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Finite Dimensional Repetitive Controller for Single Phase PWM Inverter

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Abstract— In this paper, a finite dimensional repetitive controller (FDRC) scheme is proposed to improve the performance of the output voltage of single phase two level sinusoidal pulse width modulated (PWM) inverter. A single phase two level SPWM inverter model is designed in simulation which provides the provision of deploying different control methods for comparing their sinusoidal tracking performance. Conventional PID controller and then FDRC have been incorporated in the SPWM inverter model and simulated their tracking performances. Comparison is carried out to show advantage, disadvantage or limitation of applied control schemes over conventional PID controller.

Keywords—SPWM Inverter, IGBT switch, IMP, Finite Dimensional Repetitive Controller, PID Controller

I. Introduction

Introduction Repetitive Control (RC) is a special learning control scheme for tracking periodic reference commands and attenuating periodic disturbance signal based on Internal Model Principle (IMP) [1]. In different applications like inverters, UPS, hard disk drive, robotics, and numerically controlled machines or in many industrial process applications, often such situations are encountered where the reference commands to be tracked and or disturbance to be rejected are periodic signals [2].

Inverter or power inverter is a device that converts the DC sources to AC sources. Power inverters produce one of three different types of wave output: Square Wave; Modified Square Wave (Modified Sine Wave) and Pure Sine Wave. PWM technique used to convert DC to sine wave. The DC signal is passed through the switching patterns of IGBT bridges to obtain a PWM signal (Fig 2). This signal is fed to an LC filter to obtain the desired sine wave [3, 4].

II. Development of the Control Scheme

Repetitive Controller:
It is a periodic signal generator in the feedback control algorithm satisfies the Internal Model Principle and allows for perfect tracking of periodic commands and perfect rejection of periodic disturbances. Structurally, using IMP, a controller is modeled with a delay element in the feedback loop that forms a periodic signal generator and thus creates a repetitive control (RC) system which is shown in Fig.1 .Transfer function of repetitive controller is given by: $\frac{1}{(1-e^{-sT})}$

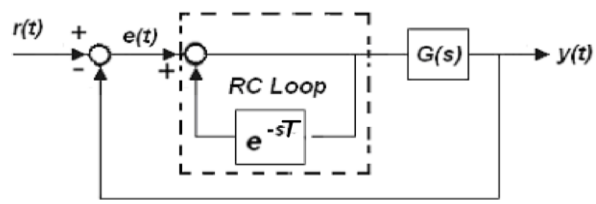

Figure 1. Block Diagram of Basic Repetitive Control System (RCS)

By the virtue of the roots of the conventional RC, it is infinite dimensional as it has infinity number of pole pairs on the imaginary axis in s-plane.

Finite dimensional repetitive controller (FDRC):
This is consists of repetitive controller with a low pass filter (LPF) in the stable close loop feedback path in series with transport delay to restrict the influence of high frequency open loop poles and to enhance the stability of the control system at the cost of tracking accuracy. Block diagram of FDRC is shown in Fig. 2.

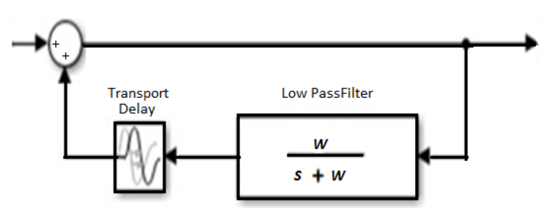

Figure 2. Finite Dimensional Repetitive Controller

In this case LPF is introduced in cascade with delay block of RC to transform the infinite dimensional repetitive controller (IDRC) to a FDRC. In IDRC infinity numbers of open loop pair of poles are present on imaginary *(jw)* axis, means infinity number of sinusoids are produced at open loop controller output which force the system towards verge instability. To restrict the instability, there is a need of a LPF to filter out the high frequency sinusoids and cut-off frequency is set in such way that it will match with reference input frequency to track the set command.

III. Modeling of a Single Phase Two Level SPWM Inverter

Some research has examined the closed-loop regulation of PWM inverters to achieve good dynamic response and most of them have focused on transient response improvement through instantaneous feedback control [5–10]. Periodic distortions in the output waveform remain when the load disturbance is cyclic by nature. Repetitive control theory, provides a solution for eliminating periodic errors which occur in a dynamic system. A repetitive controller can be viewed as a periodic waveform generator augmented within the control loop of a control system, which is closed-loop regulated by a feedback controller, so that the periodic errors can be eliminated. Haneyoshi et al. [11] and Nishida and Haneyoshi [12] have applied the repetitive control technique to eliminate periodic distortions in a PWM inverter. The performance and stability of such a repetitive control system is highly dependent upon the robustness of the original feedback control system.

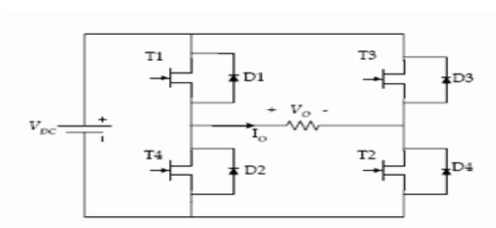

Figure 3. H-Bridge accomplished by IGBT switches

Pure sine wave inverters offer more accuracy and less unused harmonic energy delivered to a load. Pure sine wave inversion is accomplished by taking a DC voltage source and switching it across a load using an H-bridge. This H Bridge, here, is accomplished by using IGBT switches. The inverted signal itself is composed of a pulse-width-modulated (PWM) signal which encodes a sine wave.

Here, Vo is +VDC when T1 & T2 are ON and Vo is - VDC when T3 & T4 are ON.

Simulations:

From the very beginning of this work, the PWM inverter model of interest is the following model shown in Fig. 4.

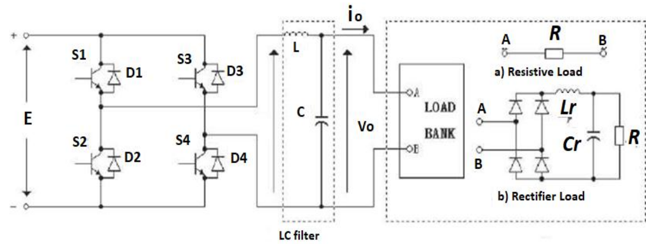

Figure 4. An Inverter model (with switches, filters and load)

The left side of this figure represents the H bridge configuration of IGBT switches, which will receive a DC voltage source of E and with an appropriate switching strategy, this will produce a PWM signal which will be further filtered by an LC filter for to get a proposed SPWM inverter. Many Simulink models has been developed and finally a model is selected in order to achieve more precise SPWM waves and hence a sine wave.

Proposed Model-1:

Figure 5 shows the first developed PWM model that employed four IGBT switches and provided their switching pulses separately. It is according to the logic of generating alternate signals by control the alternating switching action of IGBT 1 and IGBT 4 by a relational operator ((working as a logical comparator).

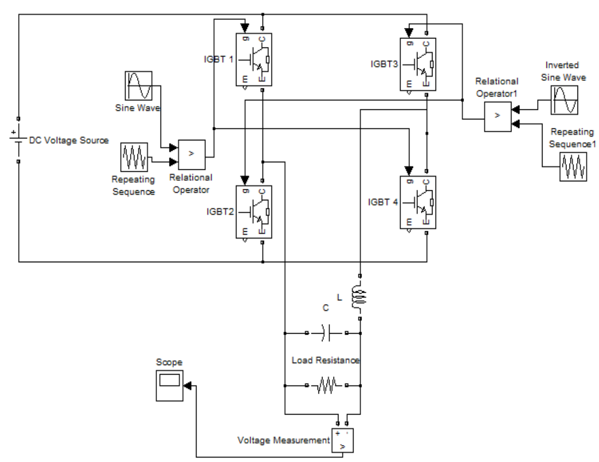

Figure 5. Proposed Simulink Inverter Model 1 with four IGBT switches

This comparator simply compares the high frequency triangular wave with a standard 50 Hz sine wave. Same thing is happening to IGBT 2 and IGBT 3 also, but their comparator is comparing high frequency triangular wave with an inverted sine wave, so that an alternating PWM signal can be received. Upon passing the model into an LC filter, an alternating voltage signal is obtained across the resistive load which is shown in Fig. 6.

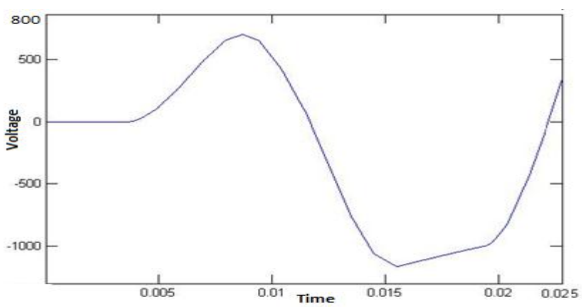

Figure 6. Output of PWM inverter for Model-1

It is obvious that the output voltage shows unsatisfactory sinusoidal tracking. After designing many arbitrary models, finally the proposed model is chosen referred as model 2 in this paper which can generate far better sinusoidal signal.

Proposed Model-2:

In the final model 2, as shown in Fig. 7, a universal bridge type IGBT gates array employed in PWM generation for switching IGBT gates. One advantage of this model is that it can be modeled in a closed loop system, after which a controller can be implemented in the system. Here a reference standard sine wave of 50Hz and amplitude 240 is given to PWM generator. Following are the specifications of the Simulink model: Filters specification: r =15Ω; L = 10 mH; C = 50μF. A DC bus voltage of 400 V is given to 2 arm 4 pulses universal bridge. PWM Generators specification: Carrier frequency is 10KHz; modulation index is 0.8. Output frequency is 50Hz (as desired) and phase is zero.

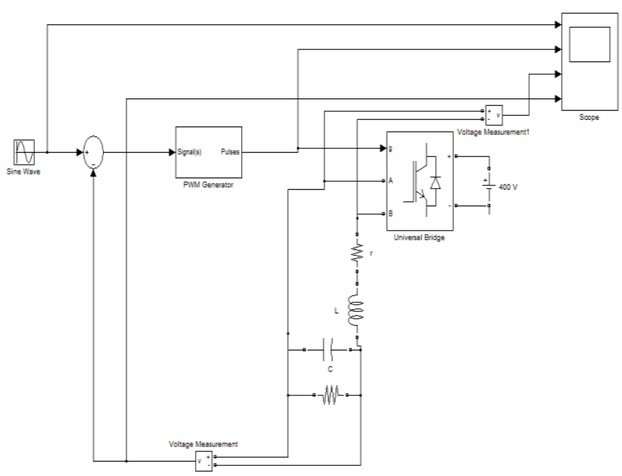

Figure 7. Proposed Simulink diagram of Model-2

Figure 8 shows the Reference sinusoid of 50 Hz and the output of PWM generator as a switching signal to Universal Bridge. Figure 9 shows a converted sine wave produced by LC filter accepting inverted PWM signals and Fig. 10 shows the complete block diagram of the experimentation.

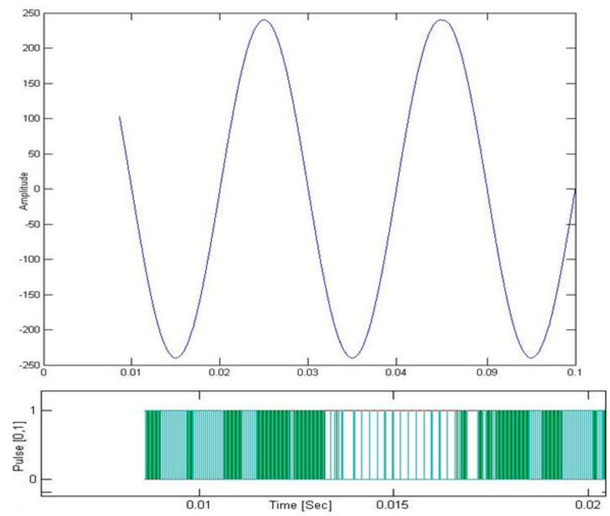

Figure 8. Top: Reference standard sine wave of 50 Hz; Bottom: The output of PWM generator, (as a switching signal to Universal bridge).

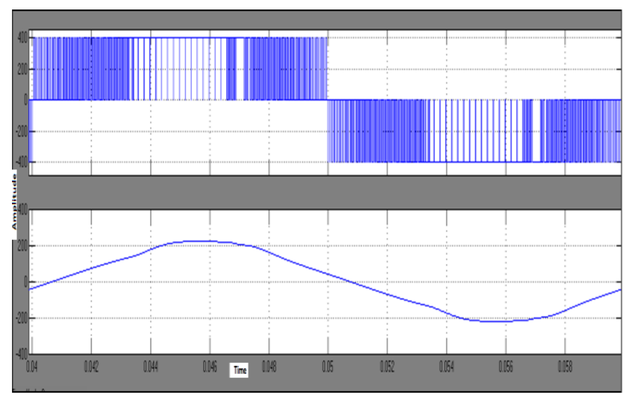

Figure 9. PWM wave is converted into sine wave by LC filter

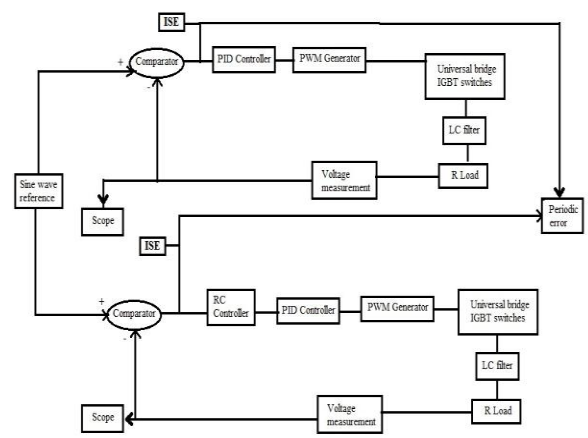

Figure 10. Block diagram representation of the complete SPWM Inverter closed loop model incorporating FRDC controllers

In the above model (Fig. 10) upper part consists of conventional controller (PID) and bottom part is of FDRC for better controlling and tracking. Subsystem-1 is the FDRC loop. Performance of the PID controller and FDRC are compared in terms of the tracking error.
Tracking error comparison with PID and FDRC subjected to PWM inverter are shown in Fig.11.

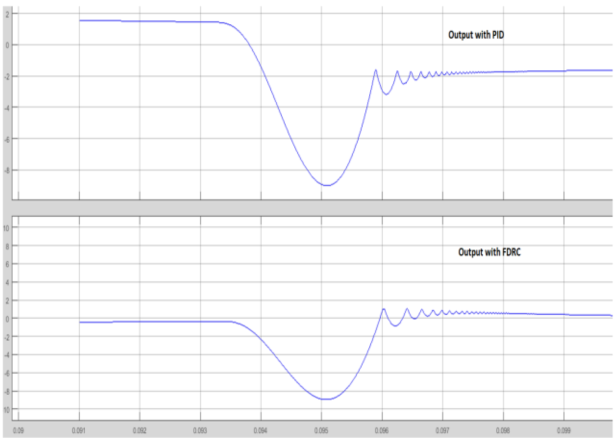

Figure 11. Tracking error of SPWM inverter with PID and FDRC

Figure 12 and Fig. 13 shows error bar diagram for PID and FDRC respectively.

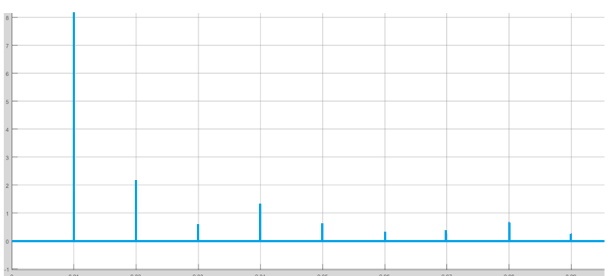

Figure 12. Error bar graph with PID controller only

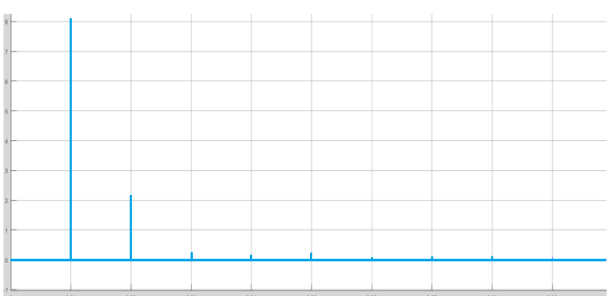

Figure 13. Error bar graph with FDRC controller.

It is found that the **ISE with PID controller is 2.603 and with FDRC is 0.084.** Hence the error is reduced by approximately 31 times.

IV. Conclusions

In this paper, modelling and simulation of a SPWM with FDRC is described in brief. Simplification and assumptions are taken to minimize the complexity of system practical system.

Performance comparison between the FDRC and PID controller is shown in terms of tracking performance.
Results shows, RC can be considered as a better option for the application in inverters and thus for periodic reference tracking, it is better to use repetitive controller instead of conventional PID controller.

Although in many cases repetitive controller is not working properly. Especially when time constant is unknown and where error is not changing significantly.

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Authors Profile

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