

ENERGY SAVING ELECTRONIC BALLAST WITH PASSIVE AND ACTIVE POWER FILTER FOR STREET LIGHTING

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Abstract— The energy usage of street lighting is not fully controlled. It is on from 7p.m to 7a.m with same brightness. This paper presents an energy saving electronic ballast with passive and active power filter. The power usage is divided into 3 duration zone by controlling the modulation index in PWM generator. Passive and active power filter is incorporated in the circuit to reduce the harmonics. The duty cycle in an active power filter can also be controlled to vary the output power. The simulation is carried out using MATLAB/Simulink.

Keywords— High Pressure Sodium Lamp (HPS), Passive Power Filter, Active Power Filter, Modulation Index, Duty Cycle

I. INTRODUCTION

Nowadays, energy problems has long become global concerns, the world is racing to find energy solution due to energy shortage, high energy price, unsecure of energy supply and not eco-friendly in energy consumption [1]. Hence, the green technologies strategies was introduced which are called energy saving solution. One of the applications in energy saving solution is to introduce electronic ballast to be installed on street lighting. Normally, all street lighting uses the conventional magnetic ballast.

The conventional street lighting consists of ballast, igniter, capacitor, photoelectric and high pressure lamp (HPS) [2]. Every component has their own function whether during starting operation or normal operation. Photoelectric or timer is a sensor to control switch ON/OFF for conventional street lighting and its design depending on the manufacturer.

Currently, there are various types of high intensity discharge lamps for street lighting model and the specification available in the market are Metal Halide lamp, High Pressure Sodium (HPS) lamps, Low Pressure Sodium (LPS) lamps and Mercury Vapor lamps. A high Pressure Sodium (HPS) lamp is widely used in public illumination [3].

In 2007, the researcher from china developed the electronic ballast that used dimmed method in street lighting. The configuration of this electronic ballast consists of EMI filter, full bridge rectifier, power factor corrector, half bridge inverter, resonant load circuit and microprocessor to drive circuit. The advantages using electronic ballast are highest system efficiency due to lower ballast losses, highest lamp colour uniformity and constant light output [4].

This paper presents strategy to control the power consumption by using modulation index. Setting the high modulation index, the consumption of energy will be increased. Passive power filter approaches are used in low power and low cost application. Passive power filter method is simple, low cost but has bulky size and heavy weight. For active power filter, it is used for high power level and low harmonic distortion. The simulation is carried out using MATLAB/Simulink.

II. METHODOLOGY

Figure 1 shows the flowchart to design electronic ballast system.

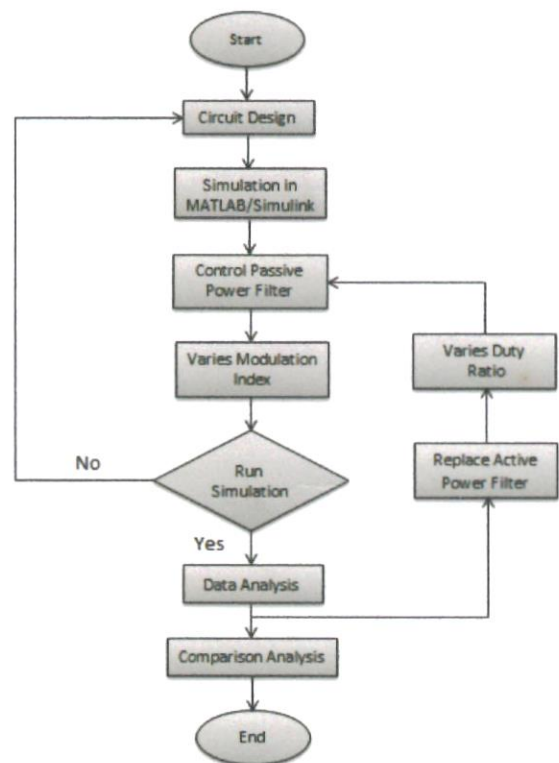


Figure 1: Flowchart of the project.

A. Circuit Design

The main circuit is divided into four important parts, EMI filter, single phase full bridge rectifier with power filter, single phase full wave inverter and lastly resonant load circuit as shown in Figure 2.

The first part, the power supply will flow into EMI filter circuit. The EMI is a disturbance that affects the electronic circuit due to electromagnetic radiation that from external source such as radio frequency, broadcasting and others. To remove that noise in this circuit, the EMI filter will be used. The function of this filter devices used in circuit is to suppress conducted interference found in a signal [5].

Secondly, it will flow into full bridge rectifier and power filter. The main function of rectifier is to produce a voltage or current which is purely direct current (DC). Then, for power filter, it will maximize both the power handling capacity of the power and current handling capacities of power distribution network [6].

Thirdly, for inverter part, it will convert the direct current from rectifier to alternating current. For this inverter, the switches is used are MOSFET. To control the switches of these devices, the pulse width modulation (PWM) can be used. Normally, in PWM system, the pulses are generated by comparing a triangular carrier waveform to a reference modulating signal that can be generated by the PWM generator [7].

Lastly in electronic ballast system, it will flow into the resonant load [8].

To draw complete circuit for electronic ballast using MATLAB/Simulink, the component only on simpower systems and simulink libraries are chosen. Set the configuration parameters to ode23tb before start drawing the circuit. Appendix A show the complete circuit for electronic ballast with passive power filter and active power filter respectively.

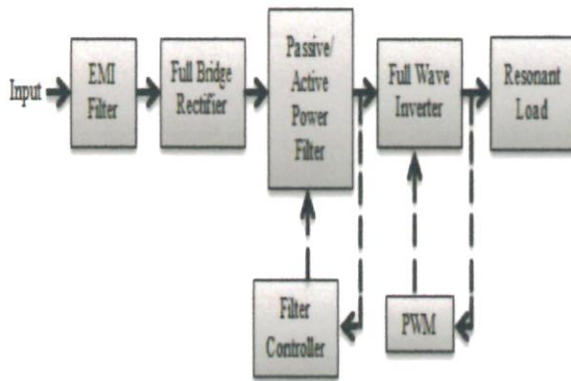


Figure 2: Block diagram for electronic ballast

B. Control Passive Power Filter

In passive power filter approaches, passive elements are used to improve the power quality of the power circuit. Passive elements like inductors and capacitors are placed at the inputs or outputs of the diode bridge. The capacitor C_f in this design has the main function to receive the reactive current from the electronic ballast. It also works as line filter with the L inductor [9]. The value for capacitor can be changed. To reduced harmonic, the value of capacitance must be high.

C. Control Active Power Filter

Active power filter circuit is small in size but the system has higher manufacturing cost and complexity. For this circuit, boost converter is used as active power filter. Active power filter is achieved by the power switch duty cycle. The inductor current ramps down to zero every time the switch is kept OFF. It is switched ON again only after inductor current touches zero for some time. SO, this active circuit is control using ON period of the switch directly [10]. The width of this pulse decides the ON time of the boost switch in a switching period and will remain constant under steady state. During the OFF period of the switch the inductor current drop and is allowed to go to zero. When the current zero is sensed, the switch is switched ON. Figure 3 shows block parameter to control duty cycle in boost converter.

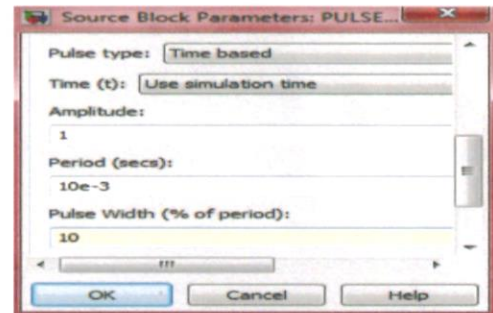


Figure 3: Block parameter to vary duty cycle

D. Varies Modulation Index

The energy level is divided into three consumption zone which are 100%, 80% and 50% of energy. The 100% of energy, operate starting from 7 p.m to 12 a.m, the 80% of energy operate starting from 12 a.m to 3 a.m and lastly for the 50% of energy operating time starts from 3 a.m to 7 a.m. By using this system, the total energy usage can be reduced. The most important part is to determine the consumption of energy by varying the modulation index in the pulse generator. Normally, the range of modulation index is between zeros to one. When the value of modulation index has come close to one, it represent the consumption of energy is increasing but when the value of modulation index has come close to zero, it show that the consumption of energy is decreasing. To save the consumption of energy daily, the value of modulation

index must be control follow the demand. Figure 4 show block parameter to vary modulation index.

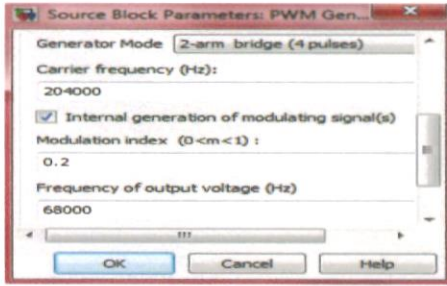


Figure 4: Block parameter to vary modulation index

E. Simulation

Simulation result was carried out using passive and active power filter connected to 40 ohm resistor as load (HPS Lamps). The peak value for voltage and current outputs was tabulated. The waveform voltage and current was captured and analysed. The voltage at rectifier circuit is recorded. This step is repeated using different modulation index of 1, 0.8 and 0.5. For active power filter, the additional part is boost converter. The duty ratio is varied with 10%, 20%, 30%, 40% and 50%.

III. RESULTS AND DISCUSSION

Figure 5 illustrates the results of voltage waveform without and with EMI filter. The peak voltage for ballast without EMI Filter is 260V and peak voltage for ballast with EMI Filter is 311.1V. It shows that voltage flow in the rectifier for electronic ballast with EMI filter is better and can achieve high peak value compare with without EMI filter. So, EMI filter mitigate noise or disturbance in electronic ballast.

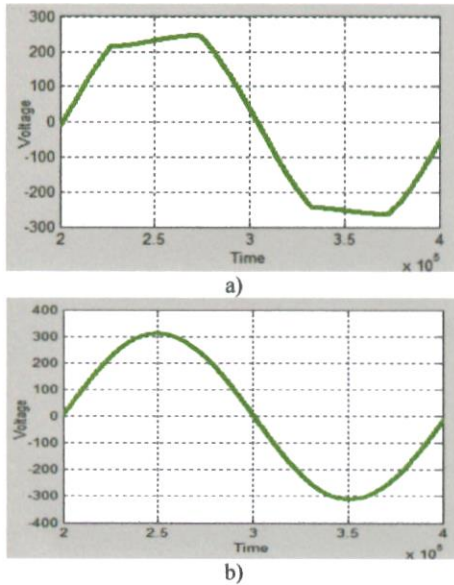


Figure 5: (a) Input voltage without EMI filter and (b) Input voltage with EMI filter

A. Passive Power Filter

Figure 6 shows the output voltage waveform from rectifier circuit which is 311.1V. The main function of rectifier is to produce a voltage or current which is purely direct current (DC) from alternating current source (AC). So, the voltage enter the inverter (MOSFET) is DC. The modulation index of a PWM generator is varied to control the energy usage. The PWM generator is used to control the level of brightness for the lamp by varying the value of modulation index. The range of modulation index is between zero to one. Increasing value of modulation index represent the higher energy usage. The setup of modulation index is divided in to three duration zone. First condition, the modulation index was put equal to 1 to represent full brightness. When midnight, the modulation index change to 80 precents brightness and in the morning, the modulation index will switch to 50 percent brightness.

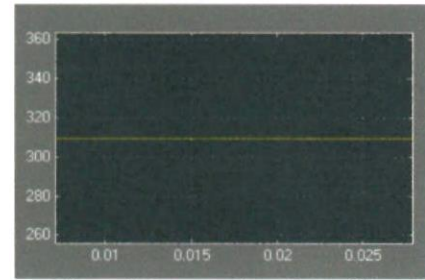
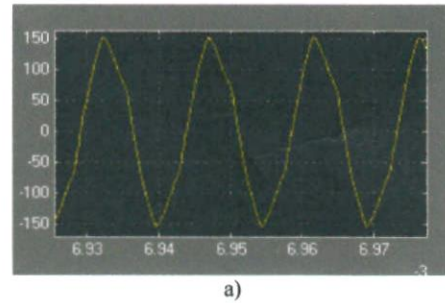
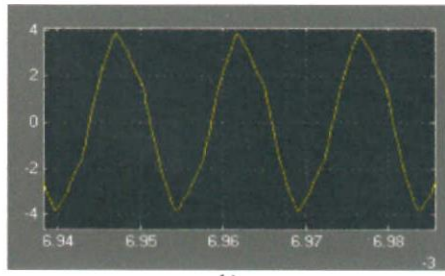


Figure 6: Output voltage for rectifier

1. Modulation Index, $m=1$

For the first level, Figure 7 shows the voltage and current when modulation index is set to 1. For this waveform, the value of voltage and current of HPS Lamp in sine wave. The peak value for voltage and current when modulation index is 1 are 154V and 3.85A respectively. The RMS value for voltage and current is around 108.9V and 2.72A respectively. The energy usage is 296W.



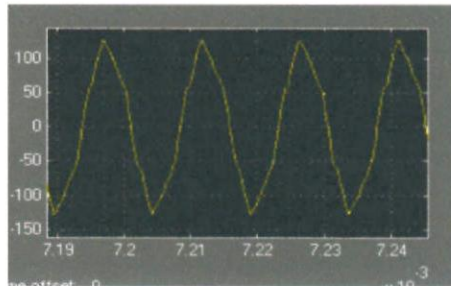


b)

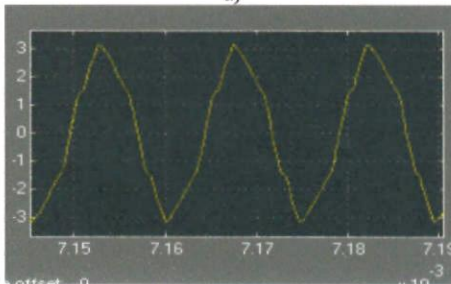
Figure 7: a) Output voltage and b) Output current waveform with $m=1$

2. Modulation Index, $m=0.8$

The value of modulation index is changed to 0.8. When the modulation index decreases, automatically the value of voltage, current and power also decrease. Figure 8 shows the output voltage and current waveform in HPS lamp. The peak value for voltage and current when modulation index is set to 0.8 are 140V and 3.50A respectively. The RMS value for voltage and current is around 98.9V and 2.47A respectively. The energy usage is 245W.



a)

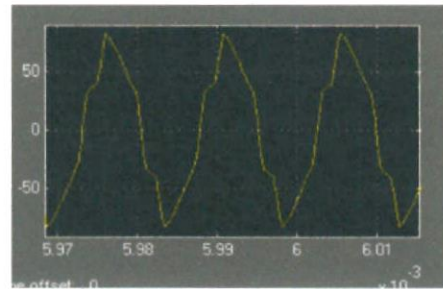


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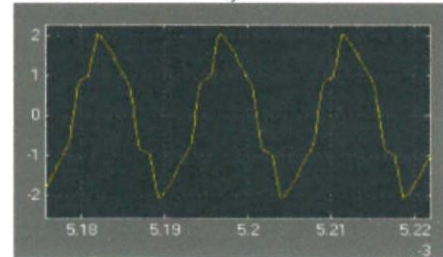
Figure 8: a) Output voltage and b) Output current waveform with $m=0.8$

3. Modulation Index, $m=0.5$

Lastly, the value of modulation index is reduced to 0.5. The peak value for voltage and current when modulation index is set to 0.5 are 82V and 2.05A respectively. The RMS value for voltage and current is around 57.9V and 1.45A respectively. The energy usage is 85W. Figure 9 shows the voltage and current waveform.



a)



b)

Figure 9: a) Output voltage and b) Output current waveform with $m=0.5$

Table 1 summarised the results when modulation index was varied. When modulation index increases, the voltage, current and power also increase. The value of voltage rectifier is constant although the modulation index was changed.

TABLE 1
SUMMARISED RESULTS WHEN MODULATION INDEX VARIES

Modulation Index (m)	Rectifier Voltage (V)	Lamp Current (A)	Lamp Voltage (V)	Lamp Power (W)
1	311.1	3.85	154	296
0.8	311.1	3.50	140	245
0.5	311.1	2.05	82	85

Figure 10 shows the graph for lamp current, lamp voltage and lamp power versus modulation index. From this graph, it can be concluded that when modulation index increase, the value of voltage, current and power also increases.

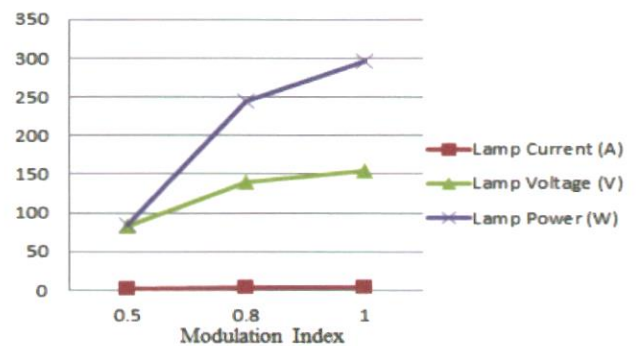


Figure 10: Graph for voltage, current and power versus modulation index

B. Active Power Factor Filter

Figure 11 shows the output voltage waveform of rectifier when using active power filter. The output voltage is 372V higher than the passive power filter. Normally, for active power filter, the boost converter topology is the most commonly used. For this active circuit, the duty cycle was set to 20%. A 20% duty cycle means the power is on 20% of the time and off 80% of the time. So, from simulation observation, increasing value of duty cycle in pulse generator, the value of voltage, current and power also increases.

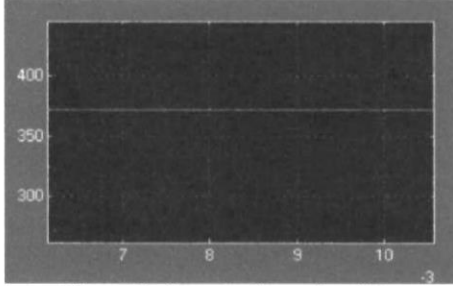
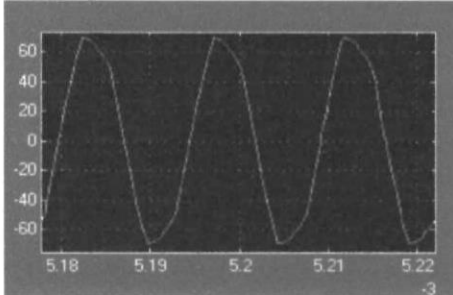


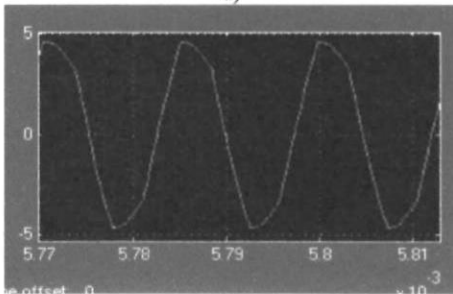
Figure 11: Output voltage of rectifier

1. Modulation Index, $m=1$

Figure 12 shows the voltage and current when modulation index is 1. The peak value for voltage and current are 69V and 4.6A respectively. The RMS value for voltage and current is around 48 V and 3.3A respectively. The energy usage is 158W.



a)

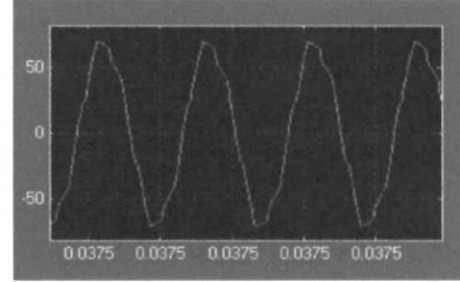


b)

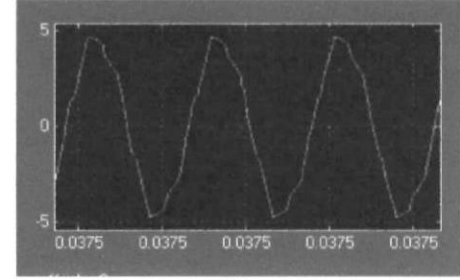
Figure 12: a) Output voltage and b) Output current waveform with $m=1$

2. Modulation Index, $m=0.8$

The value of modulation index is changed to 0.8. Figure 13 shows the output voltage and current waveform in HPS lamp. The peak value for voltage and current are 65V and 4.4A respectively. The RMS value for voltage and current is around 46V and 3.1A respectively. The energy usage is 143W.



a)

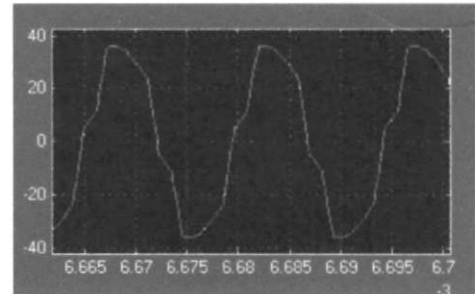


b)

Figure 13: a) Output voltage and b) Output current waveform with $m=0.8$

3. Modulation Index, $m=0.5$

Lastly, the modulation index is reducing to 0.5. The peak value for voltage and current are 36V and 2.4A respectively. The RMS value for voltage and current is around 26V and 1.7A respectively. The energy usage is 44W. Figure 14 shows the voltage and current waveform.



a)

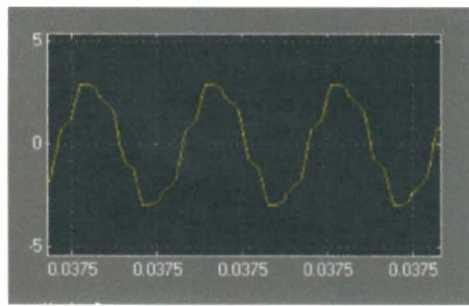


Figure 14: a) Output voltage and b) Output current waveform with $m=0.5$

Table 2 summarised the results when modulation index was varied and the duty cycle is set 20%. When modulation index increases, the voltage, current and power also increases.

Modulation Index	Duty Cycle (%)	Rectifier Voltage (V)	Lamp Current (A)	Lamp Voltage (V)	Lamp Power (w)
1	20	372	4.6	69	158
0.8	20	372	4.4	65	143
0.5	20	372	2.4	36	44

Figure 15 shows the graph for voltage, current and power versus modulation index when using active power filter. From these graphs, it can be concluded that when modulation index increases, the value of voltage, current and power also will increase.

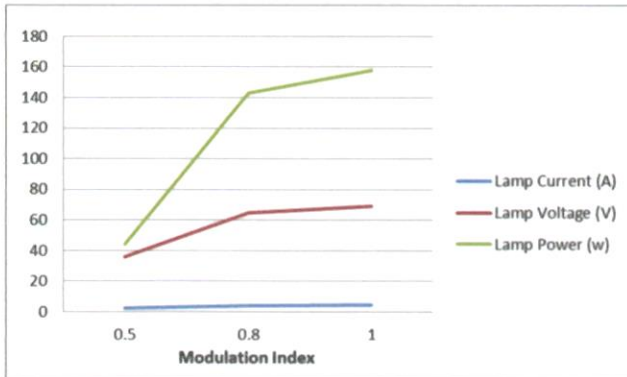


Figure 15: Graph for voltage, current and power versus modulation index

Table 3 summarised the results for varying the value of duty cycle from 10% to 50% in active power filter. When value of duty cycle increases, the voltage, current and power also increases.

TABLE 3
SUMMARISED RESULTS WHEN DUTY CYCLE AND MODULATION INDEX VARIES

Duty Cycle (%)	$m=1$			$m=0.8$			$m=0.5$		
	V	I	P	V	I	P	V	I	P
10	63	4.2	132	59	3.9	115	32	2.1	34
20	69	4.6	158	65	4.4	143	36	2.4	44
30	83	5.5	228	77	5.2	200	50	2.9	73
40	92	5.8	266	85	5.6	238	56	3.2	90
50	95	6.2	294	89	5.8	258	59	3.4	100

Figure 16 shows the graph for power versus duty cycle. From this graph, it can be concluded that when duty cycle increase, the value of power also will increase.

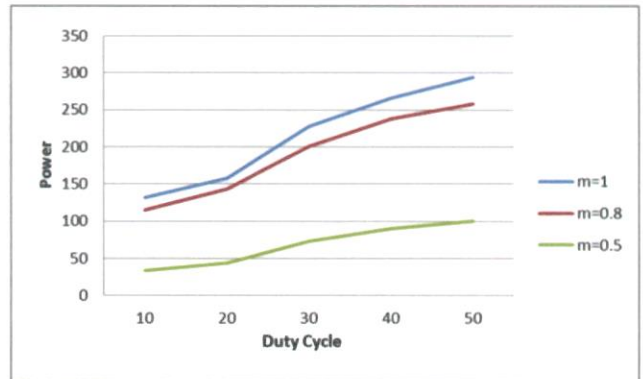


Figure 16: Graph for power when varying duty cycle

IV. CONCLUSION

From the simulation results obtained it can be concluded that energy usage can be controlled by varying the modulation index. For active power filter, the energy usage can further be controlled by varying the duty cycle. By using this electronic ballast in street lighting, the energy usage can be reduced.

For future works, hardware circuit can be constructed to the validity.

V. ACKNOWLEDGEMENT

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REFERENCES

- [1] "Green tax incentives for a sustainable Malaysia", PwC Alert Issue No.86 October 2010 PP9741/10/2010 (025623).
- [2] Alonso, J.M.; Dalla-Costa, M.A.; Cardesin, J.; Garcia, J., "Magnetic dimming of electronic ballasts," Electronics Letters, vol.41, no.12, pp. 718- 719, 9 June 2005 doi: 10.1049/el:20058340

- [3] Dos Reis, F.; Tonkoski, R.; Maizonave, G.B.; Lorenzoni, L.C.; Sarmanho, U.; Ceccon, G.B.; Libano, F.B.; Canalli, V.; Lima, J.C.M.; , "Full Bridge Single Stage Electronic Ballast for a 250 W High Pressure Sodium Lamp," Power Electronics Specialists Conference, 2005. PESC '05. IEEE 36th , vol., no., pp.1094-1099, 16-16 June 2005
doi: 10.1109/PESC.2005.1581765
- [4] Dr. Choong Weng Wai, Prof. Dr. Abdul Hakim bin Mohammed and Assoc. Prof. Dr. Buang Alias, "Energy Conservation Model for Malaysian Higher Learning Institution," Universiti Teknologi Malaysia.
- [5] Kotny, J.L.; Duquesne, T.; Idir, N.; , "EMI Filter design using high frequency models of the passive components," Signal Propagation on Interconnects (SPI), 2011 15th IEEE Workshop on , vol., no., pp.143-146, 8-11 May 2011 doi: 10.1109/SPI.2011.5898860
- [6] J.R. Coaton, Lamps and Lighting, fourth edition, Arnold 1997.
- [7] Morais, L.M.F.; Garcia, P.F.D.; Seleme, S.I.; Cortizo, P.C.; , "HPS electronic ballast with modulation index control," Power Electronics and Applications, 2009. EPE '09. 13th European Conference on , vol., no., pp.1-9, 8-10 Sept. 2009
- [8] Moo, C.S.; Yen, H.C.; Hsieh, Y.C.; Chuang, Y.C.; , "Integrated design of EMI filter and PFC low-pass filter for power electronic converters," Electric Power Applications, IEE Proceedings - , vol.150, no.1, pp. 39- 44, Jan 2003 doi: 10.1049/ip-epa:20020688
- [9] Ying-Chun Chuang; Chin-Sien Moo; Hsien-Wen Chen; Tsai-Fu Lin; , "A Novel Single-Stage High-Power-Factor Electronic Ballast With Boost Topology for Multiple Fluorescent Lamps," Industry Applications, IEEE Transactions on , vol.45, no.1, pp.323-331, Jan.-feb. 2009
doi: 10.1109/TIA.2008.2009677
- [10] Bor-Ren Lin; Hsin-Hung Lu; Yaow-Ming Chen; , "Implementation of three-level AC/DC/AC converter with power factor correction and harmonic reduction," Power Electronic Drives and Energy Systems for Industrial Growth, 1998. Proceedings. 1998 International Conference on , vol.2, no., pp. 768- 773 Vol. 2, 1-3 Dec. 1998 doi: 10.1109/PEDES.1998.1330698