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Enhanced Active Filter for Single-Phase Controlled Rectifier Applications

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Abstrak

Filter aktif dapat digunakan untuk meningkatkan kinerja penyearah terkontrol satu fasa dengan mengurangi riak yang dihasilkan dan distorsi harmonik. Filter aktif juga dapat meningkatkan faktor daya dan efisiensi thyristor. Pada penelitian ini, filter aktif dirancang dengan menggunakan NPN Bipolar Junction Transistor (BJT) dibandingkan dengan filter aktif yang dibuat dengan memanfaatkan NPN Metal Oxide Semiconductor Field Effect Transistor (MOSFET). Efisiensi filter aktif berbasis BJT dengan sudut penyalaan 0° hingga 90° diperoleh efisiensi sebesar 87,01% - 96,67%. Sedangkan filter aktif berbasis MOSFET menghasilkan efisiensi yang sebanding antara 90,62% - 96,07%. Terlihat bahwa filter aktif berbasis MOSFET menghasilkan efisiensi yang lebih tinggi pada sudut penyalaan 0° yaitu 90,62% dibandingkan filter aktif berbasis BJT yang menghasilkan efisiensi 87,01% pada sudut penyalaan yang sama. Kedua filter aktif memperoleh faktor daya yang hampir sama dalam kisaran 0,57 tertinggal - 0,92 tertinggal. Diharapkan bahwa penelitian ini dapat bermanfaat untuk perancangan filter aktif untuk berbagai aplikasi elektronika daya termasuk perancangan sistem transmisi daya High Voltage Direct Current (HVDC).

Kata kunci*—BJT, MOSFET, filter aktif, efisiensi*

Abstract

Active filter can be used to increase the performance of single-phase controlled rectifier by reducing the generated ripple and harmonic distortion. Active filter can also increase power factor and efficiency of thyristor. In this work, active filter was designed by using NPN Bipolar Junction Transistor (BJT) compared with active filter created by utilizing NPN Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The obtained efficiency of BJT based active filter with firing angles of 0° to 90° were 87.01% - 96.67%. Whereas, MOSFET based active filter produced comparable efficiency between 90.62% - 96.07%. It can be seen that MOSFET based active filter produced higher efficiency at firing angle of 0° which was 90.62% compared to BJT based active filter that has produced efficiency of 87.01% at the same firing angle. Both active filters obtained similar power factors within the range of 0.57 lagging – 0.92 lagging. It is expected that this work can be useful for the design of active filters for various power electronics applications including the design of High Voltage Direct Current (HVDC) power transmission system.

Keywords*— BJT, MOSFET, active filter, efficiency*

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1. INTRODUCTION

Electrical energy has now become a primary need of humans. Human dependence on technological progress cannot be separated from a stable supply of electrical energy. In the use of electronic equipment, AC voltage sources are often converted to DC voltages [1, 2]. In this conversion process, a rectifier component is needed [3-7]. One of the rectifiers used is a single-phase controlled rectifier called thyristor [8, 9]. Thyristor does not only operate as a rectifier but also as a gate that holds or passes the movement of electric current. However, the use of thyristors also has a negative impact on the harmonics produced. Harmonics are disruptions to the quality of electric power caused by distortion of current and voltage waveforms.

Thus, filters are required [10-15] to reduce the magnitude of the generated harmonics which are produced by rectifier. Filters not only can diminish the magnitude of harmonics but also can reduce ripple voltage and improve power factor as well as power quality produced by the rectifier. Previous works have introduced the use of filters with varying configurations. In general, filters can be classified as passive filters and active filters. In most cases, active filters are preferred [16-25] since they offer better power quality and better harmonics as well as reactive power compensation [26-33].

Bipolar junction transistor was used for the design of an active capacitance circuit and it was obtained that the circuit can replace the passive capacitors of resonators [34]. The use of BJT also proposed in the recent work of [35] where the designed filter can obtain additional noise reduction until 30 dB within the frequency of 150 kHz to 3 MHz. This shows that BJT can be one of the options for the application of active filter. However, it is well known that MOSFET also has some advantages over BJT such as more tolerant to heat, more power efficient and has higher input impedance.

In this study, the performance of BJT and MOSFET will be compared to provide clear insights of how these two devices can be used as main components of active filters. It is expected the obtained results can be useful for future design of more effective and efficient active filters that can be used in various applications including the recent development of HVDC power transmission system.

2. METHODS

The constructed active filter is shown in Figure 1 where the position of BJT was compared by replacing it with MOSFET. The choice of capacitor with the value of 1 µF was obtained using Equation (1).

$$C = I \times T / Vr \tag{1}$$

where,

I is the supplied current, T is the period and Vr is the ripple voltage.

The performance of active filter BJT vs. active filter MOSFET was analyzed by calculating important parameters. The power factor was calculated as

$$PF = \sqrt{(1-THD)^2} \times \cos \varnothing \tag{2}$$

The AC voltage was computed as

$$V_{AC} = \sqrt{{V_{RMS}}^2 - {V_{DC}}^2} \tag{3}$$

Then the ripple factor was calculated using the following equation

$$RF = \frac{V_{AC}}{V_{DC}} \times 100\% \tag{4}$$

The output powers then computed as follows

$$P_{AC} = \frac{{V_{RMS}}^2}{R} \quad (5)$$

$$P_{DC} = \frac{{V_{DC}}^2}{R} \quad (6)$$

Ultimately, efficiency was calculated using equation below

$$\eta = \frac{P_{DC}}{P_{AC}} \times 100\% \quad (7)$$

The simulation method was entirely carried out using PSPICE software.

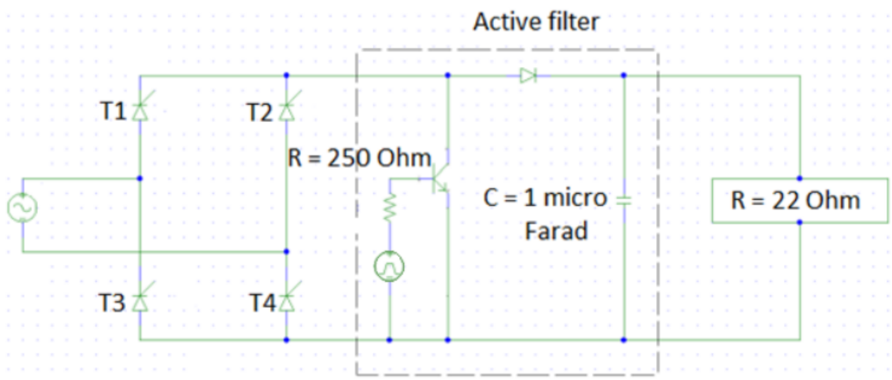

Figure 1 Schematic of the analyzed active filters.

3. RESULTS AND DISCUSSION

The simulation results show that there is an increase of RMS voltage and DC voltage regardless of the type of active filters used which can be seen from Figure 2 (a) and (b). Both Figure 2 (a) and (b) also depict that active filter MOSFET consumes lower RMS and DC voltage compared to active filter BJT. This shows one of the benefits of using MOSFET over BJT for active filter applications. However, Figure 2 (c) shows that active filter MOSFET has slightly higher AC voltage compared to active filter BJT at firing angle of 30° to 90°. Nevertheless, active filter MOSFET has significantly lower AC voltage at firing angle of 0°. Another advantage of using MOSFET compared to BJT can also be seen from the generated ripple factor for both active filters as shown in Figure 2 (d). It is clear that active filter MOSFET has lower ripple factor at firing angle of 0°, yet it has comparable ripple factor with active filter BJT at firing angle of 30° to 90°.

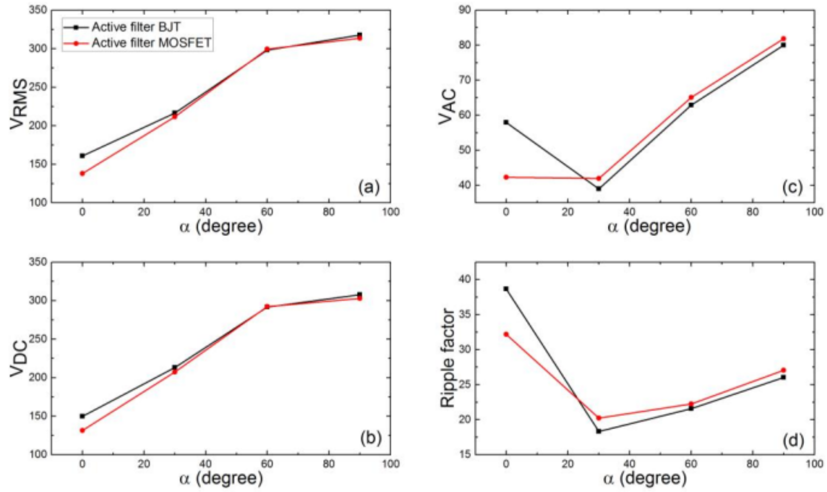

Figure 2 Voltage profile of active filter BJT and active filter MOSFET where (a) is VRMS, (b) is VDC, (c) is VAC and (d) is Ripple factor.

The efficiency of active filter MOSFET vs. active filter BJT can be analyzed by firstly examining the DC power and AC power of both active filters. It can be seen from Figure 3 that active filter MOSFET has lower DC power and AC power compared to active filter BJT at firing angle of 0°, 30° and 90°. Both active filters also have comparable DC power and AC power at firing angle of 60°. This shows that active filter MOSFET consumes lesser power compared to active filter BJT. The comparison of efficiency between these active filters can be observed in Figure 4. This figure shows that active filter MOSFET has significantly higher efficiency at firing angle of 0° compared to active filter BJT. Nevertheless, active filter BJT shows slightly better efficiency at firing angle of 30° to 90°.

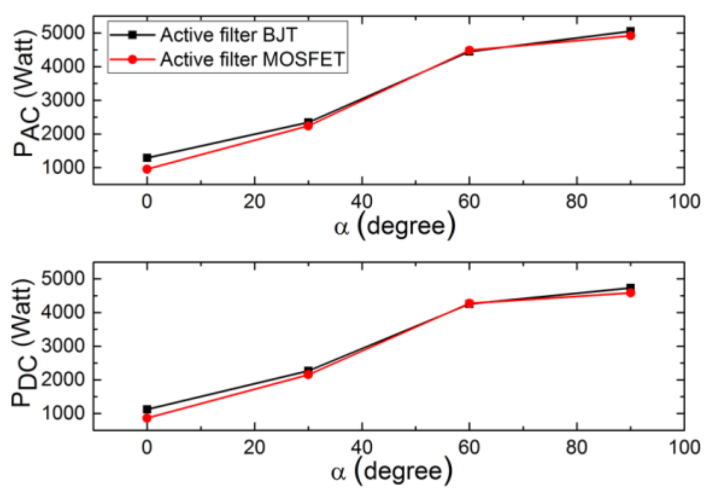

Figure 3 Power profile of active filter BJT and active filter MOSFET. (a) represents PAC and (b) denotes PDC.

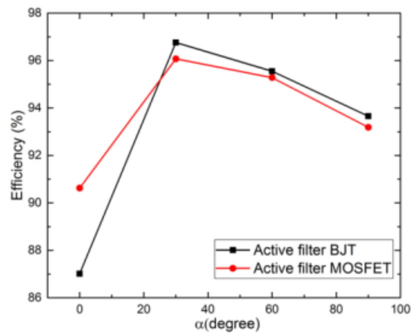

Figure 4 Efficiency of active filter BJT and active filter MOSFET.

It can be concluded from Figure 2 to Figure 4 that MOSFET active filter appears to be a better choice for a single-phase controlled rectifier application at firing angle of 0°, whereas there is no significant difference between both active filters at firing angle of 30° to 90°. Therefore, it is interesting to see voltage and current waveforms of these active filters at firing angle of 0°. Figure 5 shows the current and voltage waveforms for active filter BJT while Figure 6 depicts those of active filter MOSFET. These two figures show that voltage and current waveforms of these two active filters are not significantly different.

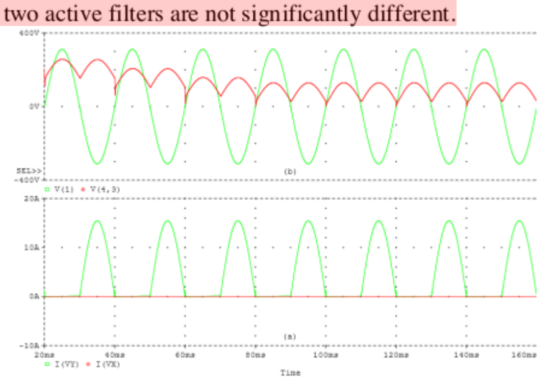

Figure 5 Input and output voltages as well as currents of active filter BJT at firing angle of 0°.

The input voltage and current are denoted with green lines whereas the red lines represent the output voltage and current.

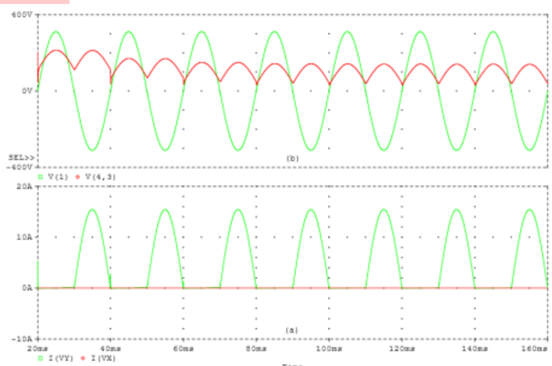

Figure 6 Input and output voltages as well as currents of active filter MOSFET at firing angle of 0°.

The input voltage and current are denoted with green lines whereas the red lines represent the output voltage and current.

The RMS and average voltages waveforms of both active filters at firing angle of 0° are shown in Figure 7 and Figure 8. The figures clearly show that active filter MOSFET has lower RMS and average voltage compared to active filter BJT.

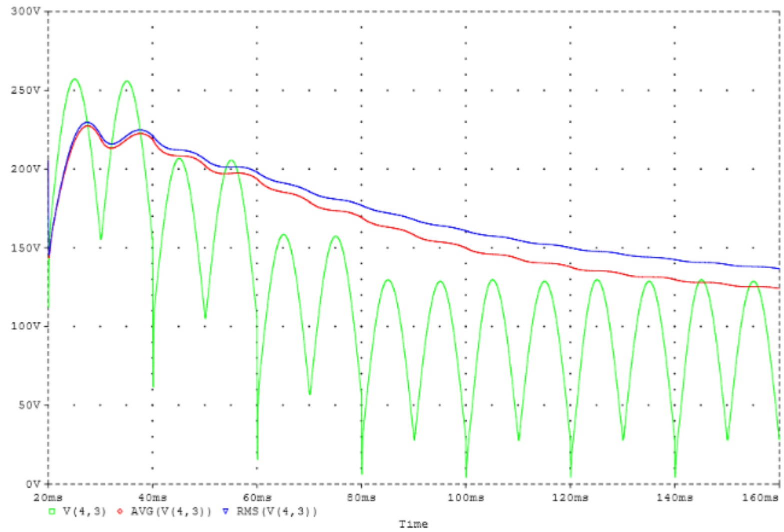

Figure 7 The voltage profile of active filter BJT at firing angle of 0°.

Output voltage is represented with green line, average voltage is denoted with red line and blue line represents the RMS voltage.

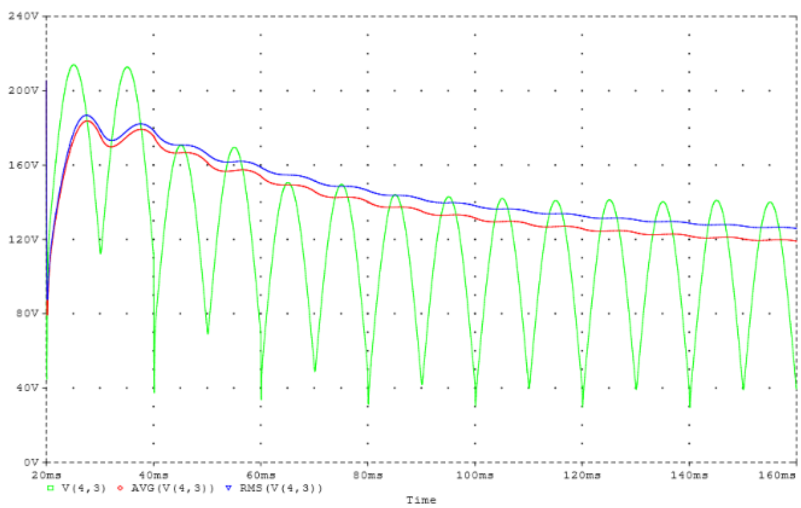

Figure 8. The voltage profile of active filter MOSFET at firing angle of 0°.

Output voltage is represented with green line, average voltage is denoted with red line and blue line represents the RMS voltage.

The total harmonic distortions (THD) of output voltage generated by the active filter BJT and active filter MOSFET are shown in Table 1 and Table 2. It can clearly be seen that MOSFET active filter produces smaller THD compared to active filter BJT. This finding supports the fact that MOSFET active filter has better efficiency than BJT active filter at firing angle of 0° as discussed earlier. The calculated power factor for both active filters are in the range of 0.57 lagging – 0.92 lagging at firing angle of 0° to 90°.

Table 1 Output voltage harmonics of BJT active filter at firing angle of 0°.

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.667E+00	1.000E+00	-9.713E+01	0.000E+00
2	1.000E+02	4.466E+01	2.680E+01	-9.433E+01	2.797E+00
3	1.500E+02	8.121E-01	4.873E-01	-1.780E+02	-8.088E+01
4	2.000E+02	8.565E+00	5.139E+00	-9.938E+01	-2.257E+00
5	2.500E+02	1.512E-01	9.071E-02	1.276E+02	2.247E+02
6	3.000E+02	3.783E+00	2.270E+00	-1.002E+02	-3.050E+00
7	3.500E+02	1.907E-01	1.144E-01	-1.264E+02	-2.923E+01
8	4.000E+02	2.203E+00	1.322E+00	-1.071E+02	-9.935E+00
9	4.500E+02	1.990E-01	1.194E-01	-1.595E+02	-6.235E+01

TOTAL HARMONIC DISTORTION = 2.741758 PERCENT

Table 2. Output voltage harmonics of MOSFET active filter at firing angle of 0°.

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	3.255E+00	1.000E+00	-1.036E+02	0.000E+00
2	1.000E+02	4.583E+01	1.408E+01	-9.537E+01	8.260E+00
3	1.500E+02	1.984E+00	6.094E-01	-1.582E+02	-5.454E+01
4	2.000E+02	9.075E+00	2.788E+00	-1.052E+02	-1.534E+00
5	2.500E+02	9.107E-01	2.797E-01	1.791E+02	2.827E+02
6	3.000E+02	3.866E+00	1.188E+00	-1.099E+02	-6.231E+00
7	3.500E+02	5.558E-01	1.707E-01	-1.746E+02	-7.092E+01
8	4.000E+02	2.205E+00	6.774E-01	-1.154E+02	-1.180E+01
9	4.500E+02	3.893E-01	1.196E-01	-1.699E+02	-6.626E+01

TOTAL HARMONIC DISTORTION = 1.443215 PERCENT

4. CONCLUSIONS

The performance of active filters based on BJT and MOSFET has been comprehensively analyzed and compared. It is intriguing to see that active filter MOSFET appears to be a more efficient choice compared to active filter BJT that can be seen from the lower RMS and DC voltages consumed by active filter MOSFET compared to those of active filter BJT. Similarly, active filter MOSFET shows significantly lower fipple voltage at firing angle of 0°. These results are also in agreement with the consumed AC and DC powers of active filter MOSFET which are obviously smaller at firing angle of 0°. The calculated efficiency also shows that active filter MOSFET has significantly higher efficiency compared to active filter BJT at firing angle of 0° which is also aligned with the lower THD generated by this active filter. However, both active filters show comparable performances at firing angles of 30° to 90°. Therefore, MOSFET active filter is suggested to be used at firing angle of 0°. However, either active filters can be used when the single-phase controlled rectifier is fired at firing angle of 30° to 90°. It is expected that this work can provide useful insights for the design of active filters in recent technological developments in various applications of power electronics.

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