General Discussion on Energy Saving

D.H.WANG and K.W.E.Cheng
Dept. of EE, The Hong Kong Polytechnic University

eedhwang@polyu.edu.hk

1. INTRODUCTION

There are two most important technologies in this century, one is biomedicine and the other is energy technology. Energy issue produced problems or adverse effects in different levels of industry or in living. The Global warming also arouse the awareness of the public in energy saving. Therefore new energy saving technologies are appearing and developing rapidly, at the same time energy regeneration or alternative technology are developing in large scale.

Basically energy problem can be classified into the following 3 solutions in general: energy saving, energy searching and energy recycling. Energy saving is an important item among the concept of environmental protection, economy and improved science and technology. This paper discusses various energy saving systems and technologies and analyzes energy saving products in order that the public understands saving methods. This paper concentrates on energy saving devices.

2. ENERGY LOSS

Firstly, to implement or to develop the energy saving devices, it is necessary to understand the cause of energy loss. Energy losses in the forms of electric power are mainly conductor loss, switching loss and magnetic loss. There is also environmental loss due to poor or non-optimized control. Every type of losses has different portion in different machines and systems.

2.1 Conduction loss

The conductor loss is caused by current flow in electrical wire, which can be described by I^2R. It is in directly proportion to resistance and in proportional to the square of current. It is noted that the conductor loss is inevitable as long as there is current flow. Resistance is inversely proportional to conductor cross-sectional area, so the larger the conductor diameter, the smaller the resistance and its loss also decreases. However it is not a good solution to just decrease conductor loss by increasing the conductor diameter that results in increasing cost and volume. In fact a compromise between the two parameters is needed in design Due to the use of the switching electronics and variable frequency device, the harmonics of conductor current increases that in turn results in conductor loss increasing. The harmonics has higher frequency than fundamental components. At higher frequency, the skin effect causes the effective resistance of conductor increases Skin effect is a phenomenon of electromagnetism. All the alternating current tends to flow near the surface of a conductor, hence the equivalent resistance increases. The phenomenon of skin effect is illustrated in Fig.1. For reducing loss, one obvious solution is that harmonics is lowered or insolated multi-stranded conductor is chosen. The phenomenon of insolated multi-stranded conductor or so-called lizt wire is shown in Fig.2. Because the outer area of insolated conductor increases, the skin effect is reduced only at the cost of high cost.

The control technology and improvement of circuit offer a solution for reducing harmonics. For example, Power Factor Corrector and Harmonic Compensation Circuit, etc .

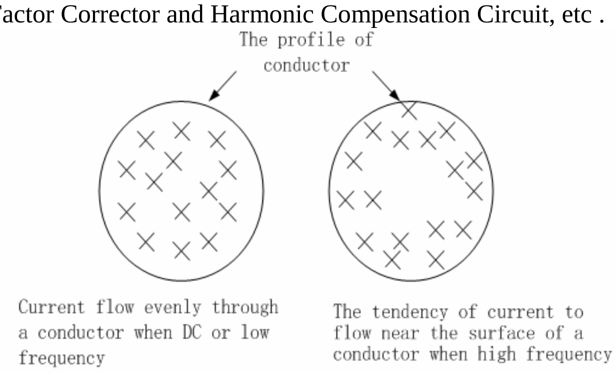


Fig.1. Skin effect

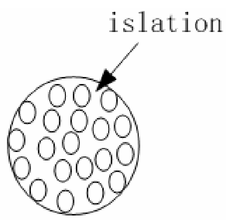


Fig.2. Insolated multi-stranded conductor

2.2 Switching loss

When every switching device is in the state of switching, overlap of current and voltage produce loss. Fig.3 shows that when a switch device is in the state of turn-on, its voltage is close to zero, and internal resistance is zero while load current flow through the switch device. The other way round, when it is in the state of turn-off, its voltage is equal to input voltage, while internal resistance is infinite. So load current doesn't pass. It is obvious from discussion above that the switching device is in either the state of turn-on or turn-off, voltage or current is zero. Losses are in proportion to voltage and current, so loss is zero theoretically.

However, a real device is not so. It takes some time to change device's states. Fig.4 shows the overlap of current and voltage that is called after overlap phenomenon in electrical engineering. The overlap produces loss that can convert into heat energy, light energy, sound energy, even EMI, etc.

The loss is very little for the low frequency switching device, but for the high frequency switching device such as thyristor and IGBT etc, loss is significant, at the same time EMI also is produced, which may in the form of conductive or radiated form, that has an adverse effect on other devices in the vicinity.

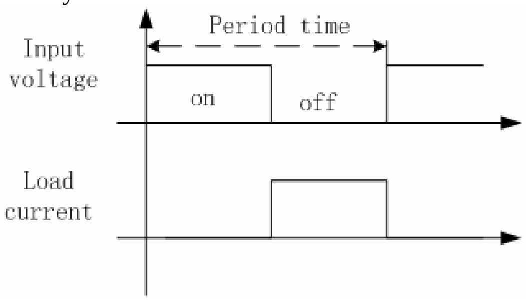


Fig.3. Ideal switch

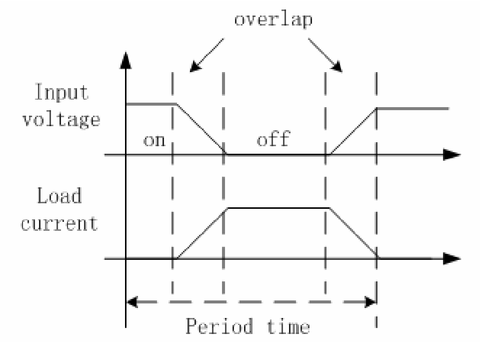


Fig.4. Overlap of real switch

2.3 Magnegtic loss

Electricity and Magnetic is not dissociative in electrics. Main electromagnetic device are motor, transformer and inductor. Every electromagnetic device produces magnetic field in its core, and its magnetic strength varies with input voltage and current. Magnetic losses are classified into 3 groups. One is eddy current loss that is caused by eddy current phenomenon. Eddy current loss is in proportion to magnetic intensity and frequency, and increases in the nonlinearly with magnetic field strength and frequency increasing. Therefore, harmonics results in increase of loss. Most of core design adopted laminated core to reduce eddy current loss. But core must be very thin to reduce eddy current, so the method does not reduce loss very well.

The other is hysteresis loss. Hysteresis loop of the magnetic core forms periodic loop in every operation cycle. The dipoles of core move in a cycle that produces loss. The loss increases linearly with frequency increasing.

Another one is residual loss but the cause of which is not fully known. Research has been conducted in different levels and scale and is to be investigated properly.

3. ENERGY SAVING TECHNOLOGY

There are various energy saving products in market. Their principles are different and they have different energy saving function in the different operating states. Many technologies and products aim at the mechanism of tariff of electric power company. The charge of electric power can be reduced through improving power quality.

3.1 Power factor corrector

Power Factor is an electric power quality coefficient. As Fig.5 shown, when power factor equal to one, all of electric power flow into load from power supply. No surplus power feeds back into power supply, on the contrary, if load is inductive or capacitive, power is stored while the power flows to the load. In every cycle, a portion of power stores in load and feeds back into power supply.

Many devices are inductive or capacitive, so power factor is less than one. When power factor is less than one, there is increased current flow through conductor that produces extra loss and increases the load of generator. Therefore power factor is restricted by power company. For example, power factor is required to correct to 0.85 or above. So there are switch capacitor bank is often used to correct unity power factor in all buildings.

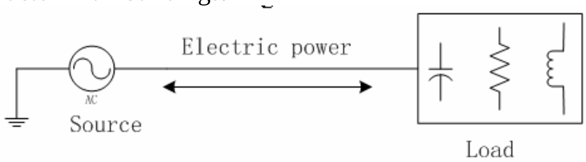


Fig.5. Power bidirectional flow when power factor equal to 1.

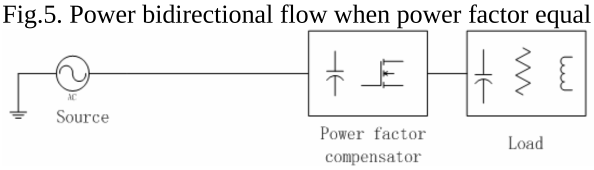


Fig.6. Power factor compensator close by load

The above design only meets the request of electric power company. If power factor of equipment can be increased, conductor loss will be reduced. Usually there is a certain distance between equipment and the distribution point of electric power company. If conductor is thin, loss could be 1 to 5 percent of the power flow. So power factor corrector is mounted on nearby equipment as illustrated in Fig.6, the conduction loss due to increase in apparent power can be reduced. Nowadays much equipment has internal power factor corrector, and there is no need to add external compensator system.

Power factor can be corrected by the passive power and active power method. Passive power method is adopted to compensate inductive loads by capacitor, such as motor etc. While active power method is adopted to control input current in phase with voltage by using semiconductor.

3.2 Harmonics compensation

The other main loss is caused by harmonics. If harmonics is lowed, conductor loss is reduced. A majority of breaker and isolator do not consider harmonics design. So as loss increases, temperature of the device rises, ageing and breakdown may be resulted that is vaused by harmonic current. Therefore harmonics compensator is also mounted in the vicinity of load. The principle of harmonics compensation is shown in Fig.7.

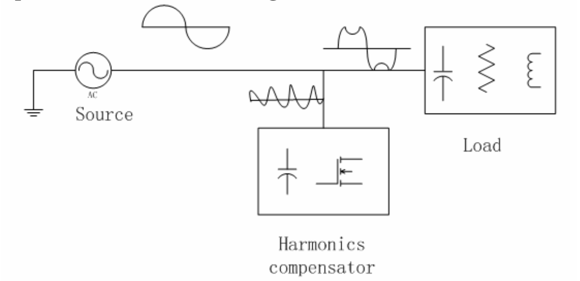


Fig.7. The principle of harmonics compensation

The semiconductor circuit can produce reverse harmonic current to compensate for load harmonic current.

Another method is passive circuit such as filter. It can filter high frequency harmonics in order to prevent harmonic current from flowing into power supply, thereby harmonic current decreases and loss is reduced. However filter cannot easily filter low frequency harmonics, so it is simple but not highly satisfactory method to compensate harmonics. Fig.8 shows its characteristics. Loss caused by harmonics can be restrained effectively by adopting the method.

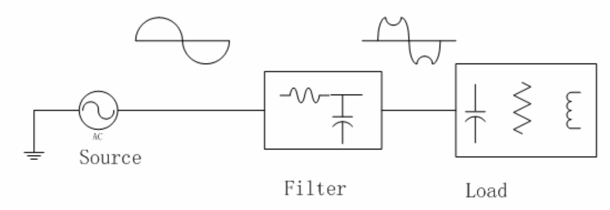


Fig.8. Passive filter

3.3 Motor control

There are various energy saving schemes for motors and can be classified into 3 groups. One is Power Factor Corrector. It corrects inductive characteristics of motor by using capacitor so that apparent power reduces, and associated current reduces. The technology aims at conductor loss as the result of which, apparent power reduces and power factor is improved. So the charge of electric power company is reduced. The technology is simple so that it is prominently effective for low power factor motor. Some products have also auto-switch compensating devices that can correct power factor under different load condition or start up condition. .

The other is Voltage Step-down System that saves electric energy by decreasing load voltage. Its principle is described as follows: core loss of motor is large when it is in the state of light load. Core loss is approximately in proportion to square of the load voltage and the requirement of torque is low in the state of light load. So loss can be reduced by decreasing voltage, but simple voltage reduction may not be a good solution as the characteristics are different for different motors and load condition. If correction is not right, motor will stall because the magnetic flux is associated to the applied voltage. Reduced voltage will therefore reduce the torque produced. Usually this device is based on Thyristor firing angle control to change voltage. Fig.9 shows that average voltage is adjusted by phase-control. However frequency is not changed by using the method, so it is not the best solution to motor control.

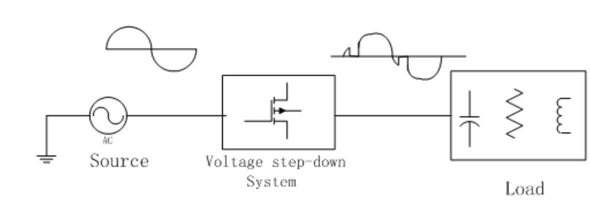


Fig.9. Voltage step-down system

The third is inverter that can change voltage and frequency together, so it has much better performance than Voltage Step-down System. It is sometimes called Variable Speed Drive (VSD). Motor magnetic flux can be regulated by to the optimized amount using voltage and frequency regulation. The motor can be run in the optimal magnetic flux and its efficiency can be as high as 0.9 in contrast with voltage control, the efficiency of which is only 0.6.

Motor is running at low rotational speed by reducing voltage in the past, and now is done by changing voltage and frequency. The efficiency of motor, as commonly known, is inversely proportional to slip frequency that is difference between motor stator frequency and rotor frequency. Using inverter to drive motor, motor can work efficiently at any rotor speed. Motor system with inverter can save energy 30 or 40 percent. But inverter cannot save electric power all the condition time. For example, if motor runs under top speed and torque all the times without any low speed condition, inverter is not effective to reduce energy consumption but increase the cost of installation. The output of inverter is PWM waveform, so higher frequency interference, or electromagnetic interference, is produced. High frequency interference takes effect on traditional motors resulting in high frequency loss and rupture. It will also increase the voltage stress to the motor because of the high dv/dt. Therefore the choice of inverter and motor is very important. A typical inverter schematic is illustrated in Fig.10. It firstly rectifies AC into DC, and then the DC is inverted into AC by adopting IGBT high frequency sinusoidal PWM. The switching mode of IGBT can change output voltage and frequency to control motor effectively.

Inverter has another advantage that surplus energy can be regenerated. When motor speed or load decreases or stop, kinetic energy can be fed back to power supply through inverter is so-called the power regeneration. The technology has been used in motor and elevator etc.

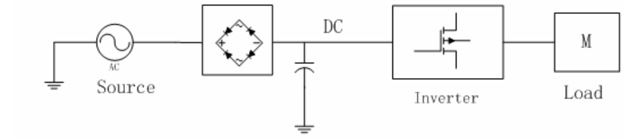


Fig.10. Schematic of Inverter

4. LIGHTING ENERGY SAVING

4.1 Electronic ballast

Energy saving method of lighting system is mainly electronic ballast that has a wide application in the world. It adopts high frequency inverter to drive fluorescent lamps in order to save energy. Fluorescent lamps have good efficiency of lighting when it works in high frequency. The efficiency of electronic ballasts is 20 to 30 percent higher than that of magnetic ballasts. Its principle is illustrated in Fig.11. It supplies power for fluorescent lamps by a power factor corrector in series with a high frequency inverter. The power factor of perfect electronic ballasts can be up to 0.99. The principle of the energy saving lighting device, such as small scale energy saving lamps, is the same as above. But most of them have no power factor corrector except high frequency inverter circuit.

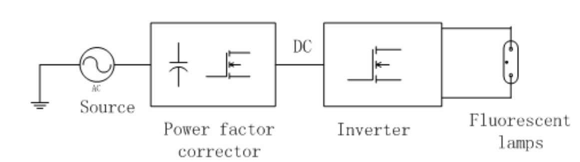


Fig.11. Schematic of Electronic Ballasts

4.2 Voltage control

Because electronic ballasts need significant materials and installation for each fluorescent lamp as compared with magnetic ballasts, therefore another energy saving lighting device emerges recently that changes fluorescent lamps by another method. It is a higher power ballast and can drive tens to hundreds of fluorescent lamps with existing magnetic ballasts. The ballast is shown in Fig.12. The ballast is used to drive a number of fluorescent lamps, and experimental results of application on 28 36W tubes are shown in Fig.13, Fig14 and Table 1-11.

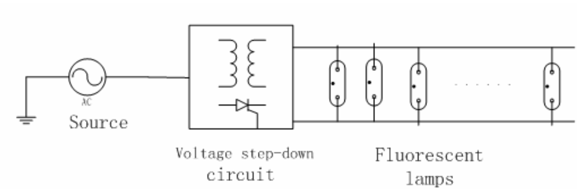
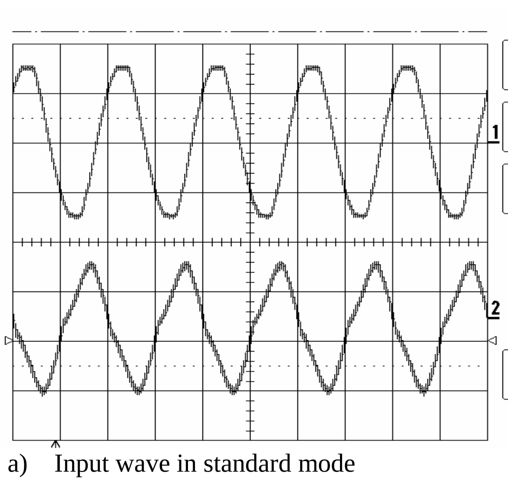
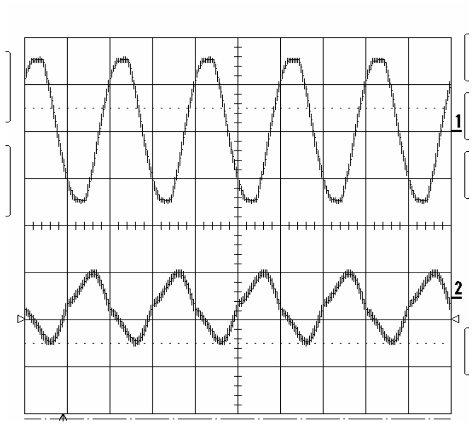


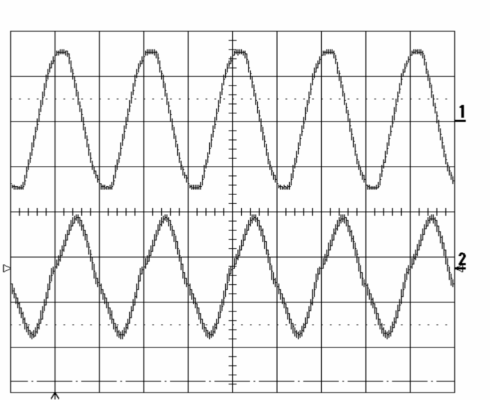
Fig.12. Voltage step-down ballasts



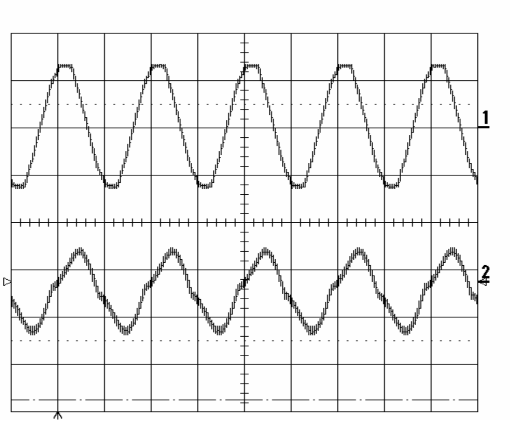
a) Input wave in standard mode
(200V/DIV，12.5A/DIV)



b) Input wave in saving mode
Fig.13. Input wave
(1:voltage wave and 2:current wave)



a) Output wave in standard mode
(200V/DIV，12.5A/DIV)



b) Output wave in saving mode
(200V/DIV，12.5A/DIV)
Fig.14. Output wave
(1：voltage wave and 2：current wave)

Table 1: The difference between the Standard mode and saving mode of the voltage step-down ballast

	Standard Mode	Saving Mode
Input Voltage	226V	226V
Input Current	11.4A	6.56A
Input Power factor	0.49	0.59
Input Power	1260W	880W
Output Voltage	226V	189V
Output Current	11.3A	7.42A
Output Power	1230W	840W
CF	1.53	1.53
THD	10.8%	13.5%

Comparison among the performance of different ballasts

	Input Power	Power Factor	THD
Voltage step-down ballast	31W	0.59	13.5%
European Electronic Ballasts)	32	0.92	16.8%
Local Electronic Ballasts	38W	0.94	25.1%
Magnetic Ballasts	51W	0.59	11.1％

Table 3: Comparison of the light output

	Light Output at 1 meter apart （LUX）	Difference of Comparing With reference ballast (%)
Voltage step down ballast	190	-5.3％
Reference Electronic Ballasts）	200	-
Local Electronic Ballasts	230	15％
Magnetic Ballasts	270	35％

The basic principle is that it lights fluorescent lamps with normal voltage. It takes a few minutes to light lamps steadily. Voltage can be reduced 5 or 20 percent by using transformer and contactor or using thyristor that saves energy. It has the advantage of simple fixing and very robust. It has also some drawbacks that it is not energy saving in reality and the system and efficiency of fluorescent lamps have not been improved, and in fact light output decreases. The device can be used in the place where low intensity of illumination is needed, or sometime during the day. If the power line connects with other electric power device, voltage to other devices will decrease as well.

4.3 Dimming control

Light dimming modulator is a familiar energy saving product, such as applied in incandescence lamps, that changes voltage by using thyristor. So it is unsuitable for energy saving lamps and fluorescent lamps. Electronic dimmer ballast for fluorescent lamps is also common. It has a high frequency inverter that transmits electric power to fluorescent lamps by controlling voltage and frequency. On the other hand, dimmer for compact fluorescent lamp (CFL) has been also produced. It reduces voltage by adjusting voltage waveform by electronic circuit that is still producing approximately sine wave, which can adjust light intensity effectively. But this CFL dimming device cannot be used in driving the general electronic ballasts. Because internal power factor corrector of electronic ballasts has capability in voltage regulating. If CFL dimmer drives electronic ballasts at low voltage, power factor corrector of electronic ballasts will regulate voltage steadily so that dimmer cannot adjust light.

Logic circuit control (LCC) is also generally used in lighting control. Lamps are turned on in groups by logic circuit design. By adopting the method, all the lightings need not to be turned on at the same time. The LCC connects different combination of connections to different lamps. Power supply then drives the different groups of lamps with your own choice. The controller needs less switches and wiring.

4.4 Intelligent energy saving

Intelligent Energy Saving Device (IESD) can control effectively the time of on-state by adopting intelligent and appropriate control methods .When not used any longer, devices are turned off in order to save energy. In the lighting system, light output can be adjusted by natural light. For example, if there is abundant light outside, light output of the lamps will be reduced. This is so-called the daylight harvesting. Time controller can turn off lighting device according to time setting. IESD can turn off or dim the lighting that is not used by infrared sensor or other occupancy sensors.

Intelligent control has been applied to escalator and lift. When not in busy hours, the house-keeping design makes part of lifts in the standby mode. Lighting and air conditioner of the lifts are turned off. Lifters are arranged to different floors to reduce the loss during startup and halting.

5. OTHER ENERGY SAVING

There are some energy saving devices that can be mounted directly in any indoor place. They claims to have energy saving capability/. It is necessary to be careful because most of them does not work in your own city or the tariff scheme. Most of them have capacitive power factor corrector, so their power factor can be only corrected to 1. This is only useful for the power factor or apparent power are part of charge in the tariff. Therefore in many cases, they do not save energy. They do have some reduction wire loss due to decrease in apparent power but the effect is small. So there is little benefit.

Energy saving devices for apparatus with motor has also been found in the market. They are suitable miniature motor. Their principle is to use timer control to stop the motor running or to decrease the voltage to the motor during light load. But this simple saving device is suitable for all motor products. A number of good motor products have their inverter that can adjust according to load condition. Using this simple energy saving devices increase the voltage stress of the products. Also, reducing the operation voltage may increase current harmonics in both input side and output side of the motor, it may make motor not to run normally, even damage motor.

5. CONCLUSIONS

According as law of conservation of energy, if output energy is maintained, input energy must be higher than the output energy. The amount of energy saving depends on the techniques of processing the energy. Therefore to summarize, the following products can be classified into 4 groups:

1) Principal efficiency of circuit or machines ---the most fundamental and real energy saving method, which adopts efficient power electronic circuit design or makes machines run by varying frequency and voltage to reduce energy loss.
2) Control and management energy saving ----- It does not save energy in real term but to turn off power devices or to reduce output to save electric power. The method includes region setting, dimming, standby devices, switch time-controllable and regeneration etc. Thus it can be seen that the real power is not reduced but energy saving is achieved by reducing unnecessary output.
3) Conductor loss saving and tariff saving scheme ---- improving power factor of devices or reducing current harmonics can reduce conductor loss because of distribution and conduction. High power factor results in reducing apparent power. So the generation cost of electric power company decreases and the tariff reduces.
4) Life time of device and indirect energy saving ---- It is not direct energy saving, but saving indirectly. If life time of products is extended, the saving in money term can be reduced. Also material is reduced that also reduce in the damage in the environment. All of these save energy indirectly, but energy saving and environment protection are realized. Usually circuit damage is caused by a few components. Repairing should be performed by replacing components rather than replacement of the whole circuit. Replaceable devices are designed to avoid replacing the whole device. Design of parts must be improved in order to save energy and protect environment better.