and detailed report of the prototype performance to the scientific community and to the industry by joint publication in a scientific journal and presentation at international conferences.

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***Authors**: Dr. Alexander Abramovitz, Assisting Professor, Department of Electrical and Electronics Engineering, Sami Shamoon College of Engineering, Beer-Sheva, Israel. Presently he is a visiting Researcher to the Department of Electrical and Computer Engineering University of California, Irvine, USA, alabr@hotmail.com; Dr. Volodymyr Yaskiv, Head of the Departement of Radiotechnical systems, Ternopil Ivan Puluj National Technical University, Ruska Street, 56, 46001, Ternopil, Ukraine, yaskiv@yahoo.com; Prof. Keyue Ma Smedley, Ph.D., IEEE Fellow Professor, Department of Electrical and Computer Engineering University of California, Irvine, CA 92697-2625, USA, smedley@uci.edu*