MS1210 FINAL PROJECT

HARVESTING PIEZOELECTRICITY

GROUP F

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TABLE OF CONTENTS

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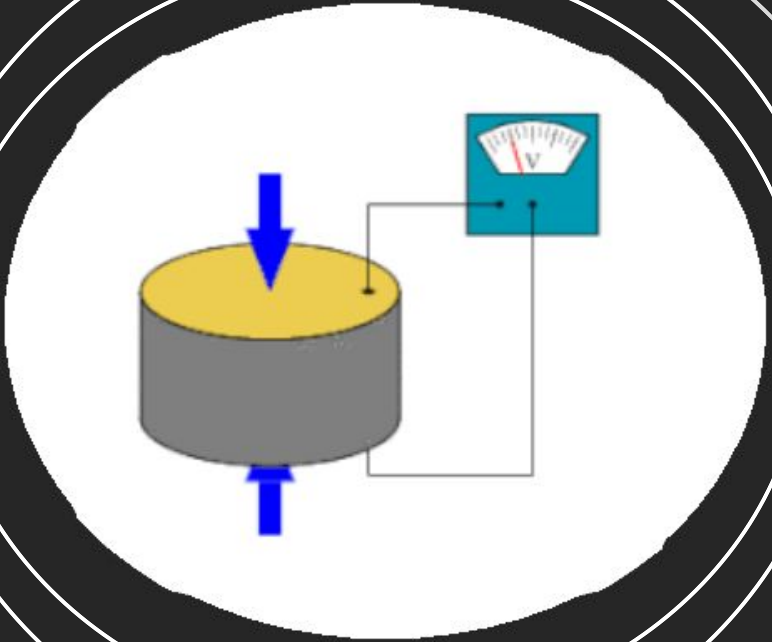


PIEZOELECTRIC EFFECT

Converting mechanical stress to electrical energy

INTRODUCTION

- Piezoelectricity translates to "Electricity from pressure."
- The prefix piezo derived from 'piezen' in greek means 'press' or 'squeeze'.
- Piezoelectricity is found in crystalline materials that possess non-centrosymmetry.

OUR AIM

- To reduce the dependency on NON-RENEWABLE RESOURCES.
- Principle used : LCE
- LCE (Law of conservation of energy):

Energy can neither be created nor destroyed. It can only be transformed from one form to another.

Here, we are transforming mechanical energy (stress) from daily life to electrical energy

BRIEF HISTORY

Piezoelectricity was first discovered in 1880 by two brothers and French scientists, Jacques and Pierre Curie. While experimenting with a variety of crystals, they discovered that applying mechanical pressure to specific crystals like quartz released an electrical charge. They called this the piezoelectric effect.

Pierre Curie with his wife Maria in his lab.

OBJECTIVE AND SCOPE

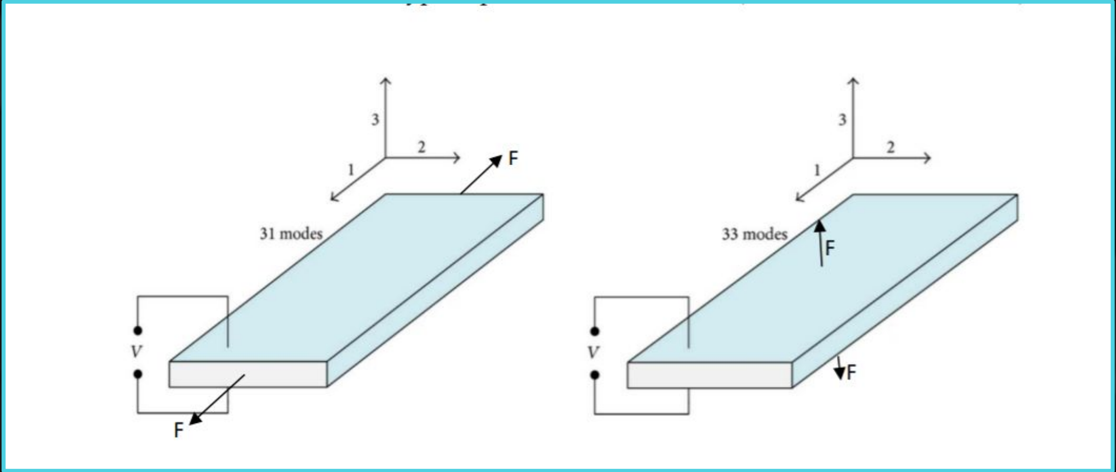
1) This study investigated the potential of applying the piezoelectric harvesting technology to the railway tracks.
2) The electricity from the piezoelectric materials can be be obtained from it by applying stress or by vibrational energy.
3) The Energy harvesting performance of the piezoelectric materials is evaluated on the based of the vibrational frequency and amplitude.

LITERATURE REVIEW

Principles of piezoelectric harvesting :

1) Piezoelectric materials generate electricity when mechanical stress is applied know as piezoelectric effect and vice versa.
2) Piezoelectricity can also be harvested using the vibrational energy.
3) Increasing the applied stress is one method of increasing the generated power and another method is to use the coupling method efficiently.
4) There are two modes of coupling d31 and d33 depending on the material poling and the force direction applied.

LITERATURE REVIEW CONT.



Piezoelectric material coupling modes.

ENERGY DENSITY STORED IN THE PZT MATERIAL :

$$U_e = \frac{1}{2}(d.g)T^2$$

INVERSE PIEZOELECTRIC EFFECT :

When electricity is applied across the terminals of the piezoelectric crystal then mechanical strain is produced.

This inverse piezoelectric effect also has many applications. One of its major application is in quartz watches.

GENERAL USES OF PIEZOELECTRIC MATERIAL

1. Actuators
2. Speakers and buzzers
3. Drivers
4. Sensors
5. Power
6. Motors
7. Ultrasounds Transducers

IMPLEMENTATION IN TRAINS

TRAINS

An average train weighs around 3 x 10^6 kg to 18 x 10^6 kg.

If it takes 2 to 5 minutes to increase its speed from 45kmph to 120kmph, the average force exerted by the train on its tracks is approx. 51x10^6 N.This force exerted can be utilised to generate electricity using piezoelectric materials.

WHY IS GENERATING PIEZOELECTRICITY FROM MOVING TRAINS A GOOD IDEA?

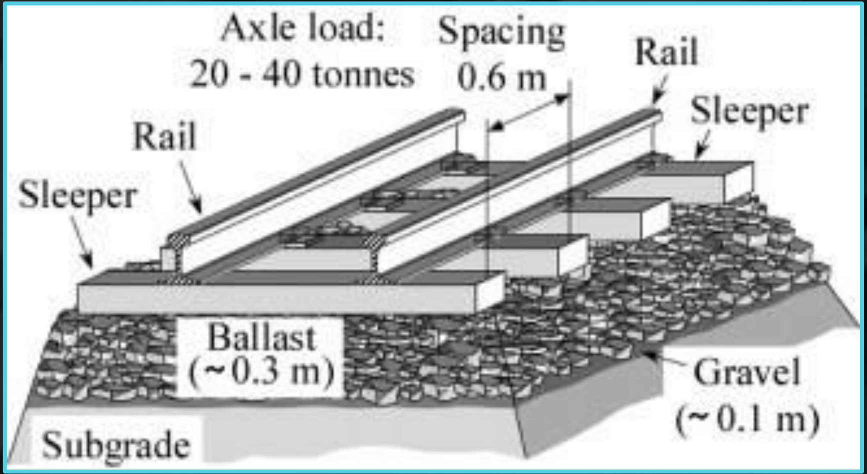
India has one of the largest rail networks in the world, meaning train routes are immensely interconnected, reaching thousands of destinations including remote villages.

Hence, it is evident that the amount of energy we can harvest is very large in scale. We can make use of this harvested energy by sending them to nearby stations or even storing them in batteries.

DESIGN AND IMPLEMENTATION

IMPLEMENTATION

The picture given is the structure of a railway track.

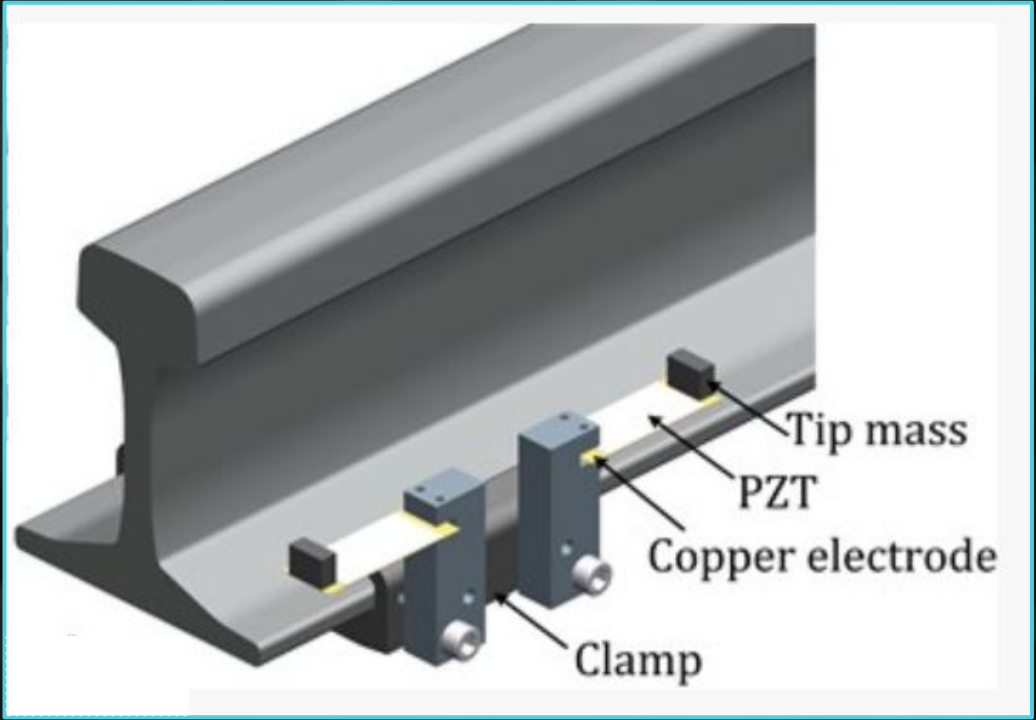


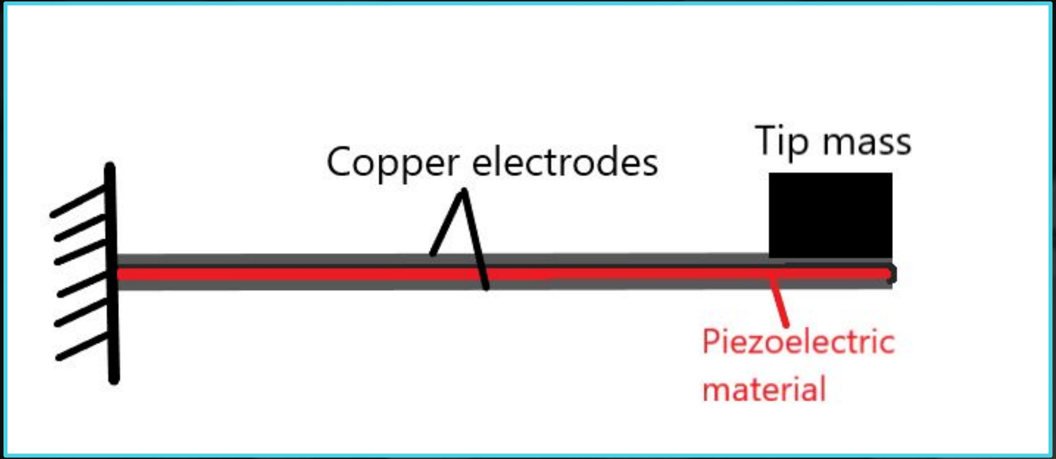
PRINCIPLE: The railway tracks undergo vibration when a train passes.

Hence, we are trying to generate electricity using these vibrations which fall in the range of the available piezoelectric crystals.

DESIGN:

Cantilevered piezoelectric beam model.

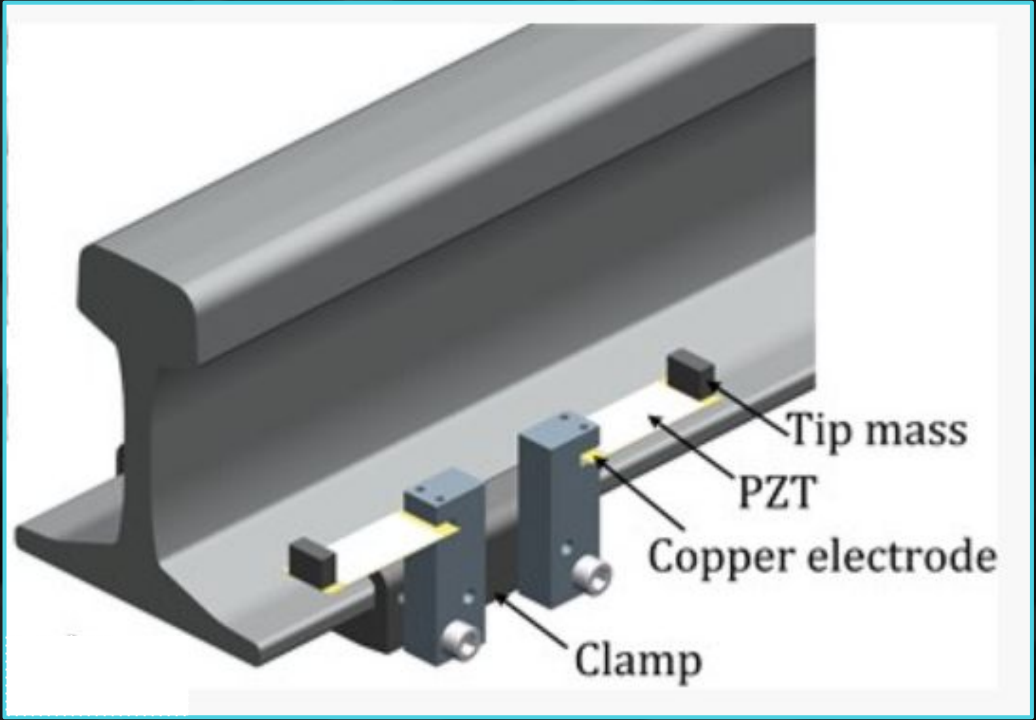




WHAT IS A CANTILEVER BEAM?

DESIGN:

Cantilevered piezoelectric beam model.



GENERATION OF ELECTRICITY

OUTPUT OBTAINED FROM A SINGLE TRANSDUCER

The frequency of the moving load excitation ranged from 3 Hz to 7 Hz, which depended on the velocity and the gauge of the rolling stocks.

- ➔ For a train vehicle with speed of **80 km/h** ,corresponding to the excitation is of **3 Hz to 5 Hz.**
- ➔ For a train vehicle speed of **250 km/h**, corresponding to the excitation of **5 Hz to 7 Hz.**

FORMULAE USED IN CALCULATING OUTPUT

Voltage induced in the transducer can be explained by the below equations for a bulk piezoelectric:

V = g33 (F)(t)/A

g33= d33/(e0)(er)

Capacitance of piezoelectric material can be calculated using the formula

C = (1500 X permittivity of free space X A)/(t).

g33- piezoelectric voltage constant

d33- piezoelectric strain constant

POWER AND VOLTAGE RELATION

Power obtained from the transducer

p= ½(C)V^2.f

P= ½(g33)(d33)(t)(f)F^2/(area)

f= frequency F=Force   t=thickness

Clearly P∝(g33)(d33)

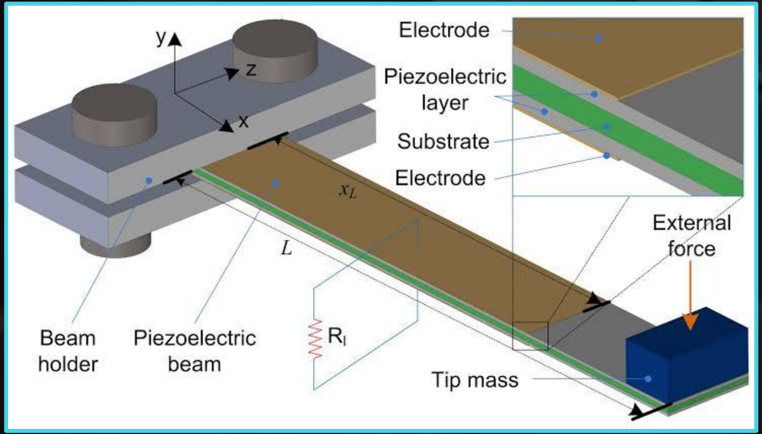
OUTPUT OBTAINED FROM A SINGLE TRANSDUCER cont. :

For an average excitation frequency between 5 and 7Hz -

Output Power: 4.9mW

Output (AC)Voltage: 22.1V

ELECTRICITY GENERATED BY A PIEZOELECTRIC TRANSDUCER



•Piezoelectric materials generate **AC voltage** when subjected to Mechanical stress.

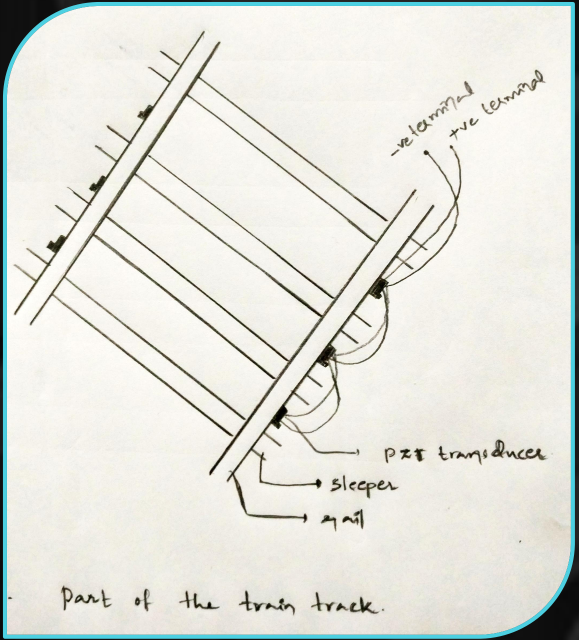
•In order to achieve optimum output Voltage and current, we have to connect Piezoelectric sensors in **combination of both Series and Parallel**.

PIEZOELECTRIC TRANSDUCER SET-UP

••••SAMPLE SPACE••••

- Length of the train is 650mts i.e a train containing 24coaches.
- Taking the Sample Space to be of 2 Coach Long i.e., 54mts.
- Usually the distance between the two sleepers is 25 to 30 inches, we are taking it to be 25 inches that is equal to 65cm.
- Over the length of the 54mts we require 83 Sleepers.

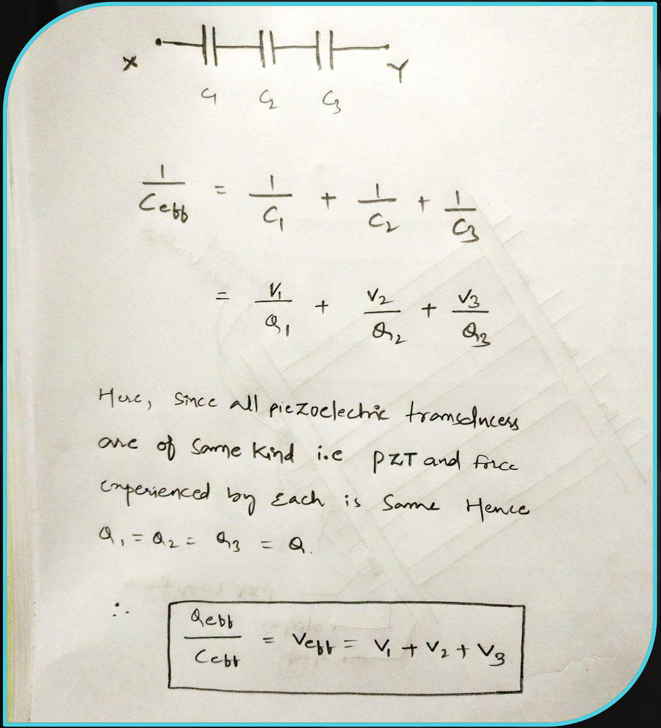
PIEZOELECTRIC TRANSDUCER SET-UP



- We are placing Piezoelectric Transducers between two adjacent sleepers as shown in fig.
- Each of these piezoelectric transducers are connected by connecting wires.
- So, over the length of 54m we require 83 Sleepers, in between two sleepers we are placing 2 piezoelectric transducers

So, in total 166 piezoelectric transducers are placed.

CALCULATING THE TOTAL OUTPUT VOLTAGE



When a force is applied on piezo material, a charge is generated across it. Thus, it can be assumed to be an ideal capacitor.

1/Ceq = 1/C1 + 1/C2 + 1/C3

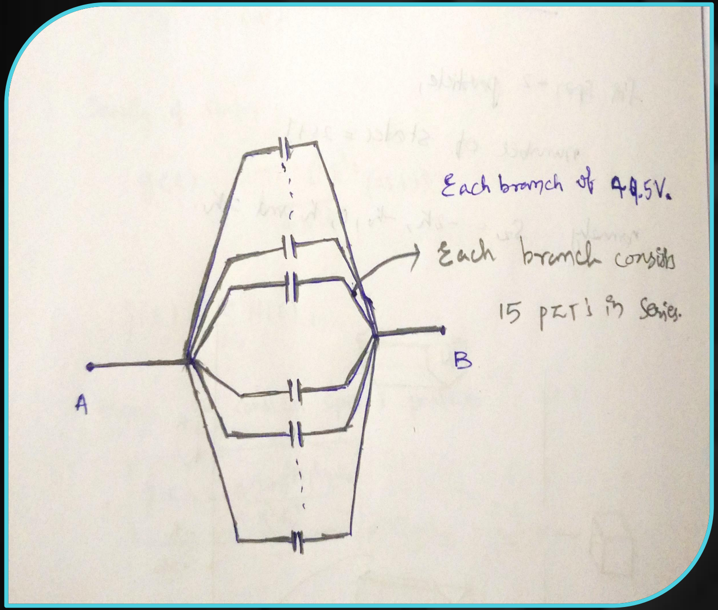
C = Q/V

1/Ceff = V1/Q + V2/Q + V3/Q

So, Veff=V1+V2+ V3

Each piezoelectric transducer produces a output of 22.1 V AC output

BOTH SERIES AND PARALLEL SET-UP.



•A combination of 15 piezoelectric transducers are made as a branch and all these branches are connected in parallel way.

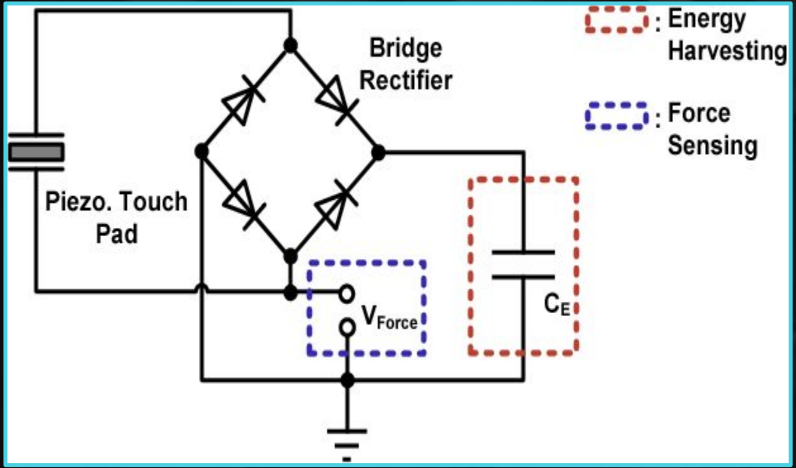
So, in total 15×22.1= 331.5V

•Terminals of the whole connection is Connected to fullwave Bridge Rectifier

•The effective Voltage between A and B is 331.5 Volts of AC.

•This Voltage then gets Converted to DC.

1.CONVERSION OF AC VOLTAGE TO DC VOLTAGE



•The Importance of transforming produced AC voltage into DC voltage is must because DC voltage can be stored and used later in various Applications.

•The transformation of AC voltage to DC voltage can be achieved by “Full Wave Bridge Rectifier” because,

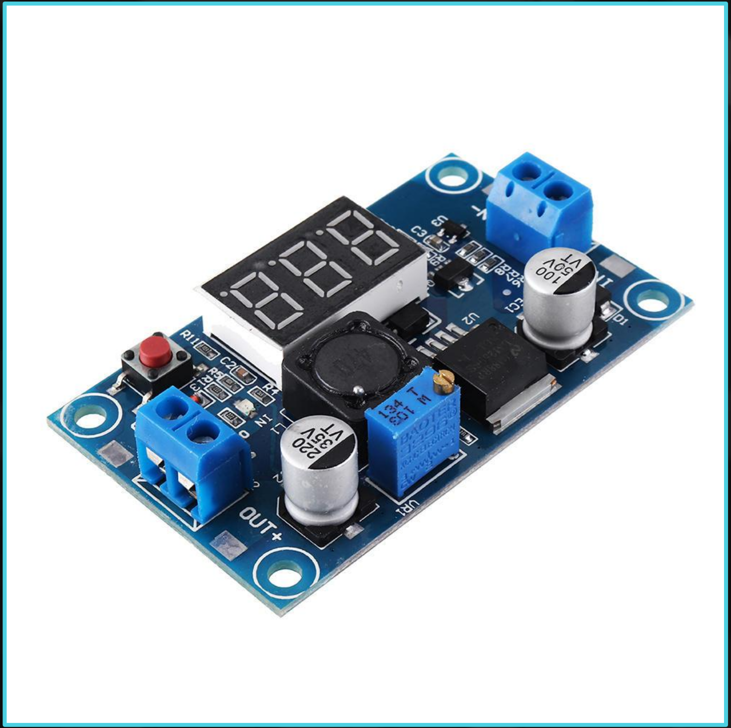
-Ease of implementation

-Cheaper and high efficient.

331.5V of AC voltage gets converted to 234.441V of DC voltage.

•The Output DC wave have ripples in it we can get rid of these ripples by using filters Such as RC filter.

2. MAINTAINING A CONSTANT DC VOLTAGE VALUE



- A constant value of DC voltage can be maintained using a BUCK CONVERTOR.
- A buck convertor is a DC-DC converter which steps down voltage while stepping up the current.
- Here, the input 234.44V (DC) gets stepped down to 49.52V of constant DC voltage.

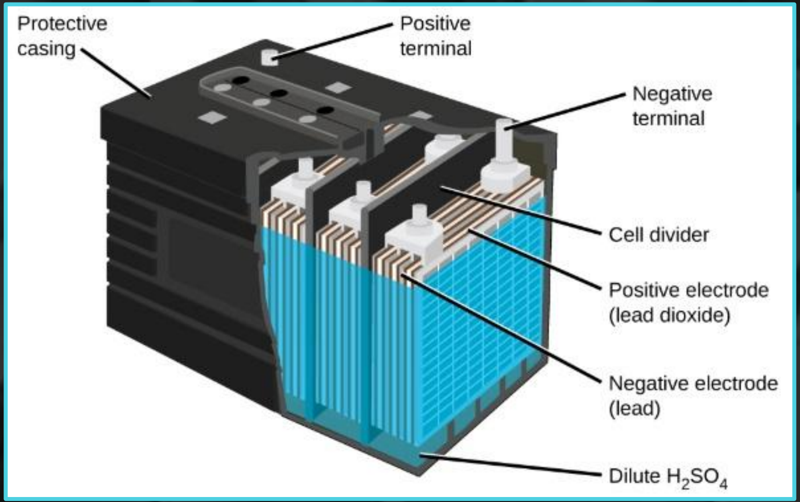
Formula used : $D = V_{out}/(V_{in} \times \eta)$

USAGE OF ELECTRICITY PRODUCED

A. Storage in batteries
B. Transmission through wires

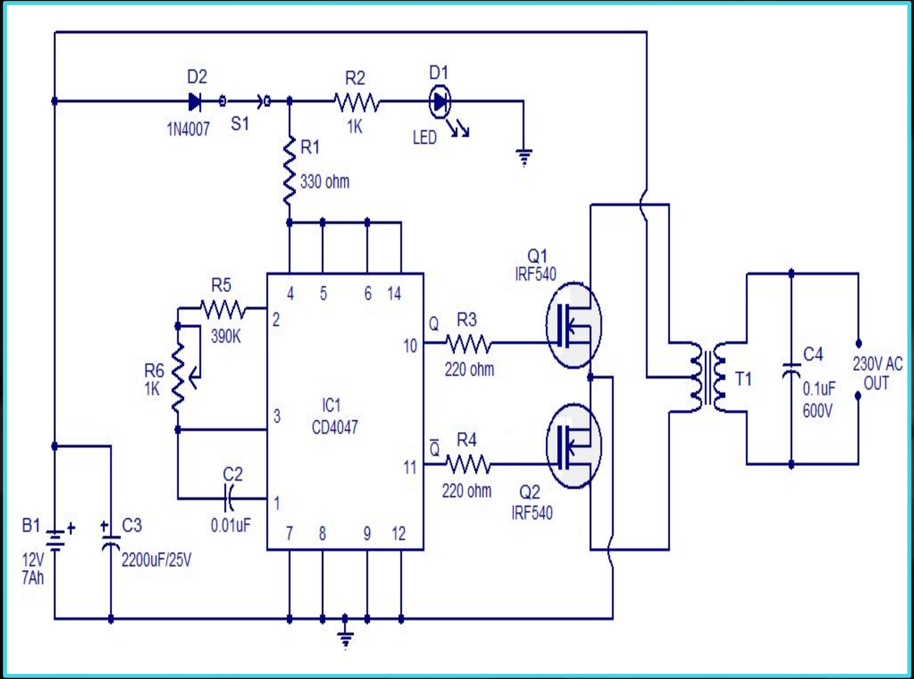
A. STORAGE IN BATTERIES

- We store the electricity produced in SECONDARY BATTERIES.



- We can use 11 Lithium high voltage cells, each having a voltage of approx 4.35V or 4.4V connected in series, giving us a 48.4V battery.

B. TRANSMISSION OF ELECTRICITY THROUGH WIRES



STEP 1 :

- DC voltage is converted to AC voltage using an INVERTER.
- This AC voltage can then be passed through the overhead transmission wires.

STEP 2 :

The AC voltage generated is transmitted to a nearby power station using OVERHEAD WIRES.

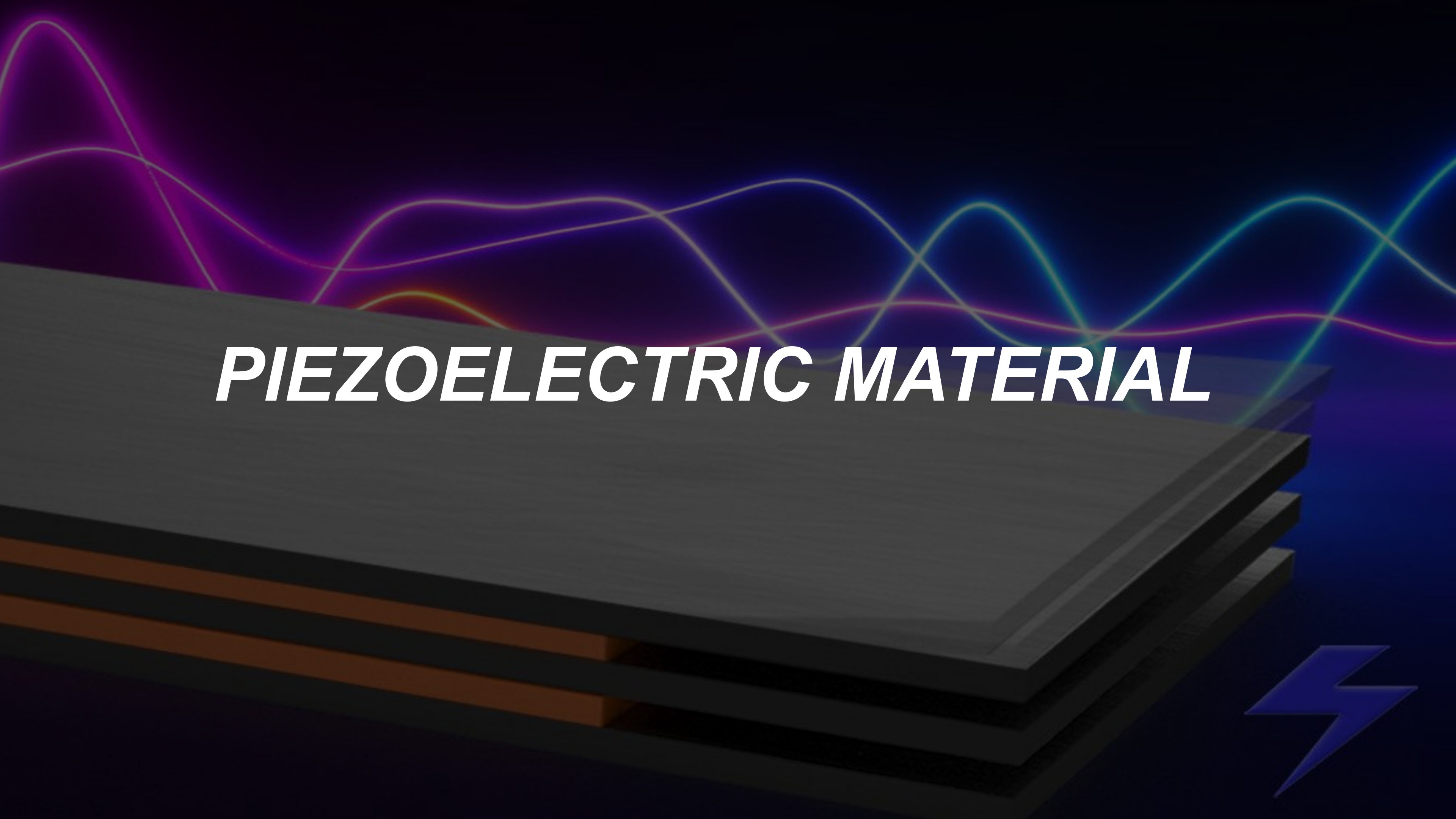
STEP 3 :

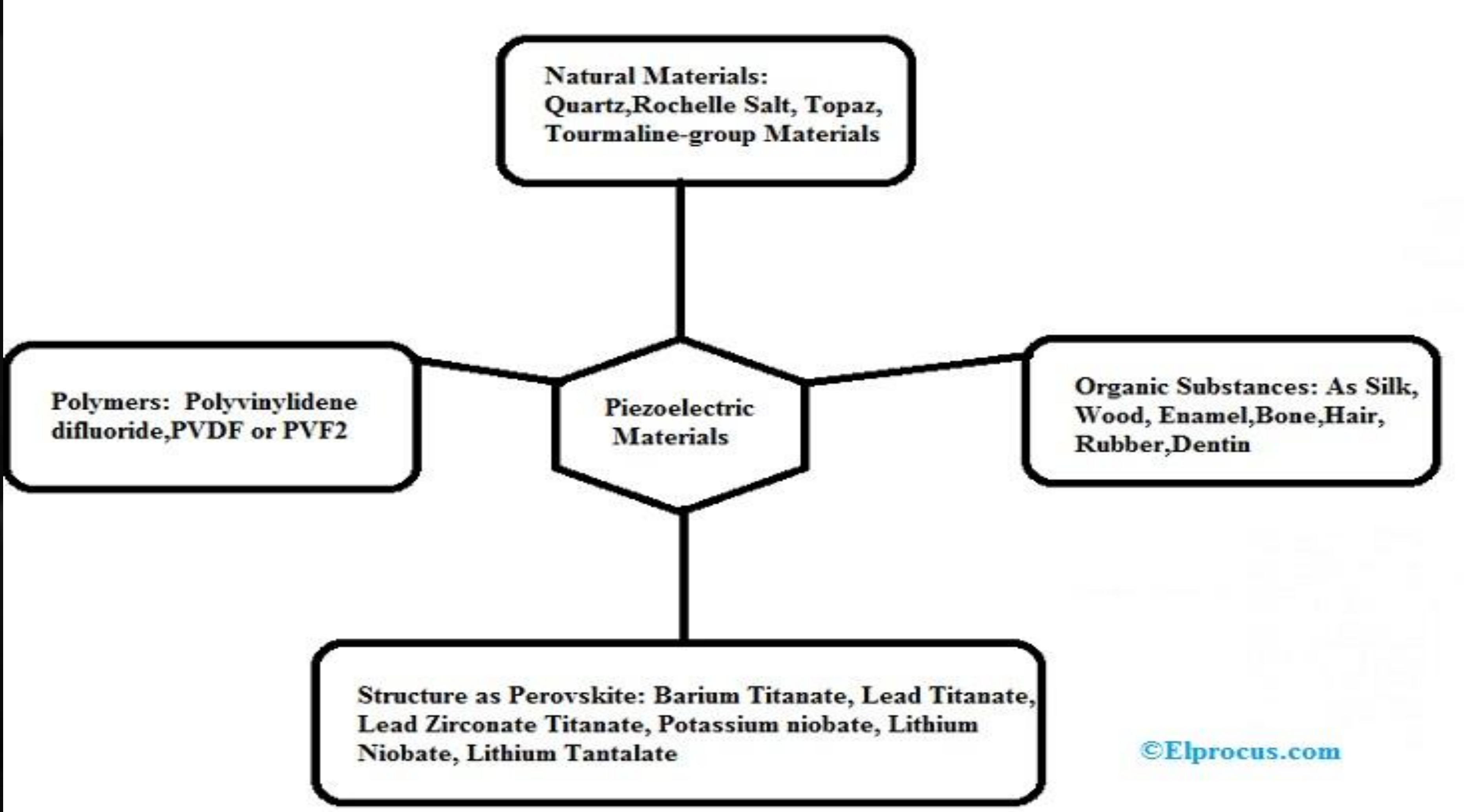
The electricity sent to the power stations can now either be sent to

1. the same electric train
2. Another electric train
3. Or used for other purposes

Besides, the placement of the transducers on all the railway tracks enables production of electricity from non-electric and electric trains as well.

PIEZOELECTRIC MATERIAL




Natural Materials: Quartz,Rochelle Salt, Topaz, Tourmaline-group Materials
Polymers: Polyvinylidene difluoride,PVDF or PVF2
Piezoelectric Materials
Organic Substances: As Silk, Wood, Enamel,Bone,Hair, Rubber,Dentin
Structure as Perovskite: Barium Titanate, Lead Titanate, Lead Zirconate Titanate, Potassium niobate, Lithium Niobate, Lithium Tantalate
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PARAMETERS FOR SELECTING PIEZOELECTRIC MATERIALS

Higher the magnitude of mechanical quality factor, electromechanical coupling factor, and dielectric constant, best is the material for application.

Materials with high electromagnetic coupling factor and high dielectric permittivity are best as transducers.

Low dielectric loss is important for materials used in off resonance frequency applications accounting for low heat generation.

One such material is the PZT.

PIEZOELECTRIC MATERIAL (PZT)

1) PZT - LEAD ZIRCONATE TITANATE. -- It is the most widely used piezoelectric material in the world which is available vastly and at less cost .
2) PZT is created and produced (under high temperatures) with two chemical elements—LEAD AND ZIRCONIUM— and combined with chemical compound TITANATE. The chemical formula of PZT is (Pb[Zr(x)Ti(1-x)]O3).
3) These materials are weighed, purified, doped and modified as we need. Many methods like drying, calcining, wet milling, etc. are included to get the desired PZT phase.
4) PZT is put in the PZT generator which on deforming or on applying mechanical pressure, electric charge is produced and a voltage is produced, then the current is sent out to rectifier. This is collectively called TRANSDUCER.

Property	Units	Symbol	PZT(P-33)
Electromechanical coupling factor		K_p	0.6
		K_{31}	0.36
		K_{33}	0.70
		K_{15}	0.70
		K_t	0.47
Relative permittivity		ε_r	1725
Vacuum permittivity.	10^{-12}F/m	ε_0	8.85
Loss tangent		tan δ_e	0.02
Compliance constant	$10^{-12}m^2/N$	S_{11}^E	15
		S_{33}^D	9
		S_{55}^D	25
Piezo strain constant	10^{-12}m/v or C/N	d_{31}	160
		d_{33}	390
		d_{15}	480

Mechanical quality factor		Q_m	75
Frequency constant	Hz-m	N_d	1950
		N_1	1470
		N_3	1880
		N_5	1130
		N_t	2250
Acoustic speed	m/s	V_d	3000
		V_1	2940
		V_3	3760
		V_5	2260
		V_t	4500
Acoustic impedance	10^6kg/m^2-sec.	Z_0	30
Curie temperature	°C	T_c	335

1) Doping pzt with donor ions such as Nb5+ or Tr5+ produces pzt like pzt-5.
2) Doping with acceptor ions such as Fe3+ or Sc3+ produces pzt like pzt-8.
3) Due to larger electromagnetic coupling coefficient PZT can be easily used in the conversion of mechanical energy to electrical energy.
4) Pzt is a better material than PLZT to make composites with higher g33 values.
5) Lower density composites of PZT ceramics impregnated with silicon elastomer could be prepare which has higher g33 value.

PZT- DRAWBACKS AND ALTERNATIVES

- PZT has huge advantages with minor modifications.
- It is brittle, cannot withstand high pressure.
- It contains 60% Lead (Pb) by weight , which is hazardous when exposed.
- So lead-free piezoelectric materials are needed.
- Some lead-free piezoelectric materials are $BaTiO_3$,KNbO3, LiNbO3, LiTaO3,BiFeO3…

ALTERNATIVE MATERIAL TO BE USED

Lead-free alternatives:

- KNBT -Potassium Sodium Bismuth Titanate

  -$(1-x)K_{0.5}Bi_{0.5}TiO_3-xNa_{0.5}Bi_{0.5}TiO_3$)

- PVDF -Polyvinylidene fluoride ($(C_2H_2F_2)_n$)
- BCZT -Barium Calcium Zirconium Titanate

  -$0.52(Ba_{0.7}Ca_{0.3})TiO_3-0.48Ba(Zr_{0.2}Ti_{0.8})O_3$

- KNNT -Sodium Potassium Niobate

  -($(K0.5Na0.5)NbO3$)

KNBT

- Formed by KBT and NBT nanopowders
- Due to MPB the composition 0.90NBT-0.05KBT shows maximum d33,kp values.
- d33 = 217(*10^-12)(CN^-1)
- Kp =61

PVDF

- PVDF is lightweight ,flexible and tough engineering plastic.
- High voltage output, high dielectric strength.
- High stability:moisture resistance.
- d33=30(*10^-12)(CN^-1)

(MPB-Morphotropic Phase Boundary)
(Kp-Electromechanical Coupling Factor)

BCZT

- BZT-BCT is prepared at very high temperatures.
- Doping with Sr,Sn enhances it’s piezoelectric efficiency.
- d33 = 470(*10^-12)(CN^-1)
- Kp = 47
- Have low curie temperature.

KNNT

- The composition at MPB at 52.5% Na have the highest electromechanical coupling factor.
- Forming of solid solutions with $BaTiO_3$,$LiNbO_3$,$SrTiO_3$...improves it’s properties.
- d33 = 390(*10^-12)(CN^-1)
- Kp = 54

OUTPUT COMPARISON FOR DIFFERENT MATERIALS

Output power of piezoelectric material considering thickness of 80mm and area of (200mm)*((170mm) :

- For PZT =4.9mW
- For PVDF=2.6mW
- For KNBT=0.24mW

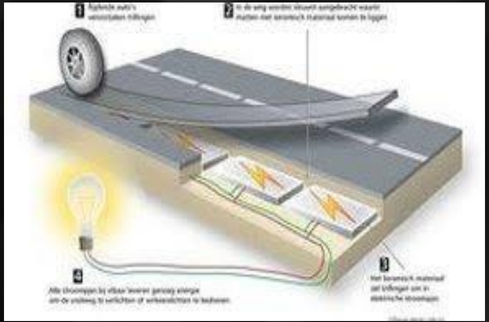
"No other material is as effective as PZT"

OTHER USES OF PIEZOELECTRIC MATERIALS

1.Tiles

2. Shoes

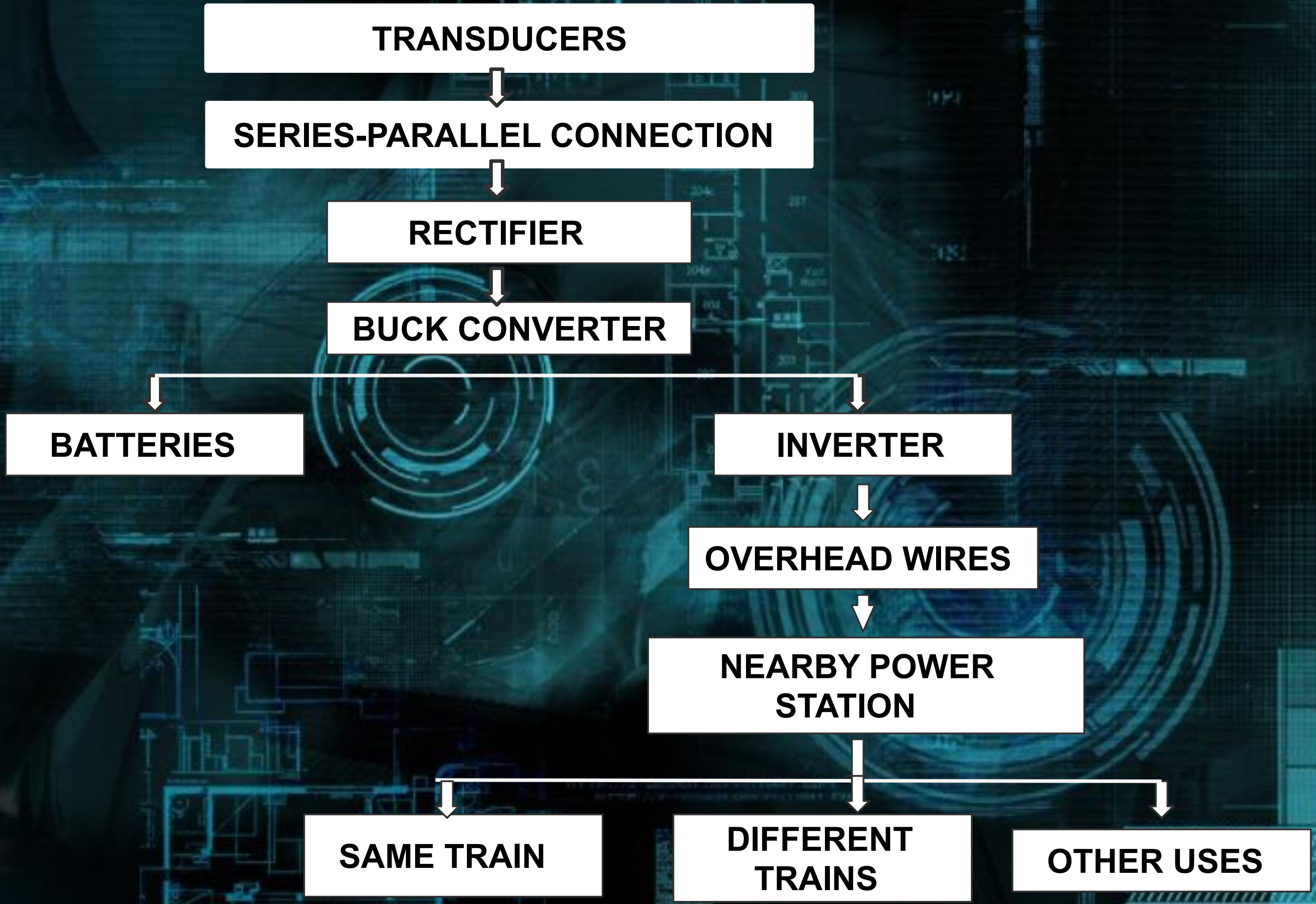
3. Roads



4. Raindrop

SUMMARY

1. Piezoelectric effect - how does it work?
2. Usage in trains - how and why?
3. Transducer set-up
4. Circuit set-up
5. Usage of electricity produced
6. Piezoelectric material used
7. Other uses of Piezoelectric effect


TRANSDUCERS
SERIES-PARALLEL CONNECTION
RECTIFIER
BUCK CONVERTER
BATTERIES
INVERTER
OVERHEAD WIRES
NEARBY POWER STATION
SAME TRAIN
DIFFERENT TRAINS
OTHER USES

CONCLUSION

- Piezoelectric energy harvesting has several advantages, such as high energy and power density,low cost, good scalability, and ease of application.
- So generating electrical energy from the mechanical energy which is being unuseful helps us use the energy in a consistent way.
- It will reduce our dependence on non-renewable resources for energy generation.
- Research and development in piezoelectric energy harvesting will be a boon for future generations to come.

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THANK YOU :)