HIGH PERFORMANCE LOW COST POWER CONVERSION AND CONTROL USING SMART POWER ELECTRONIC CIRCUITS

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ABSTRACT

A high parts count in power conversion and control systems utilizing discrete components and a mix of discrete circuits controlled by microprocessors and ASICs precludes realization of the highest system reliability due to high failure rate, and the highest efficiency due to various loss mechanisms. In addition, cost, weight and volume are also not optimal due to large number of discrete devices, and sometimes due to control and protection implementation schemes. Fortunately, new technologies are on the horizon that offer dramatic improvements in reliability, cost and performance of power conditioners. Such new technologies are: Smart Power (SP) and Power Integrated Circuits (PICs). Whereas power switching, control, protection and sensing functions are all integrated into one package in the case of Smart Power Circuits, Power Integrated Circuits have monolithic structure that is capable of performing power switching and control functions. With increasing voltage and current ratings and high volume production of such circuits, these technologies are the wave of the future in providing high performance low cost power conversion and control in small to large power applications.

This paper discusses circuit topologies that are suitable for various industrial applications such as electrical appliances, instrumentation, AC motor drives, battery chargers, automobiles, telecommunications, UPS, switch mode power supplies and photovoltaic power systems. It examines the cost of high volume production and current technological barriers associated with the development of these technologies. Some U.S. government and international programs currently in place are presented. Currently available funding opportunities are included. Government-industry partnership activities required to promote this technology and extend it to include applications in increasingly larger systems are discussed. Currently available hardware, their ratings and manufacturers are presented. Market projections of hardware sales are analyzed. As an example of current research and development activities, U.S. Department of Energy efforts to promote the application of this technology in photovoltaic power conditioning subsystems (PCSs) are discussed. Some development activities in industry are also presented.

It is concluded that as Smart Power technology matures, and available hardware ratings increase, the application market of these technologies will expand as a result of increasing synergism between application sectors, and decreasing production costs. In the meantime, efforts to eliminate technological barriers and to accelerate applications must continue with the help of government programs, industry investments and information dissemination.

Introduction

A combination of high voltage and high frequency in smart power designs permits the use of digital control such as PWM control, resulting in high efficiency designs with efficiency up to 95 percent and in substantial reductions in volume and weight. In many applications where there is a need of a dedicated low-voltage power supply for control purposes this requirement may be eliminated in a smart power implementation. This may significantly reduce the total power system weight, volume and cost (1 ,2,3).

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Smart power implementation enhances the reliability of power system because of dramatic reduction in the number of separate parts along with associated reduction in failure rate. Reduced number of interconnections also enhances the reliability. Silicon requirement is greater in PIC implementation than that required in implementation using control chips and power conversion using discrete devices. However, this additional silicon provides the isolation between the two circuits.

In addition, with smaller size, no external parts, higher frequency, better feedback and lower production cost, the PIC implementation becomes more compact and attractive. With increasing voltage, the die size is larger. For low voltage applications, smart power implementation is cheaper. Potential for increased reliability and efficiency for PCS designs using Smart Power and Power Integrated Circuits makes these technologies specially suitable for large scale commercialization.

Currently Available Hardware

This paper presents several tables showing currently available hardware with voltage, current and power ratings. It presents circuit topologies and manufacturers. It also discusses ASICs, Power Poles and Hybrid Circuits under development at Jet Propulsion Laboratory (JPL), California Institute of Technology. It lists applications associated with each circuit.

Market Opportunities

As smart power technology matures and its ratings increase, the market of its applications will expand. Presently, smart power technology finds applications in electrical appliances, instrumentation, brushless DC motors, stepper motors, flat panel displays, automatic tests equipment, avionics, printers, security systems, automobiles and telecommunications. However, terrestrial, space, military and aircraft power systems will find increasing use of this technology as it matures and its voltage and current ratings increase. This expanding market will quickly include photovoltaic systems, battery chargers, AC motor drives, robots, UPS and inverters. Generally, the selling price/kW for various electronic products decreases with their increasing kW rating. In addition, the cost is generally lower with higher production volume. In the case of PCS hardware, it is found that the decreasing price has steeper slope for scale than for production quantity. That is, larger module sizes have lower costs per watt for the same production volume.

Growth of smart power technology with application potential in various industrial sectors such as military and aerospace, automotive, telecommunication, electronic data processing, and industrial power and speed control is demonstrated.

SP/PIC Integration

Smart power development in the U.S.A. and in other countries, today, are diverse and target the lucrative automotive and motor control industries. Many of the smart power devices being developed for these industries could be applied to PCSS for other applications as well. The full impact of using this promising technology on PCS systems is not fully known at this time, but assessment of the impacts of using smart power in the PCS for the PV system is being studied by JPL and Sandia National Laboratory (SNL), under DOE contract.

Steps involved in the implementation of smart power technology include: selection of switching devices, analog and digital signal processing, signal isolation, current and temperature sensing, and obtaining chip size magnetics and capacitances. Monolithic IC circuitry incorporating power switches and hybrid packaging would improve the ruggedness of PCS hardware in the future.

The applications of smart power technology in such PCS hardware could also provide more cost-effective, utility-interactive PV systems and help expand the PV utility-interactive market, world-wide.

Technology Barriers and Thrusts

Providing adequate isolation between high-voltage devices and low-voltage circuits will continue to be a developmental effort. Developing devices and fabrication process that will deliver high-voltage, high-current PICS at reasonable cost will be essential to accelerate and enable widespread use of smart power. Operating at high frequency presents EMI problems and the use of common techniques to control effects of radiation would have to be implemented as high-voltage, high-current devices are developed. An overall optimization including the effects of high temperature, EMI, cost and efficiency will have to be addressed (1 ,2,4).

In order to achieve higher efficiency for high-voltage high current devices, on-state losses have to be reduced. Therefore, improved device designs and fabrication processes have to be developed that will yield lower on-resistance and reduce chip size, New technologies that will reduce barriers related to performance, size, ratings, isolation, etc., will continually have to be evaluated and used to fully commercialize this technology in various applications.

Government and Government-Industry Partnership Programs

There is a great deal of activity in Smart Power development in the United States and European countries. These activities are diverse and include the automotive and motor control industries. Many of these Smart Power activities are applicable to the requirements of PV power conditioners. The full impacts of these developments on PV and other systems are unknown at this time and as a result a survey and assessment of the impacts of Smart Power on the PV and other systems is timely.

A workshop on Smart Power was held at the California Institute of Tethnology (CALTECH) on May 20, 1987. The idea of organizing a workshop on Smart Power technology and applications stemmed from the realization that the full potential of this technology cannot be realized without understanding the technology and its strengths and weaknesses. It was also realized that, although this technology has an established advantage in automotive, telecommunications, and appliance systems, its superior applicability in other power systems was not fully understood in terms of reliability, costs, volume, and efficiency. The workshop concluded that no technical barrier existed to prevent the application of Smart Power concepts to PV. These solutions could greatly impact the current problems of reliability that constrain PV systems operations. The second workshop was held on December 8-9, 1993 at CALTECH with sponsorships of DOE-PV, SNL, National Renewable Energy Laboratory (NREL), Interagency Advanced Power Group (IAPG), Electric Power Research Institute (EPRI), Power Electronics Applications Center (PEAC), JPL, and CALTECH.

A PCS effort that is tailor-made for smart power technology in PV applications is one using an integrated, nearly monolithic, PCS to further the concept of an “ac PV module”. The “ac PV module” idea is being supported by funding from the Environmental Protection Agency (EPA), SBIR, and SNL. The “ac PV module” concept was discussed within the DOE PV program as early as 1975, but the necessary electronics was not of-age at that time. Any “ac PC module” would facilitate expansion of installed PV systems and add new dimensions. The idea here is to use a hybridized PCS integrated with smart power module on the panel itself for AC or DC output.

The source of present-day DOE funding opportunities includes the Small Business Innovative Research (SBIR) program. Modular power processing hardware for PV applications is an objective of this effort, There is a need for modular and manufacturable PCS hardware that is a multipurpose electronic converter with code-certifiable solid state ac and dc interfaces and control circuits (5).

Other than development of more compact, large (multi-kilowatt), ultimately cheaper and more reliable PCUS for all power levels, the advent of “smart power” has reinforced the old concept of the “ac photovoltaic module.” Work is proposed or currently under way in several other DOE programs (SBIR, PV-Bonus, PVMaT) to develop and build on the concept of the “ac PV module”. The basic idea is to integrate a small utility-interactive dc to ac inverter onto the back of a standard PV module so that the module output is standard 120v, 60 Hz ac current,

Progress within the DOE programs is very promising with a prototype (in the PV-Bonus program) 250 Watt unit showing full load efficiency of over 95%. SBIR and PVMaT are currently proposing innovative approaches. The DOE prototypes also are designed to have very low no-load losses as these dominate the year-average energy conversion efficiency.

In addition, the pursuit for generic, universal-application of this technology development has also forged alliances with Inter Agency Power Group (IAPG), U. S.DOD, NASA, Navy and EPRI.

The manuscript will present the summary of various Smart Power circuit topologies and their impact on performance and cost. Among other things, this paper will discuss the dynamics of the evolutional process of the PCS design with respect to needs of the end users of these technologies because development sectors are a moving target and are socioeconomically linked.

Conclusions

1. A new revolution in Smart Power or power integrated circuits offers opportunities for increased efficiency and reduced cost. Its application to PV and other applications will advance a new area of controllability, with an order of magnitude improvement in speed of response, accuracy, reliability and fault monitoring, while at the same time realizing a reduction in cost.

2. The Smart Power pole module and low power module power converters conceived by JPL as generic building blocks are applicable to a wide range of power processing applications including PV power conditioners, electrical actuators, hi-directional converters, adjustable speed drives (ASDs) and uninterrupted power supplies (UPS). They offer the benefits of higher power quality, lower cost, and low levels of audible noise and increasingly marketable products while dramatically increasing reliability and efficiency as compared to available alternatives. It has the potential of offering improved maintainability, fail-safe operation and user friendliness.

3. An evolving synergism with parallel design efforts in other application sectors will have positive effects on both cost and efficiency goals due to increased production volume and improved designs. Design efforts in automotive, computer, aircraft and communication industries will provide this synergism and impetus to other industrial applications.

4. Efforts to eliminate technological barriers and to accelerate applications must continue with the help of government programs, industry investments and information dissemination.

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