

Development of Single Phase Back to Back Converter with Closed Loop Voltage Feedback Controlled by Arduino Microcontroller

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Abstract: This paper presents a development of single phase back to back converter using voltage closed loop feedback using Arduino microcontroller. The key feature of this system is the ability of the Arduino as a low microcontroller to control the gate signal of power switches of the inverter by referring to the target voltage when applying with the PI control. The Matlab-Simulink has been the communication medium between software and the microcontroller. This is because, the controller structures have been developed based on the control mathematical formulae before downloaded to the microcontroller in order to test the back to back converter. Based on the results obtained, the back to back converter has successfully responded to the voltage feedback control mechanism and the Arduino is operated as a suitable low cost microcontroller for gate firing signals.

Keywords: back to back converter, Arduino, Matlab, voltage control

1. Introduction

Back to back converter also known as a power electronics device that can convert AC input source voltage to DC voltage at the midpoint/DC link and again to AC voltage at the output (AC-DC-AC). This technique requires a series of converters with control mechanism in order to have a bidirectional current flow capability. Back-to-back converter has been used in many applications such as Back-to-Back High Voltage Direct Current (HVDC) [1,2] and wind turbine generation system for grid connection. All these examples are focusing on the minimum losses on power transfer [3] and also to maintain the voltage for the renewable energy sources that can be used as the reactive power compensation response [4] at the electrical network

Back-to-back converter consists of two Voltage Source Converters (VSC) connected by a common DC-link as shown in Figure 1. The VSC is used for changing the input signal using the gate devices with the Pulse-Width Modulation (PWM) switching technique in order to allow a fast and independent control of active and reactive power in both converters [3,5,6]. The advantage of VSC is, it can independently generate or absorb reactive power at its own AC output terminals [7]. This concept has been adapted to the shunt converter application which is known as STATic synchronous COMPensator (STATCOM).

Without a controller mechanism, this back to back converter will not operate in sequence. As a result, a control rectifier and inverter are needed for the signal process. The usage of the control system will measure the

current and voltage of the converters and then will generate an appropriate system signals to allow bidirectional flow for both converters. These measurements are used to provide information for the control loops. At the meantime, these signals need to be generated by the microcontroller as a hardware device.

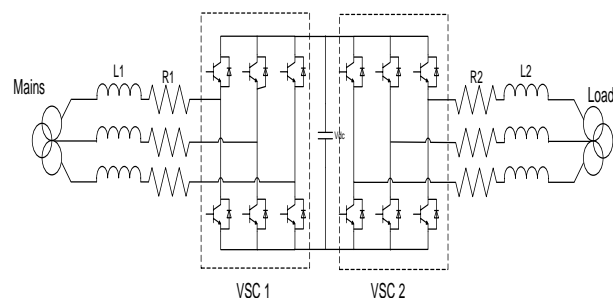


Fig. 1: An example of Back-to-back power topology in three phase network

In this project, the main idea is to use a single phase back to back converter for converting the AC voltage source to DC voltage and again to AC voltage [8]. For AC to DC conversion, the uncontrolled rectifier is used while for the DC to AC conversion it uses controllable inverter. These converters have been applied in order to minimize the complexity of the controllers itself. Another reason is to limit the usage of the low cost microcontroller that can be applied in this project.

As mentioned in many papers especially in [9,10,11], a low cost microcontroller is an appropriate device to be used as a controller. It is where, the controller algorithm can be designed easily and the input-output connection has fast respond process.

For the controller development, the Matlab- Simulink toolbox has been used. The advantage of this software is where, the controller can be designed totally based on the mathematical equations of the control theory [10,11]. The input and output of the equations need to be connected to the Arduino blocks that can be found in the Arduino library which is suitable in MATLAB 2010 or higher versions. This algorithm is operated as a closed loop feedback system for controlling the board in order to generate the control signal that is important for feedback signal. However, a necessary adjustment is needed for the Arduino board to achieve desired voltage

The project block diagram is shown in Figure 2. It consists of uncontrolled rectifier, control inverter, filter, Arduino microcontroller and output voltage processes/feedback. The voltage feedback has been used as a control strategy in order to make sure the output voltage from the inverter can follow the reference target voltage setting by the controller inside the Arduino.

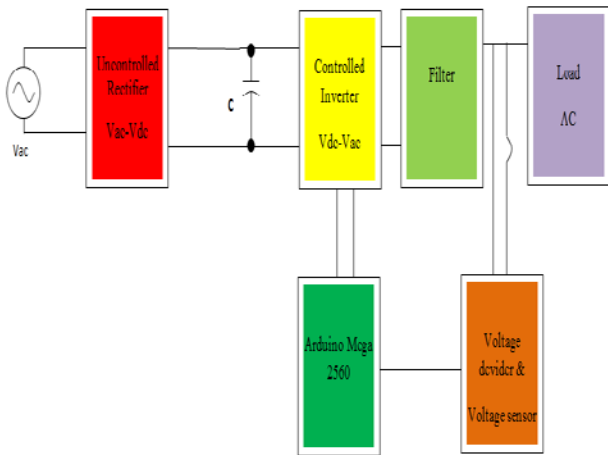


Fig. 2: Block Diagram of Project

2. Model Development with Voltage Control

The voltage feedback has been applied to this work due to simple control structure. As shown in Figure 2, the inverter output voltage has been the control mechanism for this project. The Proportional Integral (PI) control has been used for the control strategy.

The advantages of the PI control are the parameters gains are easily to select by using the try and error method and the respond of the control is faster. There are several papers explained on this control technique [9,10,11]. The function of PI controller is to compare the feedback voltage with the target reference voltage that will minimize the control error for the control. This will create a faster control response when it been injected to the PI control. The PI mathematical equation is given in Equation (1):

$$U(t) = K \left(e(t) + \frac{1}{T_i} \int_0^t e(t)dt \right) \quad \text{Eq (1)}$$

where;

t = time,

$u(t)$ = output,

$e(t)$ = control error (reference variable – measured variable),

K = Proportional gain,

T_i = Integral Time

The output value $u(t)$ for the controller is the sum of P and I gains. This mathematical equation has been transferred into Simulink Block diagram as shown in Figure 3. The value or the gains are depended on the response of the inverter output voltage in order to follow the reference voltage. Figure 3 consists the analog input block which is generated from the Analog to Digital (ADC) converter and also the Digital to Analog (DAC) converter as for the output block for switching operation.

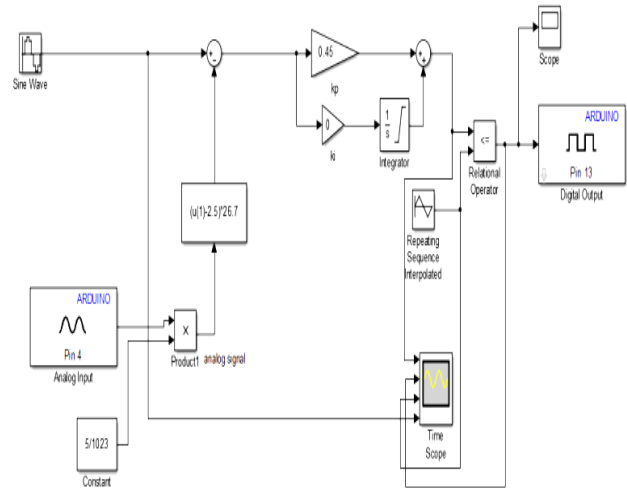


Fig. 3: Control block diagram complete with ADC and DAC blocks

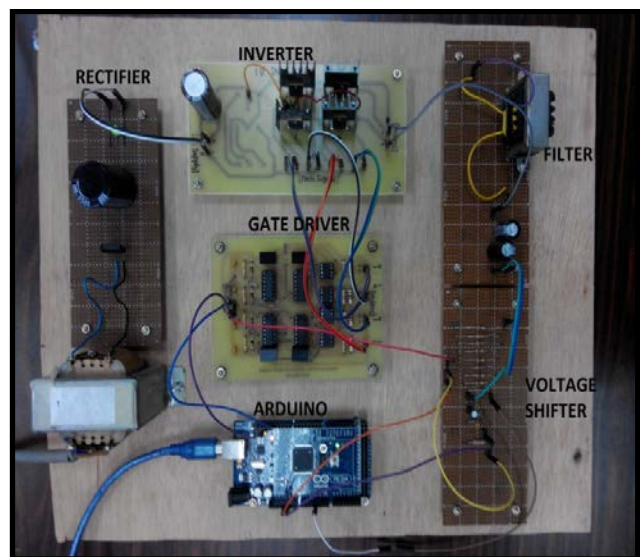


Fig. 4: Overall experiment setup

Figure 4 shows the complete experimental set up for this project. It shows the test ring with all the hardware

components in closed loop mode and with the Arduino. All the measurements have been recorded by using the oscilloscope for measuring the inverter output voltage. The other measurement results such as current and power are not given in this paper due to limited page. The feedback voltage signal is been sensed by the Arduino using the analogue input pin. Then, the Arduino will convert this analog input signal, with ADC function, in order to make a comparison from the target reference signal before feed in to the PI control. This signal will generate the PWM signal for the gate devices to the hardware setup. The value of K_p and K_i are determined by using try and error method. For more accurate gain values, the Ziglar-Niclocas technique or bode plot analysis can be conducted and will be discussed in next paper.

3. Results and Discussion

The experimental tests have been conducted with several target voltage references in order to see the effectiveness of the control strategy with the Arduino. The parameters setting for these tests are shown in Table 1 where it been chosen due to accessibility of the equipment's in the lab.

Table 1: Experiment's parameters

No	Parameters	Value
1	Input DC Voltage	44V
2	PWM Frequency Switching in Matlab	1kHz
3	Target Voltage (V_{mag})	16, 25,30,35

Figures 5-8 show the resulting output voltage of the inverter when the target voltages are changed accordingly by referring to Table 2. From these figures, the rms voltage measurement has been considered because the value is more significant with the input voltage. Figures 5 and 6 show the peak ripple problem at the inverter output voltage. These are due to filter design that has not been considered. However, when the target reference voltages are increased as shown in Figures 7 and 8, the inverter output results are much better. It indicates that the selection of the inverter size is better for high reference voltages. From those figures, it can be tabulated into reference output voltage signal as given in Table 2.

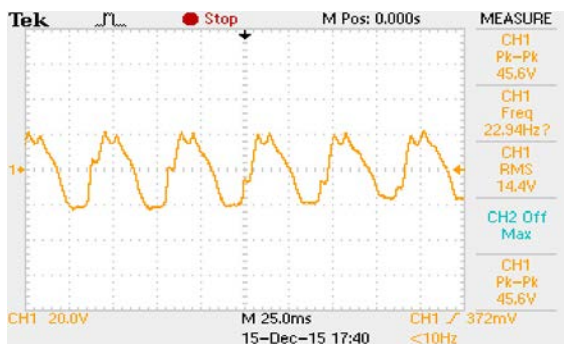


Fig. 5: Inverter Output when Voltage Reference is set at 14.1V_{rms}

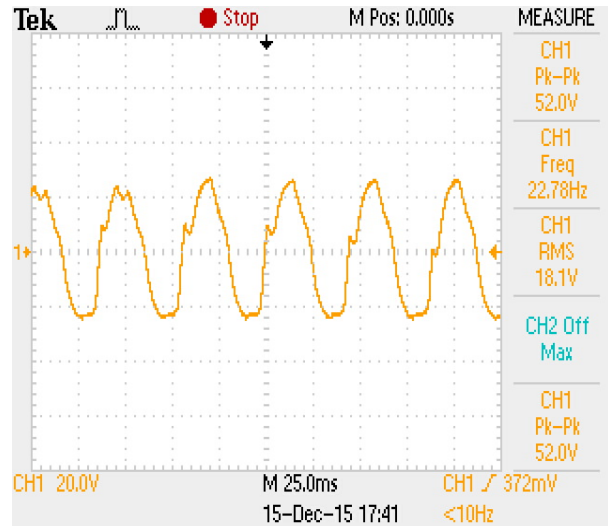


Fig. 6: Inverter Output when Voltage Reference is set at 18.1V_{rms}

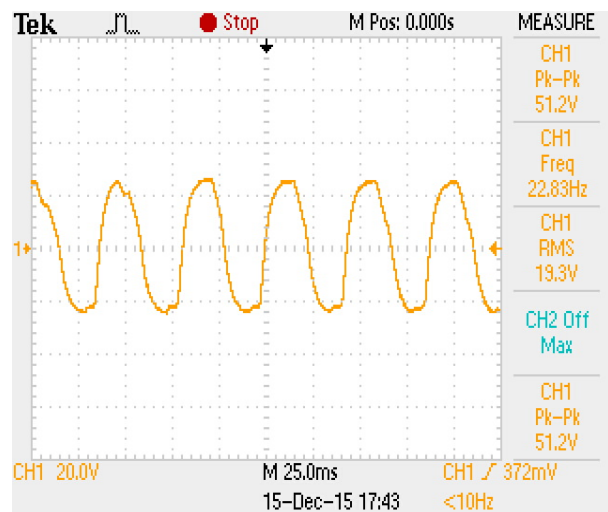


Fig. 7: Inverter Output when Voltage Reference is set at 19.3V_{rms}

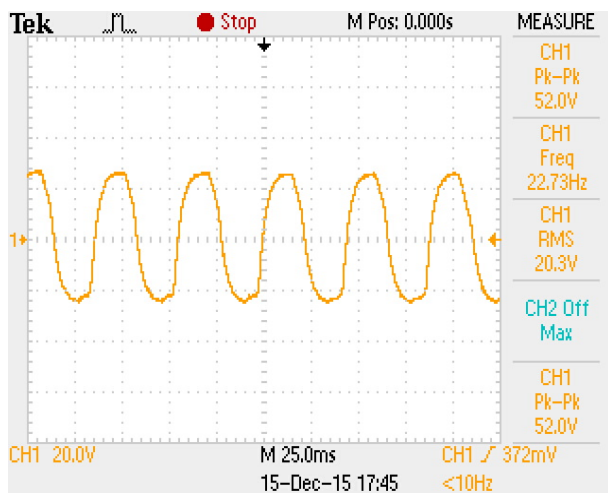


Fig. 8: Inverter Output when Voltage Reference is set at 20.3V_{rms}

Table 2: Input and Output experiment test

No Test	V_{rms} @ V_{mg} (ref@input)	V_{rms} (output)
1	14.1@ 16	14.4
2	17.7@ 20	18.1
3	21.2@ 24	19.3
4	24.7@ 27	20.3

As a summary from Table 2, when the target voltage reference is set to $14.1V_{rms}$ the control error is calculated at 0.3 due to the inverter output is at $14.4V_{rms}$. This error is considered low due to acceptable range of the error in the range of -1 to 1 [9,10,11]. This low control error remains same for the target voltage references at $17.7V_{rms}$ and for $21.2V_{rms}$ which is less than 1. When the target voltage value is set more than $20V_{rms}$ and above, the voltage error is increased due to limitation of the PI gains values. As mentioned before the PI gains are selected based on the try and error technique, whereby these gains have it limitation boundary due to unsupervised gains.

As for the Arduino microcontroller, the output switching can withstand at low frequency due to frequency split response at the DAC pin outputs. This problem can be solved, by using a high end microcontroller such as the Texas Instruments or D-Space microcontroller.

4. Summary

As a conclusion, a single phase back to back converter has been developed and tested by using Arduino microcontroller. This strategy gives a promising technique to be used in order to understand the concepts of power converters with closed loop feedback application. By using a simple PI control theory, it shows that the controller is working for controlling the outputs inverter in order to follow the target reference voltage that can create a minimum error signal for the controller.

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