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Current Measurement with Optical Current Transformer

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Abstract *–The development of power electrical systems causes attention to accuracy of protection elements and measurement values. So we need some new measuring devices with high accuracy for power transmission lines. One of these devices is Optical Current Transformer (OCT). Optical current transformers are suitable for power system protection and can replace the magnetic current transformers. In this paper, we described a comparison between optical current transformers and conventional current transformers. Using an optical current transformer has several advantages, e.g. high accuracy, low weight, easy installation and no-saturation. But it has some disadvantages also, like if the magnetic fields induced by the currents through other conductors is sufficiently high, the fault current measured will have some errors. In general, the optical current transformer device is more reliable and suitable for new power systems.*

Keywords*: Optical Current Transformer, Fiber Optic, Current Sensor, Protection, Current Transducer*

INTRODUCTION

Two of the most important components of a high voltage substation are CT and PT. Their task is the sampling of voltage and current for use in measurement and protection [15]. We use this equipment since the voltage and current at high voltage substations cannot be directly used for measurement and protection and voltage and current transformers must be used to bring down large amounts. In conventional CT and PT are used the current and voltage transformers that have the primary winding core, secondary winding that convert voltage and current. Resin, oil and gas insulating are used to insulate primary and secondary voltage. For various uses such as the protection and the measurement are used of separate cores. It causes measurement device to become bulky. The information of voltage and current are conducted by a wire to control room and there they are used specially. Conventional CT and PT were and are the best in the market for high voltage substations but their Grandeur decrease too much by introducing optical equipment lately. When with the increasing of Core or Burden for the substations, we have to replace CT due to the limitations of rated current or we want add a relay. We will not be worried due to this new method for this problem, because new CT does not have these problems. Its reason is that they can convert a current from the lowest amount to nearly 4000 ampere and core support by main sensor [12].

The information transition has by optical fiber from the main equipment and it caused a connection at CVT or a disruption at the Beginning CT to terminate that it eliminates the worry of equipment explosion. In many of the new optical CT and PT, Faraday principle was used that it is explained in this paper. In some creative factories, Faraday principle was not used and they use optical fiber for the information transition from equip to control room digitally that the methodology of it is explained in this paper. In years, recently with the improvement in big transition networks, the recognition of connections has to do with the measurement of current and voltage rapidly that it's possible with new methods.

Theory

Faraday found that when a piece of special glass is affected by a strong magnetic field, it becomes active. And optic surface spin when a flat polarized optic forwards through a glass in parallelism with magnetic lines. Since the Faraday's discovery this phenomenon was seen in many solids, liquids and gases. The amount of whirl in each material is proportional to the amount of magnetic field and the distance that an optic go in a material impractically [3,5,6,9,10,11,13,14].

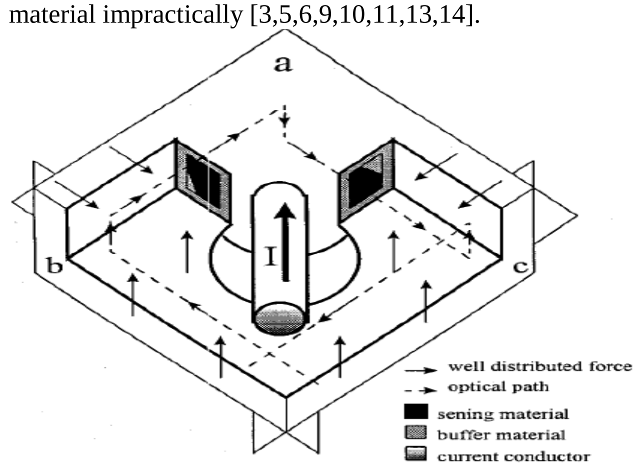

Figure 1. Construction of MOCT

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Magnetic - optical or Faraday Effect was reported by Michael Faraday first in 1845 AD [6,10,12,14]. Serious research and development for the application of Faraday Effect on highly accurate flow measurement applications began in the late 1970s. These efforts led to a series of successes in the development of measurement systems using optical sensors [12].

Faraday equations are explained briefly [3,5,8,11]:

$$\theta = \mu VHL \quad (1)$$

θ = Rotation angle of the plane of polarization
μ = Sample absorption Magnetic factor
V = Verdet Constant
H = Field intensity
L = Length of light beam

The distance travelled by light in a glass. Verdet Constant for a particular material represents the intensity of the effect Faraday that it expresses based on the amount of turning on the field intensity unit multiply at the unit of distance. The exact relationship between the magnetic field (H) and electric current (I) depends on the relative geometric position to another. If this relationship expresses to form the coefficient of K so [11,12,14]:

$$\theta = \mu V(KI)L \quad (2)$$

In the design OCT that shown in this figure[3,6,9], the concentrator field concentrator senses the uniform field relatively that Faraday create it so Eq.2 is honest about it, on the other hand, because the light flow a full round around the conductor carrying, Eq.1 become the following form:

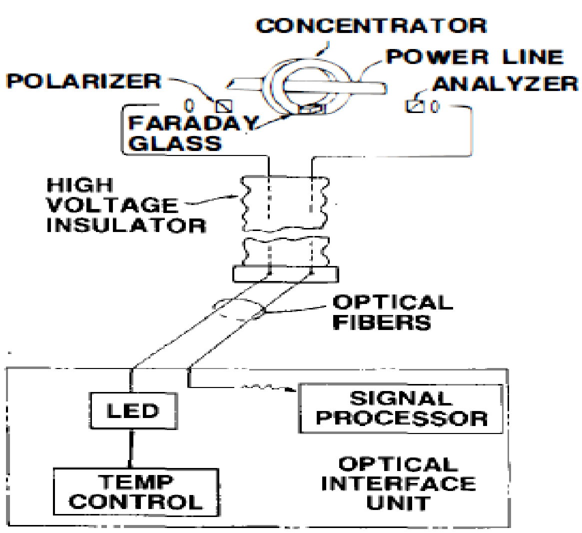

Figure 2. Schematic configuration of optical current measurement [11].

$$\theta = \mu V \oint H dl \quad (3)$$

Eq.3 is written based on amp spin:

$$\theta = \mu VIN \quad (4)$$

The number N is the conductor spins.

Fig.3 shows an example of a Faraday sensor that the axis transfer, subscription and the parser have than to another a 45-degree rotation [3,5,9,10,11,12]. This rotation causes the release light intensity to do modulation in all systems. Meanwhile, light intensity or TD (optical power) on the Manifest is as follows [3,5,16]:

$$TD = (\tau 0/2)(l+\sin 2\theta) \quad (5)$$

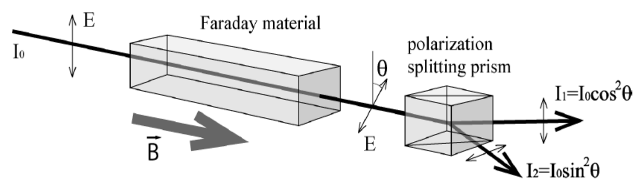

Figure 3. The three key optical elements in the sensor head of an optical current transducer

The Electrical Signal processor admeasurement AC component of waveform ($\tau 0 \sin 2\theta/2$) on DC component ($\tau 0/2$). So the resulting waveform is independent of the range of light intensity so an output optical signal become as the following form [2,3,11]:

$$m = \sin 2\theta \quad (6)$$

Then the processor combines the two equations (2 and 5) and produces an AC output signal that is proportional directly to the primary flow in a high pressure conductor, for example in an OCT of concentrator plant [11]:

$$I = \sin\text{-}1(m)/2\mu kl \quad (7)$$

In the OCT of circular plan:

$$I = \sin\text{-}1(m)/2\mu VN \quad (8)$$

In all of these relationships m is the measuring quantity and another is constant. The analog processor circuit produces an output that is directly proportionate its domain with pipeline flow and a type of optical CT also use in phase with that. It is expressed theoretically in this paper.

MATERIAL AND METHODS

OCT Optical-CT was proposed by the creators of several methods by using common theory:

1. Conventional CT with optical readout [1, 5]:

In this type, one channel of optical and completely insulated information connects to the output of CT so instead of the typical copper wire is used the optic fiber in the output data transmission. The methodology of converting the CT output to optical signal form is out of the discussion of this article, but we can say that do not open the output heads of CT is the benefit of this CT that it is the most important factor in the explosion of the CT

Magnetic concentrator (core) with optical measurement [5,11,14]: A magnetic circuit arises around the conductor by ferrous core. The difference with the traditional CT is it that an air gap is generated in the core and magnetic field in the core measure in this air gap with optical instruments. The advantage of this design is that the path of light is short and simple, and smaller optical elements are required.

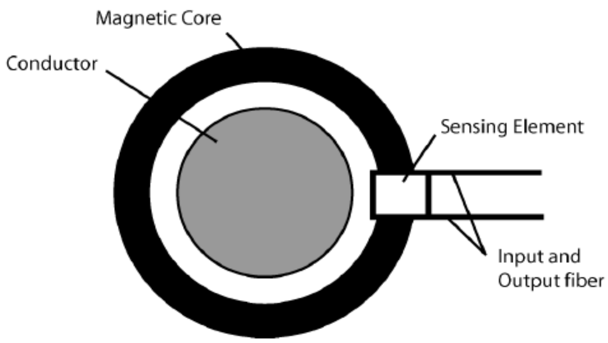

Figure 4A. Schematic of Faraday current sensor using a magnetic concentrator

2. Optical path around the conductor [2,4,5,6]:

If the path is put around the conductor carrying of current that through it the magnetic field effects on the light ray. This optical package path around the conductor measures current similar to normal CT core. In our Division, this is the first plan that is not including the Ferromagnetic component. This type includes two alternatives.

A piece of light-sensitive [5,14]: In this alternative of light path, actually, a piece of optical active materials that one round surrounds around the conductor according to Fig.4.

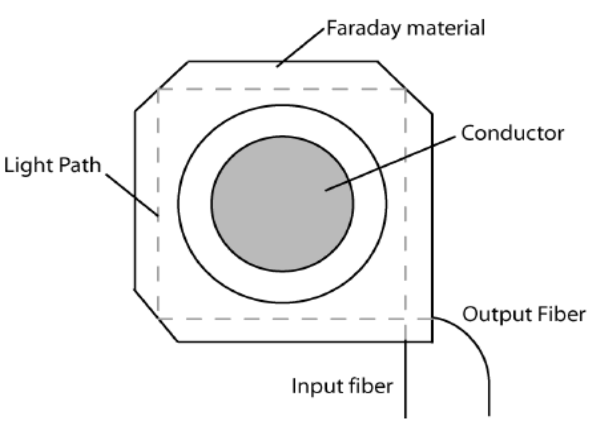

Figure 4B. Schematic of Faraday current sensor using a Bulk Optic

3. Fiber Optics [11,13,14]:

Here the light path around the conductor consists of an optical fiber that it is wrapped to the number of rounds that it required to achieve the desired sensitivity.

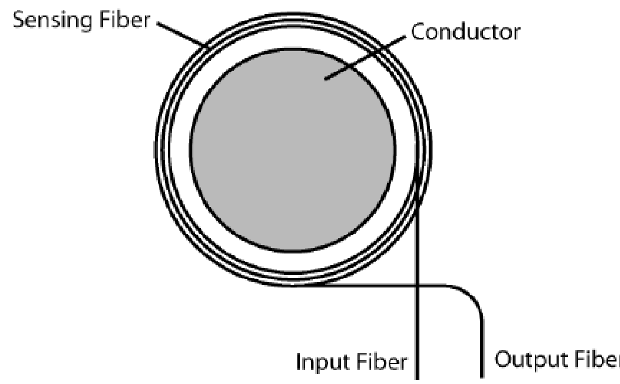

Figure 4C. Fiber Optics Based Current Measurement

4. Witness Sensor [5,14]:

This converter is the latest type in our assortment and it is only type that measurement of it does not include the surrounding of conductor completely. Instead, as shown in Figure 6, the magnetic field at a point closer to the conductor affects on the light distribution.

And therefore, it is not a real current transformer. Although it can be said a field constant distribution around the conductor is a function of its current. It can be said that light with arbitrary polarization is composed of two independent components. In the case of linearly polarized components can be simply said that two components are perpendicular to each other.

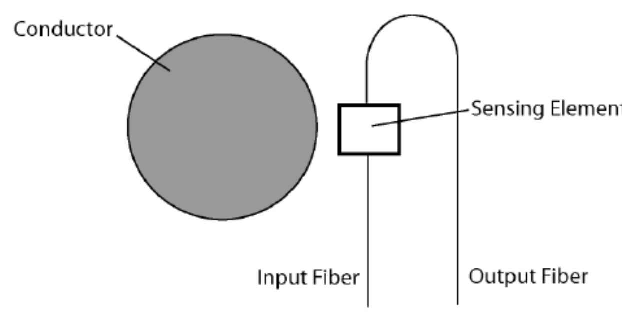

Figure 4D. Schematic of a Faraday-effect sensor, unlinked (Witness) type geometry

In the OCT a light becomes polarized linearly initially. Any type of non-polarized light can be easily polarized light by passing through a polarizer. The next issue is to measure the spin of polarization surface. In fact, it is not directly measurable. Light detectors in any way is not sensitive to the polarization of light, rather they measure the power of incoming waves. In fact, it is proportional to field square. The methods described are too short in this paper:

Method A:

In this method after the exiting of light from the optical sensor, it is entered to the other polarizer that it is called a parser. By placing the light parser at the side and right angle, we can be extracted the range of (value) component linearly polarized in any direction so the amount of light power is important [2,5].

If the angle between the transmission axis of a polarizer and a parser call α and the power of light wave when entering a detector called a pin. Then we have [11]:

PDET is the light power of the detector.

In most designs, angle A is considered the amount of π and can be proved that the measured current is independent of the input light power [3,5].

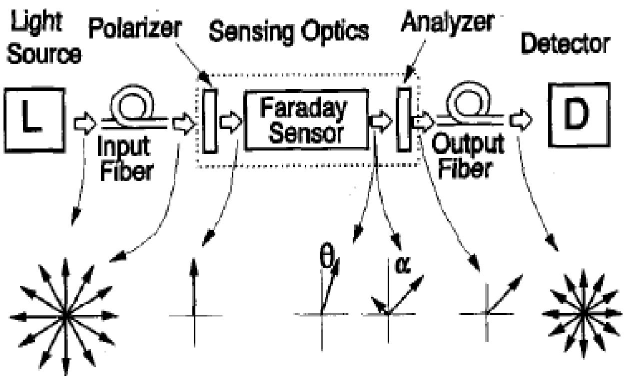

Fig5. Arrangement of Optical Components in Faraday sensor [5]

Method B:

In this method, the output of the parser that they are in the amount of relative angle equivalent π to each other is used. This set are within a single optical element called a polarization splitter. Then outputs subtract from each other and it is divided by the sum. A result is similar to method A; it is not different from method A In terms of sensitivity and failure. But in terms of hardware is a complex plan so it's less used [5,9].

Method C:

Since Faraday materials are not ideal double refractive index so some distortion and noise are created in the route of Sensor due to internal stress or temperature and it causes elliptical polarization finally. And as a result, a complete analysis of output light requires using different angles of polarization and check frequently of output [3,5,7,11].

OPD

OPD optical voltage transformer: Faraday's law can be applied to PTs, like OCTs. Voltage measurement has a fundamental problem and it’s that MOCT has been just sensitive to the magnetic field. To create such a flow, connecting a resistor between the line high voltage and ground is the easiest way. Despite the simplicity of this method will cause a great loss, in addition, the resistance depends on the temperature cause accurately measure to lose. The best way is to use a capacitor that has no resistance problems [3,6].

The capacitor I = Cdv/dt so I = -j2πfCv, 90 degree phase difference between current and voltage value is easily compensated by electronic circuits [6]. Fig.2 shows the MOVT.

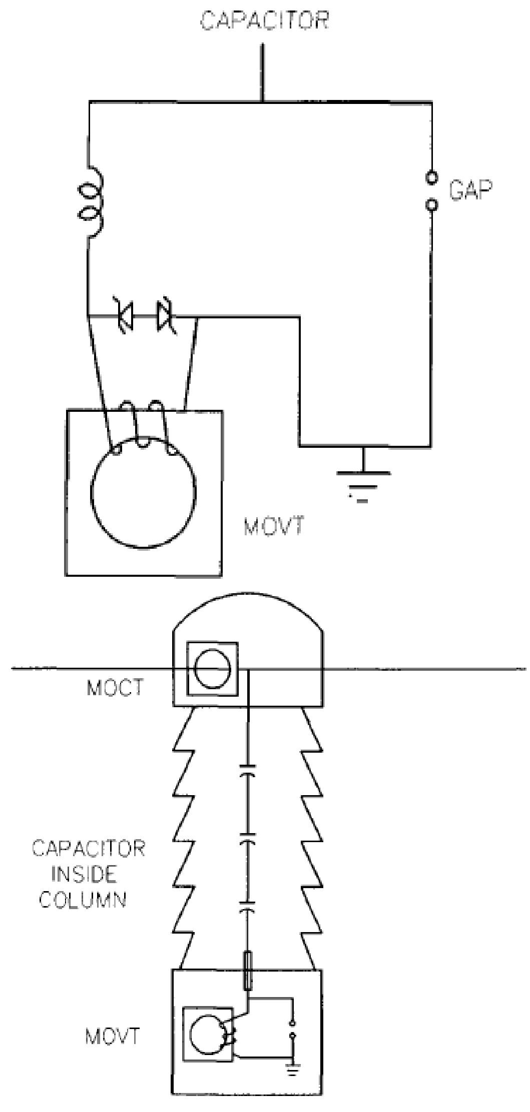

Figure 6. MOVT Schematic & Insulating Column

Calculations show that current through the capacitor is not sufficient that a MOCT be measurable with a spin of current. We know that MOCT like CT with iron Core is sensitive to the number of current carrying wire Spin so with the increased of these numbers, we can create the sufficient magnetic field for glass sensor. Fig.6 shows it.

MOCT can be used together and a MOPT and Base and bushing are put. The digital method can also be used for CVT that it has advantages of DOCT. Fig.7 shows it:

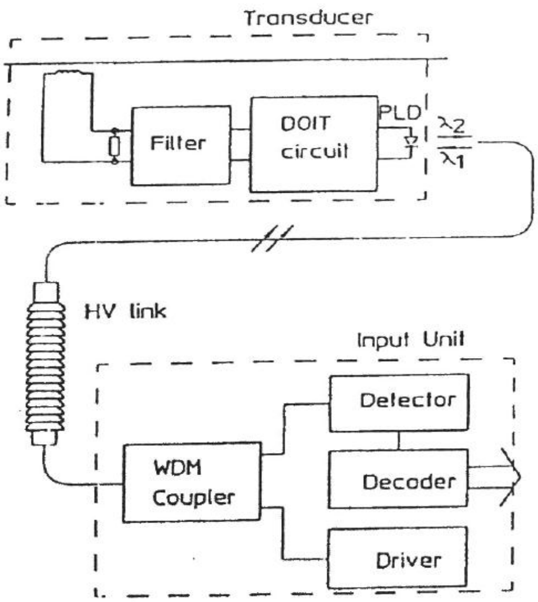

Figure 7A. Digital method for using CVT

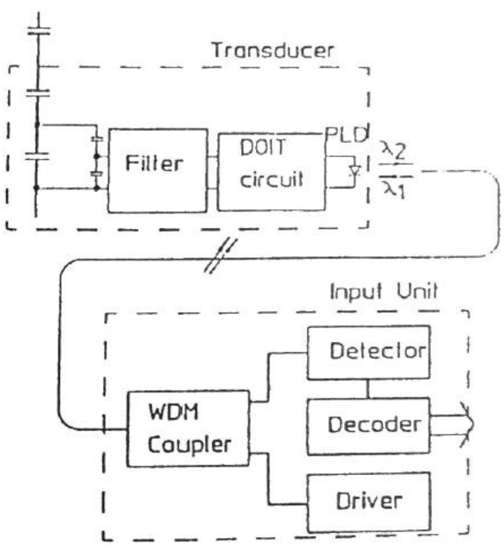

Figure 7B. Digital method for using CVT

Advantages and disadvantages

The use of MOIT and DOIT (Digital Optic Instrument Transformer) has many advantages that they are reasons of Expand its use. The equipment is used in measurement and protection units of substations from the distribution voltage to high voltage.

The use of electronic–Monitoring systems creates measurement, protection with high reliability and wide dynamic range.

A. Advantages:

1. The subject of creating noise is ruled out due to the use of optical fiber [3,5,13,15].

2. Resistance to Acoustic and Electromagnetic parasites is excellent that it plays an important role in protecting [2,14].

3.The internal problems of MOITs and DOITs cause connecting with lines and substations so it causes the traditional equipment to explode very dangerous. In addition, it can damage surrounding equipment [10,14].

4.In terms of size and weight, they have small size and low weight. The size of equipment can be a great help in substations that have land problems and they cause the foundations and structures to remove and they have high costs. The probable installation and relocation does not require heavy machinery that it is huge economy [5,12,13,14].

5.During installation, do not require cutting the insulated conductors. It causes re-insulating to prevent [2,13].

6.Having sufficient electrical insulation resistance [5,14].

7.Lack of magnetic saturated. Due to Lack of core, there is no saturation that it solves many protection and Measurement problems [10,14].

8.Lack of Ferro resonance phenomena and hysteresis [6,10,14].

9.The measurement error is less, than 0.3% [1,2,3,16].

10.The power supply is not used in the HV section in DOITs [8].

11.Self-supervision is possible in DOITs [8].

12.In DOIT and MOIT, the lack of transmission signal attenuation is problematic in conventional CTs.

13.The ability of high mechanical withstands [6].

14.The ability to install common with other equipment [5].

15.Complete isolation in high voltage section and control room [11].

16.Full compatibility the output with computers that will have the most responsibility in the future and new substations [11].

17.The output of conventional CT and PT can support new optical systems (Relays and measuring devices) and conversely.

18.Protection against the opening of output in CTs and shorts PTs [3,15].

19.PCB that is severe environmental pollutants are not used [6,10].

20.The measurement and analysis of current with higher harmonics [5,7,9,12].

21.There are not any Burden and Class [5,12].

B. Disadvantages:

1. If the magnetic fields induced by the currents through other conductors is sufficiently high, the fault current measured will have some errors. Since many conductors in the substation adopted air insulation, it is

possible for the Faraday sensor to detect the fields resulting from the fault current by other conductors [5].

2. The effect of temperature on glass sensitive sensor causes duality of the refractive index and it causes polarized light to distort and Light with linear polarization has become into elliptical and it causes unwanted disturbances to create (refractive index becomes various amounts at different temperatures) [3]. Of course, with modern methods, this problem has been solved. One of these methods is the use of diamagnetic glass. It is independent of the effects of temperature and it can be used without danger from 50 to 110° C [2,11].

3. Faraday Effect is related to the wavelength of light in the system. To remain constant wavelength of led, a temperature controller is used. Thermal expansion and vibration effect on the magnetic field adversely and this problem is solved by loop system.

4. In the optical fiber sensors being used on materials such as adhesives, Resin, thin strips of electrical insulation and these materials evaluated carefully. Because it is difficult to assess each material separately, longevity or aging experiments are done for optical sensors overall.

5. Bending of Optical fiber amply causes the refractive index of the fiber of changes and response sensitivity to Reduce and the influence of temperature to increase, especially in hoops that have several rounds of wire.

6. Because output quantities of MOITs are negligible, despite the simplicity of the building they need to have very high accuracy when they design and build.

7. In MCVTs, optical fiber must pass through the oil and the inside of the tank and it causes its Coating to be destroyed so must forecast that it reinforce.

CONCLUSION

Rapid advances in the quality of performance and costs of the optical fiber and electronic equipment to encourage development of measuring trances based on new technology.

We have provided an experimental comparison of the performance of the optical current transformers with conventional magnetic current transformers. The results have confirmed that the OCTs are suitable for power system protection and can replace the magnetic CTs. Similar comparison can be performed with other technologies of optical CTs, like magneto-optic and fiber optic current sensors.

Future goals are systems for advanced tariff measurement and protective relays for this technology. Waveform of Measurement and Protection by MOCT was set both in terms of time zones and the frequency very excellent. Values of RMS of Output current in conventional CTs and Moct are measured by less than 0.1% difference from each other that it showed the high quality of the Moct output signal, it can use with a great inductor to connect with applications and devices and observed that MOCT does cloning and replication expected harmonics in the power system.

The results of parallel comparing experiments (Two types CT) showed that during a 4-month period of operation only a 0.4 percent difference has occurred in the counter numeration.

Continuous activities and research investments in the development that has been done by different companies and manufacturers decrease costs naturally and make advanced technology in future.

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