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Supply Voltage Optimisation Using Power Electronic Devices And Pic Microcontroller

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Abstract:
A new voltage optimiser purely based on Power electronic devices was proposed to ensure the voltage on a site maintained at the optimal level. The system was designed in such a way that the voltage supplied to the load was reduced and brought in line with the actual needs of the equipment on the site. Controlling the voltage was one of the simplest and cost-effective ways to reduce electricity use, resulting in electricity cost savings and reduction in carbon emissions, with the additional benefit of equipment protection. In this project, an uncontrolled diode bridge rectifier and controlled bridge inverter formed by MOSFETs were used. The Inverter is an electrical power converter, which converts the direct current to alternating current. 'The converted AC can be at any required voltage and frequency with the use of Power Electronic Switches,' by using this principle the project goal was achieved. The Professional ISIS and ARES were employed for simulation studies and practical design of the proposed project. The Inverter was controlled by means of a PIC microcontroller which was programmed using 'PIC C' and was able to meet the requirements of controlling the output AC voltage by switching the MOSFETs of the Inverter circuit.

Key words: *Bridge rectifier, Controlled bridge inverter, PIC microcontroller, switching circuits, Professional ISIS, Professional ARES, PIC C*

1.Introduction

The project was to design and implement a voltage optimiser that will ensure the voltage on a site was maintained at the optimal level. Voltage and frequency were the two primary factors in the quality of supply for power distribution systems. In the distribution systems, voltage control was only considered, as the supply frequency was generally controlled elsewhere [14].
Voltage reduction was the reduction of energy consumption resulting from the reduction of feeder voltage. Several studies [15] and utility experiences [1] have supported the application of this method for the purpose of energy conservation. The organisations had no control over the voltage entering into their site, which led to the pay for electricity they haven't used. Therefore, tighter control means more savings and power wastage costs can be avoided. Every 1% of power savings had a greater impact with the rise in electricity prices.
Voltage Optimization was an effective means of saving energy in the United Kingdom, because there was a national problem of over voltage. As a result of European Harmonisation in 1995, the declared electricity supply in the United Kingdom was 230V with a tolerance of ±10% [16]. This means that supply voltage can fluctuate between 210V and 253V depending on local conditions. However, the average voltage supplied from the national grid in UK was 242V [25]. Whereas, the nominal voltage in Europe was 220V and hence most of the electrical components manufactured for Europe and the UK were rated at 220V and may operate satisfactorily at voltages down to 200V[26].
The 17th edition of the Electricians Guide BS7671 makes the following statements in relation to overvoltage: "A 230V-rated lamp used at 240 will achieve only 55% of its rated life", and "A 230V linear appliance used on a 240V supply will take 4.3% more current and will consume almost 9% more energy" [27], [2]. This means overvoltage causes a reduction in equipment lifetime and increases in energy consumed with no improvement in performance. Therefore, by efficiently bringing supply voltages to the lower end of the

statutory voltage range, voltage optimisation technology could yield average energy savings of around 13%, and the long life of the connected equipment [27].

The general block diagram showing the function of the proposed project was shown in Figure 1. The voltage optimiser was connected directly to the supply mains, which takes the un-optimised voltage and converts it into the optimised voltage at which the load operates with maximum efficiency. The voltage optimiser was controlled by a controller which was usually a microcontroller programmed as per requirement.

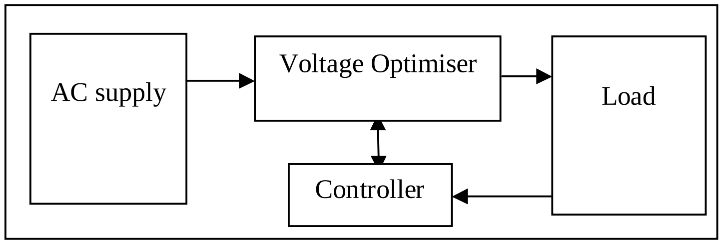

Figure 1: Block Diagram Of The Showing The Function Of The Proposed Project

2.Voltage Optimiser

2.1.Micro Controller

For production of Sinusoidal Pulse Width Modulated Signal (SPWM), a code was written in separate software called 'PIC C'. The code was dumped into the microcontroller and the circuit was simulated and the output was checked with the help of Oscilloscope available in the component library. The output was shown in the Figure 2

The below schematic shows the first circuit that was drawn with only PIC microcontroller:

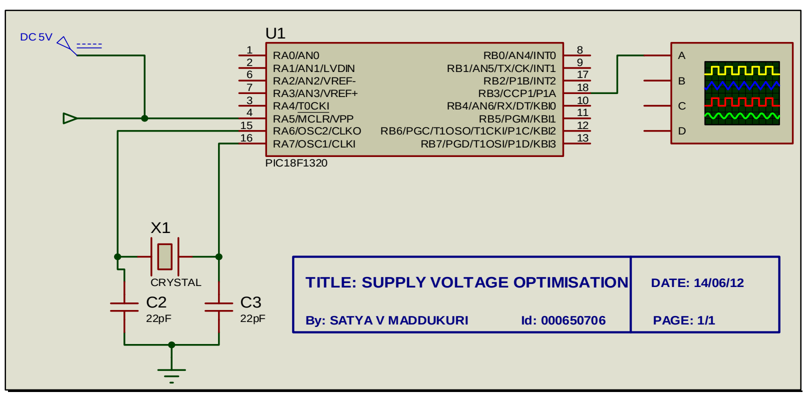

Figure 2: Schematic Diagram With The PIC18F1320

2.2.Micro-Controller With Bridge Driver

The PIC18F1320 produces only one Sinusoidal Pulse Width Modulation Signal, whereas the project requires four SPWM signals to trigger the MOSFETs of the controlled Inverter circuit. Hence, a full driver circuit was connected to the output of PIC. The other major task done by the full bridge driver was, it increases the voltage of the SPWM signal to the level required enough to trigger the MOSFETs. The modified circuit was shown in Figure 3

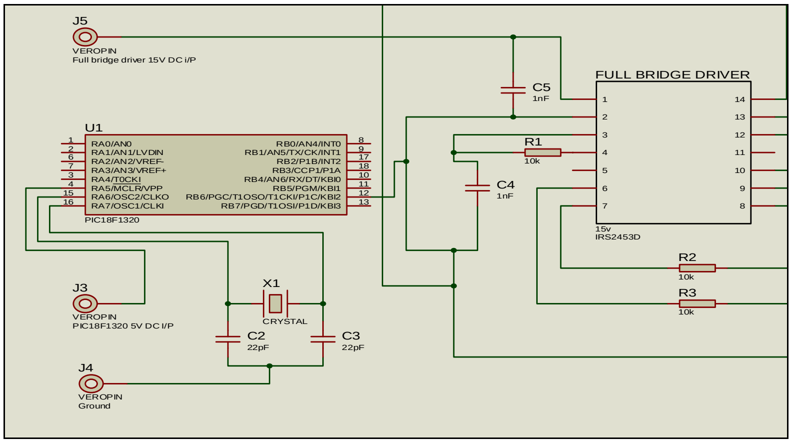

Figure 3: Voltage Optimiser With PIC And The Full Bridge Driver

Once the SPWM circuit was constructed, the next step was to give the signal to the controlled inverter.

2.3.Inverter

Then emerged the important part of the entire circuit, which was controlled Inverter with MOSFETs. The reason for choosing the MOSFETs was their high efficiency for low power applications. The schematic with the rectifier, PIC, the full bridge driver and the controlled inverter was shown in Figure 4.

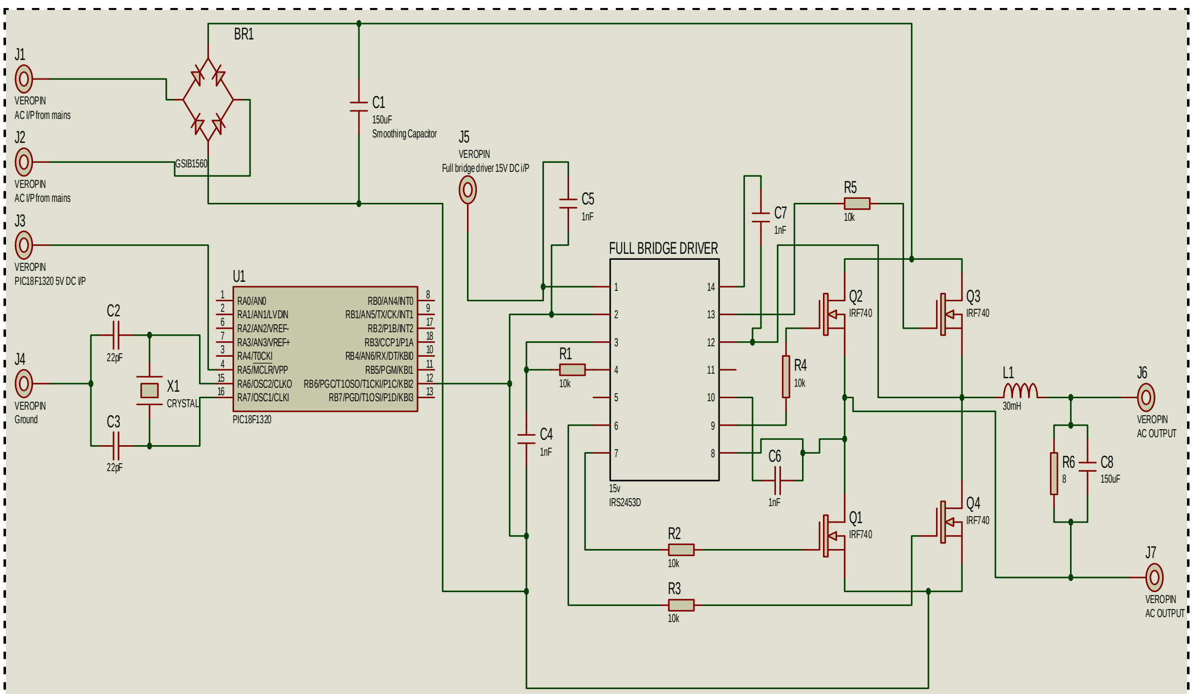

Figure 4: Voltage Optimiser

3.Software Flowchart

The flow used for producing the Sinusoidal Pulse width Modulation signal using the PIC18F1320 using 'C' language was shown in Figure 5

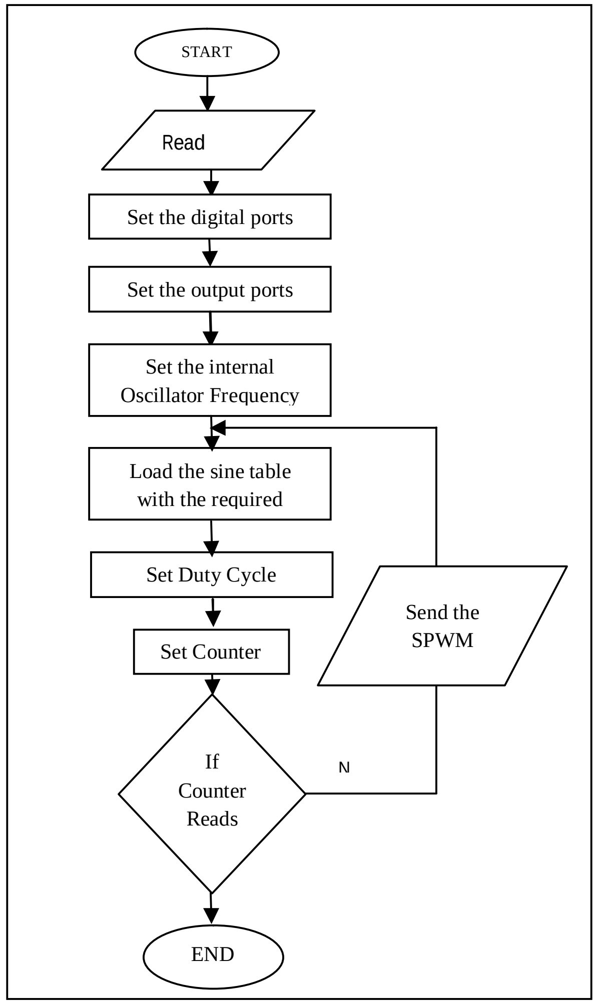

Figure 5: Flow Chart For Producing The SPWM Using The PIC18F1320

4. Simulation Results

4.1.Production Of SPWM Signals By PIC18F1320

Figure 6 shows the schematic of PIC microcontroller producing the SPWM signals. The ICD3 debugger was used to load the HEX file into the microcontroller. In programming, the main aspect was the switching signal time period, which should be 20ms (T= 1/f = 1⁄50HZ), as the frequency of the generated signal was 50Hz. But initially, the generated signal has a time period of 10ms (f=1/T=100Hz), which was very inappropriate. So, in order to achieve the required time period, the pulse count in the program was increased. Thereby, the SPWM signal with a 20msec time period was achieved, which was shown in the Figure 7.

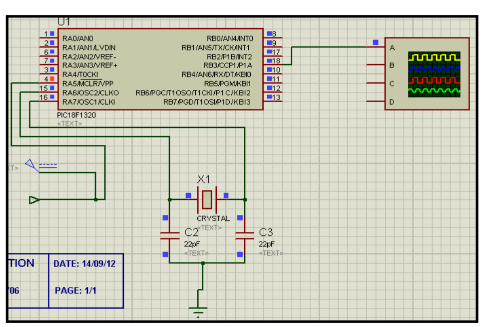

Figure 6: Schematic Showing The Production Of SPWM Signals By PIC

In the below shown figure only a few cycles were shown for the purpose visualisation. From the figure, the change in the width of pulses with time can be easily identified.

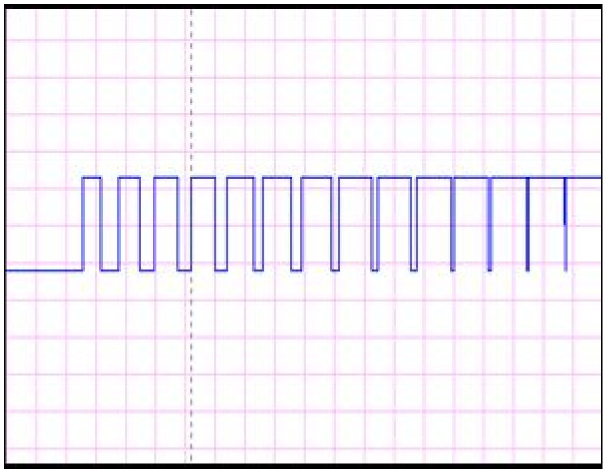

Figure 7: The SPWM Signal Produced By PIC Microcontroller

4.2.Simulation Of The Whole System

The schematic with PIC, full bridge diode rectifier IC and the controlled Inverter formed by MOSFETs was simulated and the output waveform was shown in the Figure 8. In this project the input voltage was 13V, which was approximately 20^{th} of the un-optimised voltage of 250V and the output generated was 11V (V_{out}= 11x20=220). The output generated voltage was almost pure sinusoidal which was achieved with the RLC filter connected at the output terminals.

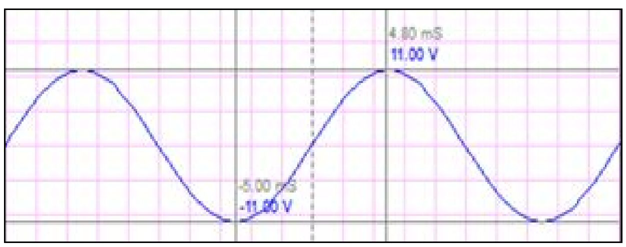

Figure 8: Simulated Results Of The Designed System Whose Magnitude Was 11V

5.Practical Results

The next step was to analyse the Sinusoidal Pulse Width Modulation (SPWM) signal, which was done by connecting the powered target board to the Oscilloscope. In order to observe the pulses, only one fourth of the cycle, shown in Figure 9**,** was captured and analysed.

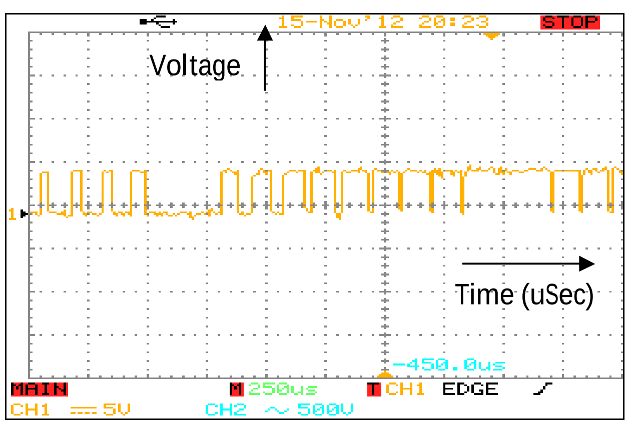

Figure 9: SPWM Waveform Generated By The PIC18F1320

Then PIC was placed into the PCB and the whole system was powered again. The system worked according to the program. The output from filter capacitor connected to the full bridge rectifier, GSIB1560 was observed using the oscilloscope, which was shown in Figure 10. The generated DC wave has low ripple content and of good quality, which was then fed through the Inverter Bridge.

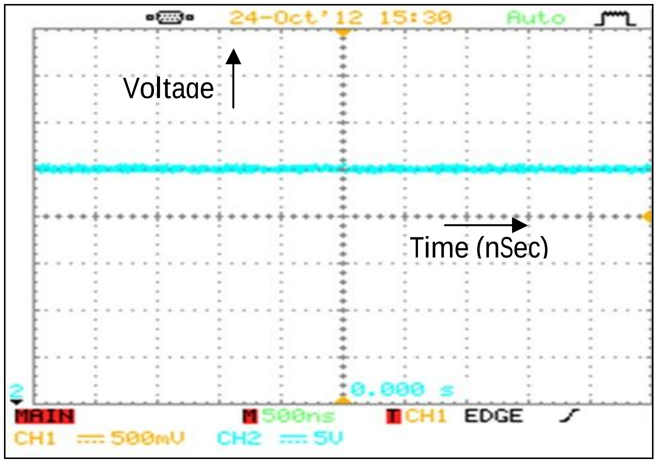

Figure 10: DC Waveform Generated By The GSIB1560 With A Filter Capacitor

The next step was fed this DC signal through the Inverter Bridge formed by the four MOSFETs, which were triggered by the SPWM signal produced by PIC. The output was a fluctuated sine wave which was then filtered using the RLC filter The output waveforms from the RLC filter were shown in Figure 11.

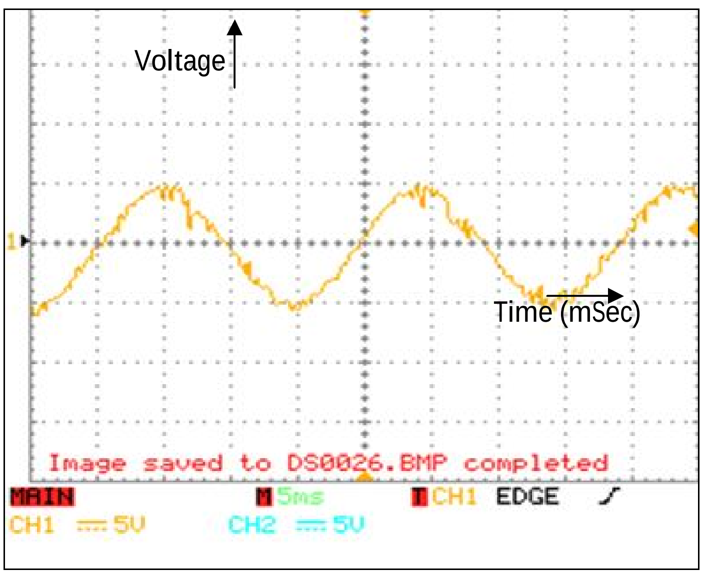

Figure 11: First Output Waveform From The Designed System

The sudden drop in signal amplitude, when travelling from positive peak to the negative peak was observed from the output waveforms, which was due to the improper switching of the switches. The drop in signal amplitude was not continuous but varied with time. The improper switching was due to the presence of noise in the tracks. The other aspect was to be considered was, expected output voltage was 11V which was 20^{th} of the optimised voltage, which was 220V. But, the obtained voltage was only 10.4V which was due to the presence of huge inductor in the RLC filter circuit. The frequency of the produced signal was within the acceptable limits.

6. Cost Analysis

The cost analysis was made with the help of two simple examples, first one with the non-optimised supply and the second with the optimised supply voltages which are supplying to the same load of 20Ω resistance.

6.1.Example 1: Non-Optimised Load

Consider the average supply voltage in the UK was 242V and a load of 20Ω resistance operating continuously for 10 hours a day and 100 days an year.

$$Power(P) = \frac{V^2}{R} = \frac{242^2}{20} = \frac{58564}{20} = 2928 \text{ Watts}$$

Energy consumption per day= 29.28Kwh.
Energy consumption per annum= 2928 Kwh

6.2.Example 2: Optimised Load

The optimised supply voltage was 220V and a load of 20Ω resistance operating continuously for 10 hours a day and 100 days a year.

$$Power(P) = \frac{V^2}{R} = \frac{220^2}{20} = \frac{48400}{20} = 2420 \text{ Watts}$$

Energy consumption per day= 24.20Kwh.
Energy consumption per annum= 2420 Kwh

- Based on a cost of £0.10 per KWh.
- Example 1 costs £2.9280 Vs. Example 2 costs only £2.42 per day.
- Example 1 costs £2928 Vs. Example 2 costs only £2420 per annum.
- Hence, the optimised supply resulted in a savings of £508 per annum.
- After adding the costs of equipment for manufacturing the kit, provision of cooling, the kit installation and labour will further costs a total of approximately £700 to £800, which makes the total cost of the Voltage optimiser as £732-£832.
- This shows that, the payback period after installation was typically between 1.5 to 2 years.

7.Discussion Of Results

This chapter gives a clear overview of the results that were obtained at different stages of testing the system.

- The continuity test performed from beginning to the end of fully constructed PCB resulted in various modifications to the PCB. All the components were perfectly connected to each other. This was checked using the multimeter when set at the continuity check point and tested all the connections, which were read positive. Hence, the system was perfectly connected.
- During the power supply test, the microcontroller had functioned perfectly but the full bridge driver was found to be heated and hence the 15V voltage optimiser was removed and the supply was given using a separate DC source available in the laboratory.
- The resistors were used between the power supply and the PIC microcontroller to limit the current. As the maximum voltage that the PIC18F1320 could take was only 5V, and the current was in milli- amperes, which was a very low value. To avoid the damage of PIC, the resistors were very helpful.
- In the coding part, the generation of the SPWM signal with the time period of 20ms was of great importance as this decides the frequency of the output signal. When programmed and tested, the output had met the requirements and the wave form was shown in Figure 7
- The output from the full bridge rectifier IC with a filter capacitor was quite good and it met the requirement of the system.
- The optimised output voltage was effectively produced from the designed system but the waveform was not a pure sine wave due to the presence of more noise. The frequency of the produced signal was quite good, which was within the allowed limits.
- It was also observed, the sudden drop in signal amplitude of the output voltage waveform, when travelling from positive peak to the negative peak. This was due to the improper switching of the MOSFETs.
- The reason for the improper switching of MOSFETs was the sinusoidal pulse width modulation signal generated by the PIC microcontroller was having more fluctuations, which were due to presence of more noise in the tracks.
- The noise can be eliminated by making a bigger board and placing more space between the components'.
- The use PIC microcontroller with more internal memory can also improve the quality of the Sinusoidal Pulse Width Modulation (SPWM) signals.
- The payback period for the equipment, calculated in section 6, was typically between 1.5-2 years which was a short duration and this attracts more customers to use this equipment.

8.Conclusion

From the results obtained from several tests performed, the designed system was able to produce the optimised voltage at which the load operates with maximum efficiency. Due to its small size, low cost and easy programming, it would definitely replace the pre-existing optimisers made of transformers. The only problem was presence of few fluctuations in the output waveform which was observed due to the presence of noise in the tracks, which can be eliminated by giving enough space between the tracks. As the basic requirement was specially to design a system which produces the optimised voltage and hence the designed system met the requirements. The control system made of PIC microcontroller was efficient enough to generate the SPWM signals, which were used to control the Inverter circuit. The frequency of the produced voltage was within the allowed limits.

9.Future Work

According to the project, the idea was to efficiently bring the supply voltages to the lower end of the statutory voltage range, which could yield average energy savings of around 13%, and the prolonged life of the connected equipment. The idea of making the system based on Power Electronic devices was a great approach and very advanced and economical. The additional idea emerged while working on the project was; the quality of the sine wave produced from the H-bridge can be further improved by making the SPWM pulses more smooth, which can be achieved with the more memory PIC microcontrollers such as PIC18f2331/41. This will also add the advantage of reduction of size of the RLC filter components.

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