A DSP based Controller for Boost Converter and 3 Phase Rectifier with UPF used in Microgrid

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***Abstract*—Nowadays it has become necessary to increase the use of renewable energy sources. However, the main disadvantages of RES are the uncontrollability and limited availability, depend on weather conditions.The application of DSP processors for energy management system of renewable and non-renewable energy sources intended for grid connected applications is presented here.The presented scheme explains the generation of PWM gated pulse signals using the Texas Instrument's DSP with the help of MATLAB Code/Simulink and Code Composer Studio.The main components for the switching and regulation of the power sources are DC-DC and AC-DC converters. The mathematical model and state space equations for a small signal model of boost converter operating in continuous conduction mode and 3 phase rectifier for unity power factor are developed. Based on the transfer functioncontrollers are designed and implemented it onTMS320F28335 DSP processor with the help of MATLAB Simulink and CCS. The proposed design ensures good tracking performances and maintains stability in the system. Since the control methods allow real time modification in the required reference according to the change in required output. Designed controller capabilities, load voltage variations and inductor current variations are demonstrated through MATLAB simulation results.**

***IndexTerms*—Renewable Energy Sources (RES), Pulse width modulation (PWM), Digital Signal Processor (DSP), Code composer studio (CCS).**

I. INTRODUCTION

A Micro-grid is a discrete energy system consisting of distributed energy sources (including demand management, storage, and generation) and loads capable of operating in parallel with, or independently from, the main power grid. The micro-grids are smaller versions of the traditional power grid. Like current electrical grids, they consist of power generation, distribution, and controls such as voltage regulation and switch gears. However, micro-grids differ from traditional electrical grids by providing a closer proximity between power generation and power use, resulting in efficiency increases and transmission reductions. Micro-grid also integrates with renewable energy sources such as solar, wind power, small hydro, geothermal, waste to energy, and combined heat and power systems [1].

The demand for energy, particularly in electrical forms, is ever-increasing in order to improve the standard of living. Power electronics helps with the efficient use of electricity,Thereby reduce 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 the development of such 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 [2].

Modern electronic systems require high-quality, small, lightweight, 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. Linear regulators can, however, provide a very high-quality output voltage.

Their main area ofapplication 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. Because there is a small power loss in those states (low voltage across a switch in the 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. The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors.

The main objective of this paper is to present DSP-based energy management system and development. The hybrid energy sources are connected parallel with auxiliary power unit for storage and to improve transient and system stability to achieve dedicated control system [7]. The dedicated control system is designed with help of the DSP processor TMS320F28335 and uninterruptible power supply is designed. This hybrid combination of power supplies provides better static and dynamic response of the system.

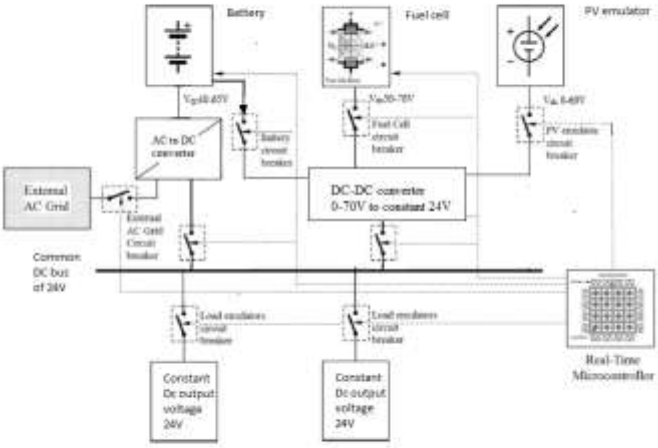


Figure.1.Block diagram of Micro-grid for Boost converter and 3 phase rectifier [7].

It was concluded and suggested in our previous paper [1], the use of active filter for 3 phase rectifier and voltage/current control mode for boost converter, based on DSP processor to have lossless and regulated output. The main components for the switching and regulation of the power sources are DC-DC and AC-DC converters. The conventional three-phase rectifier with bulky LC output filter has been widely used in the industries.By eliminating the bulky LC filter and replacing it with Power electronic device 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 verified by MATLAB simulation for 3 phase rectifier to have regulated output for the load and unity power factor at supply side. The testing of the designed processor is done with software and a DSP using different platform for programming and simulation. Figure 1 shows block diagram of Microgrid with different power electronic devices.

A conventional boost converter employed with the different sensors, output voltage and inductor current is fed back to the DSP processor through analog to digital convertor. The TMS320F28335 DSP processor is programmed with the C code generated by the embedded coder which the implementation of MATLAB Simulink model using code composer studio. The code written in C language for the processor provides flexibility in changing the frequency of PWM pulse. To write code in C language in code composer studio is a problematic and tedious job rather it is very easy to create a model in MATLAB/Simulink and then convert it to C language using embedded coder [1].

The structure of the paper is as follow. In section II, the complete description of DSP peripherals and the implementation of the algorithm for PWM pulse generation are discussed.In Section III, brief description of the controller and algorithm is discussed, and MATLAB simulation and Results are also explained in this section. The last section IV concludes the paper with final remarks.

II. DSP PERIPHERALS AND CONTROL SYSTEMS

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.A floating point controller TMS320F28335 DSP is the cheapest among the processors and simple in use when compared to the DS-1104 dSPACE which is complex, costly and bulky.The installation space requires for DSP-FPGA quite large for small size electrical appliances, which is not economic for the low cost and compact devices. Compared to the others work which uses real time microcontroller with FPGA required more time to integrate, which makes the device complex [1].

The main contribution of this paper is implementation of the algorithm that generates the PWM gated pulse for power electronics converters. For this generation of PWM pulse, the DSP controller is considered. In today's technology there are a lot of DSP processors are available but the most recent and the better than the other are TMS320F28335. It is very efficient tools for the real time application and designing various control technology for mobiles, power supplies, medical, industrial controls, home theatres. The previous version of DSP board TMS320F2812 for this application has lots of drawbacks and it cannot support floating point calculation. The application of this TMS320F2812 is explained in [2]. The motivation of this paper is to implement the control algorithms using the Delfino family DSP platform digital signal controller. It has the flash memory 256K x 16 which for more than TMS320F2812. It has the maximum speed of 150MHz. There are the numbers of ways to write the algorithm in DSP controller, some of these are:

1) Writing the source code using the code composer studio in C language.
2) Implementing MATLAB/Simulink models using the embedded coder with help of code composer studio and control suite.

Writing the control algorithm in MATLAB/Simulink is easy compared to the general C language code writing in the Code composer studio [16]. The complete development PWM pulse generation and data acquisition with sampling and processing is presented. The DSP- Based application rapid prototyping is easy with the algorithm written in C language. It can be easily reused and it provides better flexibility in changing the frequency of PWM pulse [11]. There are lots of applications available for DSP based control system for power electronics converters and designs, as in [12].

DSP TMS320F28335 Peripherals for PWM Generation

The generation of PWM pulse requires the analog input from the outside of the board. It sense the both the analog current and the analog voltage signals. The ADC module can sense the analog input from 0 to maximum 3Volt. This analog voltage is converted to the digital equivalent value by the given formula;

$$digital\ value = 4096 * \frac{(analog\ input - ADCLO)}{3}$$

Where ADCLO is the ADC lowest operating voltage. That is ideally zero.

From the above formula it is observed that ADC give digital output from 0 to 4096 for its analog input voltage from 0 to maximum 3 volt.There are three type of counting mode available for PWM generation and each can be selected from the program setting.

1) Count Up mode
2) Count Down mode
3) Count Up and Down mode

The count up mode is used for inverter and the count-down mode is used for the chopper [12]. The dead time problem is available in the PWM generation that can be avoided using some dead band in the program for PWM generation. During the dead time both the transistor on and large amount of current flow through transistor making them short circuited.

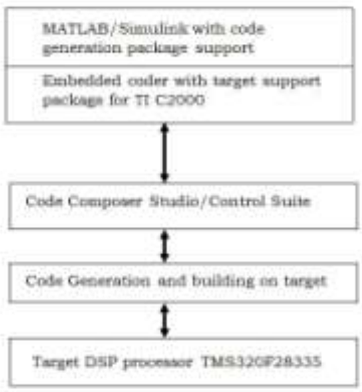


Figure.2.Code composer working procedure.Figure.3.Code generation from embedded coder.

Embedded Coder for Code Generation

The embedded coder is code generation package available in the MATLAB/Simulink. It can generate the readable, compact and fast C/C++ language code for use on embedded processor, on target prototyping boards. The support package for the same can be downloaded from the Math-works support center. The generated code by embedded coder is developed in the block of MATLAB/Simulink and is defined by the target language compiler script in ert.tlc [16]. The complete generation procedure is shown in fig.2. The embedded coder generates the code that may be complicated in problem with synchronization between the sensed signals from the sensor and the generation of the firing pulse. The support package for MATLAB/Simulink embedded coder is available at [13].

Integrated Development Environment (IDE)

The IDE used for the separate code writing without the code generation is code composer studio (CCS). This CCS provides the integrated platform for design, implementation, simulation and verification on target board for real time application. There are several of versions of the IDE developed by the Texas Instrument [13]. It includes compiler, assembler, linkers and automatic code built procedure for the development boards. The complete flow of the procedure is shown in fig.3.

III. MATLAB Simulation and Results

Three Phase Rectifier

For three phase input power factor correction, a boost converter is used at the output of the rectifier. Overall system effciency is reduced as this DC-to-DC converter needs heavy filtering at the input. For a conventional three-phase bridge rectifier, low current distortion and unity power factor at the input are the most important design criteria. For AC-to-DC rectification via a capacitive filter, these criteria provide maximum throughput power with negligible ill effects. Rectification needs to be controlled precisely in order to obtain low-distortion input current at unity power factor. This is achieved through active power factor correction at the input of the rectifier, using Pulse Width Modulation [1]. PWM controls the input currents to make them sinusoidal and in phase with their respective input voltages. Thus power factor at the input is maintained close to unity.

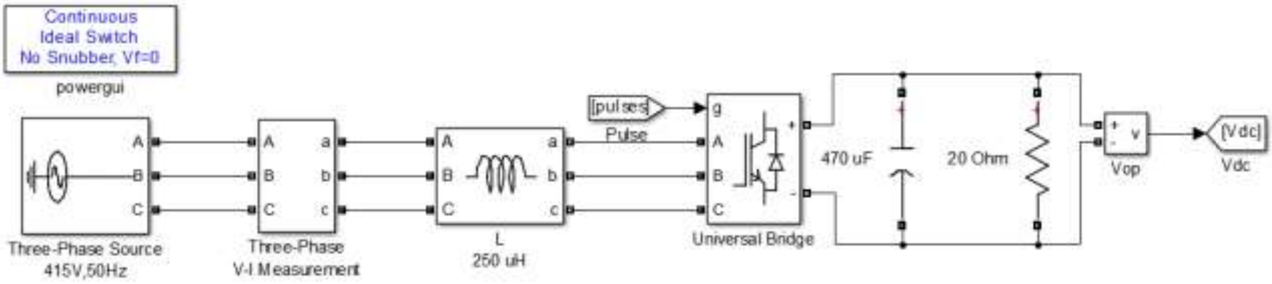


Figure.4.Three Phase Rectifier

Designed PI controller for 3 phase rectifier for unity power factor

In above control scheme Proportional-Integral (PI) controllers are used in order to minimize the inputerror signals. The error signals are derived by calculating difference between reference set point and feedback signals. For the implementation of dynamic system control; Park and Inverse Park transformation are used i.e. control signal which is used for PWM generation is derived from Inverse Park transformation of V_d, $V_q$whereas control action takes place after Park transformation. Rectifier DC voltage is controlled by comparing it with DC voltage reference which will provide I_{dref} (active power reference).

For unity power factor operation I_{qref} (reactive power reference) is maintained to zero. PI controller gains(Kp, Ki) are optimized for proper control action.

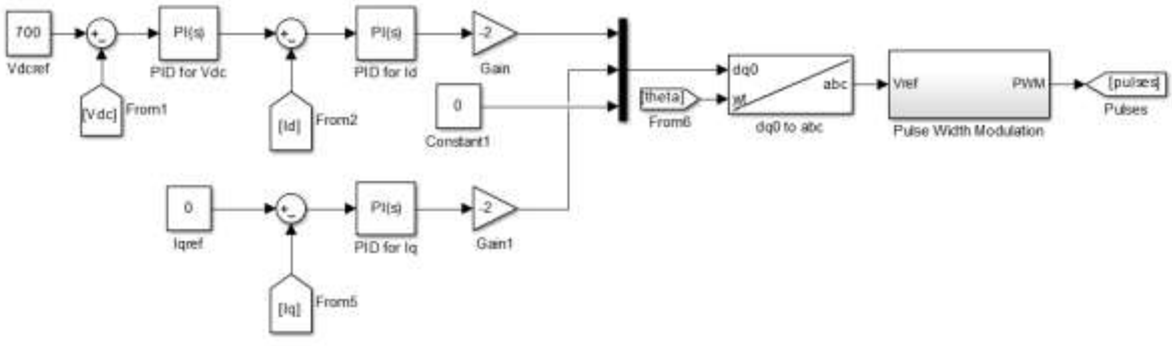


Figure.5.Controller for3 Phase Rectifier for unity power factor

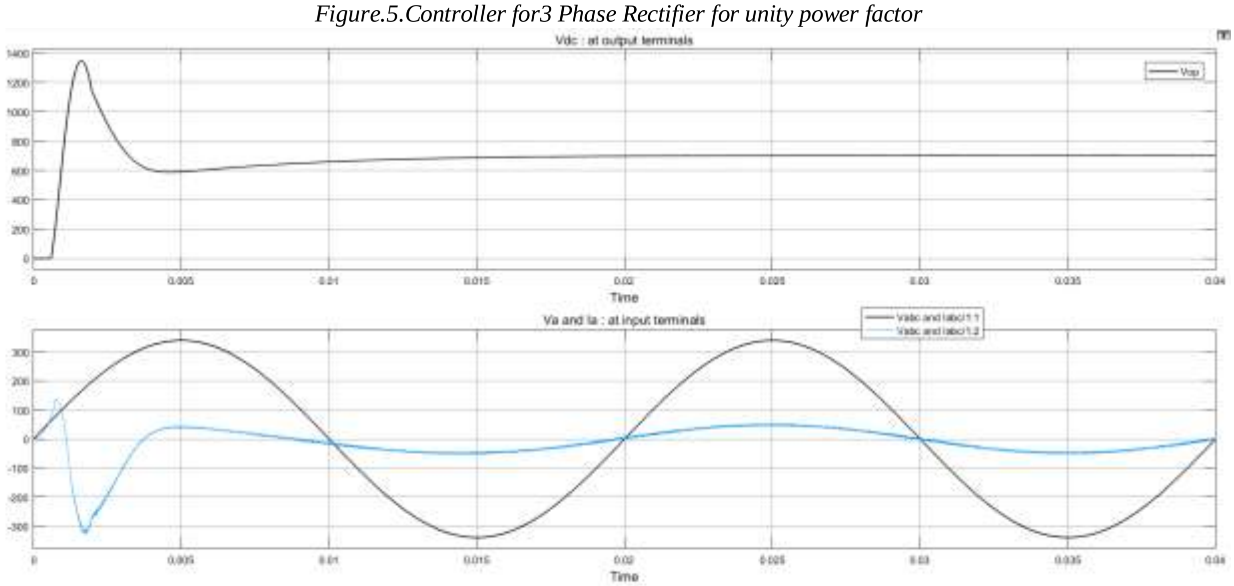
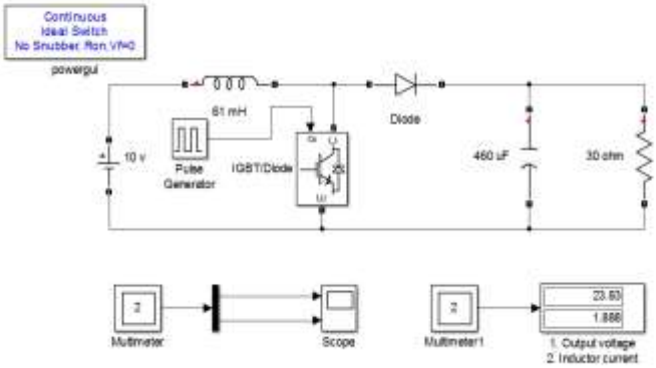


Figure.6.Three phase rectifier Output and Input waveform with UPF

Boost Converter

DC/DC choppers are electronic power components whichconvert DC voltage level to another DC voltage level. DC/DC converters are basic components for renewable energy system because of the fact that they are employed to adjust DC voltage of energy sources for voltage of loads. Particularly, DC/DC choppers were commonly used for voltage stability and improvement of controllability in smart grid applications [1]. There are two basic chopper types: buck and boost for DC/DC conversion. Switched mode power supply technique is commonly used to control the output voltage of DC/DC choppers.

The duty cycle of the generated PWM pulse is 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 to switch on and off the boost converter. The control of the boost converter for the micro-grid application is done in current mode control and voltage mode control.



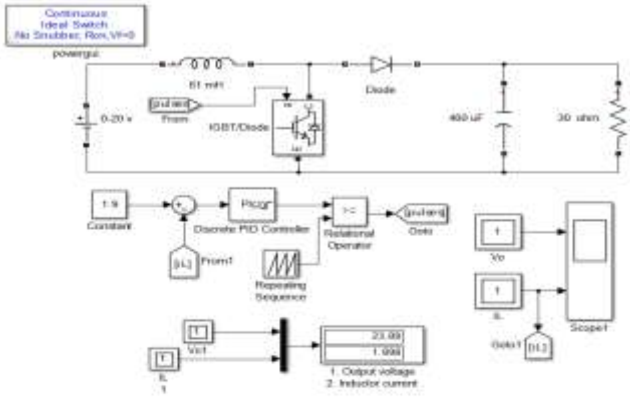


Figure.7.Open loop Boost converter model *Figure.8.Closed loop Boost converter model*

DSP based model for Boost converter

The model shows how to develop DC-DC power conversion application for Texas Instrument's TMS320F28335 processor; it can also be implemented on other DSPs of the same family. To implement the model on DSP requires Texas Instrument's c2000 Digital power experimental kit and compatible JTAG emulator. The model shown in figure 9 is built on the experimental kit with the help of MATLAB Simulink and code composer studio.

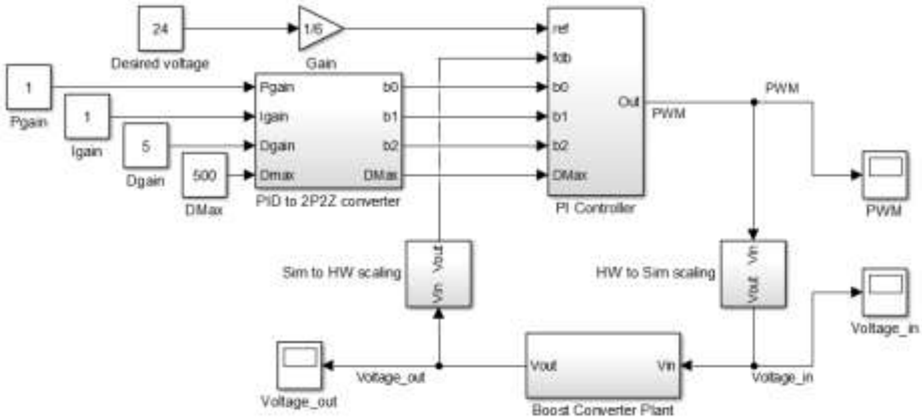


Figure.9. PI controller for Boost converter

The output for both open loop and closed loop boost converter is given below in figure 10 and 11.The required output can be achieved with closed loop control. Here, DSP acting as a controller which gives corrected signal and pulse width modulation (PWM) block generates 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 [1].

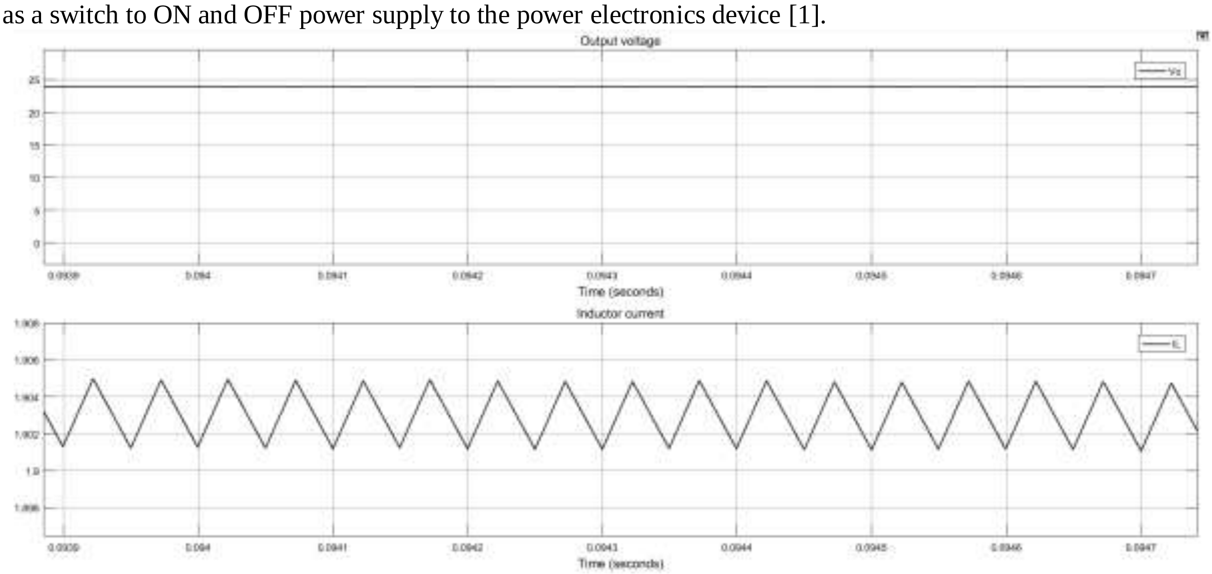


Figure.10.Output of Boost Converter in closed loopwith PI controller

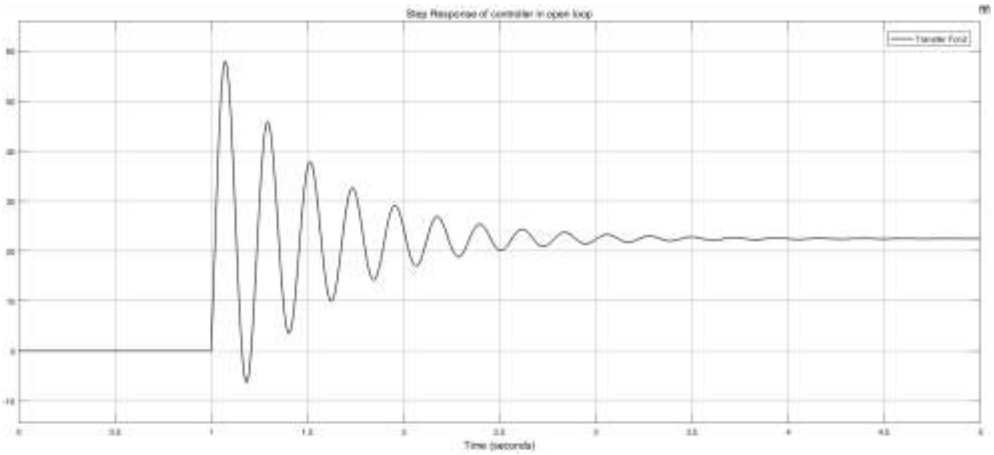


Figure.11. Output of Boost Converter in closed loopwithout PI controller

Designed PI controller for Boost converter

Boost type DC/DC converter with PI controller is shown in Fig.8 and fig.9. Closed loop PI controller driving pulse width modulation is utilized to improve the voltage stability in the DC/DC choppers. In this method, measured output voltage is subtracted from reference voltage to obtain an error signal. Then, it is applied to PI controller and the control signal is used to generate PWM signal. The PWM signal is employed to control power switch. This control feedback aims to zero the error signal.
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 measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value. The PI controller is applied during steady state to reduce oscillation of the duty cycle and improve the systems stability [1].

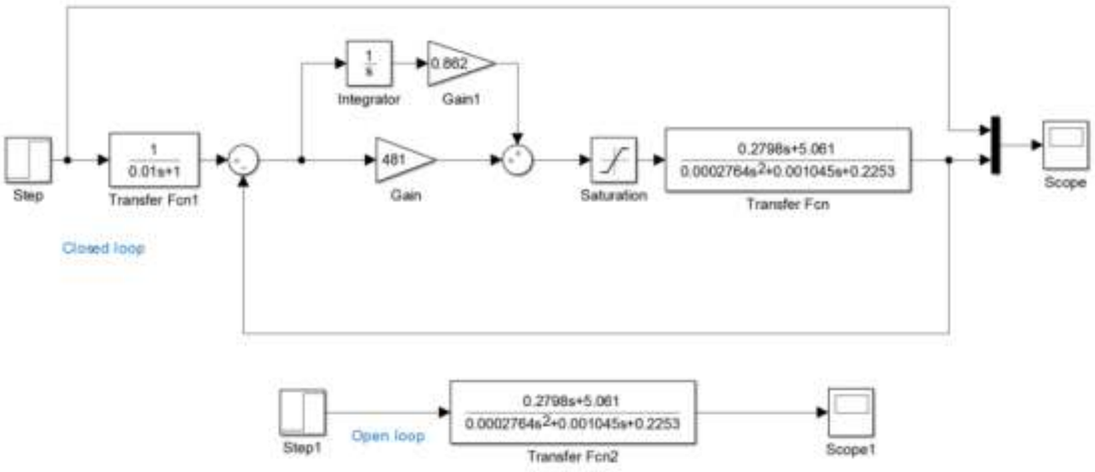


Figure.12. PI controller for Boost converter

In this controller, average current control mode has been implemented. The reference current & actual current through the inductor are compared and based on the error, the modulating signal is generated for controlling the duty cycle of the switch. The carrier wave is a 20 kHz saw-tooth waveform. The modulating signal is compared with the carrier wave to generate the control signal for the switch. A limiter is present in the control circuit to limit the modulating signal between 0 & 1 in case the error is too large (to avoid over-modulation).

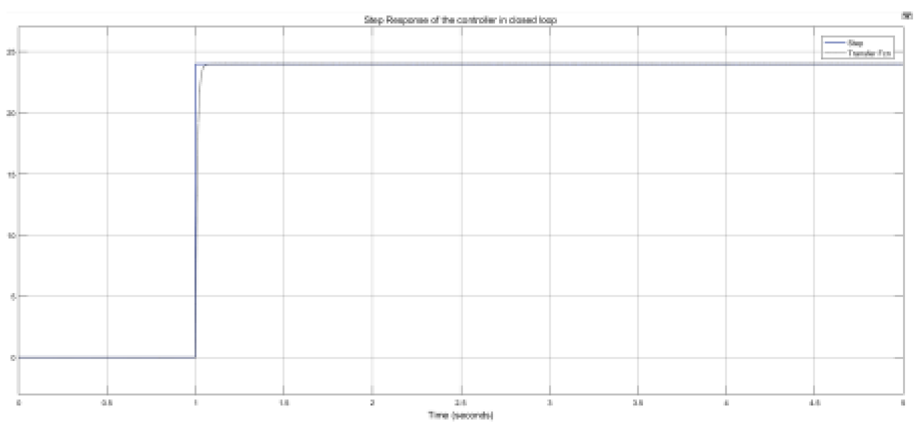


Figure.13. Step response ofBoost converter with PI controller

IV. Conclusion

A Micro-grid with hybrid power supplies uses electronics devices to control and regulate the terminal voltage and current. The literature [1] suggests the use of digital controller for power electronics devices, instead of bulky and costly passive filters which makes the system uncontrollable.Here, Digital Signal Processor worked as a controller for boost converter and 3 phase rectifier with unity power factor to have regulated and efficient output. The proposed scheme is tested and verified with the help of MATLAB simulation and code composer studio.

The complete mathematical model developed and the control scheme is processed by a dynamic, fast in-response, real time processor TMS320F28335. Effectiveness of the proposed controller to generate PWM control signal is analyzed with MATLAB Simulation and implementing it on DSP processor with the help of code composer studio. The DSP based controllers application for different converters verifies the performance satisfactorily. These results demonstrate that controller guarantees to track the required output which is comparatively better than other works presented in various literatures.

It is almost impossible to have an algorithm suitable for all situations. It is, therefore, important to consider some of the situations for which the further study is required.The algorithm should include a multiple optimization process; practical application of this scheme may demand high computational integrity. Hence, the hardware implementation of proposed hybrid configurations is a challenging task.Hence, there is a scope to implement the suggested hybrid power system configurations in real time application.

References

[1] FarhaNaz, SarfarazShaikh, Dr. Alice Cheeran, Electrical Dept. VJTI, Mumbai, "DSP Based Controller for various Power Electronics Converters Used in Micro-Grid"*International Journal of Recent Trends in Engineering & Research (IJRTER), Vol.02, Issue 10*, pp. 18-23, Nov 2016.

[2] R.J. Wai and L.C. Shih, "Design of voltage tracking control for DC-DC boost converter via total sliding-mode technique," *IEEE Trans. Ind. Electron.*, vol. 58, no. 6, pp. 2502–2511, Jun. 2011.

[3] Kirubakaran, K. Jain, ShailendraNema, "DSP-Controlled Power Electronic Interface for Fuel-Cell-Based Distributed Generation," in *Power Electronics, IEEE Transactions on* , vol.26, no.12, pp.3853-3864, Dec. 2011.

[4] XudongHuang, Virginia Polytechnic inst. and State University , Blacksburg, VA, USA, "A DSP based controller for high-power interleaved boost converters" in press 2017

[5] Saed El Beid, National school of Applied Science, ChouibDoukkali,University,El Jadida,Morocco,"DSP-Based Implementation of Fuzzy Output Tracking Control for a Boost Converter" In IEEE Trans. 61(1): 196-209. Jan 2014.

[6] P.T.Tang, Dept. of Electronic Engg. Hong Kong Polytechnic University, "Design of DSP-based controller for switching power converters" in press 2017

[7] Belvedere, B. Bianchi, M. Borghetti, A. Nucci, C.A. Paolone, M.Peretto, A., "A Microcontroller-Based Power Management System for Standalone Micro-grids With Hybrid Power Supply," in *Sustainable Energy, IEEE Transactions on* , vol.3, no.3, pp.422-431, July 2012.

[8] Belvedere, B. Bianchi, M. Borghetti, A.Paolone, M., "A microcontroller-based automatic scheduling system for residential micro-grids," in *PowerTech, IEEE Bucharest*, vol.3 no. 2, pp.1-6, June 28 2009-July 2 2009.

[9] Kirubakaran, A. Jain, ShailendraNema, R.K., "DSP controlled DC/DC boost converter for renewable/green power applications," in *Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on* , vol.3, no.2, pp.1-6, 20-23 Dec. 2010.

[10] Hercog, D. Curkovic, M.Jezernik, K., "DSP based rapid control prototyping systems for engineering education and research," in *Computer Aided Control System Design, 2006 IEEE International Conference on Control Applications, 2006 IEEE International Symposium on Intelligent Control, 2006 IEEE* , vol.2, no.10, pp.2292-2297, 4-6 Oct. 2006.

[11] Lesan, A.Y.E. Doumbia, M.L.Sicard, P., "DSP-based sinusoidal PWM signal generation algorithm for three phase inverters," in *Electrical Power & Energy Conference (EPEC), 2009 IEEE* , vol.3, no.11, pp.1-6, 22-23 Oct. 2009.

[12] N.Mohan, T.M. Underland, and W.P. Robbins, Power Electronics Converters, Applications and Design, 3rd ed. Hoboken, NJ: Jon Wiley & Sons, 2001.

[13] Mathworks Embedded Coders, (Jan 2015). [Online]. Available: http://in.mathworks.com/products/embedded-coder/

[14] Mathworks TI C2000 Support from Embedded Coders, (Jan 2015). [Online]. Available: http://in.mathworks.com/hardware-support/ti-c2000.html

[15] Texas Instruments Inc. *TMS320×281x DSP Analog-to-Digital Converter(ADC) Reference Guide* Houston, TX: Texas Instruments Inc., 2007.

[16] Texas Instruments, *Code Composer Studio TM IDE*. Houston, Texas Instruments Inc., 2009. Available: http://www.ti.com.