Energy Harvesting From the Magnetic Field of an Overhead Transmission Line for Smart Grid Applications

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Abstract: - One of the most dependable and efficient ways to power in-house PCBAs for FACTS devices is to capture energy from the magnetic field of an overhead transmission line. Condition monitoring is becoming more prevalent in electrical power networks, where it can assist reduce maintenance costs, improve supply dependability, and allow for increased equipment capacity utilization by providing a measure of actual operating conditions. In most developing countries, load demand is always increasing, and because of the incapacity to improve the transmission infrastructure, the quality of power transmission is deteriorating, and power losses in the lines are increasing. Transmission lines are not used to their full capacity due to insufficient and inefficient power delivery. FACTS devices can help with this issue. However, in order to provide power to FACTS (flexible alternating current transmission system) devices and other transmission line equipment, a stable power source is required in the rapidly expanding network of power systems. FACTS (flexible alternating current transmission system) devices and other transmission line equipment are not powered by batteries. Their dependability is uncertain, and they are prone to catastrophic failures. As a result, we may provide power to FACTS devices and other transmission line equipment by harvesting energy from an overhead transmission line's magnetic field.

Key Words: — ***Energy harvesting, Magnetic field, Harvesting from Overhead Transmission line.***

I. Introduction

Energy harvesting is the method of obtaining power from external sources and storing it for use in small, wireless devices such as electronics and wireless sensor networks in power systems. For low-energy electronics devices, energy harvesters supply a very little quantity of electricity. In a rapidly expanding network of power systems, some power source is required to power FACTS devices that monitor the transmission lines, which are the transmission system's backbone.

II. Literature Survey

Energy harvesting (EH) technique is one of the most promising solutions for powering self-sustainable wireless sensing devices. These devices have been extensively demanded by the industry such as in smart grid applications [1-3].

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Energy Harvesting devices have been widely researched for many different energy sources in the safe environment such as oceanic wave [4], solar [5],[6], wind [7], [8],vibration [9] and kinetic [10]. However, solar and wind energy harvesters mostly depend upon the weather condition and require energy storage devices for night or low wind operations, respectively [11].

2.1 Energy Harvesting System

The energy source, energy management unit, and load device are the three essential components of an energy harvesting system. These three components are critical if we want to harvest energy.

The components of a typical energy harvesting system are shown in the diagram below.

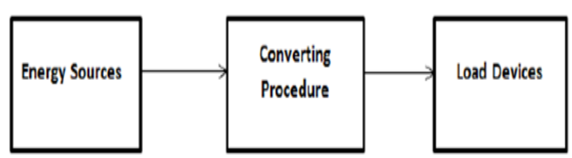

Fig.1. Components of Energy Harvesting System

2.2 Sources of Energy

Electric and magnetic field energy are extremely significant in today's world. We primarily generate electrical energy from kinetic and potential energy. We can also use magnetic energy by shifting magnetic lines of force through a coil by moving it in a magnetic field or by moving a magnet around a stationary coil. These two types of energy are extremely important in today's world since electricity has become a basic requirement. We cannot live a regular life without power. As a result, some sources are required through which we can readily manufacture these energy at a minimal cost.

2.3 Converting Procedure

Safe energy sources can be found all around us, and we can use them in a variety of ways, as detailed below.

2.3.1 Piezoelectric Effect:

The dynamics of the piezoelectric effect can be transformed into electrical energy via vibrations or vibrations. Piezoelectric generators transform regular waste vibration into energy, providing a powerful and dependable alternative. Frequency of input vibration, acceleration of base / host structure, and research scope are all external elements. The piezoelectric effect produces a small percentage of the overall quantity of electricity produced. Noise levels of less than 75 decibels boosted efficiency by 50%. The resonant frequency of the nano tubes boosted the efficiency at 10 kHz.

2.3.2 Photovoltaic Effect:

The photovoltaic effect is the process of a solar cell creating voltage or electricity when exposed to sunshine. Because the solar panels' cells turn sunlight into electricity, this effect makes them valuable. Lighting, sensors, recording devices, switches, equipment, telephones, televisions, and electrical equipment are all powered by batteries. Power DC or AC devices can be powered by battery PV systems. Silicon (monocrystalline, polycrystalline, or amorphous), gallium arsenide, metal chalcogenides, and organometallics are the most common materials used in solar devices. Mesoscopic solar cells have recently dominated the commercial market.

2.3.3 Thermoelectric Generator:

Thermoelectric generator (TEG), also known as the Seebeck Generator, is a solid-state device that uses the Seebeck effect to transform thermal energy (temperature fluctuations) into electrical energy (a form of thermoelectric effect). In contrast to the thermoelectric generator, the thermoelectric cooler works. An electric current is generated when a voltage is supplied to a thermoelectric cooler.

2.4 Low Power Loads:

Energy harvesting systems are mostly used to provide electricity to low-power devices. These are low-power sensors that are commonly used for condition monitoring. Battery storage systems are not suited for storing electricity during peak times to be used later in power harvesting systems where power supply is not uniform. As a result, we'll have to rely on these methods to power up the sensors.

III. PROBLEM STATEMENT

Real-time monitoring of transmission line metrics such as efficiency, voltage regulation, and power factor systems is critical for smart grid applications. The state of electrical lines can be monitored and reported using FACTS devices. In a rapidly expanding power system, there is a need for a stable power supply to power FACTS (flexible alternating current transmission system) devices and other transmission line equipment. Battery dependability is not achievable in this situation. Batteries are not allowed to be used to power FACTS devices by power utility companies. Our difficulty is figuring out how to create such a power source.

IV. PROPOSED METHODOLOGY & CURRENT TRANSFORMER

The power grid has had an issue with peak power management for several decades. We needed to install a new transmission line and generation system to meet the ever-increasing load requirement. However, due to the short durations of peak hours, it is not economically possible to build a new line, so we need the transmission line's power handling capacities to be enhanced during peak hours, which is done using FACTS devices. FACTS gives us the ability to improve, control, and stabilize the power system. Current transformers (CTs) can be used to monitor current or to convert primary current into a lower secondary current that can be used in metres, relays, control devices, and other instruments. CTs that transform current isolate the high-voltage primary, allow the secondary to be grounded, and reduce the magnitude of the measured current to a standard value that the instrument can safely handle. To figure out which CT is best for a specific application.

The CT current ratio is the ratio of main current input to secondary current output at full load. When 400 amps flow through the main, a CT with a ratio of 400:10 is rated for 400 primary amps at full load and produces 10 amps of secondary current. The secondary current output will alter correspondingly if the primary current varies. If 200 amps flow through a main rated at 300 amps, the secondary current output will be 5 amps (200:400 = 5:10).

A complete bride rectifier converts AC voltage to DC voltage using a diode and the biassing concept. We are all aware that a diode in reverse bias stops current flow. The diode bridge divides the sinusoidal input voltage into two paths, one for the positive cycle and one for the negative cycle. The positive cycle remains unchanged with modest drops, whereas the negative cycle inverts in the output. The boost converter circuit is similar to the buck converter in many ways, however the boost converter's circuit architecture and use are slightly different.

A boost converter or step-up converter's basic circuit consists of an inductor, diode, capacitor, and a switch operated by a pulse width modulator. A boost converter is a DC to DC step-up power converter that boosts voltage while lowering current flow from the source to the load. The simplest circuit has a diode, a transistor, a capacitor, and/or an inductor, and it is an example of switched-mode power supply (SMPS). Filters, like buck circuits, are used to reduce voltage ripple at the input, output, or both, depending on the application. In a boost converter circuit, the input and output voltages, as well as the load current, are determined according to the application, but the inductance and ripple current are not dependent on each other; instead, they are inversely proportional to each other. As a result, a greater inductance is used to lessen the ripple.

An inductor, diode, and capacitor with a switch control circuit system make up the fundamental circuit for a simple buck converter. A step-down converter is another name for it. The circuit works by altering the length of time the inductor gets energy from the source. A pulse width modulator controls the switch, and a set frequency oscillator drives the switching. It's a DC-to-DC power converter that reduces voltage while simultaneously amplifying current from its input to output (load). It can be used as a switch-mode power supply example (SMPS).

The current in an inductor in a buck converter is regulated by two switches: a diode and a transistor. When the switch is on, the diode and the inductor have zero voltage drop and zero current ow, and the inductor has zero resistance. Furthermore, the input and output voltages are supposed to remain constant throughout the cycle. These converters have two modes of operation. If the current through the inductor I never drops to zero throughout the commutation cycle, the buck converter is in continuous mode. In discontinuous mode, the current through the inductor drops to zero during the first half of the period, and the inductor is discharged fully at the end of the commutation cycle.

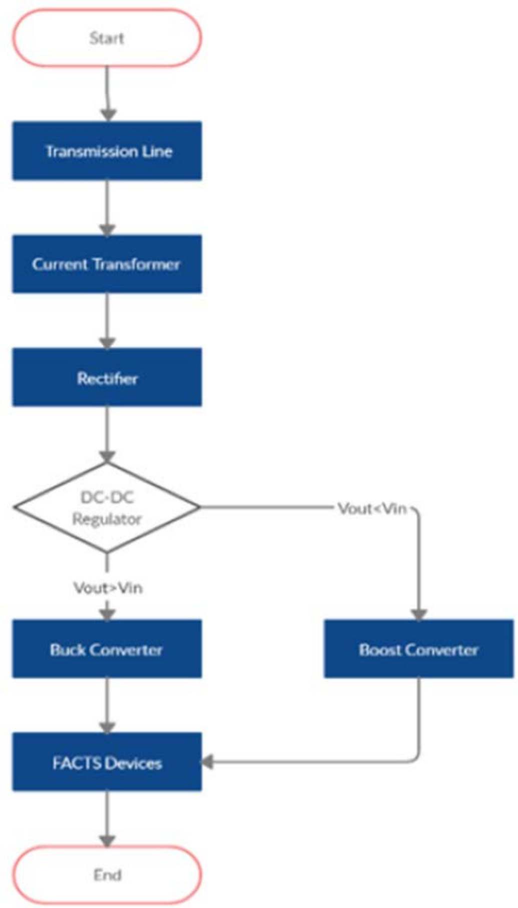

Fig.2. Block Diagram

V. CURRENT TRANSFORMER (CT)

The current transformer (CT) is a transformer that reduces or multiplies alternating current (AC). It generates an electric current in its secondary that is proportional to the current in its primary. It serves a variety of functions. These are utilized in high-power circuits that have a lot of current flowing through them. They're mainly utilized with relays to monitor current in conductors or cables in AC power circuits. It can, however, be utilized as an energy harvester.

5.1 Design of CT

The amp-turn equation must be satisfied by a current transformer, just like any other transformer, and we know from our course on double wound voltage transformers that this turns ratio is equal to:

$$T.R = n = \frac{Ip}{Is} = \frac{Ns}{Np}$$

Then,

$$Is = Ip(\frac{Np}{Ns})$$

The turns ratio is determined by the current ratio, and because the primary normally has one or two turns while the secondary can have hundreds, the ratio between the two can be fairly big. Assume the primary winding's current rating is 100A, for example. The secondary winding is rated at 5A, which is the industry standard. Then the primary and secondary currents have a ratio of 100A to 5A, or a 20:1 ratio. To put it another way, the primary current is 20 times the secondary current.

5.2 Area of Core:

Area of Core can be calculated as:

$$Ac = \frac{Vs * 10^4}{Kf * Bac * Ns}$$

Where:

A_c = Area of core, V_s = Secondary voltage, K_f = Waveform factor, B_{ac} = Operating flux density, f = Operating frequency of the sinusoidal voltage, N_s = Number of secondary winding turns

By putting following values of above parameters:-

V_s = 30V, $B_{ac} = B_{max}$ = 1.5T, f = 50Hz, N_s = 20 turns

The **Area of cross section** comes out to be **50cm^2.**

5.3 Material Selection:

Soft iron is a type of ferromagnetic iron that is easily magnetized and demagnetized. This is advantageous in transformers since the core magnetism is continually changing in transformers. The steel M6 was chosen for the CT's core construction. Because the CT is usually performed at the material's knee point on the BH curve, the flux density at the knee point is 1.5T.

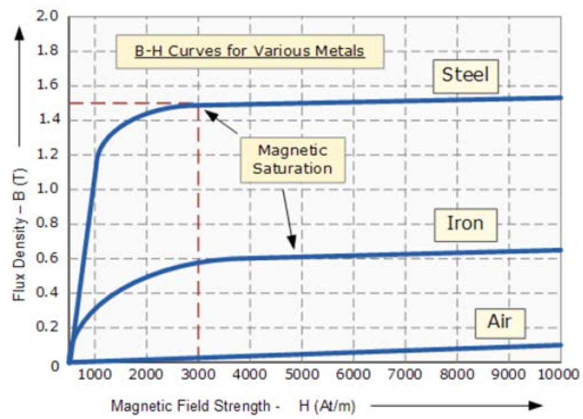

Fig.3. Magnetization Curve for Transformer

5.4 Winding Wire Selection:

Copper is selected as the material for winding wire as secondary wire the area of cross section of the wire is calculated as:

$$Aw = \frac{SecondaryCurrent}{CurrentDensity}$$

Where for safe operation;

$$\sigma = 1.2\frac{A}{mm^2}$$

$$Aw = \frac{5}{12} = 4.167mm^2$$

AWG	Diameter [inches]	Diameter [mm]	Area [mm^2]	Resistance [Ohms / 1000 ft]	Resistance [Ohms / km]	Max Current [Amperes]	Max Frequency for 100% skin depth
0000 (4/0)	0.46	11.684	107	0.049	0.16072	302	125 Hz
000 (3/0)	0.4096	10.40384	85	0.0618	0.202704	239	160 Hz
00 (2/0)	0.3648	9.26592	67.4	0.0779	0.255512	190	200 Hz
0 (1/0)	0.3249	8.25246	53.5	0.0983	0.322424	150	250 Hz
1	0.2893	7.34822	42.4	0.1239	0.406392	119	325 Hz
2	0.2576	6.54304	33.6	0.1563	0.512664	94	410 Hz
3	0.2294	5.82676	26.7	0.197	0.64616	75	500 Hz
4	0.2043	5.18922	21.2	0.2485	0.81508	60	650 Hz
5	0.1819	4.62026	16.8	0.3133	1.027624	47	810 Hz
6	0.162	4.1148	13.3	0.3951	1.295928	37	1100 Hz
7	0.1443	3.66522	10.5	0.4982	1.634096	30	1300 Hz
8	0.1285	3.2639	8.37	0.6282	2.060496	24	1650 Hz
9	0.1144	2.90576	6.63	0.7921	2.598088	19	2050 Hz
11	0.0907	2.30378	4.17	1.26	4.1328	12	3200 Hz
13	0.072	1.8288	2.62	2.003	6.56984	7.4	5300 Hz
14	0.0641	1.62814	2.08	2.525	8.282	5.9	6700 Hz
15	0.0571	1.45034	1.65	3.184	10.44352	4.7	8250 Hz
16	0.0508	1.29032	1.31	4.016	13.17248	3.7	11 k Hz
17	0.0453	1.15062	1.04	5.064	16.60992	2.9	13 k Hz
18	0.0403	1.02362	0.823	6.385	20.9428	2.3	17 kHz
19	0.0359	0.91186	0.653	8.051	26.40728	1.8	21 kHz
20	0.032	0.8128	0.518	10.15	33.292	1.5	27 kHz
21	0.0285	0.7239	0.41	12.8	41.984	1.2	33 kHz
22	0.0254	0.64516	0.326	16.14	52.9392	0.92	42 kHz
23	0.0226	0.57404	0.258	20.36	66.7808	0.729	53 kHz
24	0.0201	0.51054	0.205	25.67	84.1976	0.577	68 kHz
25	0.0179	0.45466	0.162	32.37	106.1736	0.457	85 kHz
26	0.0159	0.40386	0.129	40.81	133.8568	0.361	107 kHz
27	0.0142	0.36068	0.102	51.47	168.8216	0.288	130 kHz
28	0.0126	0.32004	0.081	64.9	212.872	0.226	170 kHz
29	0.0113	0.28702	0.0642	81.83	268.4024	0.182	210 kHz
30	0.01	0.254	0.0509	103.2	338.496	0.142	270 kHz
31	0.0089	0.22606	0.0404	130.1	426.728	0.113	340 kHz
32	0.008	0.2032	0.032	164.1	538.248	0.091	430 kHz
33	0.0071	0.18034	0.0254	206.9	678.632	0.072	540 kHz
34	0.0063	0.16002	0.0201	260.9	855.752	0.056	690 kHz
35	0.0056	0.14224	0.016	329	1079.12	0.044	870 kHz
36	0.005	0.127	0.0127	414.8	1360	0.035	1100 kHz
37	0.0045	0.1143	0.01	523.1	1715	0.0289	1350 kHz
38	0.004	0.1016	0.00797	659.6	2163	0.0228	1750 kHz
39	0.0035	0.0889	0.00632	831.8	2728	0.0175	2250 kHz
40	0.0031	0.07874	0.00501	1049	3440	0.0137	2900 kHz

Fig.4. American Wire Gauge (AWG) cable/conductor sizes and properties

5.5 CT Specifications:

- The core size specifications are:-

  Length = 10cm

  Width = 5cm

  Height = 10cm

  Cross sectional Area = 50 cm^2
- Operating primary current range is 100A.
- Operating frequency, sine wave 50Hz.
- Diameter of wire = .303mm
- Turn ratio = 1-20
- It will always be work at **saturation.**

VI. EXPERIMENTAL VERIFICATION

6.1 Rectifier and filter

AC to DC converter converts the AC signal to dc that comes from the output terminal of the current transformer. Some functions about diode and filter are given below-

- Rectifier converts AC signal into DC signal
- Minimizes ripple in voltage
- Filters higher harmonics
- Reduces Noise
- Diode voltage drop is 2V DC
- Operating current of rectifier is of range 1-5A AC.
- Operating frequency, sine wave 50Hz.

6.1.1 Simulation Model of Rectifier:

Rectifier converts the AC signal into the DC signal and filter removes the ripples in the DC signal. MATLAB simulation model of rectifier and filter is given below-

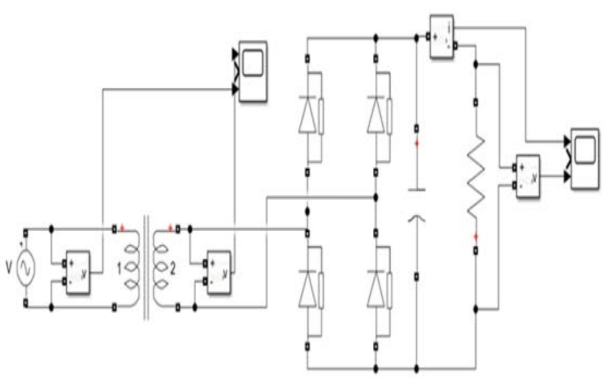

Fig.5. Bridge Rectifier with Filter

6.1.2 DC-DC Regulator:

- To regulate output voltage
- Based on the design of Buck-Boost converter
- Mode of converter depends upon the input voltage
- If the input voltage is less than the required voltage than buck boost, converter boost up the input voltage up to required voltage.
- If the input voltage is greater than the required voltage than buck boost converter decreases the input voltage up to required voltage.

Simulation Model of DC-DC Regulator:

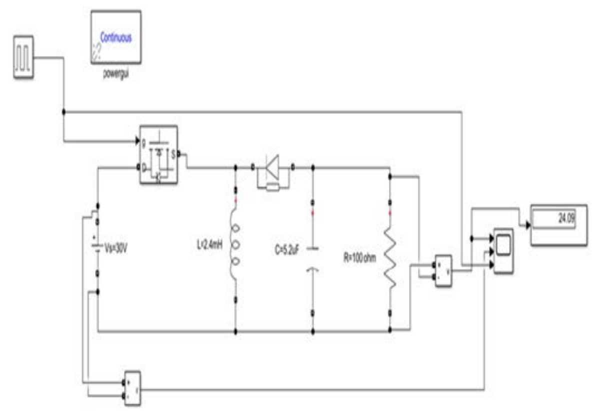

Fig.6. Buck Boost Converter

6.1.3 Simulations:

Buck Mode:

MATLAB simulation result in buck mode of buck boost converter is given below:-

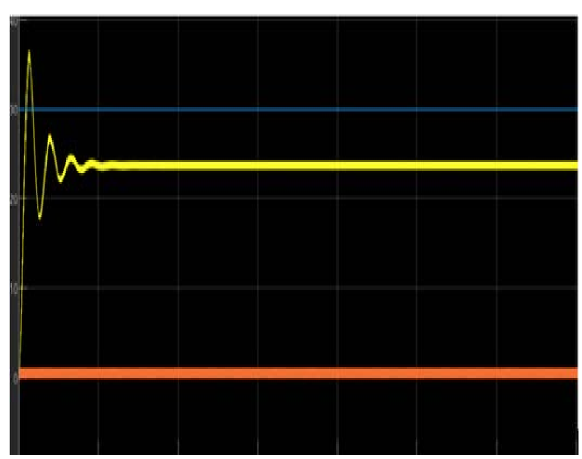

Fig.7. Simulation result in Buck Mode

Boost Mode:

MATLAB simulation result in boost mode of buck boost converter is given below-

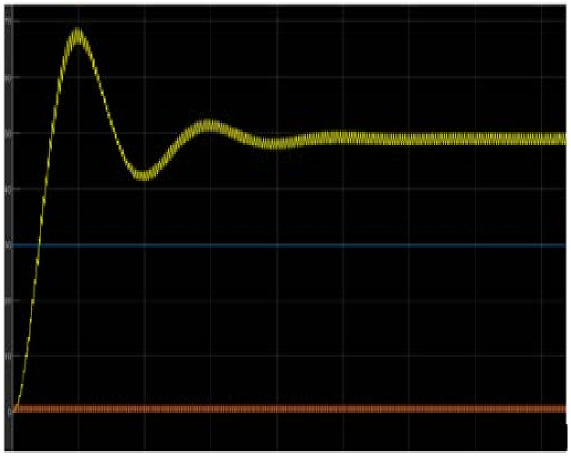

Fig.8. Simulation result in Boost Mode

VII. CONCLUSION & OBSERVATIONS

From this research, we can conclude that this project can be implemented practically as a **Final Year Project**. First of All we need to pass transmission line conductor from the hollow of CT. In Final Year Project you just need to make a Prototype of Transmission line.

7. 1 For Transmission Line Prototype:

We require High Current and Low Voltage Source. We may use High Voltage Low Current Source. We can connect Step-Down Transformer Next to High Voltage and Low Current Source. And in result this step-down transformer steps down the voltage in result current will increase.

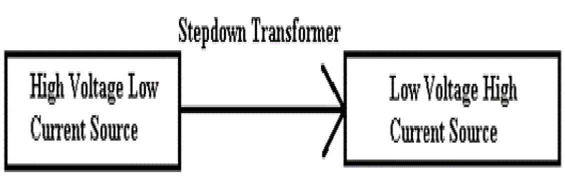

Fig.9. Stepdown Transformer Functionality

$$P_{Input} = P_{Output}$$

- Then get output from CT.
- Then Rectify the Output.
- Buck-Boost Converter.
- Fact Device.

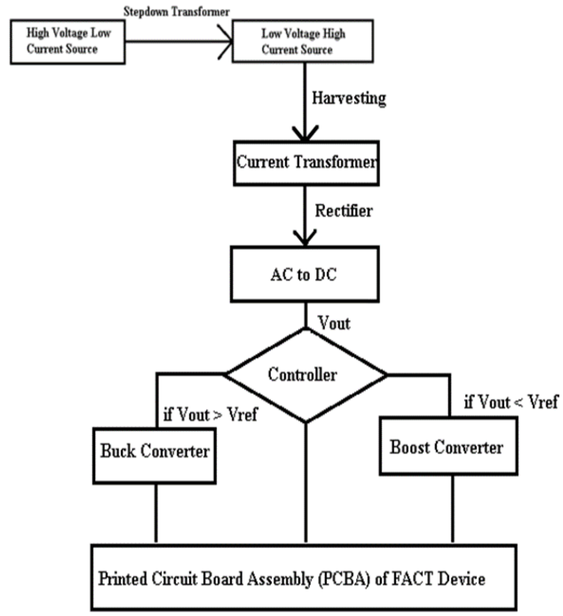

Fig.10. Practical Flow Diagram

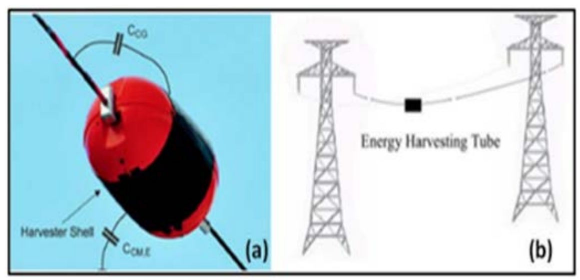

Fig.11. Energy harvester mounted on transmission line

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