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Research paper

Application of Low Cost Microcontroller in Rapid Control Prototyping for Single Phase Back to Back Converter

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Abstract

This project is carried out in order to develop a Rapid Control Prototyping (RCP) process using a PI control which can be employed in a low cost microcontroller device for online measurement. Therefore, the Raspberry PI has been chosen for beeing set as a real-time response and combined with a closed loop feedback control. Here, a back to back converter has been developed using the Matlab-Simulink in order to interface in real time processing system. At the end, all the results have shown the desired output which responses to the target referenced which has been observed in real-time using Matlab Graphical User Interface model. It indicates that, the selected low cost microcontroller can be used as a real time measurement for reducing the total cost of experimented setup, ensure safety of the system and increase the accuracy of the system

Keywords: *back to back converter, low cost microcontroller, Raspberry PI, rapid control prototyping*

1. Introduction

The main idea of this project is to apply the concept of Rapid Control Prototyping (RCP) [1,2] in a single-phase back-to-back (B2B) converter. This setup has been selected because it can give better understanding on the output when it been applied to the system control strategy using a low cost microcontroller. The RCP is described as a online control system that can be tested instantaneously in real time mode compared to the traditional process where it needs to be downloaded and tested separately with the specific control functions. Figure 1 shows the example of RCP concept on the real system using Raspberry Pi microcontroller. Four (4) main components have been identified for this project which are the input supply to the system, a linear load, a rectifier-inverter converter and the MATLAB in order to generate Pulse Width Modulation (PWM) generation response to the circuit.

In this project, the Raspberry Pi (RPi) microcontroller is used for controlling the signal generation which is supported/ developed using MATLAB Simulink Toolbox software for real time monitoring condition. It operates similarly to the closed-loop system in order to collect the current output feedback signal from the B2B converter for the RCP process. As known, RCP enables user to minimize the cost and time for the controller setup [3,4], to eliminate a tedious error coding [3] and to improve the accessibility performance of the control [5] by changing the control gain in online mode which is required when the system is running. It will enable the designer or developer to have an easy transition from the model-based control design to the target implementation [6] which runs and controls in real time control mode.

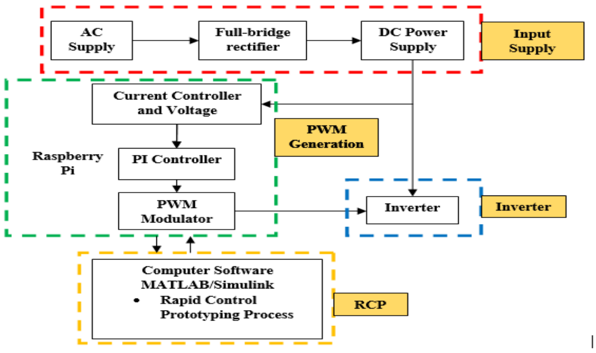

Fig.1: Block diagram for Rapid Control Prototyping of a single-phase back to back converter for a single phase network

The reason why the RPi is been used in this process is because of the equipment cost which is very low, flexibility in the choice of programming languages and can be operated as external mode when it been connected to the MATLAB [1,2,7-10]. Other than that, the RPi microcontroller is a compact sized microcontroller [8] and capable of generating high switching rating.

2. Prototype Setup For Back to Back (B2B) Converter

This section will describe the development of the B2B converter in software and hardware modules in order to be applied for the RPi.

2.1 Design Specification

The system development starts with the design specification of the proposed design which is shown in Fig. 2. Four main components have been identified for this project which are the full wave uncontrolled bridge rectifier, the MATLAB for controlling the rapid control prototyping and to develop the controller, single phase rectifier and single phase inverter with current feedback for pulse generation.

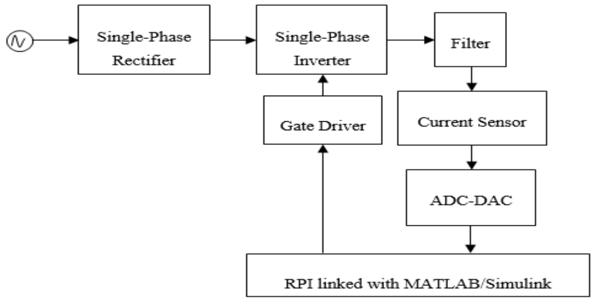

Fig. 2: Block diagram for RCP of a single-phase B2B

The controller part of the B2B converter is used the Proportional Integral (PI) control and it will not be discussed here. The real time simulation is conducted with RPi and Arduino together with the current feedback or voltage feedback sensors [12-13]. At the end, this project uses the Graphical User Interface (GUI) where it gives MATLAB to have real control of the PI gains without trying to stop the hardware running mode and is also used to capture the inverter output in real time mode by the GUI system design.

2.2 Software Development

The software development involves several parts which are the Analog to Digital (ADC), Digital to Analog (DAC) converter and a current control in PI control strategy that have been developed in MATLAB-simulink blocks. The ADC and DAC are used due to RPi does not have any analog inputs. Therefore, the Arduino has been selected for conversion unit by modeling the ADC/DAC based on the Simulink function as shown in Figs 3 and 4. These blocks have be downloaded to RPi and Arduino separately.

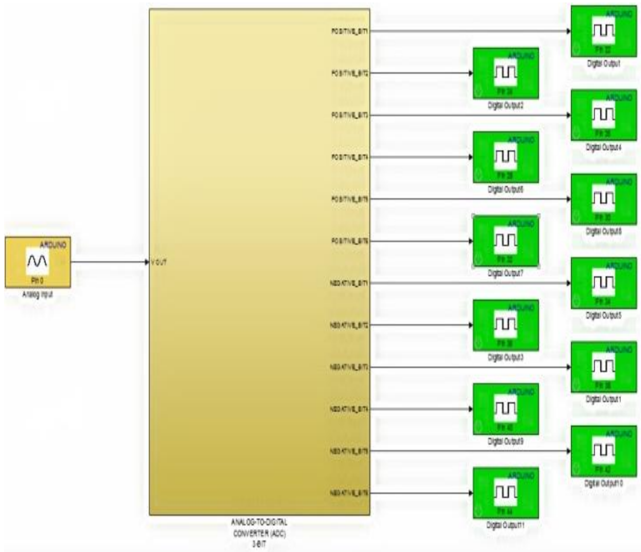

Fig. 3: ADC 3-Bit system

However, the digital signal output from the Arduino needs to be sent back to RPi for converts the analog signal using DAC for completing the closed loop cycle of the B2B in real time process.

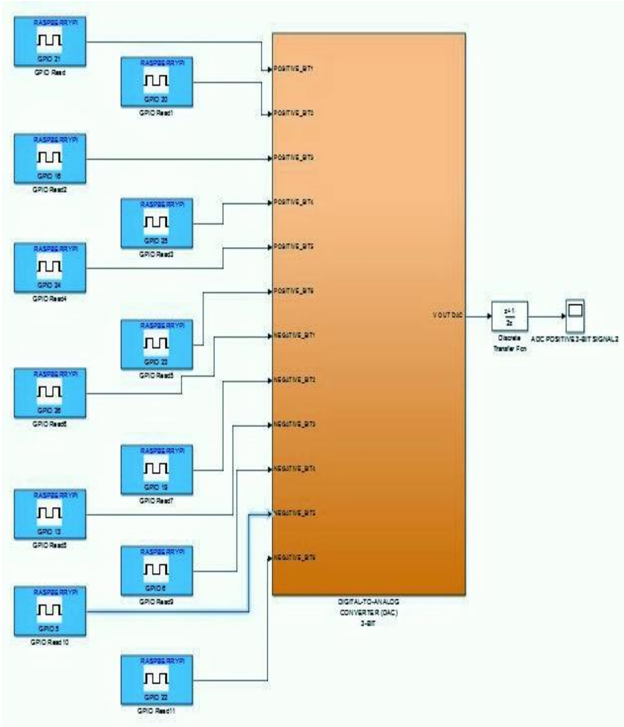

Fig. 4: DAC 3-Bit system

The PI control block with the gain values are shown in Fig.5, which then been downloaded into the RPi. These PI gains are in an adjustable mode value where the specific gain for those gains can be changed using sliding function that has been built in GUI format as shown in Fig. 6.

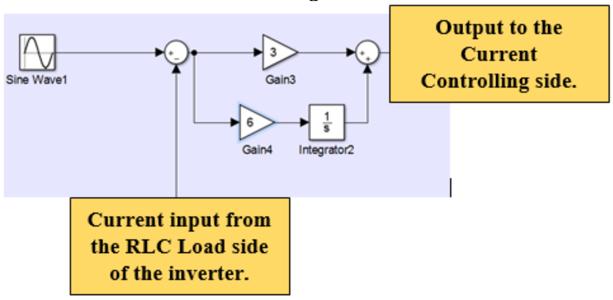

Fig.5: PI Controller block in MATLAB-Simulink

The PI-GUI sliding model it has been created with the PI gains which ranging from -10 to 10. At the meantime, the run and stop functions are used to consequently run and stop the model as preferred by the user with the scope respond for online measurements.

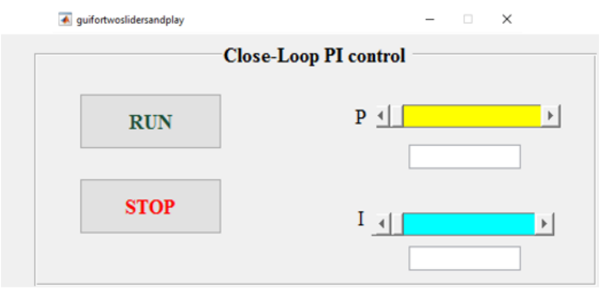

Fig.6: GUI model

2.3 Hardware Development for Back to Back Converter

The complete hardware setup is shown in Fig.7. As for the RCP, the control process has been conducted in the MATLAB while the complete hardware is used to vary the response of the low cost microcontroller in RCP system. The hardware setup includes the

AC transformer, DC supply, uncontrolled rectifier, Arduino Mega 2560, RPi Model B+, gate driver and a single-phase inverter.

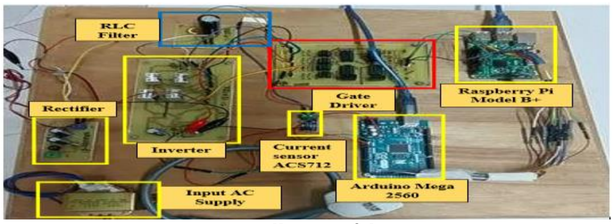

Fig.7: Overall setup of the project

3. Results and Analysis

This section explains the results and findings of the of RCP process in the B2B converter. The results consist of the simulation on closed loop conditions, the real hardware test and the RCP real time process and as for hardware measurements after the communication between the software and hardware has been established.

3.1. Closed Loop System Simulation

At this stage, the simulation is done in closed-loop system where the PWM signal for the inverter is obtained through the implementation of a PI current control. Output current of the inverter is injected to a PI control, thus producing switching frequency for the gate. The simulation model is shown in Fig. 8.

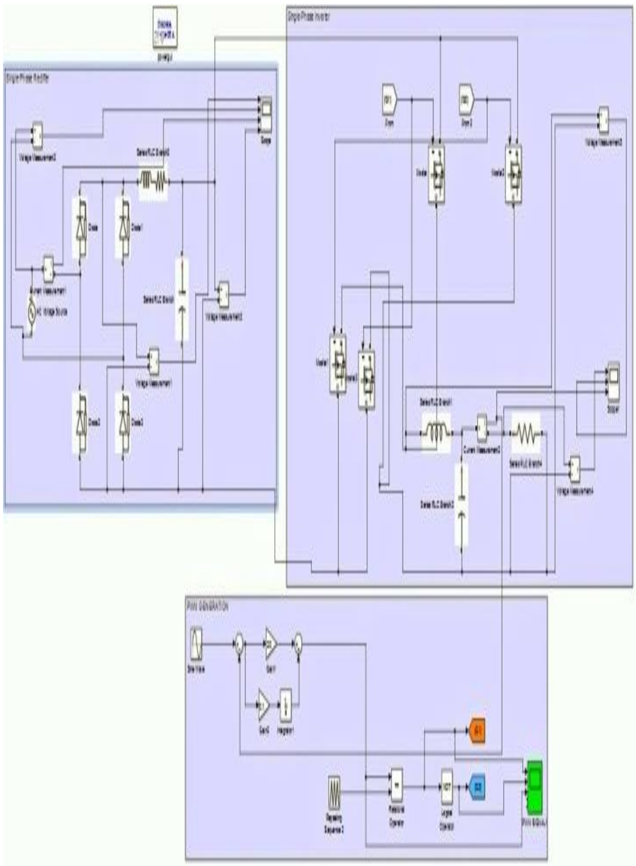

Fig.8: Full simulation model of the back-to-back converter with current controller input

It can be observed, the current feedback is responding to the reference control target value. It is because the current control acts as a controller mechanism for the PWM switching frequency. The result for the inverter outputs after implementing the current control are shown in Figs. 9 and 10.

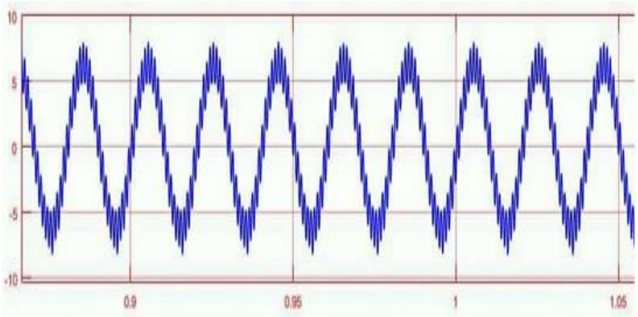

Fig.9: Voltage output of inverter after current controller implementation

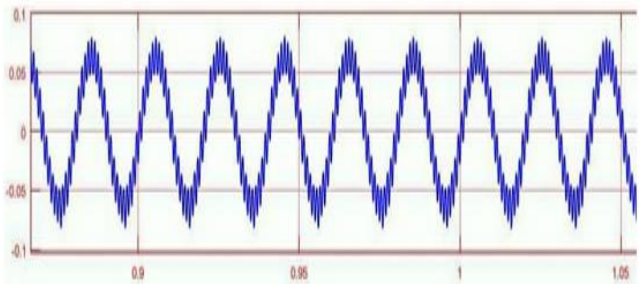

Fig.10: Current output of inverter after current controller implementation

3.2. Closed Loop System Hardware

In this analysis, the tests are done on the hardware model by implementing the current control using RPi and Arduino. The outputs have been measured after the LC filter has been connected at the inverter output.

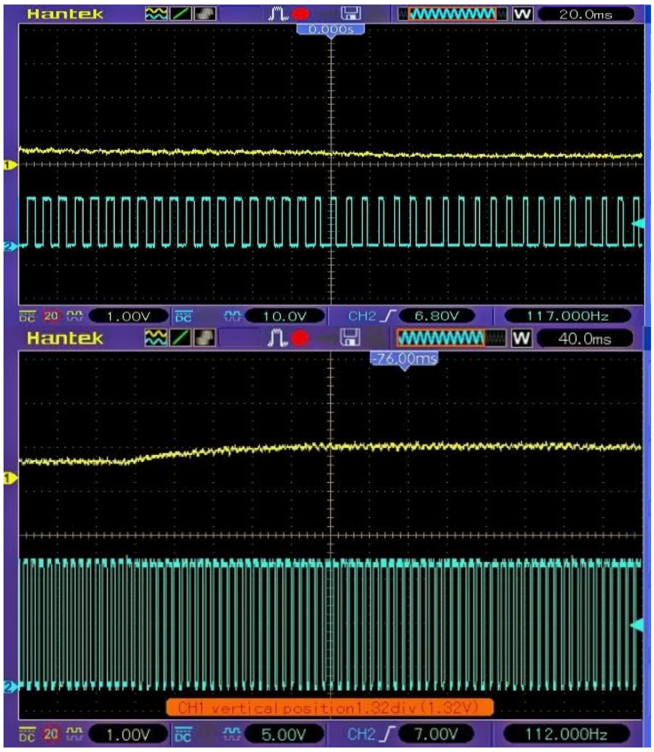

Fig.11: Output of the PWM signals to the inverter with current control

By referring to Figs. 11 and 12, it can be seen that, the changes of current has influenced the PI closed-loop system in order to produce different widths of PWM signal. Both have different frequencies ranges as 117Hz and 112Hz as shown in Fig.11. Therefore, it is proven that current changes influence the switching frequency of the PWM.

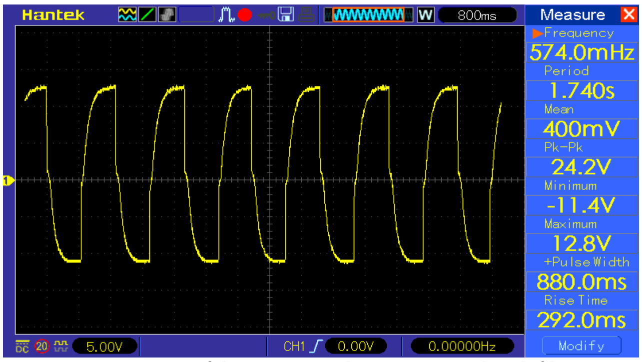

Fig 12: Output of the inverter with current control with filter

Meanwhile, Fig 12 shows the output voltage of the inverter after implementing the current controller. It indicates that the current feedback for the closed-loop system is effected the output of the inverter.

3.3. Real Time Simulation during RCP Mode

For the implementation of the RCP mode, a real-time simulation is conducted and the Simulink model is interfaced with the hardware to run in Simulink-External mode by setting an 'infinite' at the time. It enables the MATLAB to perform continuous iteration on the Simulink model and the results have been varied in real-time to show that the RCP has taken place accordingly when the load change. Since this project is focused on the current-control part, two parameters are changed, which are voltage and resistance to indicate how changes in current can affect the inverter output.

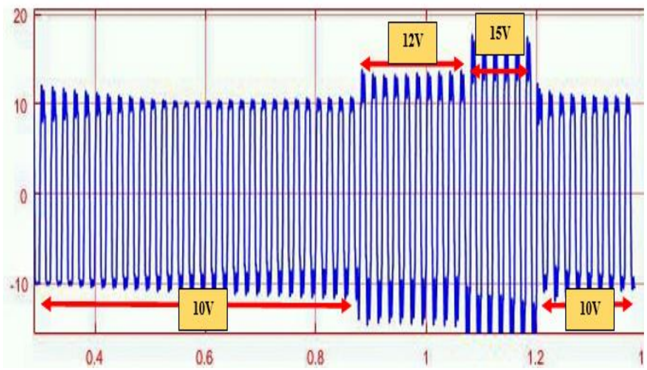

Fig.13: Output Voltage of inverter at varying inputs (filtered)

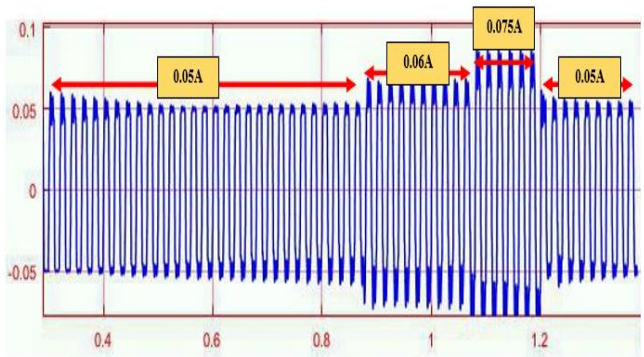

Fig.14: Output Current of inverter at varying inputs

Figs. 13 and 14 show the results which have been displayed in GUI during RCP process as example for the voltage output of the inverter whenever the input voltage is changed. The changed are immediate and followed the PI control response and it has very minor down-time which is approximately of 20ms. At the meantime, the current waveform output follows the voltage changes in instant mode which enables the PWM to generate smoothly with current close-loop system in real time mode

The next test had been conducted when the load is changed to 500Ω. By changing the load but maintain the the voltage during the real time mode, the current value will be different as shown in Fig. 15. This verified the RCP can also be conducted instantaneously even during the changing of the PI gains.

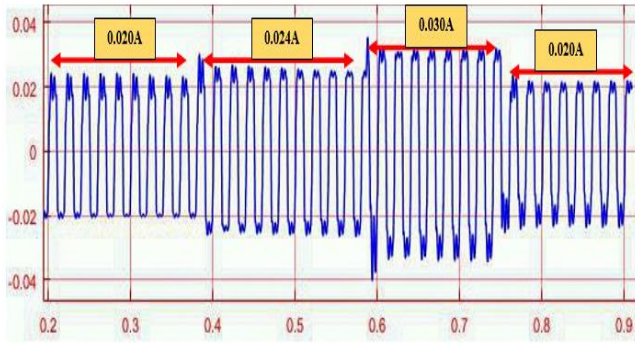

Fig.15: Output Current of inverter

4. Conclusion

This project shows the function Raspberry Pi as a low cost microcontroller and as to be RCP in real time mode. The tests have been performed using RPi for generating switching signal for the operation of the gate driver during hardware test. The current control with the Arduino which has used for current detection for feedback system and then been controlled using PI control through the RPi also been tested and it proves that the closed loop system can be achieved. As a conclusion, the application of RCP using a low cost microcontroller is effective as it is managed to reduce time for designing process and minimal usage of real-life measuring apparatus such as voltmeter and oscilloscope and is also able to change the controller instantaneously whenever the hardware is running.

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