DSP Based Controller for various Power Electronics Converters Used in Micro-Grid

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Abstract—Although in recent years renewable energy is the targeted solution for energy crises, it is a friendly solution which is free from pollution. Development of Renewable Energy Sources (RES) arises from the requirement to increase the reliability, continuity of power supply and to reduce greenhouse effect, emission of carbon dioxide etc. However, the main disadvantages of RES are the uncontrollability and limited availability of resources. If these systems are not properly controlled, their connections to the utility can lead to grid instability or even failure. In this paper a control system/controllers based on DSP processors for energy management system of Micro-grid, is proposed. Processors and controllers are used with distributed power generation and power distribution in conjunction with Micro-grid. The referred papers explain the generation of Pulse Width Modulation (PWM) gated pulse signals using the Texas Instrument’s Digital Signal Processor (TI’s DSP) with the help of MATLAB Code/Simulink and Code Composer Studio (CCS). Main components for the switching and regulation of the power sources are DC-DC and AC-DC converters, for this purpose an efficient method is to use of digital controllers to reduce the control system’s size and cost. The conventional three-phase rectifier with bulky LC output filter has been widely used in the industries. By eliminating the bulky LC filter from the conventional diode rectifier without losing most of the advantages of the conventional rectifier, power conversion with high power factor can hence be achieved. The proposed scheme will be verified by MATLAB simulation and the implemented DSP processor will be tested with the buck/boost converter, isolated buck/boost converter model in both current control mode and voltage control mode and 3 phase rectifier to have regulated output for the load and unity power factor at supply side.

Keywords—Digital Signal Processor (DSP), Pulse width modulation (PWM), Code composer studio (CCS)

I. INTRODUCTION

The demand for energy, particularly in electrical firms, is ever-increasing in order to improve the standard of living. Power electronics devices are used to control the different devices with the efficient use of electricity, thereby reduction in power consumption. In recent years, the field of power electronics experienced a large growth due to confluence of several factors. The controller consists of linear integrated circuits/digital signal processors but the revolutionary advances in microelectronics methods have led to the development of controllers. Moreover these advances in semiconductor fabrication technology have made it possible to significantly improve the voltage and current handling capabilities and the switching speed of power semiconductor devices. These devices are used as switches for power conversion or processing [10].

Modern electronic systems require high-quality, small, light-weight, reliable, and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient. This is because they are limited to output voltages smaller than the input voltage, and also their power density is low because they require low frequency (50 or 60 Hz) line transformers and filters [10]. Linear regulators can, however, provide a very high-quality output voltage.
The main area of application is at low power levels. Electronic devices in linear regulators operate in their active (linear) modes, but at higher power levels switching regulators are used. Switching regulators use power electronic semiconductor switches in ON and OFF states. There is a small power loss in those states (low voltage across a switch in ON state, zero current through a switch in the OFF state), switching regulators can achieve high energy conversion efficiencies. Modern power electronic switches can operate at high frequencies [1] [2]. The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors. In addition, the dynamic characteristics of converters improve with increasing operating frequencies. Digital signal processors (DSP’s) are finding wide application in many engineering fields and these are suitable in almost all high frequency power conversion applications. This is because of their ability to perform complex mathematical computations faster than other processors. It has already been implemented and verified with a fuel cell based distributed generation [1].

Research [1][2][3] on Microcontroller based power management system for standalone Micro-grid with hybrid power supplies, concludes with experimental results that the action of the PID regulators has been designed/tuned in order to be adequate to avoid the intervention of the protection relays of the battery inverter also for the case of critical load rejection maneuvers.

Number of studies has been done on several issues of residential DCDS. The majority of studies have purely analytical in nature, involving no demonstrations or laboratory measurements In [7] the potential energy savings has been estimated by replacing AC-DC converters with a more efficient centralized rectifier (that converts AC power coming from the grid to DC) and using DC distribution within the house to power DC-internal loads.

In this paper, after referring [4][7], by considering the importance of Micro-grid and comparing the AC distribution with DC distribution, we propose the design of controllers for different electronics devices used in Micro-grid, which will act as an intermediate device between Micro-grid and DC load, and provide better regulation with higher efficiency in the real time operation.

The structure of the paper is as follow. In Section II, brief description of the controller and algorithm is discussed. In section III, the complete description of DSP peripherals and the implementation of the algorithm for PWM pulse generation are discussed. In section IV experimental observation and results are discussed. The last section V concludes the paper with final remarks.

II. IMPORTANCE OF MICRO-GRID

Generally, the micro-grid is defined as a cluster of loads with relatively small energy sources operating as single controllable network to supply consumer power demand; it is shown in figure 1, as in [3]. One of the technical challenges with micro-grid is the protection issue. It has to be isolated safely from the central grid during faults. Furthermore, it requires a large power capacity, control flexibility, and better quality of supply to meet local demands during islanding operation and utility grid connected operation. It also requires high performance controllers for proper operation of the system in both grids connected and islanding modes.
A Micro-grid is a model of a power system that integrates the renewable energy sources along with storage, for optimal generation and distribution of power for a connected area. When a general scenario is considered, the transmission losses are of about 30% of the energy generated, hence representing the drawback of a largely interconnected power system. The general power system in effect, of course can fulfill a large power demand but when it comes to the case of generation or transmission mission or distribution failures, the solution becomes a much complicated one [3]. But, when a Micro-grid power system is taken into account, there are no transmission losses besides renewable energy and eco-friendly power.

The importance of micro-grid is listed below [1] [2] [3].

- Autonomy: Micro-grids allow generation, storage and loads to seamlessly operate in an autonomous fashion, balancing out voltage and frequency issues with recent technology advances.
- Stability: Control approaches are based on frequency droops and voltage levels at the terminal of each device, allowing the entire network to operate in a stable manner.
- Compatibility: Micro-grids are completely compatible with the existing centralized grid, serving as a functional unit that helps build out the existing system, helping to maximize otherwise stranded utility assets.
- Scalability: Micro-grids allow many small generation, storage and load devices in a parallel and modular manner in order to scale up to higher power production and/or consumption levels.
- Efficiency: Energy management goals including economic and environmental can be optimized in a systematic fashion.
- Economics: Droop frequency control techniques allow for economic decision making to be programmed into standard operating protocols.

III. PROPOSED SCHEME

The proposed procedure for implementation of the idea is motivated by the increasing demand of energy. To have controlled, regulated, lossless and efficient power electronics devices, controller will be designed which will be based on the Digital Signal Processor (DSP). The DSP will act as a controller which will give a corrected signal and pulse width modulation (PWM) block will generate PWM signal. The generated PWM signal will be given to the IGBT (power electronics switch) which will act as a switch to ON and OFF power supply to the power electronics device.

One of the power electronics devices is a boost converter; the proposed block diagram from the controller of boost converter is given below in figure 2, as in [14]:

*Figure. 2 The proposed controller for boost converter with DSP.*

Another power electronics device as a part of micro-grid, is a conventional three-phase rectifier with bulky LC output filter which has been widely used in the industry because of its distinctive advantages over the active power factor correction rectifier such as simple circuit, high reliability, and low cost. Over than 0.9 power factor can be achieved, which is acceptable in most of industry
applications [11]. This rectifier, however, is not easy to use for high power density applications since
the LC filter is bulky and heavy.
To solve this problem, [11] refers a new simple rectifier is proposed in this paper. By eliminating the
bulky LC filter from the conventional diode rectifier without losing most of the advantages of the
conventional rectifier, very high power density power conversion with high power factor can be
achieved. Operation principle and design considerations are illustrated and it will be verified by
MATLAB simulation and it will be implemented on DSP with the help of CCS and MATLAB
Code/Simulink.
MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-
generation programming language. A proprietary programming language developed by Math-Works,
MATLAB allows matrix manipulations, plotting of functions and data, implementation of
algorithms, creation of user interfaces, and interfacing with programs written in other languages,
including C, C++, Java, Fortran and Python. For programming TI DSP, we will be using embedded
coder for code generation which is included in the package of MATLAB code/Simulink [9].
Embedded Coder generates readable, compact, and fast C and C++ code for use on embedded
processors, on-target rapid prototyping boards, and microprocessors used in mass production.
Embedded Coder enables additional MATLAB Coder and Simulink Coder configuration options to
advance optimizations for fine-grain control of the generated code functions, files, and data [15].
These optimizations improve code efficiency and facilitate integration with legacy code, data types,
and calibration parameters used in production.

![Figure 3 Code targeted from CCS to DSP.](image)

The three devices buck/boost converter, isolated buck/boost converter and 3 phase rectifier for
regulated output and unity power factor at input side, will be tested and verified with the help of
MATLAB Simulink and Code Composer studio. A simple procedure to implement it on DSP is
given below in a flow chart in figure 4, as it is in [9].

![Figure 4 Flow chart for code development in CC Studio IDE.](image)
1.1 PI controller
A proportional-integral (PI) controller is a phase-lag controller. A PI controller is used to increase the low frequency loop gain, thus reducing steady-state error. ‘P’ accounts for present values of the error. For example, if the error is large and positive, the control output will also be large and positive. ‘I’ accounts for past values of the error. For example, if the current output is not sufficiently strong, error will accumulate over time, and the controller will respond by applying a stronger action. PI controllers are fairly common, since derivative action is sensitive to noise, whereas the absence of an integral term may prevent the system from reaching its target value. The PI controller has a pole at the origin and is first-order controllers. The PI controller is applied during steady state to reduce oscillation of the duty cycle and improve the system’s stability.

1.2 PWM generation
The use of pulse width modulation to control converters has the advantage in that the power loss in the switching transistor is small because the transistor is either fully "ON" or fully "OFF". As a result, the switching transistor has a much reduced power dissipation giving it a linear type of control which results in better speed stability [10]. Pulse width modulation is a great method of controlling the amount of power delivered to a load without dissipating power. The term duty cycle describes the proportion of ON time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there being practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero [10]. PWM also works well with digital control, which is because of their ON/OFF nature, can easily set the required duty cycle.

After targeting code on DSP processor, the DSP processor will work as a controller to the power electronics device. It will generate a PWM pulse as shown below. The output of the power electronics device depends upon the pulse applied to it, which is a PWM pulse, output of the controller. The duty cycle of the generated PWM pulse depends on the input signal to the analog to digital converter and the constant values of the proportional integral. The generated output from the proportional integral is considered as the duty cycle to control the 3 phase rectifier and buck/boost convertor or isolated buck/boost convertor separately. The control of the buck/boost convertor, isolated buck/boost convertor and 3 phase rectifier for the micro-grid application will be done to regulate the output, reduce the harmonics content and increase the power factor.
IV. CONCLUSION

Presently, standalone Micro-grid with hybrid power supplies helped to understand the use of power electronics devices to control and regulate the terminal voltage and current. Further they suggest the use of digital controller for power electronics devices, instead of bulky and costly passive filters which makes the system uncontrollable. The high performance, fast response, floating point Digital Signal Processor (DSP) can work as a controller for buck/boost converter, isolated buck/boost converter and 3 phase rectifier to have regulated and efficient output with unity power factor at input side. The proposed scheme will be tested and verified with the help of MATLAB simulation and code composer studio.

REFERENCES