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A NEW SMART INVERTER FOR VOLTAGE CONTROL IN DISTRIBUTION SYSTEM USING PV-STATCOM

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ABSTARCT

This paper presents a novel smart inverter PVSTATCOM in which a PV inverter can be controlled as a dynamic reactive power compensator - STATCOM. The proposed PVSTATCOM can be utilized to provide voltage control during critical system needs on a 24/7 basis. In the nighttime, the entire inverter capacity is utilized for STATCOM operation. During a critical system disturbance in the daytime, the smart inverter discontinues its real power generation function temporarily (for about a few seconds), and releases its entire inverter capacity for STATCOM operation. Once the disturbance is cleared and the need for grid voltage control is fulfilled, the solar farm returns to its pre-disturbance real power production. The Low Voltage Ride Through (LVRT) performance of the PV-STATCOM is demonstrated through both EMTDC/PSCAD simulations and laboratory implementation using dSPACE control. This proposed PV-STATCOM with a response time of 1-2 cycles, can provide an equivalent service as an actual STATCOM in a given application and possibly seek revenues for providing this service.

1. INTRODUCTION

SMART Inverters (also previously known as Advanced Inverters) represent a paradigm shift in the integration of Distributed Energy Resources (DER). These inverters can perform multiple functions involving both reactive and real power control in addition to their main task of converting DC power to AC power. These functions include voltage regulation, power factor control, active power controls, ramp-rate controls, fault ride through, and frequency control, etc. Various grid support functions offered by smart inverters are presently being demonstrated on real distribution and transmission systems in different counties, to motivate their rapid deployment. The benefits of reactive power control strategies with PV inverters are described. Grid interconnection standards are currently being revised to facilitate the adoption of smart inverter functions. The voltage control related smart inverter functions e.g., volt/var are mainly a set of operating points which are implemented in open-loop with time constants of a few seconds. The ongoing IEEE P1547 Standard Full Revision is contemplating that DERs shall be capable of injecting a finite amount of reactive power (typically 44%) even at 100% of nameplate active powerrating (kW). This implies that DER inverters will have to be oversized. The LVRT function requires that the DER shall stay connected even if the voltage goes below a specified limit. However, if the voltage continues to be at a low level for more than a prespecified period of time, the DER must disconnect.

1.2 SCOPE OF THE PROJECT

This paper presents a novel smart inverter PVSTATCOM in which a PV inverter can be controlled as a dynamic reactive power compensator - STATCOM. The proposed PVSTATCOM can be utilized to provide voltage control during critical system needs on a 24/7 basis. In the nighttime, the entire inverter capacity is utilized for STATCOM operation. During a critical system disturbance in the daytime, the smart inverter discontinues its real power generation function temporarily (for about a few seconds), and releases its entire inverter capacity for STATCOM operation. Once the disturbance is cleared and the need for grid voltage control is fulfilled, the solar farm returns to its pre-disturbance real power production. The Low Voltage Ride Through (LVRT) performance of the PV-STATCOM.

2. EXISTING SYSTEM

A unique concept of utilizing PV solar farms as STATCOM during nighttime for providing different grid support functions as well as for providing the same benefits during daytime with inverter capacity remaining after real power generation was proposed in 2009 [15], [16]. STATCOM is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) device [17]. It can provide dynamic reactive power compensation with a response time of 1-2 cycles, and can provide rated reactive current for voltages as low as 0.2 pu. The utilization of PV solar farm as STATCOM, termed PVSTATCOM, was demonstrated for increasing the connectivity of neighbouring wind farms [18], [19] and enhancing the power transmission capacity during night and day [18]–[20]. The controller design of a Voltage Source Converter based Distribution STATCOM (D-STATCOM).

1.4 EXISTING SYSTEMS TECHNIQUE:

D-STATCOM

3. CONCEPT OF PV-STATCOM

A static synchronous compensator (STATCOM), also known as a static synchronous condenser (STATCON), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. It is inherently modular and electable.

2.1 uses

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation.[4] There are however, other uses, the most common use is for voltage stability.

2.2 construction and operation

A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC

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voltage at the point of connection, the STATCOM generates reactive current; conversely, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power.[5]The response time of a STATCOM is shorter than that of a static VAR compensator (SVC)[6], mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

2.3 similar device

A static var compensator can also be used for voltage stability. However, a STATCOM has better characteristics than an SVC. When the system voltage drops sufficiently to force the STATCOM output current to its ceiling, its maximum reactive output current will not be affected by the voltage magnitude. Therefore, it exhibits constant current characteristics when the voltage is low under the limit. In contrast the SVC's reactive output is proportional to the square of the voltage magnitude. This makes the provided reactive power decrease rapidly when voltage decreases, thus reducing its stability. In addition, the speed of response of a STATCOM is faster than that of an SVC and the harmonic emission is lower, however STATCOMs typically exhibit higher losses and may be more expensive than SVCs, so the (older) SVC technology is still widespread.

2.4 concept of PV-STATCOM

The paper presents a novel smart inverter PV-STATCOM in which a PV inverter can be control as a dynamic reactive power compensator-STATCOM.In the nighttime,the entire inverter capacity is utilized for STATCOM operation.During a critical system disturbance in the daytime,the smart inverter discontinues its real power generation function temporarily,and releases its entire inverter capacity for STATCOM.Once the disturbution is cleared and the need for grid voltage control is fulfilled.These functions include voltage regulation,power factor control,active power controls,ramp-rate controls,fault ride through,and frequency control,etc.A unique concept of utilizing PV solar farms as STATCOM during nighttime for providing different grid support functions as well as for providing the same benefits during daytime with inverter capacity remaining after real power generation.

These project presents :

a) the proposed PV-STATCOM control concepts,

b) EMTDC/PSCAD simulation studies and

c) Laboratory implementation of this technologgy on a 10kw

PV solar inverter,for voltage control with full inverter capacity

during night and day.

Photovoltaic(PV) power system have becomes one of the most promising renewable generation technologies because of their attractive characteristices such asabundance of solar and clean energy.Unidirectional DC/DC converter is installed to control the power of PV arrays .PV-STATCOM used here will be used to track the maximum power and maintaining the active power supply to the VSC converter.Comprehensive control and power management system. Rajiv K et al, " have discuss the new smart inverter for voltage control in distribution system using PV-STATCOM. THE pv-statcom can be utilized to provide voltage control during the critical system need on 24/7 basis.

4. RESULTS AND DISCUSSION

3.1 SIMULINK DISCRIPTION

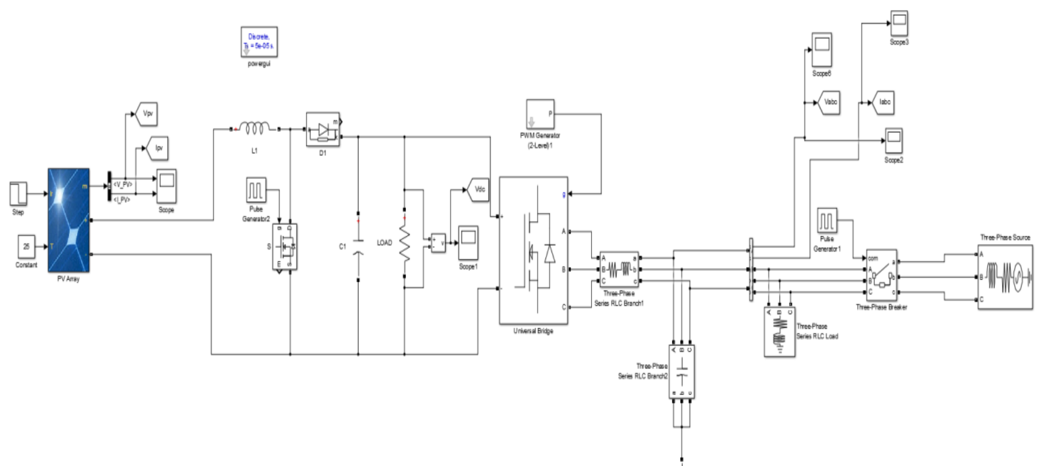

Fig 3.1 simulink circuit without FACT device

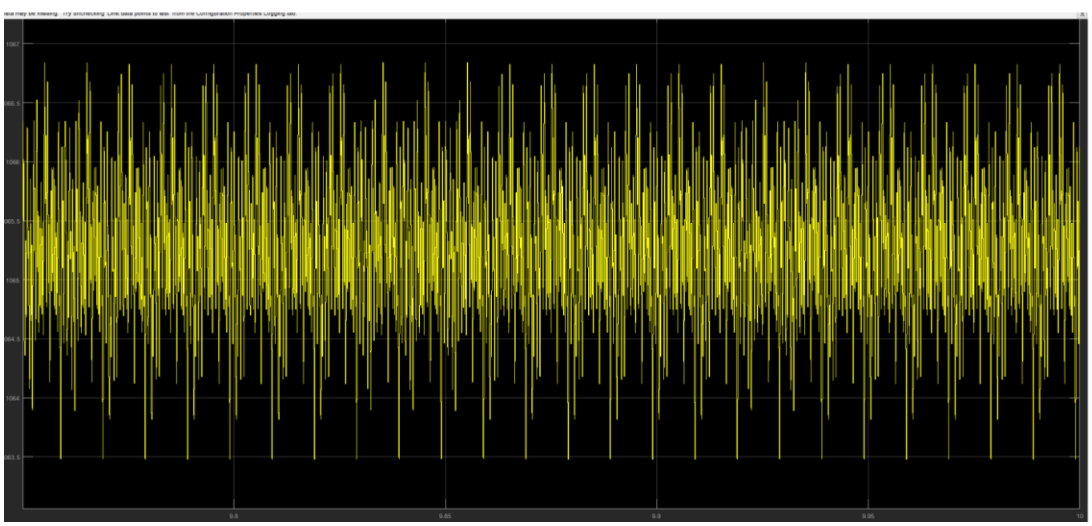

FIG 3.2 BOOSTUP VOLTAGE IN BOOST CONVERTOR

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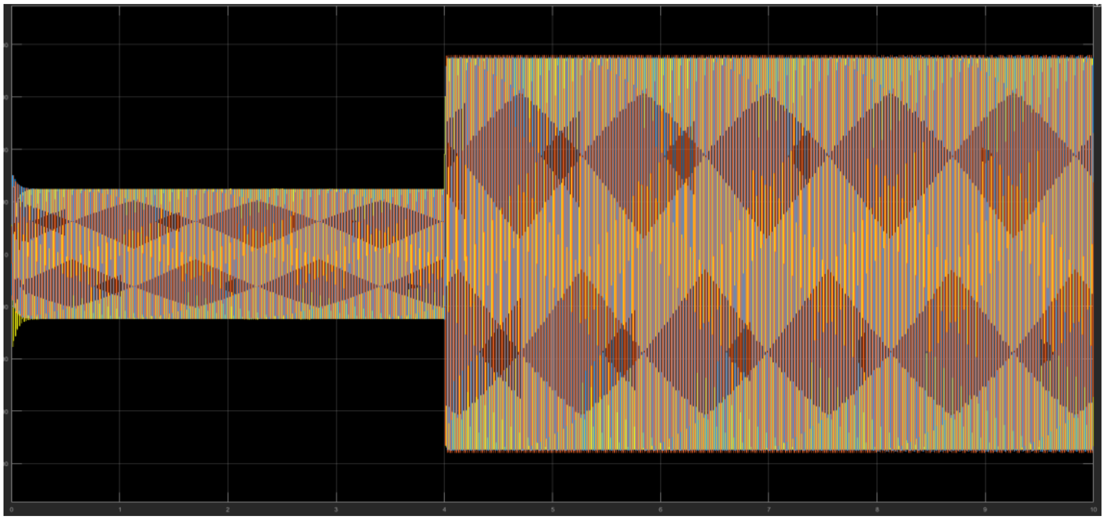

Fig 3.3 voltage output with fact device

3.2 Block diagram description

AC supply is called as sending voltage. Is transmit to the transmission line and finally received to the receiving end. Continuous advanced in modern life, demand for power will keep increasing. Voltage or frequency instability ,line overloaded and power system blackout. Due to long transmission the voltage in the transmission line will get drop and receive less voltage in the receiving station and could not satisfy the load demand. So fact device in used in the receiving end to satisfy the load demand. Here PV-STATCOM is used which will act as a fact device for reactive power compensation. Solar power in given to the voltage source boost converter (STATCOM).STATCOM is called as static synchronous compensator , at may be a source of reactive power or sink of reactive Ac power. The gate pulse give to the three phase inverter , which will give the three phase supply to the three phase load circuit. Finally the reactive power in given to the load demand. If can also provide active power when connect to source of power, if exhibit constant current characteristic, to improve power factor and voltage regulation and act as a voltage source controller device. STATCOM consist of coupling transformer, power converter, reactor & controller. The power is step down by the transformer and the step down voltage in given to the pick controller work in DC , so the input power in rectified by the rectifier.

- The output of solar panel is given to the three phase load through the boost convertor and three phase invertors
- The RLC load is connected across the input of three phase load to create the fault for RLC load circuit
- Power from the PV cell in given to the boost converter.
- The boost converter consist MOSFET switches, inductance and capacitance R load and diode .
- Boost converter is step up by switch mode power supply.
- Inductor and capacitor is normally used for filteration.

- The output from the boost converter in given to the bridge rectifier , that will convert dc into three phase AC supply.
- The three phase supply in given to the load circuit through the RLC branch circuit.
- In order to create the fault the RLC circuit in connected across the inverter and RLC load.
- The voltage in get drop when we connect the RL circuit and the less the voltage occur in the load which will not satisfy the load demand.

3.2 Simulink with FACT device

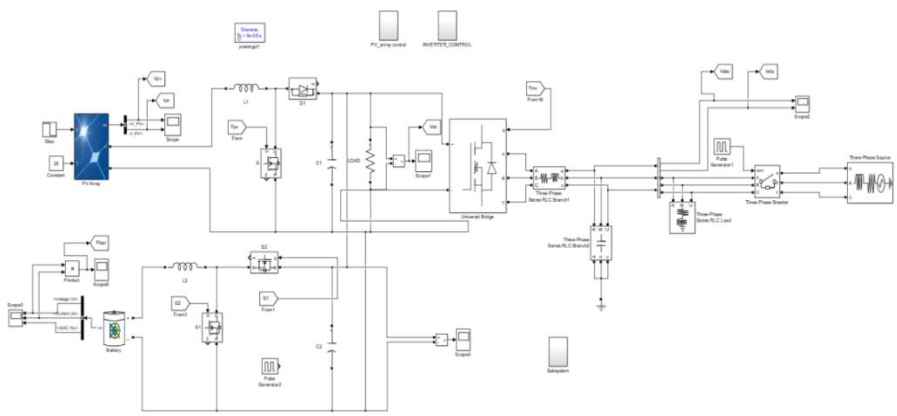

Fig 3.4 SIMULINK CIRCUIT WITH FACT DEVICE

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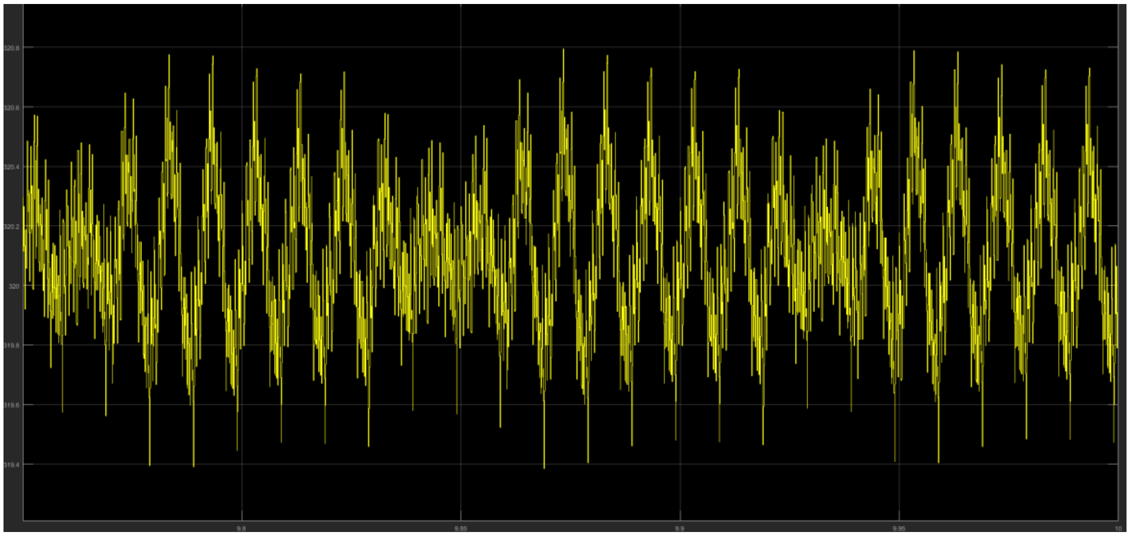

Fig 3.5 BOOST UP VOLTAGE IN BOOST CONVERTOR

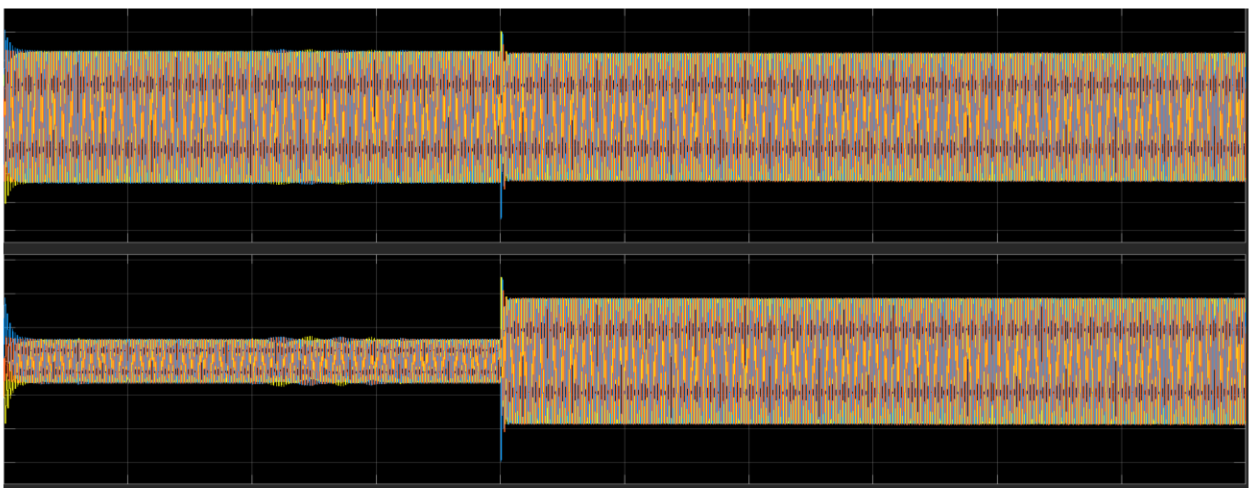

Fig 3.6 VOLTAGE OUTPUT WITH FACT DEVICE

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Fig 3.7 EXPERIMENTAL SETUP

3.3 SIMULINK WITH FACT DEVICE

The output of solar panel is given to the three phase load through the boost convertor and three phase invertors .The RLC load is connected across the input of three phase load to create the fault for RLC load circuit.The FACT device is connected across the RLC load to compensate the fault .The power from the battery in given to the boost converter and the boosted voltage in given to the three phase inverter.STATCOM which provide the adjustable constant of reactive power to the AC power system it is connected.So it can avoid over voltage ,voltage flicker , avoid networks harmonics.It consist of converter value, control protection system, dc capacitor , line inductor , three phase step down transformer, and high voltage equipment.The solar output is given to the boost converter.The solar output is non linear, so the low voltage from solar output is step up by the boost converter.Diode used on the boost converter is to block the reverse current.

3.4 controller unit

A Microcontroller (sometimes abbreviated µC, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

PICs are popular with both industrial developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability. Microchip announced on September 2011 the shipment of its ten billionth PIC processor.

The PIC architecture is characterized by its multiple attributes:

1. Separate code and data spaces (Harvard architecture) for devices other than PIC32, which has a Von Neumann architecture.
2. A small number of fixed length instructions. Most instructions are single cycle execution (2 clock cycles, or 4 clock cycles in 8-bit models), with one delay cycle on branches and skips.
3. One accumulator (W0), the use of which (as source operand) is implied. (i.e. is not encoded in the opcode)
4. All RAM locations function as registers as both source and/or destination of math and other functions.
5. A hardware stack for storing return addresses and fairly small amount of addressable data space (typically 256 bytes), extended through banking.
6. Data space mapped CPU, port, and peripheral registers.
7. The program counter is also mapped into the data space and writable. (this is used to implement indirect jumps)

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI.) The USART can be configured as a full-duplex asynchronous system that can communicate with peripheral devices, such as CRT terminals and personal computers, or it can be configured as a half-duplex synchronous system that can communicate with peripheral devices, such as A/D or D/A integrated circuits, serial EEPROMs, etc.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4kHz, for low power consumption (milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nanowatts, making many of them well suited for long lasting battery applications. Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP), with higher clock speeds and power consumption.

The first single-chip microprocessor was the 4-bit Intel 4004 released in 1971, with the Intel 8008 and other more capable microprocessors becoming available over the next several years. However, both processors required external chips to implement a working system, raising total system cost, and making it impossible to economically computerize appliances.

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The Smithsonian Institution says TI engineers Gary Boone and Michael Cochran succeeded in creating the first microcontroller in 1971. The result of their work was the TMS 1000, which went commercial in 1974. It combined read-only memory, read/write memory, processor and clock on one chip and was targeted at embedded systems.

Partly in response to the existence of the single-chip TMS 1000, Intel developed a computer system on a chip optimized for control applications, the Intel 8048, with commercial parts first shipping in 1977. It combined RAM and ROM on the same chip. This chip would find its way into over one billion PC keyboards, and other numerous applications. At that time Intel's President, Luke J. Valenter, stated that the microcontroller was one of the most successful in the company's history, and expanded the division's budget over 25%.

Most microcontrollers at this time had two variants. One had an erasable EPROM program memory, which was significantly more expensive than the PROM variant which was only programmable once. Erasing the EPROM required exposure to ultraviolet light through a transparent quartz lid. One-time parts could be made in lower-cost opaque plastic packages.

In 1993, the introduction of EEPROM memory allowed microcontrollers (beginning with the Microchip PIC16x84) to be electrically erased quickly without an expensive package as required for EPROM, allowing both rapid prototyping, and In System Programming. The same year, Atmel introduced the first microcontroller using Flash memory. Other companies rapidly followed suit, with both memory types.

Cost has plummeted over time, with the cheapest 8-bit microcontrollers being available for under $0.25 in quantity (thousands) in 2009, and some 32-bit microcontrollers around $1 for similar quantities. Nowadays microcontrollers are cheap and readily available for hobbyists, with large online communities around certain processors. In the future, MRAM could potentially be used in microcontrollers as it has infinite endurance and its incremental semiconductor wafer process cost is relatively low. About 55% of all CPUs sold in the world are 8-bit microcontrollers and microprocessors. According to Semico, over four billion 8-bit microcontrollers were sold in 2006.

A typical home in a developed country is likely to have only four general-purpose microprocessors but around three dozen microcontrollers. A typical mid-range automobile has as many as 30 or more microcontrollers. They can also be found in many electrical devices such as washing machines, microwave ovens, and telephones.

Microcontrollers must provide real time (predictable, though not necessarily fast) response to events in the embedded system they are controlling. When certain events occur, an interrupt system can signal the processor to suspend processing the current instruction sequence and to begin an interrupt service routine (ISR, or "interrupt handler"). The ISR will perform any processing required based on the source of the interrupt before returning to the original instruction sequence. Possible interrupt sources are device dependent, and often include events such as an internal timer overflow, completing an analog to digital conversion, a logic level change on an input such as from a button being pressed, and data received on a

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communication link. Where power consumption is important as in battery operated devices, interrupts may also wake a microcontroller from a low power sleep state where the processor is halted until required to do something by a peripheral event.

Microcontrollers usually contain from several to dozens of general purpose input/output pins (GPIO). GPIO pins are software configurable to either an input or an output state. When GPIO pins are configured to an input state, they are often used to read sensors or external signals. Configured to the output state, GPIO pins can drive external devices such as LEDs or motors.

Many embedded systems need to read sensors that produce analog signals. This is the purpose of the analog-to-digital converter (ADC). Since processors are built to interpret and process digital data, i.e. 1s and 0s, they are not able to do anything with the analog signals that may be sent to it by a device. So the analog to digital converter is used to convert the incoming data into a form that the processor can recognize. A less common feature on some microcontrollers is a digital-to-analog converter (DAC) that allows the processor to output analog signals or voltage levels.

In addition to the converters, many embedded microprocessors include a variety of timers as well. One of the most common types of timers is the Programmable Interval Timer (PIT). A PIT may either count down from some value to zero, or up to the capacity of the count register, overflowing to zero. Once it reaches zero, it sends an interrupt to the processor indicating that it has finished counting. This is useful for devices such as thermostats, which periodically test the temperature around them to see if they need to turn the air conditioner on, the heater on, etc. A dedicated Pulse Width Modulation (PWM) block makes it possible for the CPU to control power converters, resistive loads, motors, etc., without using lots of CPU resources in tight timer loops.

Universal Asynchronous Receiver/Transmitter (UART) block makes it possible to receive and transmit data over a serial line with very little load on the CPU. Dedicated on-chip hardware also often includes capabilities to communicate with other devices (chips) in digital formats such as I²C and Serial Peripheral Interface (SPI).

FEATURES

- Floating channel designed for bootstrap operation
- Fully operational to +600V
- Tolerant to negative transient voltage dv/dt immune
- Gate drive supply range from 10 to 20V
- Under-voltage lockout for both channels
- 3.3V logic compatible
- Separate logic supply range from 3.3V to 20V
- Logic and power ground ±5V offset

- CMOS Schmitt-triggered inputs with pull-down\
- Cycle by cycle edge-triggered shutdown logic
- Matched propagation delay for both channels
- Outputs in phase with inputs

A micro-controller is a single integrated circuit, commonly with the following features:

- Central Processing Unit - ranging from small and simple 4-bit processors to complex 32- or 64-bit processors
- Volatile Memory (RAM) for data storage
- ROM, EPROM, EEPROM or Flash memory for program and operating parameter storage
- Discrete Input and Output bits, allowing control or detection of the logic state of an individual package pin
- Serial Input/Output such as serial ports (UARTs)
- Other Serial Communications Interfaces like I²C, Serial Peripheral Interface and Controller Area Network for system interconnect
- Peripherals such as timers, event counters, PWM generators, and watchdog
- Clock generator - often an oscillator for a quartz timing crystal, resonator or RC circuit
- Many include analog-to-digital converters, some include digital-to-analog converters
- In-circuit programming and debugging support

Analog Applications:

10-bit, up to 8-channel Analog-to-Digital Converter (A/D), Brown-out Reset (BOR), Analog Comparator module with, Two analog comparators Programmable on-chip voltage reference (VREF) module, Programmable input multiplexing from device inputs and internal voltage reference, Comparator outputs are externally accessible

High-Performance RISC CPU:

Only 35 single-word instructions to learn, All single-cycle instructions except for program branches, which are two-cycle, Operating speed: DC – 20 MHz clock input DC – 200 ns instruction cycle, Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory, Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

CONCLUSION

This paper thus presents a novel concept of utilizing a PV solar farm as a STATCOM on a 24/7 basis, for supporting the grid as needed. Such applications will of course require grid code approvals and appropriate agreements amongst the different stakeholders, i.e., the solar farm owner, inverter manufacturer, the interconnecting utility and system operator. This PV-STATCOM function also opens up a potential revenue making opportunity for the PV solar farm by providing similar grid support functions at critical times as an actual STATCOM in a given application. This lab validated PV-STATCOM has been successfully installed and demonstrated in the utility network of BluewaterPower Distribution Corporation, Sarnia, Ontario, Canada, in December 2016. This demonstration was performed for the first time in North America, the results of which will be described in a subsequent paper.

5 REFERENCES

[1] L. F. Casey, C. Schauder, J. Cleary, and M. Ropp, "Advanced inverters facilitate high penetration of renewable generation on medium voltage feeders - impact and benefits for the utility," in Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), 2010 IEEE Conference on, Sept 2010, pp. 86–93.

[2] K. Turitsyn, P. Sulc, S. Backhaus, and M. Chertkov, "Options for control of reactive power by distributed photovoltaic generators," Proceedings of the IEEE, vol. 99, no. 6, pp. 1063–1073, June 2011.

[3] J. W. Smith, W. Sunderman, R. Dugan, and B. Seal, "Smart inverter volt/var control functions for high penetration of PV on distribution systems," in Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES, March 2011, pp. 1–6.

[4] EPRI, "Common functions for smart inverters, version 3," Palo Alto, CA, Feb 2014.

[5] C. Schauder, Advanced inverter technology for high penetration levels of PV generation in distribution systems. National Renewable Energy Laboratory, March 2014.

[6] B. Mather, "NREL/SCE high-penetration PV integration project: Report on field demonstration of advanced inverter functionality in Fontana, CA," National Renewable Energy Laboratory (NREL), Golden, CO., Tech. Rep., 2014, Report NREL/TP-5D00-62483.

[7] T. Stetz, F. Marten, and M. Braun, "Improved low voltage gridintegration of photovoltaic systems in Germany," in 2013 IEEE Power Energy Society General Meeting, July 2013, pp. 1–1.

[8] M. Morjaria, D. Anichkov, V. Chadliev, and S. Soni, "A grid-friendly plant: The role of utility-scale photovoltaic plants in grid stability and reliability," IEEE Power and Energy Magazine, vol. 12, no. 3, pp. 87–95, May 2014.

[9] R. G. Wandhare and V. Agarwal, "Reactive power capacity enhancement of a PV-grid system to increase PV penetration level in smart grid scenario," IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1845– 1854, July 2014.

[10] L. Liu, H. Li, Y. Xue, and W. Liu, "Reactive power compensation and optimization strategy for grid-interactive cascaded photovoltaic systems," IEEE Transactions on Power Electronics, vol. 30, no. 1, pp. 188–202, Jan 2015.