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Analysis and Comparison of Switching Techniques of Electronic Load Controller for Micro-hydro Power Plants

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Abstract

This paper presents the four common switching techniques used in today's ELCs. Switching techniques cited in this paper are Binary dump loads control (BDLC), Phase angle control (PAC), Mark to space ratio (MSR), and Pulse width modulation (PWM). The paper modelled the four switching schemes in Matlab-Simulink and compares the switching techniques in term of power and voltage response, total harmonic distortion induced, and frequency deviation of the systems. Furthermore, this paper presents a significant difference of the said switching techniques that could be a basis for future designs and implementation of ELC for small and micro hydro power plants.

***Keywords**:* switching techniques, self excited induction generator (SEIG), electronic load controller (ELC).

1. Introduction

1.1 The Background

In the past decades, electronic control of voltage and frequency for small and micro hydro plant had a significant development over the electrical control (generator control) and mechanical control (turbine control). The key feature of electronic control that makes it more attractive is that it responds quickly on load changes, it offers low maintenance than mechanical, and it is less complex than electrical control. Figure 1 is a block diagram of a power system that consists of a single generator and a single load with an Electronic load controller.

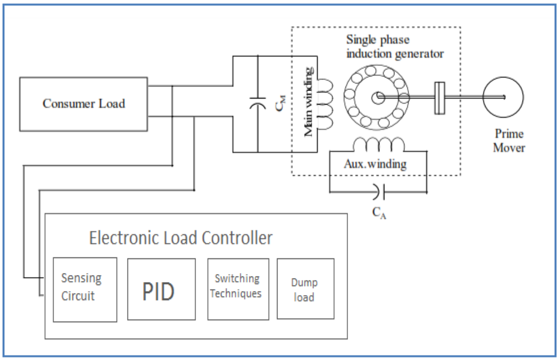

Figure 1. Block diagram of a simple power with electronic load controller

The basic concept an ELC is to let the turbine and generator run at their full power, or possibly a manually set partial power, and keeps the electric load just right to attain the correct speed (Vimal *et al.*, 2012). ELC measures the voltage and frequency and control the power to the dump load(s) to compensate the change in the main load. Maintaining a near constant load (user load plus dump load) seen by the generator will result to a stable voltage and frequency. Figure 2 shows the ideal power curve of a generator (black line) with an ELC and a variable main/user load (blue line). However, selecting the appropriate switching technique in controlling the dump load is crucial hence it would affect the performance of ELC. Thus, this paper discusses the common switching technique used in ELC.

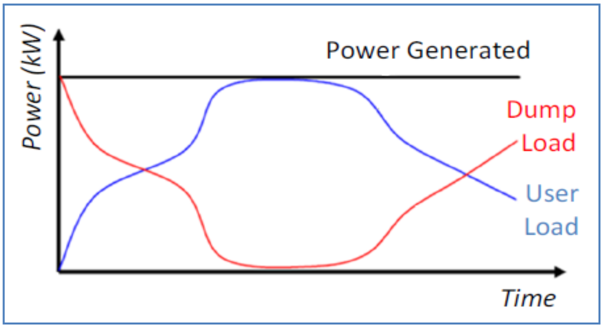

Figure 2. Power Curve of a Typical ELC

1.2 The Objectives of the Study

The main objective of the study is to compare the existing ELC switching techniques i.e. Step Size, Phase Angle control, Mark to Space Ratio, and PWM control. Specifically, the study aimed to compare these control schemes based on their system performance and the induced harmonic distortions.

2. Methodology

To simulate and to compare the four electronic load controller switching techniques, a generator and load was first modelled using Matlab and Simulink. Figure 1 is a schematic diagram of the modeled SEIG-ELC system. It consists of a single phase two-wingding squirrel cage induction machine operating as SEIG driven by an unregulated prime mover (e.g. small or micro hydro turbine). The excitation capacitors are connected at the terminals of the auxiliary (CA) and main windings (CM) as shown in figure 8. These capacitors have fixed values to result in rated terminal voltage at rated load (Gao *et al.*, 2012). The ELC consists of four basic subsystems: the sensing circuit to read the rms line voltage, The Proportional Integral Proportional controller (PID), Dump load, and the Switches.

In this study, the SEIG, consumer load, and some portions of the ELC parameters are held constant. The Switching method, PID constants and dump load are the only components of the Matlab-Simulink model that were varied. Constants and assumptions used is this study is listed in appendix B.

2.1 BDLC-ELC Model

Figure 3 is a model of step size control of dump load with the necessary measurement and plot block. Details of the triggering circuit and dump load block in shown Figure 4. It consists of a triggering circuit, triac, and dump loads. There are 10 dump loads switched independently to provide the necessary dump load variations. The dump loads are rated 160 watts each.

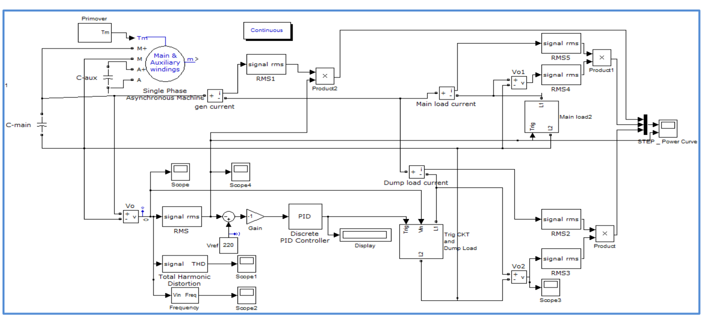

Figure 3. BDLC Matlab Simulink Model

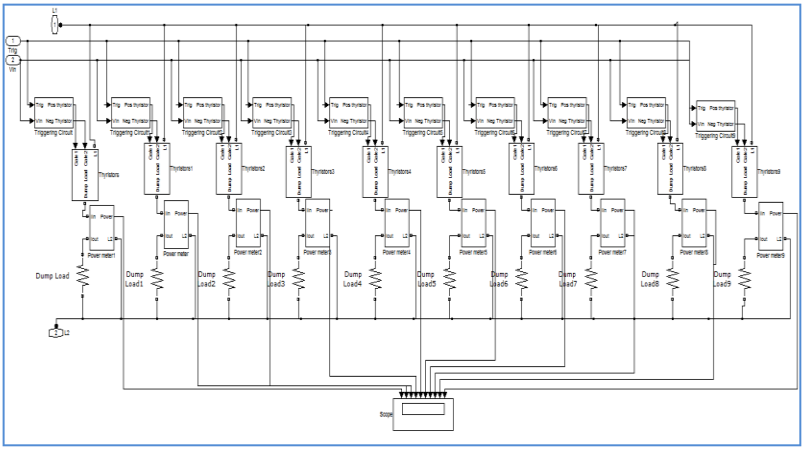

Figure 4. Triggering and Dump Load Circuit of BDLC Model

2.2 Phase Angle Control Model

As mentioned, switching method, dump load, and PID constants are the parameter that will be changed in the system. The triggering circuit and dump load blocks in step dump load model were replaced with thyristors connected back to back to represent a triac and a triggering block. The triggering block provides the firing angle/delay of the thyristors that is proportional to the output of the PID controller. Figure 5 is the Matlab-Simulink model of the PAC.

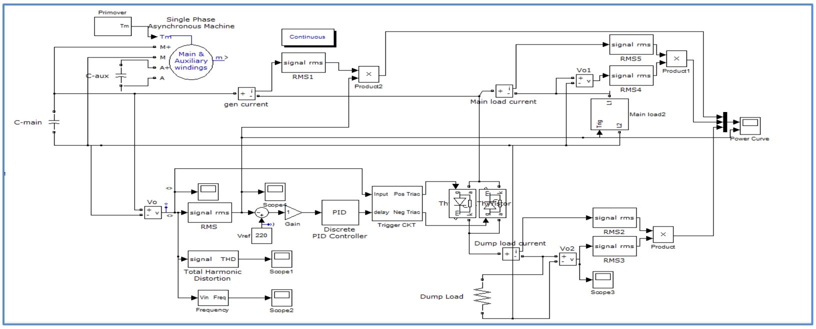

Figure 5. Phase Angle Control Matlab Simulink Model

2.3 Mark to Space Ratio Model

Figure 6 shows the dump load mark to space ratio control. In this model, a bridge rectifier's AC terminals are connected across the line. Also, bridge rectifier's negative and positive terminals are connected to ground and to the IGBT's collector terminal respectively. The dump load is connected to IGBT's emitter, ground, and measuring blocks. The pulse width that is proportional to the PID output is provided by a PWM generator (represented by repeating sequence, rational operator and gain blocks) running at 1kHz.

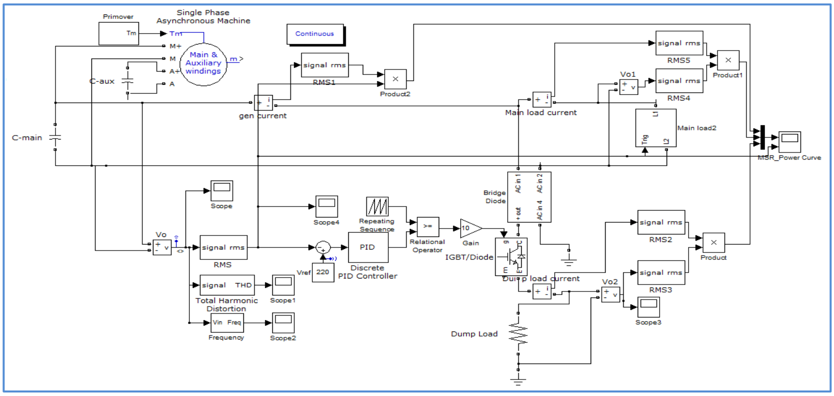

Figure 6. Mark to Space Ratio Matlab Simulink Model

2.4 PWM ELC model

This scheme is basically patterned from MSR. The only difference of PWM with MSR control is the filter capacitor that is connected to the DC terminals of the rectifier. The capacitor is rated 1000 uF. This is sized to provide a less than 5% ripple factor. Figure 7 shows the PWM control model of ELC.

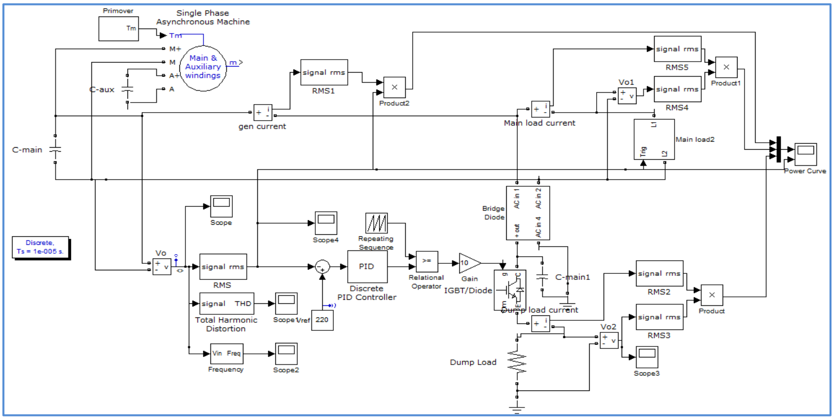

Figure 7. PWM Matlab Semolina Model

2.5 System Response and Harmonics

In this paper, the voltage, frequency, total harmonic distortion (THD) , and power responses including the settling time were determined and quantified graphically using the Matlab Simulink plot block.

3. Results and Discussion

The Matlab Simulink models were simulated for a duration of 8 seconds. The main loads are divided into two resistive loads of 200 watts and 1000 watts and were switched separately, 2 seconds after the generator start generating and 5 seconds after the generator starts generating.

3.1 Power and Voltage responses

Figures 8 to 11 are the power and voltage response of the ELC controllers. The upper graph of each figures are power wave forms with the vertical axis in watts. Blue, red, and green lines are generator, dump load, and main load powers respectively. The lower graph is the line rms voltage with vertical axis in volts. The horizontal axis is time in seconds.

In the figures, the settling time of the four switching techniques is almost the same. Settling time of four systems are approximately 2.5 sec. Also, it can be observed that PWM has the finest and smoothest response and Phase Angle Control has the roughest response.

Moreover, PWM has the best voltage regulation and PAC has the largest voltage fluctuation, with around 40 to 50 volts difference.

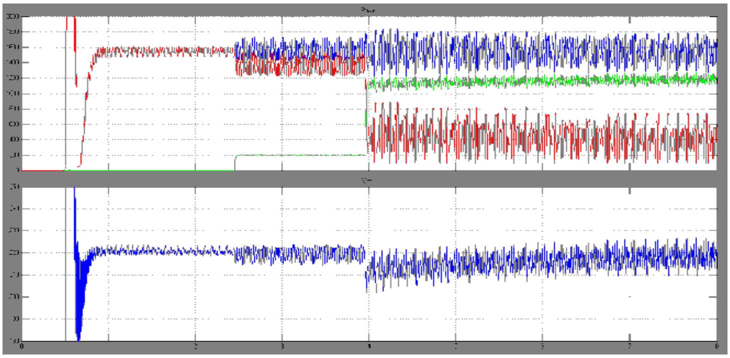

Figure 8. BDLC Power and Voltage Response

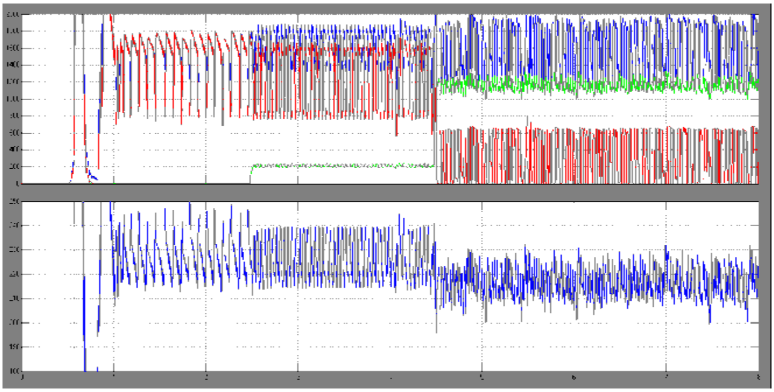

Figure 9. Phase Angle Control Power and Voltage Response

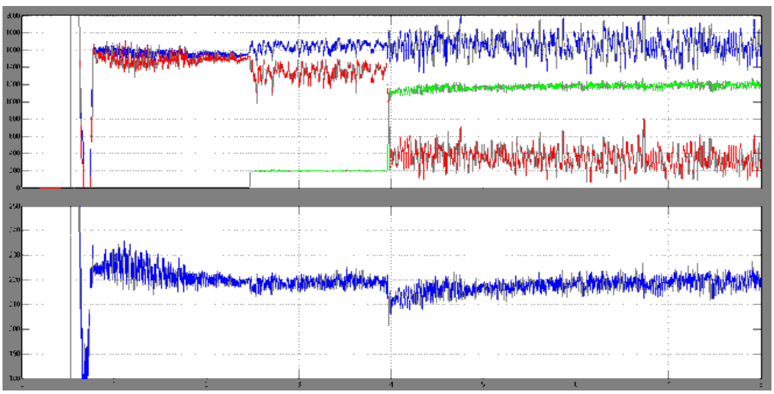

Figure 10. Mark to Space Ratio Power and Voltage Response

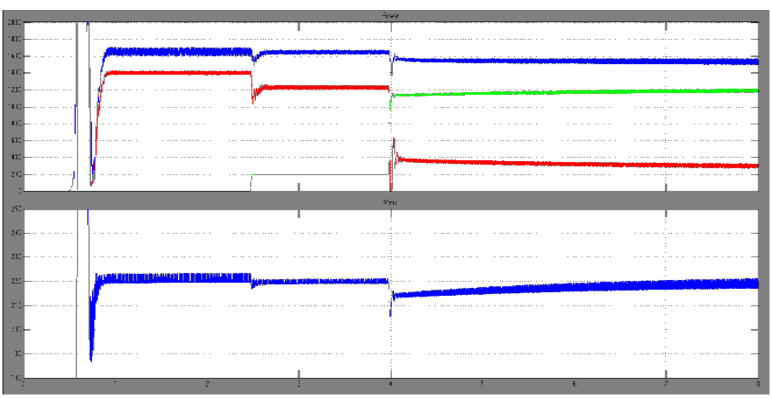

Figure 11. PWM Power and Voltage Response

3.2 Line Voltages

Figures 12 to 15 are the line voltages of the four switching techniques employed in an ELC. The vertical axis is voltage in volts and the horizontal axis is time in seconds. From Figures 12 it is observed that Step size dump load control's line voltage magnitudes were not the same yet it is a smooth sine wave. While in Figure 13, PAC line voltage magnitudes are not the same and wave form is distorted this is due to the firing of the thyristors at the middle of the wave (not at zero crossing). In Figure 14, MSR's line voltage wave form magnitudes are the same but with distortion. In Figure 15 is the PWM's line voltage, whose magnitudes are the same but whose top or peak of the wave is flat.

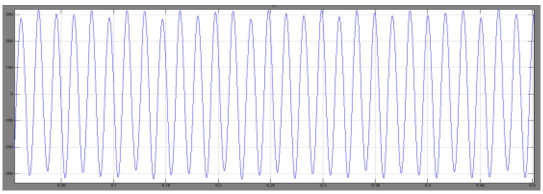

Figure 12. Step Dump Load Line Voltage Wave Form

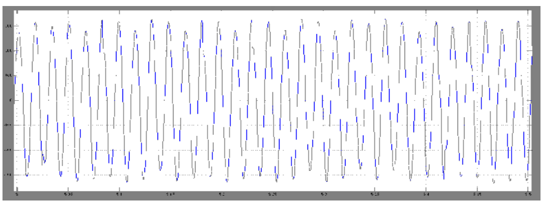

Figure 13. PAC Line Voltage Wave Form

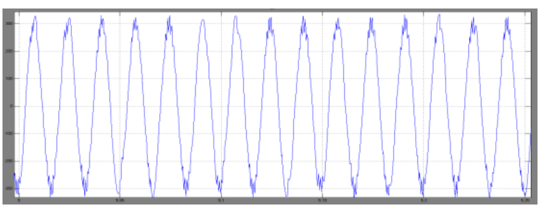

Figure 14. MSR Line Voltage Wave Form

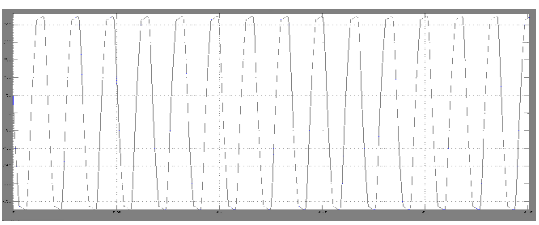

Figure 15. PWM Line Voltage Wave Form

3.3 Total Harmonic Distortion

Figure 16 to 19 are graphs of the induced total harmonic distortions of four switching techniques. The vertical axis is the THD in % while horizontal axis the time in seconds. It can be observed that PWM has the highest magnitude of Total Harmonic Distortion with a maximum of 32.5% and Step has the least THD with a maximum of 10%. The rest more likely have the same magnitude.

Although MSR and PWM were running at the same switching frequency, PWM has a greater THD because it has a filtered DC voltage available for the dump load. Thus, when dump load is suddenly switched on/off there is a huge change in current or inductive kick occurs.

Furthermore, THD of the switching techniques did not met the tolerable limits defined by the Philippine Distribution Code (ERC, 2001).

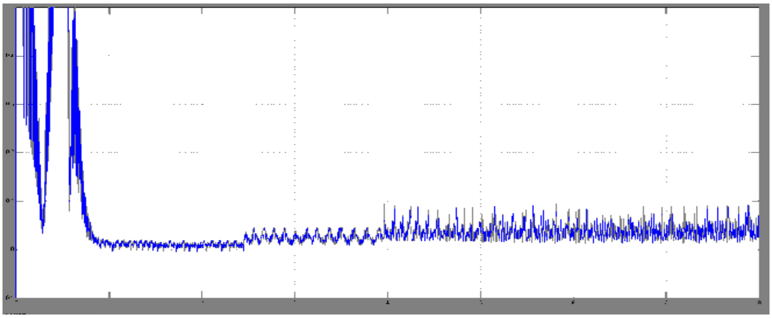

Figure 16. Binary Dump Load Induced THD

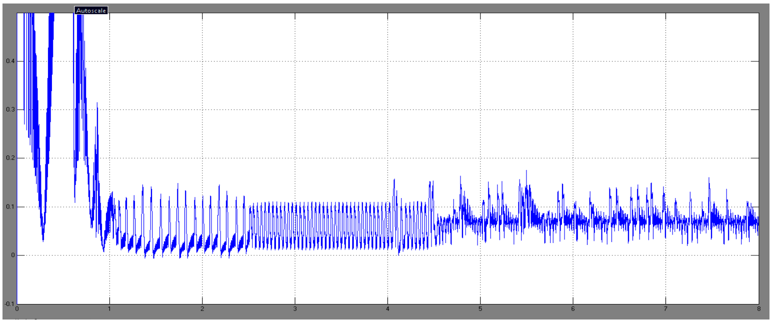

Figure 17. PAC Induced THD

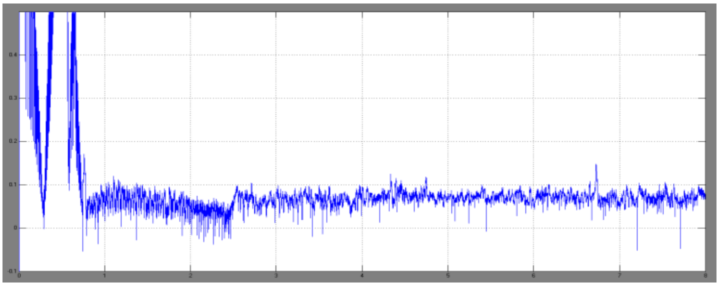

Figure 18. MSR Induced THD

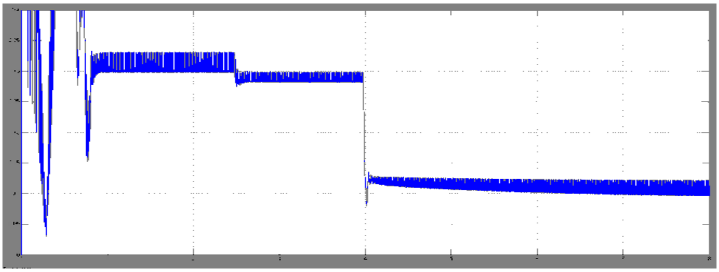

Figure 19. PWM Induced THD

3.4 Frequency

Table 1 is the average frequencies of different switching technique employed in an ELC. It can be observed that frequency of the controllers are within the tolerable limits set by the Philippine Distribution Code (ERC, 2001).

Table 1. Average Frequency of ELCs

Switching Techniques	Ave. Frequency (Hz)
BDLC	59.43
PAC	60.29
MSR	59.86
PWM	59.97

4. Conclusions

In previous chapters, common switching techniques were modelled and simulated using Matlab and Simulink. Table 2 shows the tabulated results of the simulations. It is observed that switching schemes has a significant difference in their THD and RMS voltage fluctuations.

Table 2. Simulation Results

	BDLC	PAC	MSR	PWM
Settling time	~2.5sec	~2.5sec	~2.5sec	~2.5sec
Max. THD	9%	15%	12%	33%
Line voltage wave Form	Magnitudes are uniform	Unequal and distorted	Uniform and distorted	Uniform and peaks are flatted
RMS voltage fluctuations	15V	25V	12V	3.5V
Average Frequency	59.43Hz	60.29Hz	59.86 Hz	59.97 Hz

Furthermore, in the modelling the ELCs no filters that were used. Thus, THDs of the ELCs could be minimized without affecting the performance.

5. References

Energy Regulatory Commision (ERC), (2001). Philippine Distribution Code.

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