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CURRENT DIRECTIONS IN PHOTOVOLTAIC POWER CONDITIONER DEVELOPMENT USING SMART POWER/POWER INTEGRATED CIRCUIT TECHNOLOGIES

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ABSTRACT

PV power applications are currently concentrated in intermediate or residential size for L]tility-interactive or small stoncf-alone modes of operation. Consequently, the development of low cost , highly efficient and reliable power conditioning subsystems (PCS) in the small to medium power range is critical for the viability of PV systems rrs an alternative energy source.

The paper summarizes current directions and development efforts in photovoltaic PCS designs and development. 1 t presents new opportunities arising from increased availability and capabilities of semiconductor switching components such as smart power devices and power integrated circuits (PICs). It also describes developmental efforts of manufacturers of these components for various applications and evaluates [heir synergistic impacts that will assist in required PCS development and will accelerate PV power applications. It is found that the usc of these technologies in fut u re PCS designs offers significant promise of improved PCS reliability, cost and performance, thereby making PV AC power more competitive with utility power. The concept of an AC photovoltaic module can be implemented with current technology,

RACKGROUND

In order to become a significant component of the nation's energy mix, photovoltaic (W) power systems have to expand their application niches and become sources of reliable and affordable power. To that end, efforts have been underway to improve the performance of arrays and the Balance-of-Power (BOS). The Power Conditioning Subsystem (PCS) being a key subsystem has seen development efforts for many years to achieve this goal. It is anticipated that continuing development activities with new design techniques and new devices will result in improved performance that will ultimately make PV system competitive with conventional sources of energy and be accepted by the utility. A dedicated partnership of the U.S. Department of Energy Headquarters (DOE/HQ) PV program, Sandia National Laboratories (SNL) Photovoltaic Systems Applications Department, and Jet Propulsion Laboratory (JPL) technology devotees and technical management shares this upbeat anticipation.

New technology component developments such as Smart Power/Power Integrated Circuits (SP/PIC) devices have the potential to produce a new industrial revolution in power electronics hardware. Initial evaluations find them adaptable toward improving hardware performance and lowering costs for future PV applications.

SMART POWER TECHNOLOGY DEVELOPMENT

Smart Power (SP) concept refers to integration of power, control, protection and sensing functions into one package. The term power integrated circuit (PIC) implies a monolithic structure capable of performing power switching and control functions. In power hybrids, individual PICs have a common stru cture and arc packaged into a single m odule. The term

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Power Management and Distribution (PMAD) implies bow power control and switching functions connect the power source to the user loads. Both smart power and PICs are used interchangeably sometimes. Although al] terms and concepts have not been fully standardized yet and sometimes there' is lack of unanimity in usage of terms, there is little doubt about the ability of smart power technology in providing improvements in performance, volume, weight, reliability and life (Bulawka et al, 19941), (Bulawka et al, 1994 b).

Steps involved in the implementation of smart power technology include: selection of switching devices, analog and digital signal processing, level shifting and signal isolation, current and temperature sensing, obtaining chip size magnetics and capacitances, power IC monolithic circuitry, hybrid packaging, use of novel conductor, and mechanical and thermal structures. Therefore, to utilize potential benefits of smart power technology, it is imperative that these challenges arc addressed for full range of applications requiring small to large power and specified control functions. l'he present concern of increased cost associated with PIC implementation will gradually disappear as the volume of production increases.

The new and revolutionary extension 10 the PIC is the "marl" module. It performs integrated drive functions and protective functions such as short circuit protection, over current protection, under voltage lockout and over temperature protection, Power and cent ml functions, with ample voltage isolation, arc integrated within the same module.

DOE interest in this technology goes back some 6-7 years. DOE, JPL and SN1. staged the first workshop on SP/PIC(2) at Caltech in Pasadena, California, and followed up by sponsoring the second onc in 1993(3) at the same location. Quite a few lessons have been learned about SP's powerful potential in resolving BOS problems in PV. Thus, DOE is looking to SP/PIC as a long range, advanced R&D commitment, and is expecting it to be the cornerstone to future, long range PCS R&D. The ultimate goal would be that small but aggressive industry recognizes and embraces this technology into its future hardware evolution. Some already arc doing so.

In order for PCS reliability to improve, DOE is attempting to attract the attention and consideration of this "new breed" of PIC manufacturers that currently caters to the Iargc-scale user. There is considerable activity in S1'/1'1 C development in the U.S.A., and it is likely that the costs of the devices will come down significantly. Applications in the automotive industry and ac motor control could become significant markets for SP/PIC, and the resulting componentry could be adapted for PV applications hardware such as PCSs, charge controllers and system controllers.

DOE MOTIVATION

DOE motivation in current research and development of PCS for photovoltaic power systems includes tbc following considerations:

- Current PCS designs use large number of discrete components affecting reliability and performance. Currently, PCS efficiency dots not meet DOE goals.
- New devices and technology presently available and emerging (SP/PIC, Power Pole, ASIC, MCT, etc.) will improve both reliability and performance.
- AC PV-modules (with a small DC-AC inverter onto the back of a standard PV-module like a standard 120V, 60 Hz AC output and utility interaction) will revolutionize PV industry.

SMART POWER IN PV APPLICATIONS

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 re-surfaced the old concept of the "ac photovoltaic module." Work is proposed or currently under way in several DOE programs (SBIR, PV-Bonus, PVMaT) to develop and build on the concept of the ac PV module. The basic idea is 10 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, 60Hz ac current.

A major focus in the development of an ac PV module is to incorporate concepts, such as high levels of integration via application specific integrated circuits (A SIC S), "smart power" devices, designs utilizing reduced component count and variety, that accommodate automated assembly and incorporate "smart" control and diagnostics for manufacturing and field service. The ac module Offers the ultimate in simplicity, system modularity and flexibility (Krauthamer et a], 1987), (Krauthamer et al, 1993a), and (Krauthamer et al, 1993b).

The basic building block, a single (50 watt to 300 watt size) module with ac output requires no additional electrical dc BOS equipment and is appropriate for use in virtually all utility-interactive PV applications. The ac module reduces system complexity and the need for customized system engineering, eliminates dc componentry and wiring (enhanced safety by elimination of high voltage de), lowers overall system cost (mass production, reduced BOS component count), and enhances reliability ("smart" circuitry, redundancy). The ac PV module design improves PV system flexibility and increases PV utilization with individual module maximum power point tracking which is a fundamental advantage in building applications.

SMART POWER AVAILABILITY

For application 10 the large, individual inverters, the development of SP/PICs has been in a dynamic phase. Companies are starting 10 develop products that will continue to sell year after year, to recover their investment and to develop new products that arc the result of pure and applied research. In the past few years there has been a virtual revolution in available new "smart power" devices. These SP/PICs encompass a broad range of devices, performing functions such as drivers, ad/dc converters, power supplies, sensors and inverters. Man)' of these off-the-shelf, commercially available [it\'ices arc applicable to PV PCS applications.

An example of such a device, manufactured by several companics, is t hc dc 10 ac invcrl cr. The modules have been designed primarily for ac motor spccd control applications and frequency changcrs. The modules arc available in applications for single-pkrsc and Ihrcc-phase opcralions. Single-phase modules arc available in power ratings up to 30 kW and 7.5 kW for three-phase applications. Switching frequencies arc up 1020 kHz and voltage ratings arc up to 1200 vdc. Usc of 3 power poles allow power ratings up to 90 kW in three-plmsc configurations. Some of these modules arc shown pictorially in Figure 1 and a power pole is shown in an internal block diagram in Figure 2.

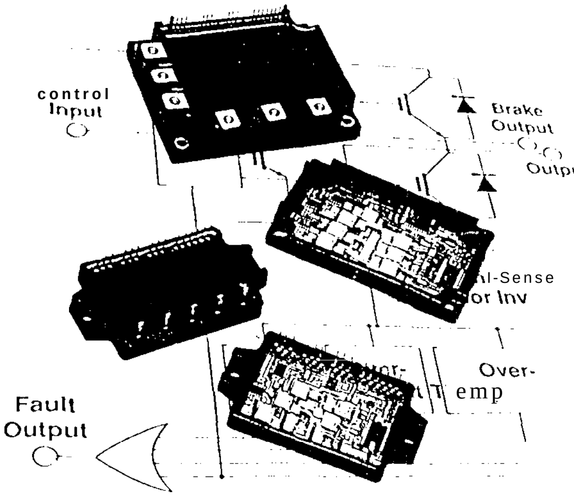

FIGURE 1. SP/PIC MODULES SUITABLE FOR PV APPLICATIONS

The modulcs shown can bc incorporated in a PV power conditioner by the inclusion of an output transformer, filler, switchgear and control electronics, with the resultant power conditioner able to perform all the ncccssary functions for a PV application. This will permit the power conditioner manufacturer or the PV system fabricator to build units with generally standard, commercially available SP/PIC modules. Functions such as anti-islanding, maximum and power point tracking and ac interface can now be handled with microprocessors and ASICs. In the final analysis, wc expect to scc krrge-scale, inexpensive, generic, off-the-shelf, SP/PICs that effectively contribute to the PV balance of system.

Industry has the prospect now for developing PV PCUs with the following required module capabilities:

Voltage: 1200V max., 6V min.
Current: 600A max.,12A min.
Power: 50kW max., 1W min.
Temperat urc: Standard commercial environments

This rating range covers an ample spectrum for today's practical and typical applications, in both, multi-kilowatt and ac module range. If prices arc to become reasonable and competitive DOE/industry must bc more intensely involved with the module manufacturers, who supported both workshops) and guide in the promotion of generic, "smart, " off-the-shrif modules. DOE engaged in successful and encouraging dialogue with the module and hardware manufacturers and anticipate further cooperation.

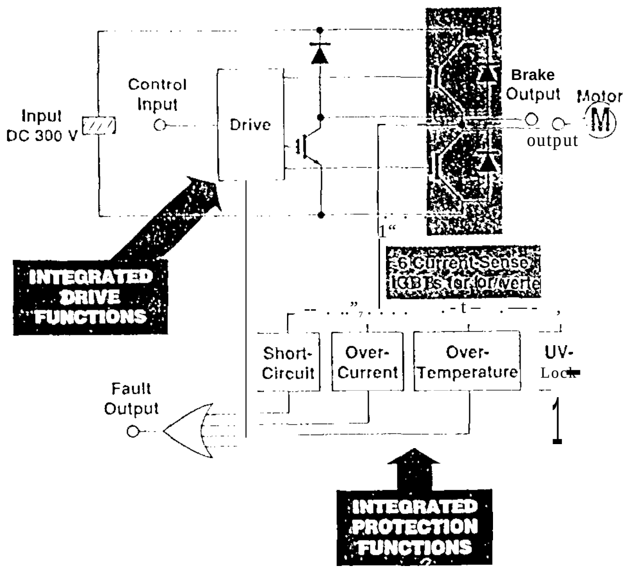

FIGURE 2. INTERNAL BLOCK DIAGRAM SHOWING A POWER POLE

DOE support and promotion for this promising and revolutionary hi-tech go well beyond the sole PV application. The pursuit for generic, universal-application development has forged alliances with the lntm--Agcncy Power Group (IAPG), DOD, NASA, U.S. Navy and EPRI. Finally, in this "smart power" endeavor, the success will bc measured in the large scale prod uction of SP/PIC photovoltaic inverters and associated power electronic modules.

MARKET PROJECTIONS

There arc now two basic scenarios that PV PCSS can follow to commercialization: individual, large "smart" inverters that take the output of the entire array, or multiple (distributed) small inverters each of which converts the output of onc individual module to ac power. Using industry market projections, the former approach (inverters in the multi-kilowatt range) results in a total market for such inverters measured in thousands to low tens-of-thousands of units, in the year 2010. The latter approach, using ac modules, results in a potential market size of many hundreds of thousands of units, at least an order of magnitude larger. The comparison is based on industry market projections (Krauthamer, 1993) and (Smith, 1988).

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.

SMART POWER/POWER INTEGRATION

There will be a revolutionary impact of using smart power on how BOS components are manufactured and integrated into PV systems. As a result, the market will experience the following advantages:

- Commercial PV panels
- Small distributed PV systems
- High reliability and low maintenance cost
- Expansion of PV systems possible at any increment of increased power requirement
- Reduced hand labor in manufacturing
- Portable PV low power systems.

Low-power photovoltaic system can use hybridized power conditioning system integrated with smart power module on the panel itself for either AC or DC output. As cheap photovoltaic system market expands world-wide, the use of smart power converters will also proliferate.

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 test 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 and synergism will quickly include photovoltaic systems, battery chargers, AC motor drives, robots, UPS and inverters.

AC PANEL - AN OPPORTUNITY FOR PV SYSTEMS

Ac panel development and commercialization will greatly assist in large scale penetration of PV Systems in utility-grade power production. The PCU will be a smart power module. The manufacture of PCUs will require reduced hand labor resulting in reduced cost compared to PCUs with discrete components. The selling price of AC panels will be low. As a result, new markets Will open up. Performance anti reliability of PCUs will improve, resulting in reduced downtime and smaller loss of revenue due to reduced maintenance.

Extensive efforts to develop AC panels are currently underway in many countries. European manufacturers of AC panels exhibited their products at the First World Conference in Hawaii in December 1994. Attendees and exhibitors showed tremendous interest in smart power technology. Their response to DOE/JPL paper on Smart Power anti European AC Panel Activities was unusually positive. Hopefully, the DOE/PV task at JPL to assess, monitor and promote smart power activities will provide needed impetus.

EFFORTS REQUIRED TO DEVELOP SMART POWER TECHNOLOGY AND AC PANELS

If PV power systems have to reach a stage where utilities and users consider them seriously as a source of highly efficient and reliable power, the use of smart power technology is absolutely critical. For distributed PV power on a large scale, the commercialization of PV panel is also critical. As a result, there is an immediate need to address the following tasks:

- Continuation of funding of smart power workshops. As in the past, the opportunity to present and disseminate results, and identify needs and concerns in these forums will accelerate the commercialization of PV power.
- Current international developments of PV related smart power hardware must be identified.
- Smart power module manufacturers have to be surveyed and data on their products and services have to be compiled.
- There has to be a technology transfer of accumulated database to PV power conditioner and systems manufacturers.
- Government-industry jointly funded development opportunities have to be identified for PV PCS developments.

CONCLUSIONS

Based on current status and future research and development efforts presented in this paper, the following conclusions can be summarized.

1. Smart power usage in high volume production of PV PCS and components offers new opportunities in the expansion of photovoltaics as a reliable, efficient, fail-safe and user friendly power source.
2. AC PV-panels concept provides potential opportunity for large scale penetration of photovoltaic power systems in energy production in the U.S.
3. DOE and other government-industry partnerships and financial assistance are needed to direct efforts required to capture all available technological advances in order to commercialize PV power systems on a large scale.
4. Presently available government programs must continue and, if possible, expanded.
5. Information dissemination process in terms of organizing workshops, publications, industry monitoring and hardware evaluation will accelerate the rate of realization of DOE goals.

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